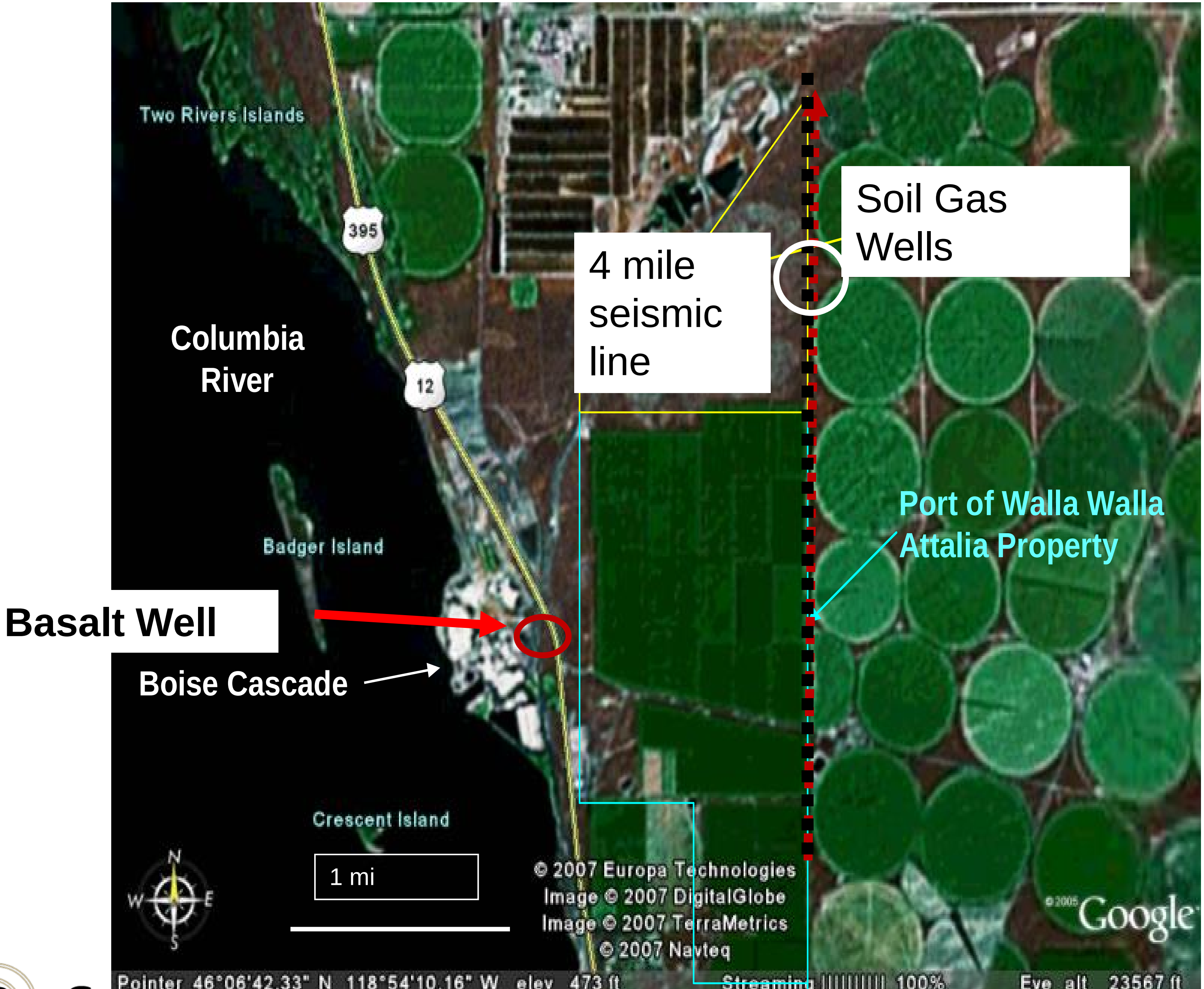

BIG S SEQUESTRATION PARTNERSHIP

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Seismic Survey

- **Four mile- 3C reflection seismic survey completed 12/07/2007**
- **Two large Vibroseis trucks, activated together**
- **Five line swath of three-component geophones to capture both shear and compressional wave data**

Big Sky Carbon Sequestration Partnership

Pacific Northwest National Laboratory

Montana State University

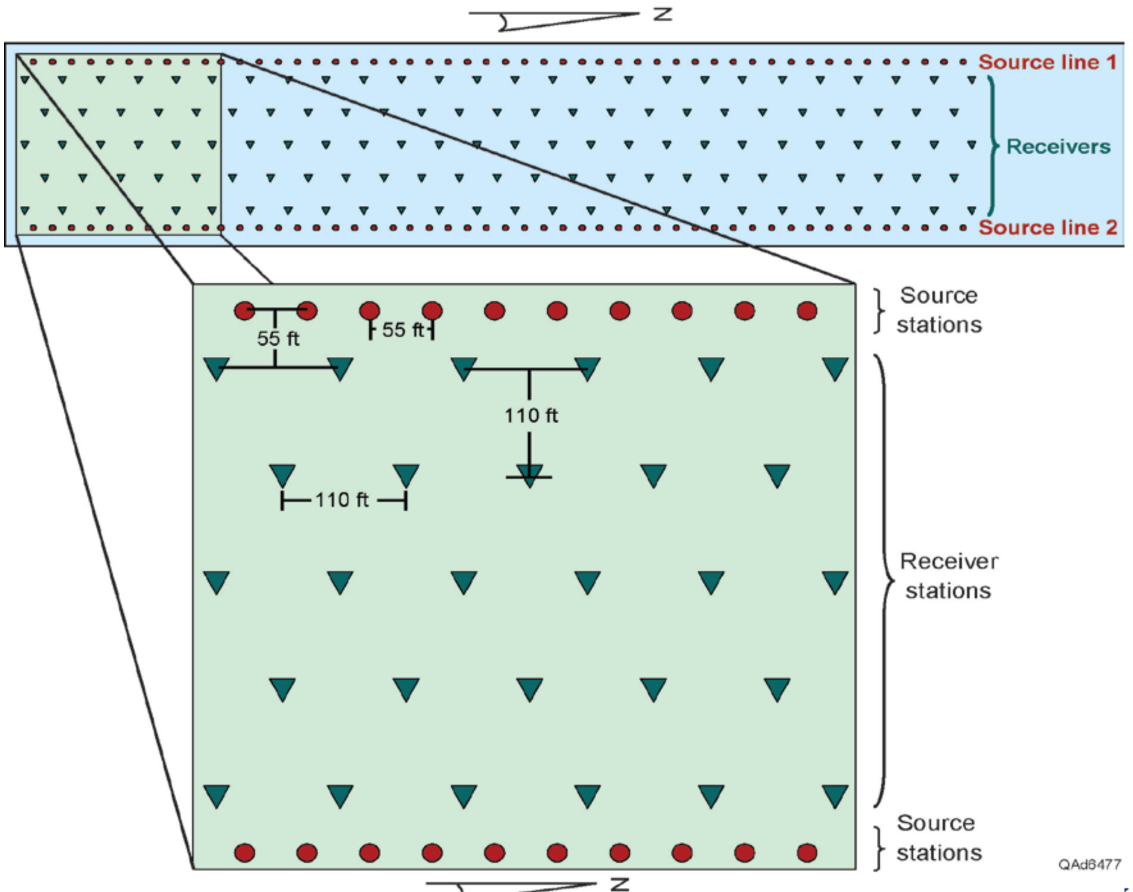
Innovative Seismic Acquisition Design

Pacific Northwest
NATIONAL LABORATORY

Three Component Geophones: Arranged in a 5-Line Swath

Swath design:

- Five 3C receiver lines flanked by two source lines
-
- Frequency 12-120 Hz, 8 sec sweep
- Two vibroseis sweeps per station.
- Recording time 4 sec.



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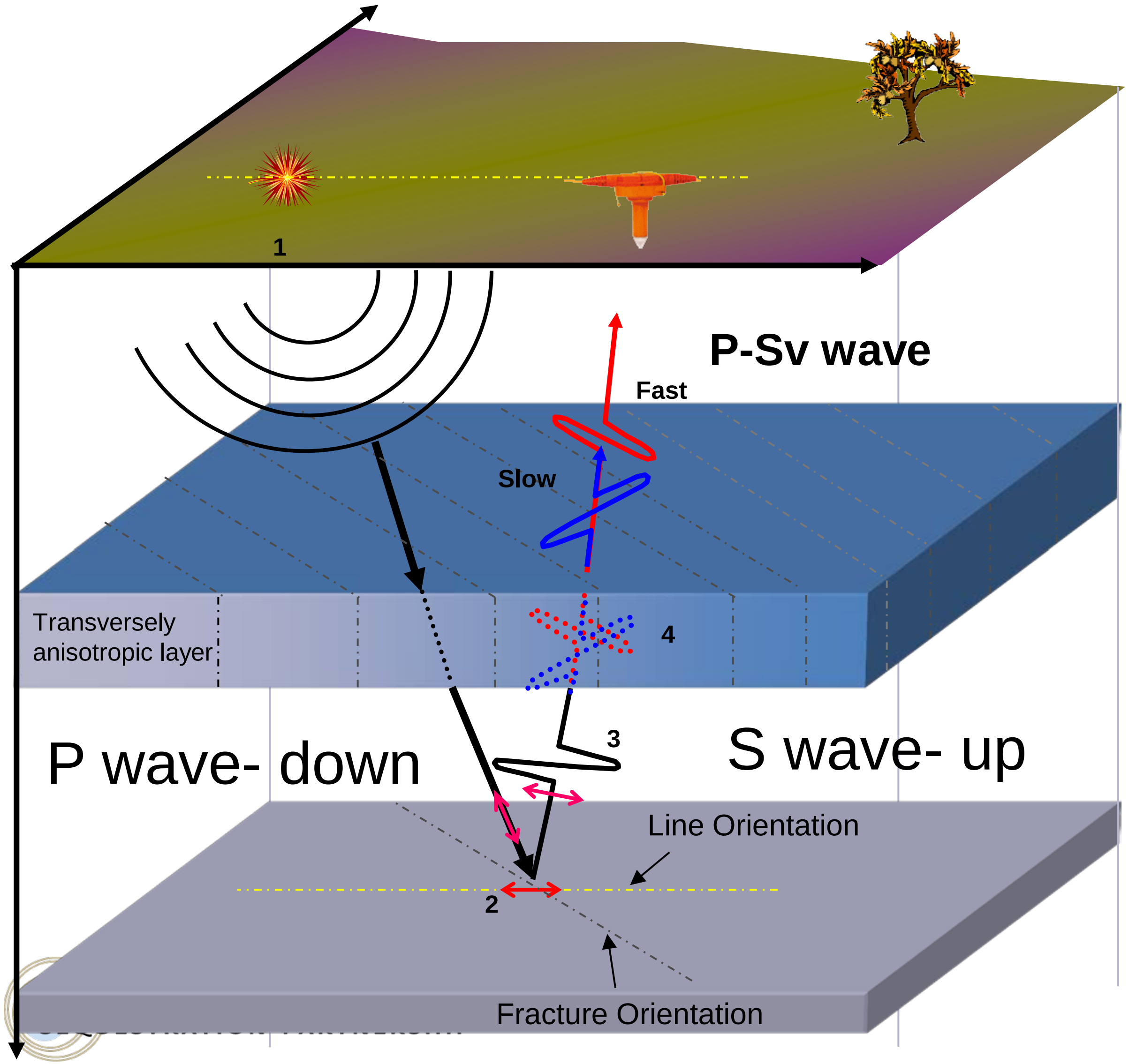
Result: For the first time, able to separate shear-wave noise from the P-wave signal



The surface source generates P-Sv and S-Sv noise that swamps all 3 geophone receivers

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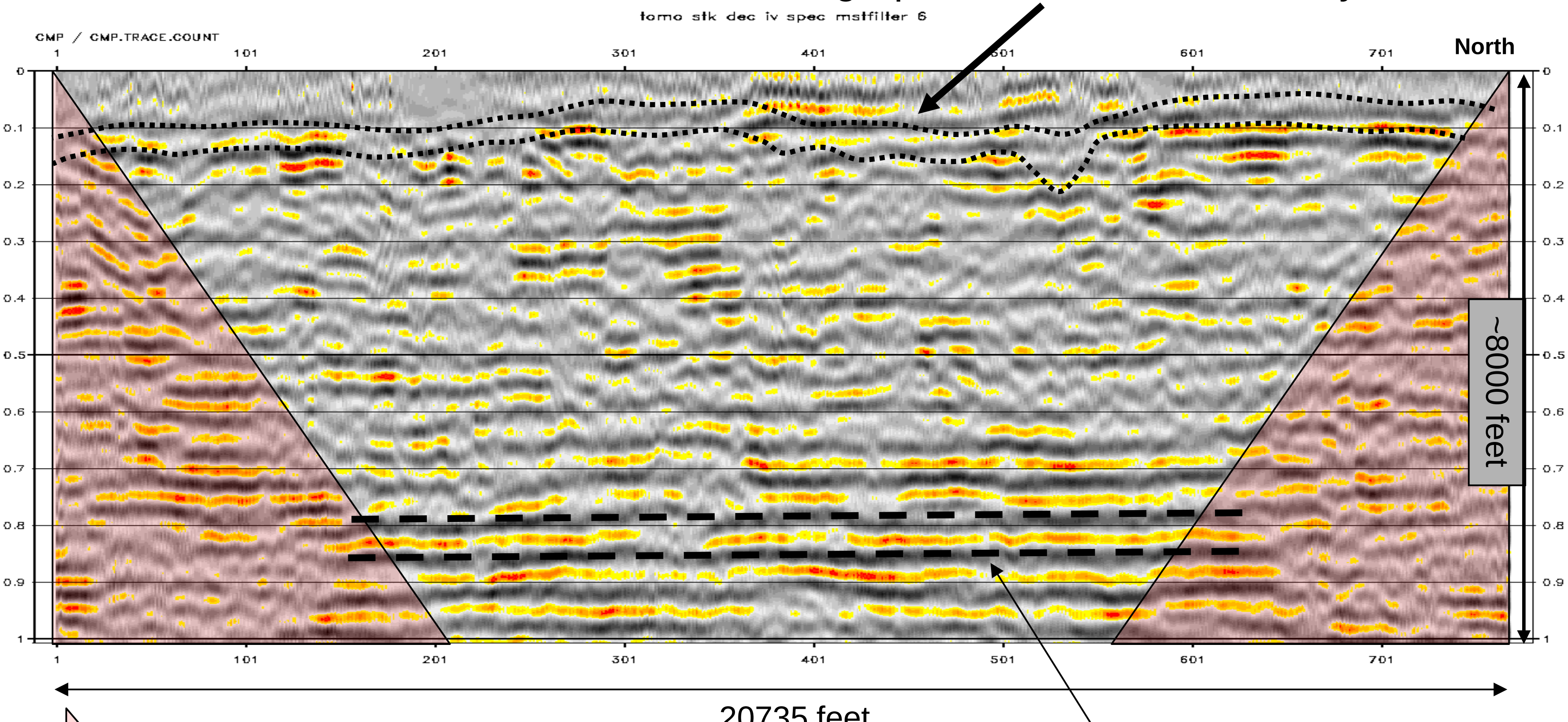
Intermediate Processing Stage

Migrated P-wave section

Approximate shapes of isovels from tomographic near-surface velocity model

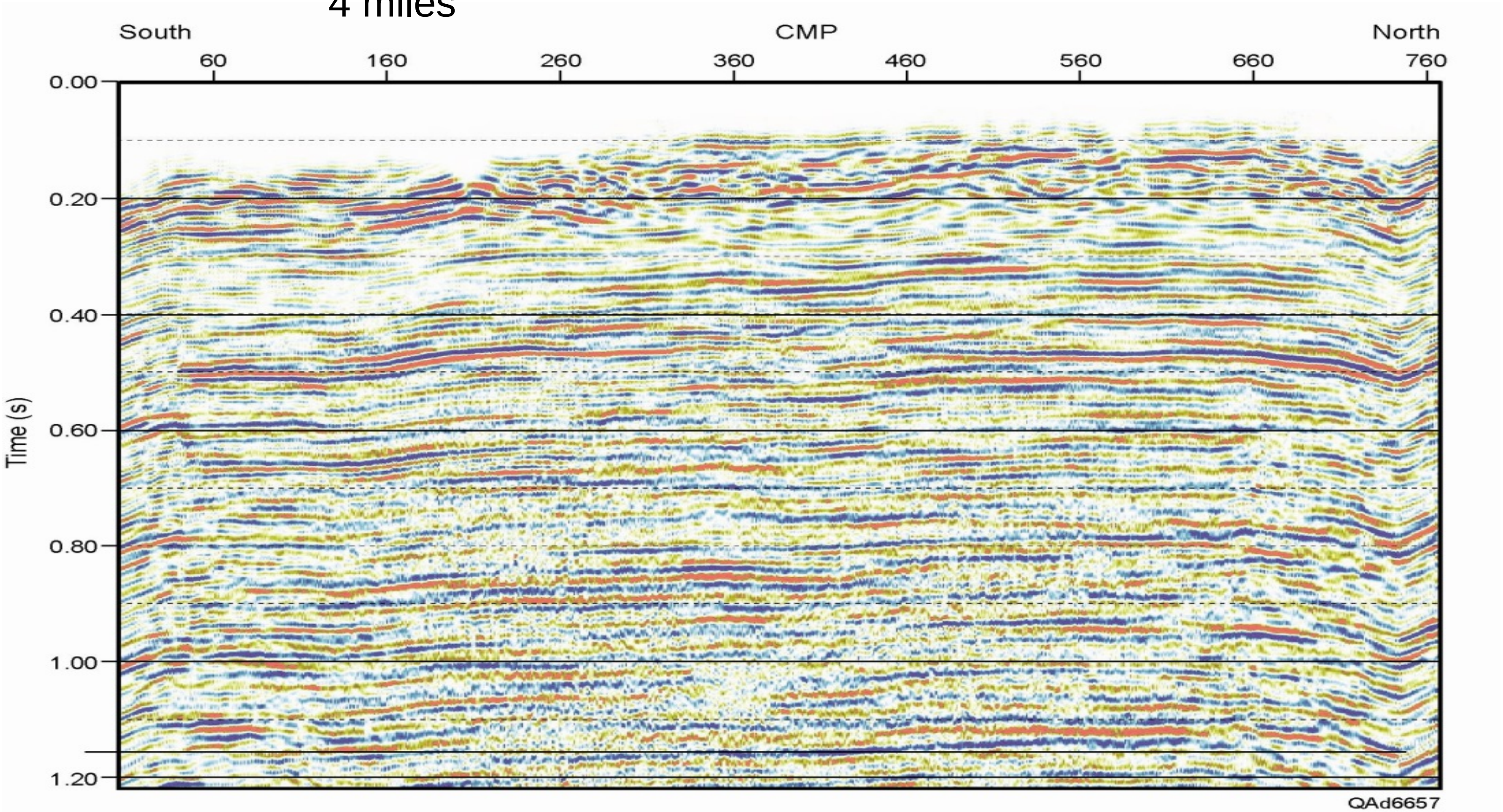


Area of incomplete migration aperture

Planar reflectivity at z ~ 6000'

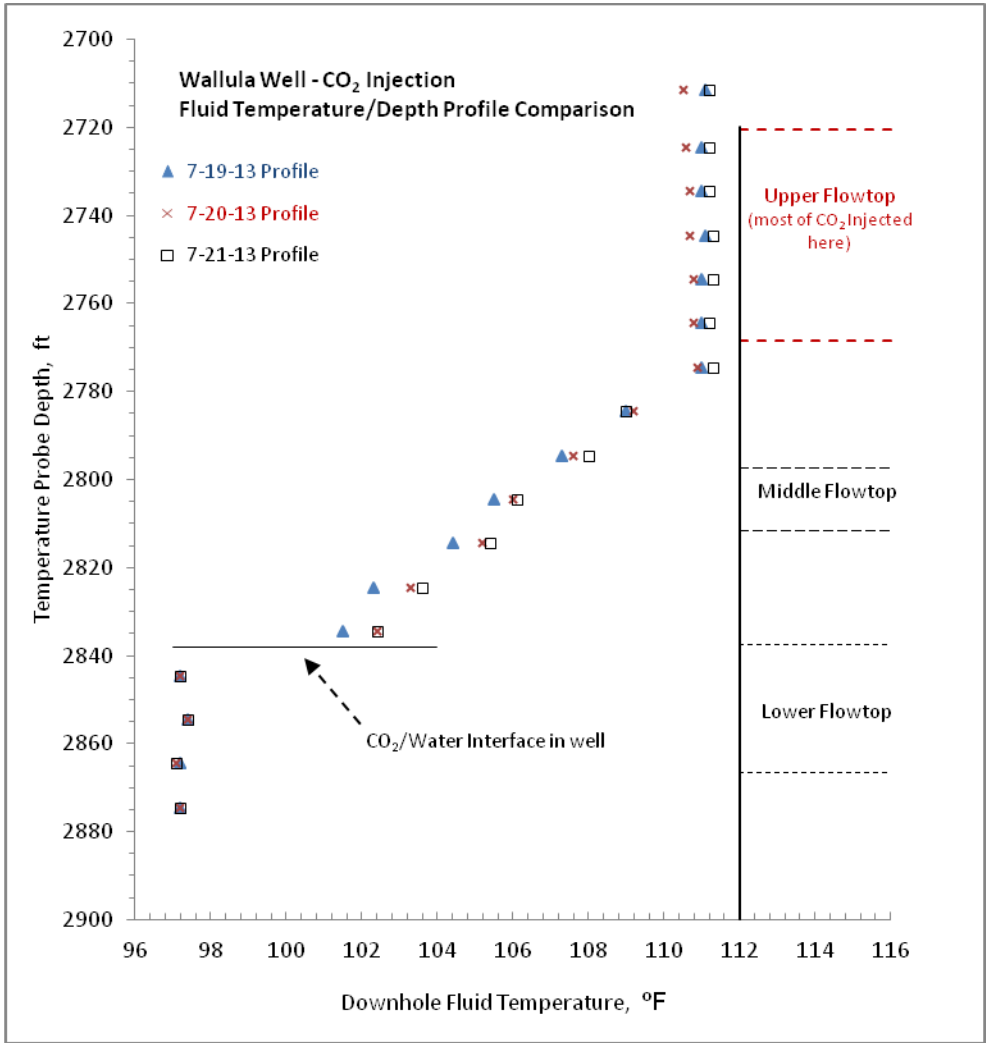
Final Velocity-Filtered Image

4 miles



Two-way time, 1.0 Sec approximately = to 8,000 ft depth

Interpretive Fluid Temperature /Depth Profile Comparison for the Wallula Basalt Pilot CO_2 Injection



Kevin Dome CO_2 Storage Demonstration Project

Lee Spangler
Big Sky Carbon Sequestration Partnership

U.S. Department of Energy
National Energy Technology Laboratory
Review
Aug, 2013

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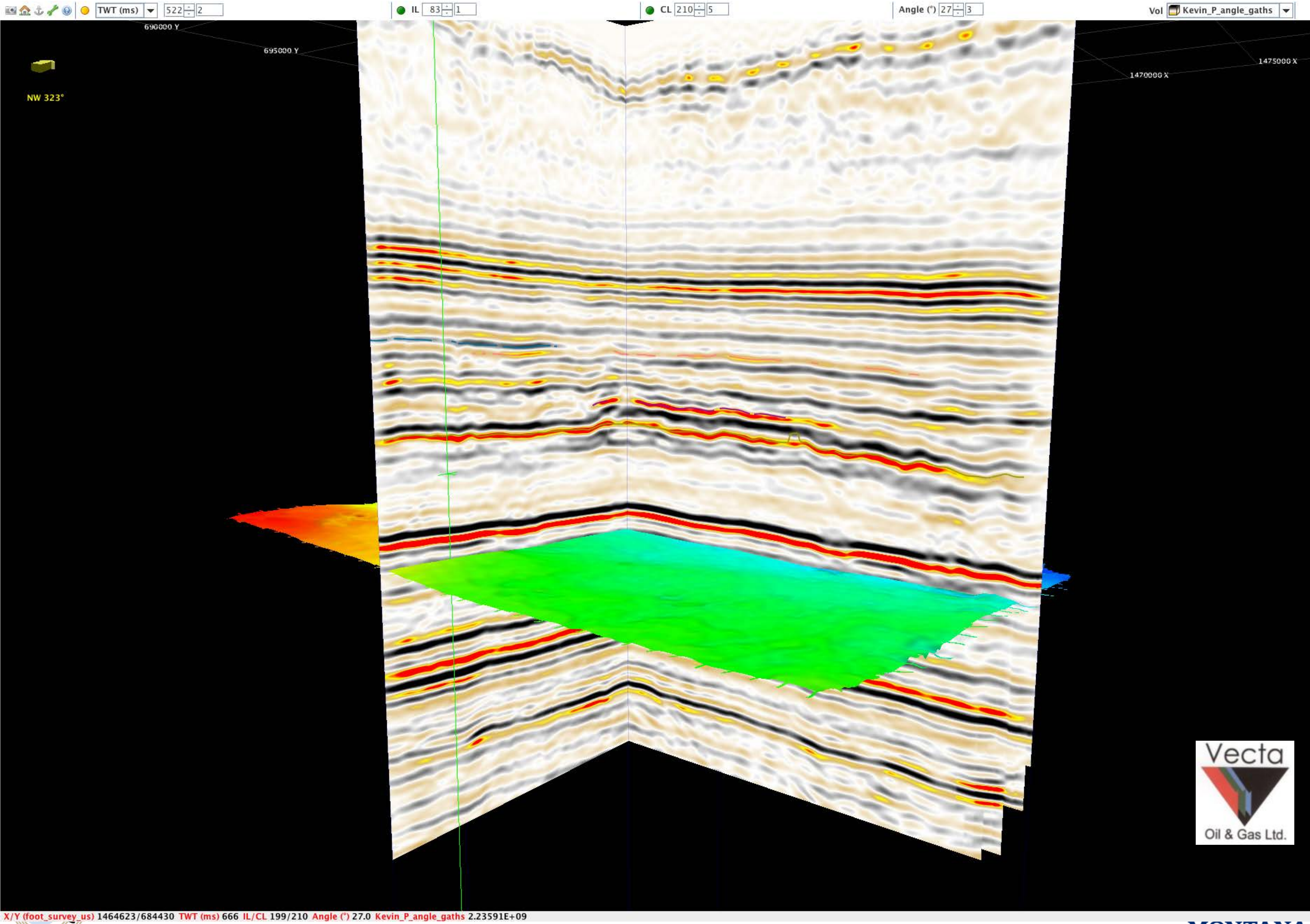
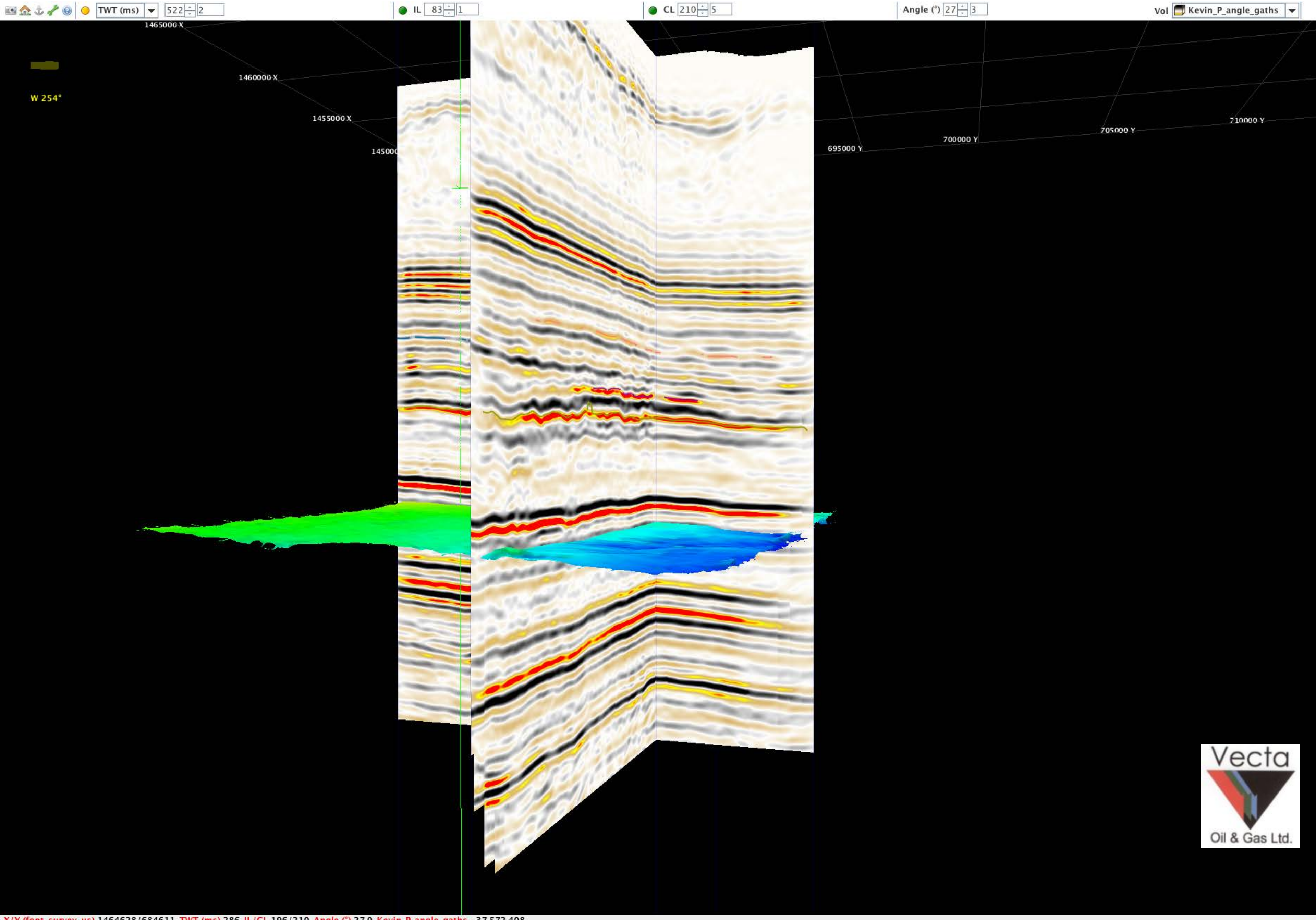
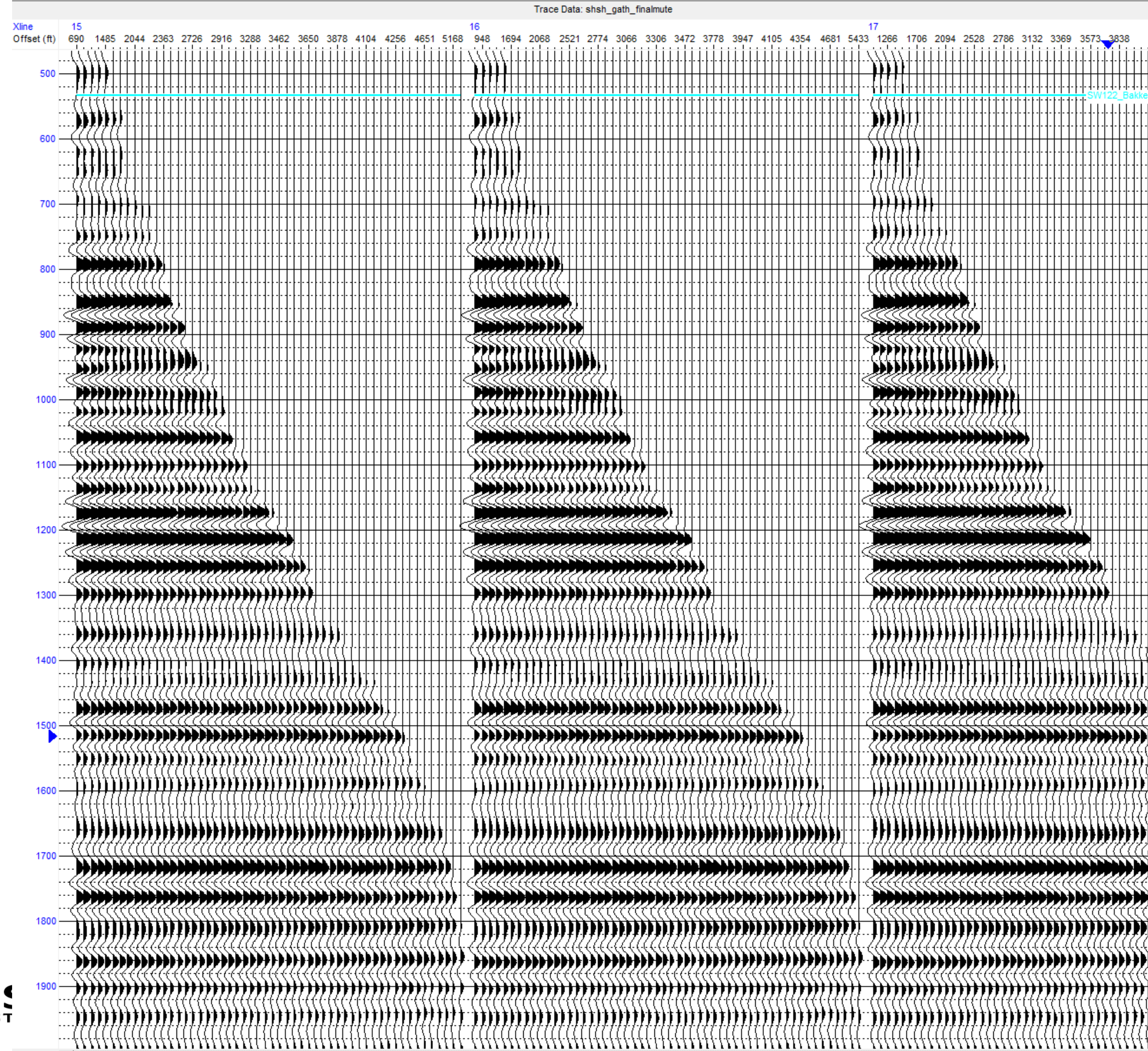


Vecta Oil & Gas Ltd.

MONTANA STATE UNIVERSITY


TWT (ms) 522 2
IL 83 1
CL 210 5
Angle (°) 27 3
Vol Kevin_P_angle_gaths
1465000 X
1460000 X
1455000 X
W 254°
695000 Y
700000 Y
705000 Y
710000 Y
Vecta
Oil & Gas Ltd.
X/Y (foot_survey_us) 1464628/684611 TWT (ms) 286 IL/CL 196/210 Angle (°) 27.0 Kevin_P_angle_gaths -37,572,408



BIG S
SEQUEST

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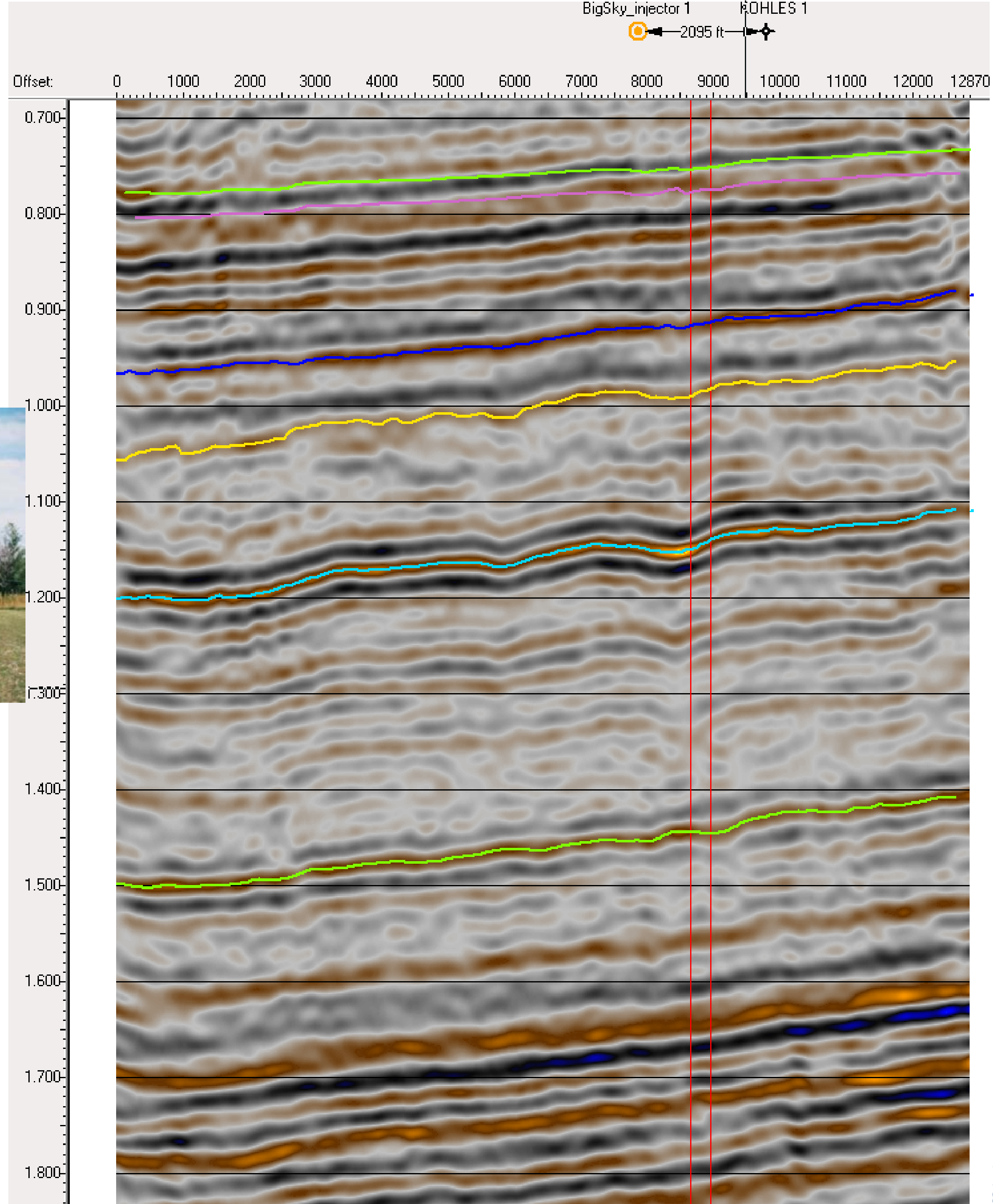

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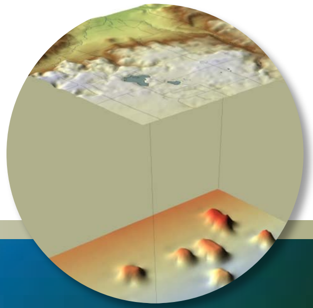
MRCSP Onshore Monitoring Experience

Carbon Storage R&D Project Review
Pittsburgh
August 20-22, 2013



Neeraj Gupta, Ph.D.
Senior Research Leader
Battelle, Columbus, Ohio
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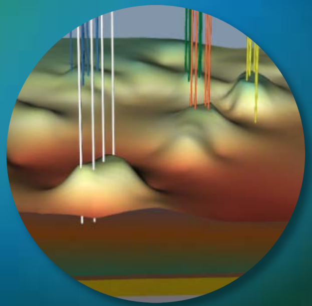

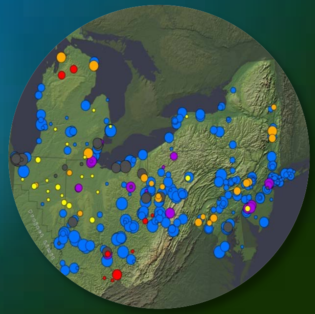

Site specific monitoring has been conducted at four MRCSP projects

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The Business of Innovation

Phase II (Michigan Basin, Appalachian Basin and Cincinnati Arch)

- Class V Permits
- Deep saline reservoir targets (3500 to 8000 ft)
    - Carbonates and sandstones
- Plans developed based on target depth, available existing wells, total injection amount, and regulatory requirements
- Injection is completed and all sites are closed

Phase III Michigan Basin (Core Energy's EOR Fields)

- Class II EOR permits
- Target includes multiple Niagaran reef oil fields
- Operational since early 2013
- Extensive monitoring suite in multiple fields

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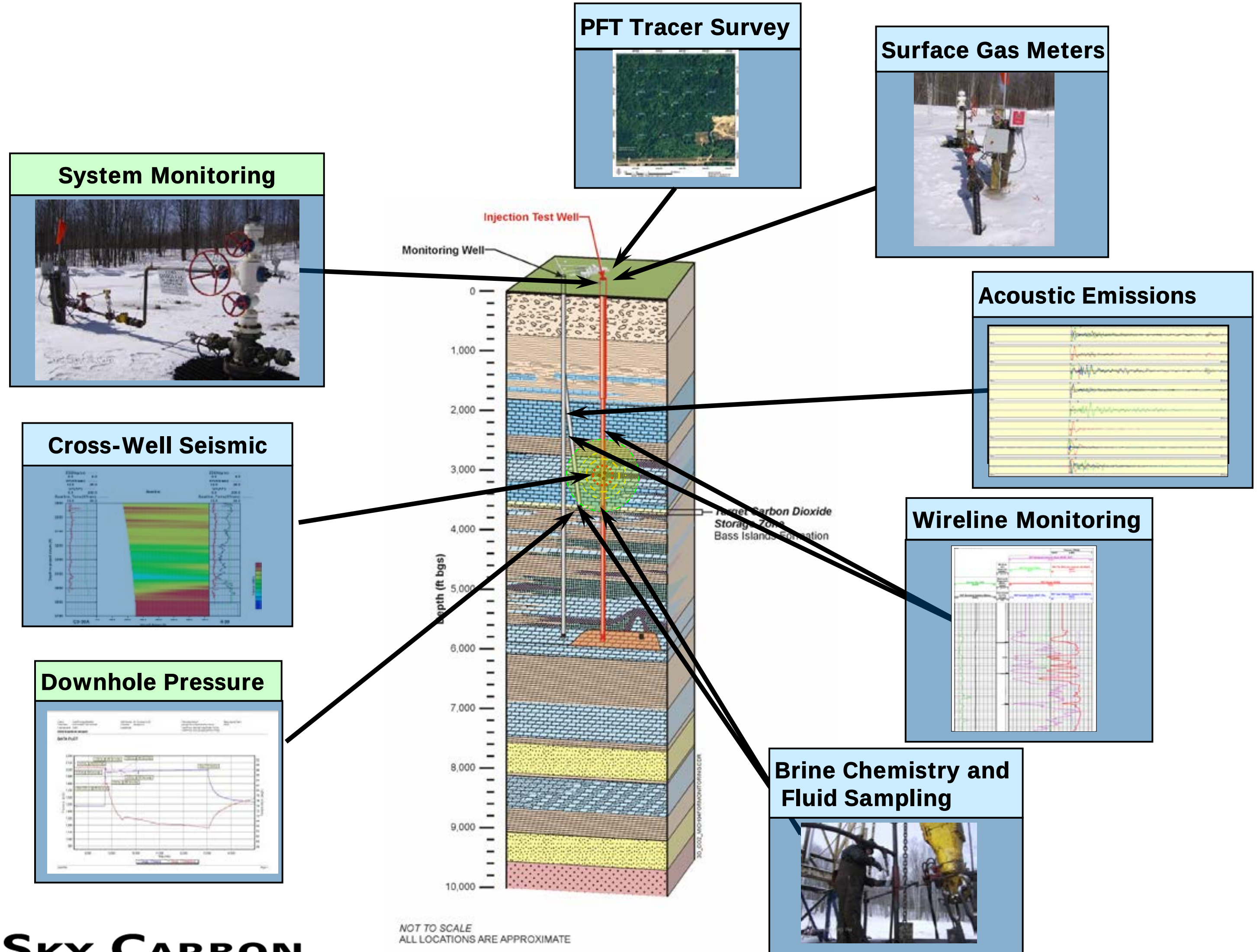
The Business of Innovation

Phase II Michigan MVA Program allowed for small scale testing of multiple technologies



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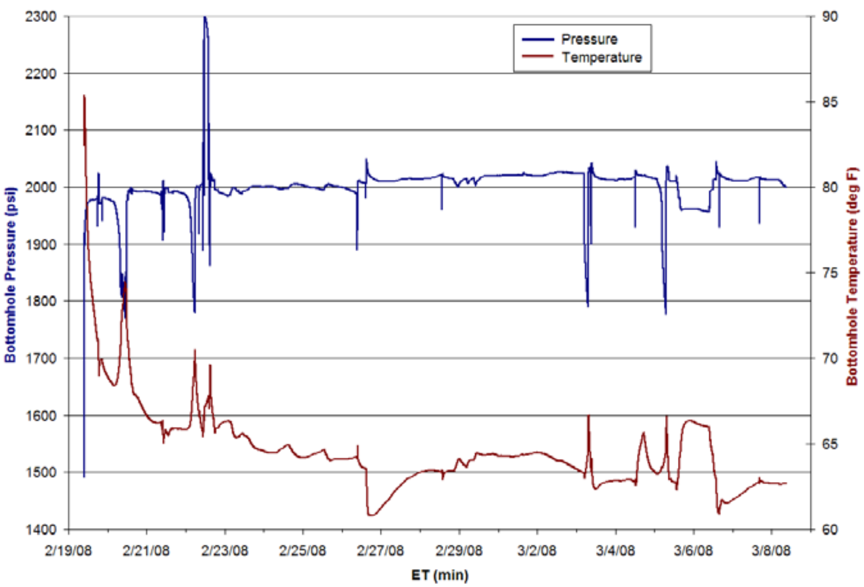
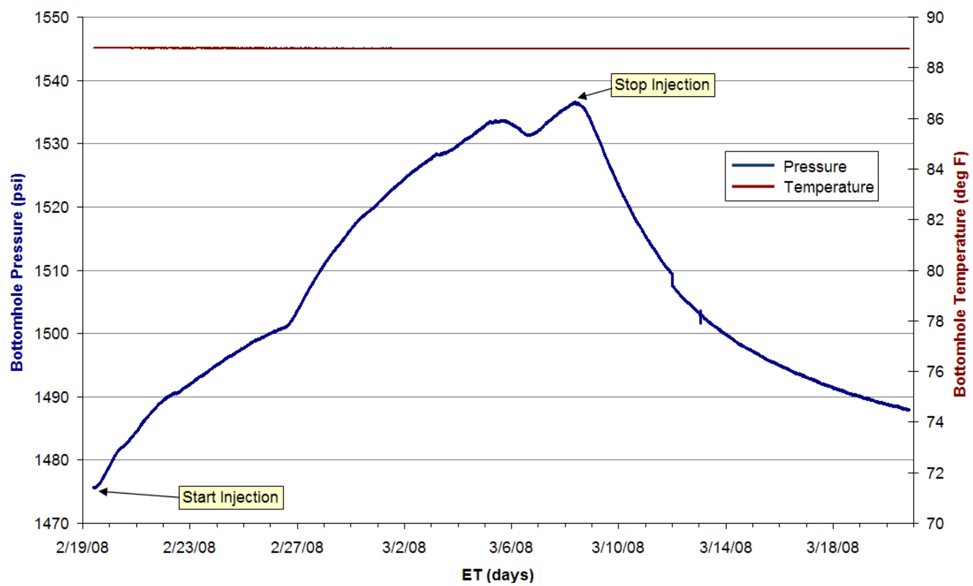
Pressure data analysis provides most valuable information for geologic storage

- Pressure testing and monitoring key to every stage of storage projects – characterization, selection, design, safe operations, modeling, monitoring, compliance, risk management, site closure
- Essential for appropriate site conceptualization
- Relatively low cost and simple for surface or downhole gauges
- Used effectively at every site, including Phase III closed reservoirs



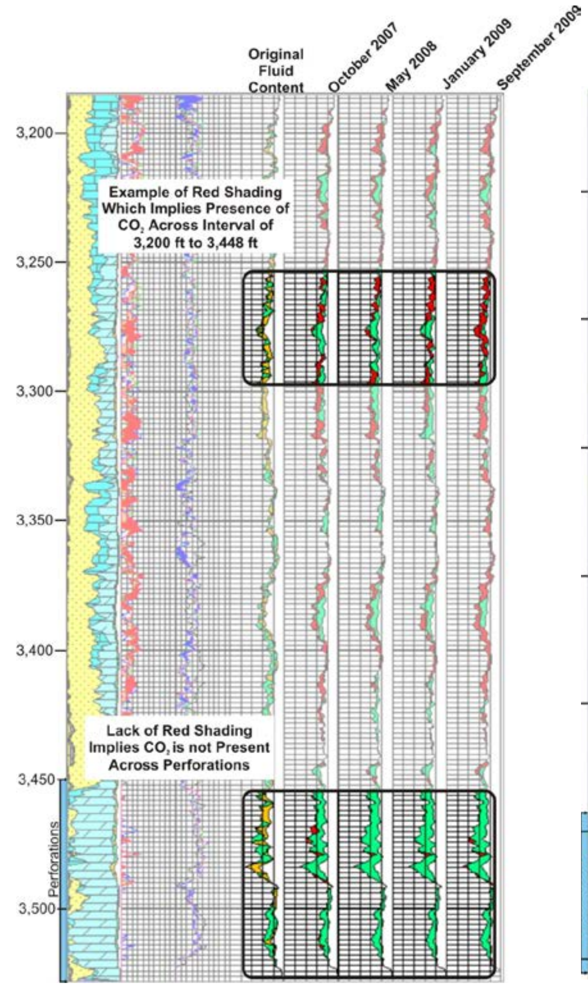
MRCSP Phase II Michigan C4-30 Injection Well Bottomhole Pressure and Temperature



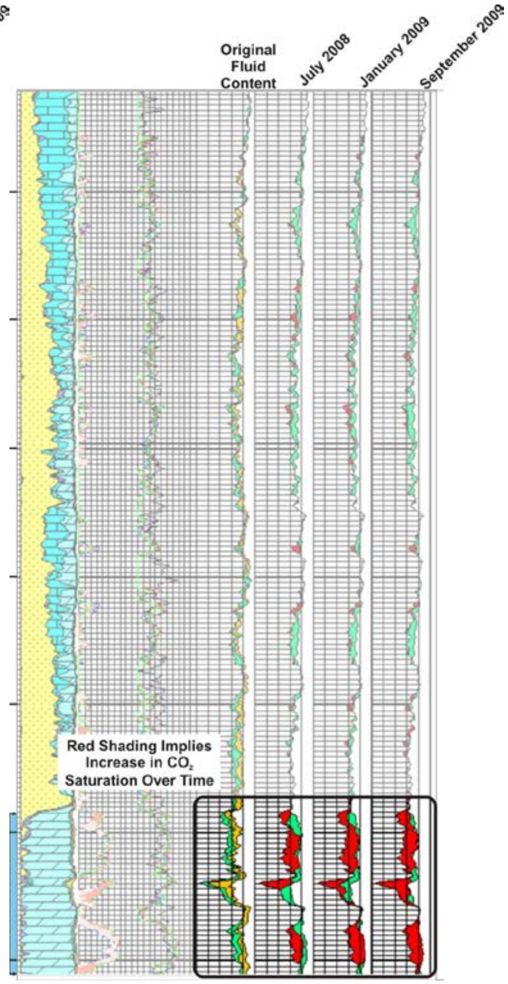
MRCSP Phase II Michigan C3-30 Monitoring Well Bottomhole Pressure and Temperature

PNC logs found to be a useful monitoring tool

- Useful for vertical mapping of fluids and subsurface migration
- Helped validated seismic (VSP) observations
- Complexities
  - CO_2 vs. methane
  - Oil vs. CO_2
  - Well workover, pressure control can affect observations by changing saturations



Phase II Michigan Monitoring Well PNC Logs



Phase II Michigan Injection Well PNC Logs

Cross well seismic used to image CO_2 plume before and after both injection episodes

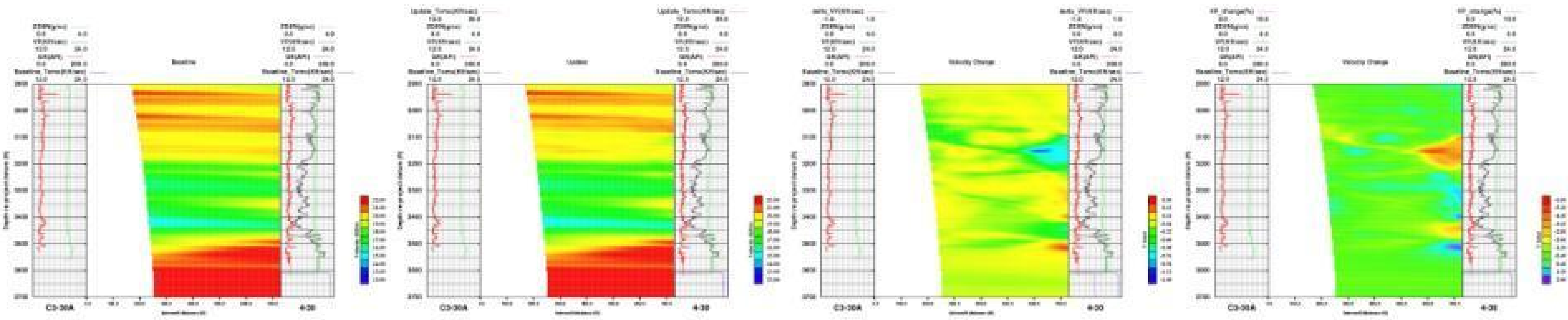
- Useful for evaluating CO_2 migration in complex setting
- Data validated through PNC logs, cased-hole sampling, cement evaluation etc.
- However, seismic technologies challenging for large-scale due cost, size, permitting, uncertainties

Baseline Survey

Repeat Survey

Straight Difference

% change from baseline to repeat



Reds-yellows indicate decreases in velocity

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MRCSP large-scale test site is the only CO_2 – EOR site in the Midwest

Location:
Otsego County, Michigan

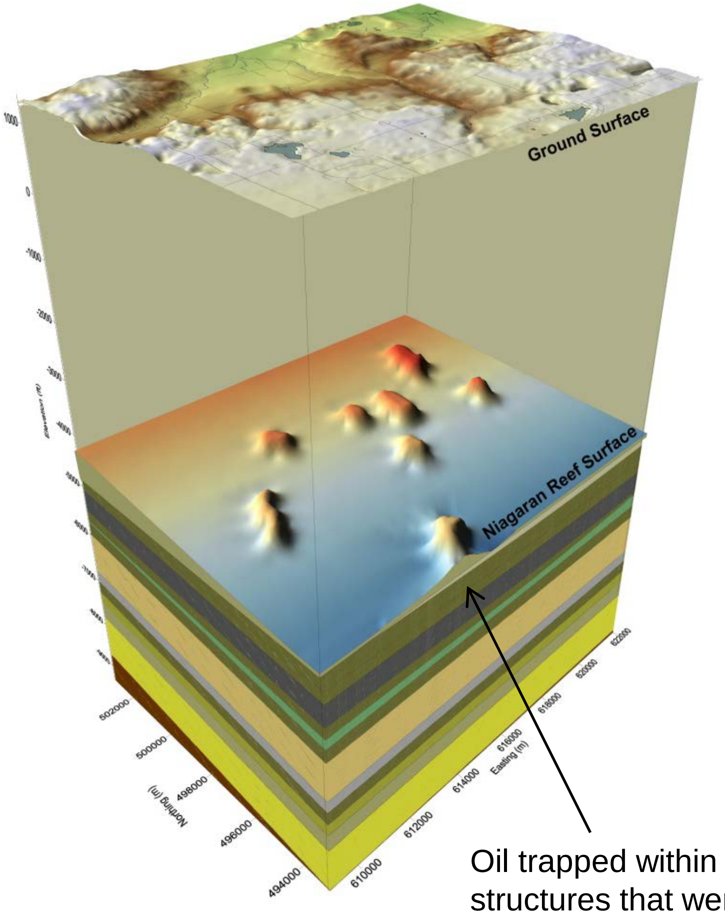
Host Company:
Core Energy LLC

Reservoir Type:
Closely-spaced, highly compartmentalized oil & gas fields located in the Northern Michigan Niagaran Reef Trend

Source of CO_2:
Natural Gas Processing Plant

Injection Goal:
At least 1 million metric tons of CO_2 over ~four years

Status:
Injection and monitoring started during Spring 2013



Oil trapped within ancient buried reef structures that were formed millions of years ago when oceans covered this part of the world.

Monitoring plan is designed to achieve the objectives of the Phase III field test

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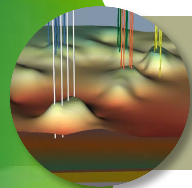
Site Characterization

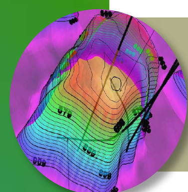


Assess the variability among adjacent reefs

Reservoir Models

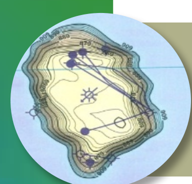
Validate using injection and production volumes

Operational Models



Predict CO_2 storage and oil production; suggest approaches to optimize both

Monitoring Techniques and Equipment

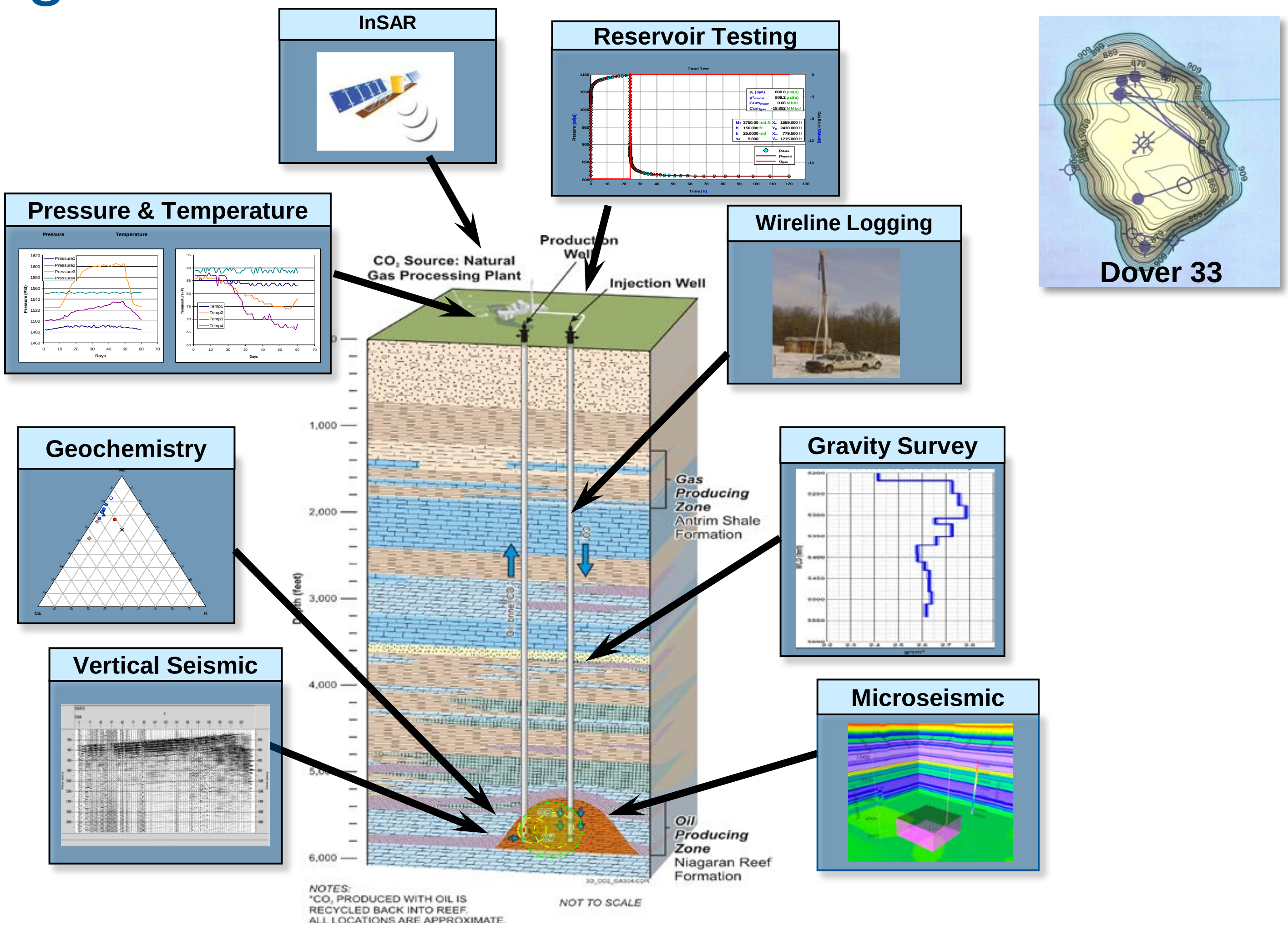


Identify cost effective and useful techniques and methods

Reef Capacity and Injectivity

Identify key parameters and variability; address uncertainty

Dover 33, a late stage field, is our test bed for identifying cost effective and useful monitoring methods



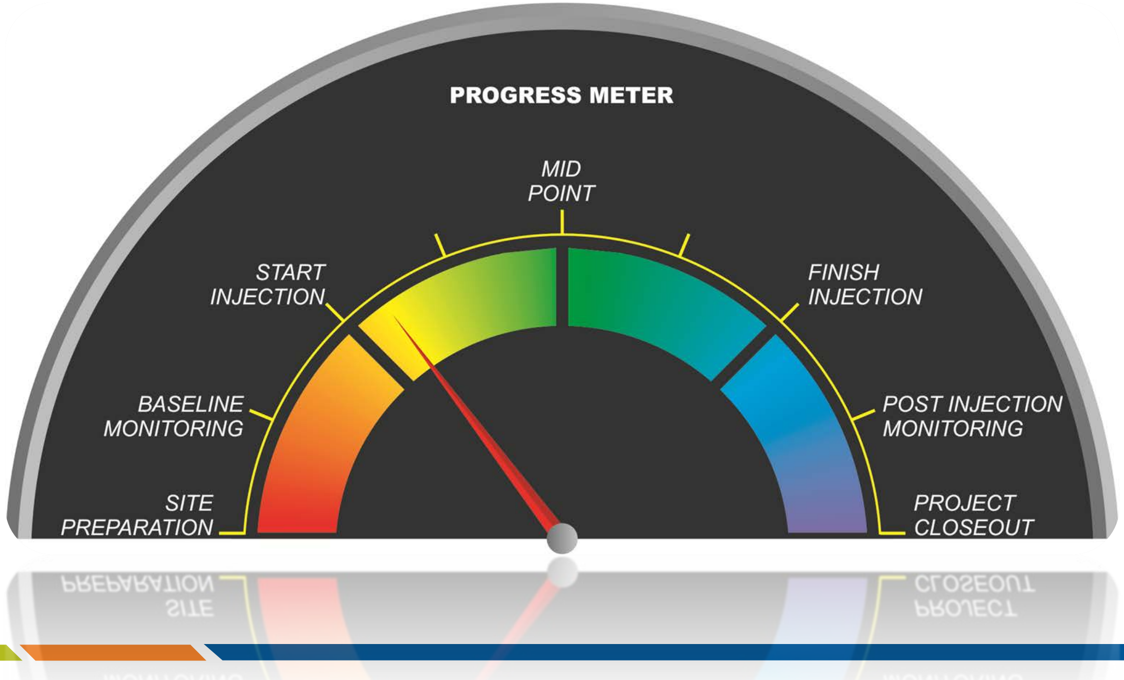
Monitoring options under testing at Dover 33 field

Monitoring schedule for Dover 33

Activity	Before Injection	Early Injection	Mid Injection	Late Injection	After Injection
CO_2 Injection		X	X	X	
Pressure and temperature	X	X	X	X	X
Wireline Logging	X		X		X
Fluid Sampling	X		X		X
Borehole Gravity	X				X
VSP	X				X
Microseismic	X			Maybe	
InSAR	X	X	X	X	X

MRCSP will continue to monitor reef after injection

- Late-stage reef injection began April 2013 (~80K tCO2 by July 2013)
- Up to 500,000 tonnes of CO_2 over the next 2 to 3 years
- Additional fields will be selected for new CO_2-EOR tests
- More than 125,000 tonnes injection/recycling monitored in active reefs by July 2013
- Wells returned for normal operations by Core Energy at the end



MVA technologies need to be tested more extensively to increase robustness, reliability, and confidence

- Small-scale tests have been very useful for testing technologies
- Monitoring experience also builds credibility for large-scale tests
- No substitute for actual field deployment
- This calls for more small-scale demonstrations along with the larger-scale projects and collaboration with oil industry
- Pressure monitoring is fundamental technique for storage life-cycle
- Seismic technologies appear useful but could be challenging at commercial-scale for some geologic settings and due to cost, logistics, area of investigation, and data uncertainty

PCOR Partnership's Approach to MVA for CO_2 EOR Projects

Carbon Storage R&D Project Review Meeting
Developing the Technologies and Infrastructure for CCS

Pittsburgh, Pennsylvania
August 20, 2013

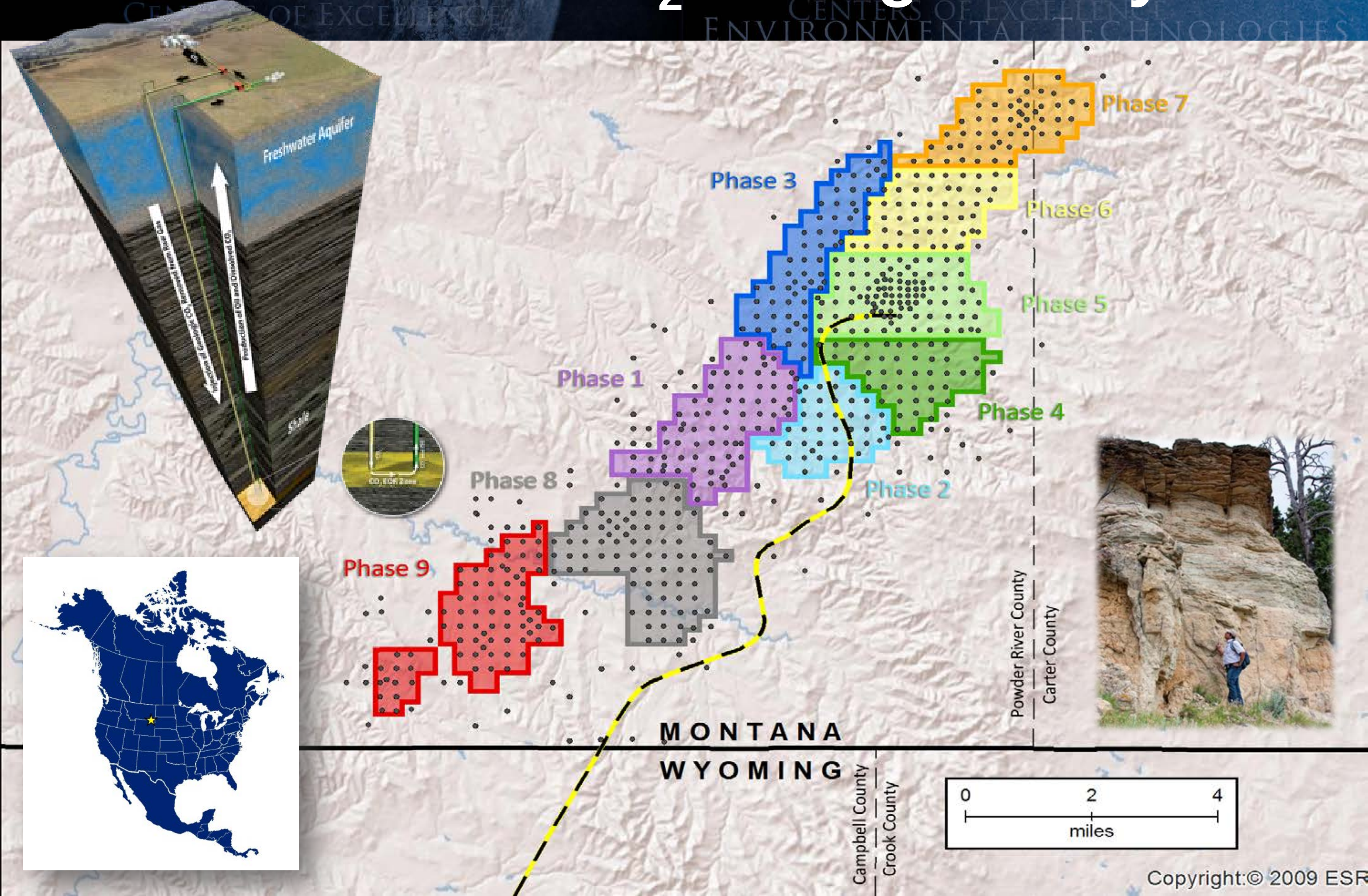
Charles Gorecki
Senior Research Manager

Energy & Environmental Research Center (EERC)…
The International Center for Applied Energy Technology®

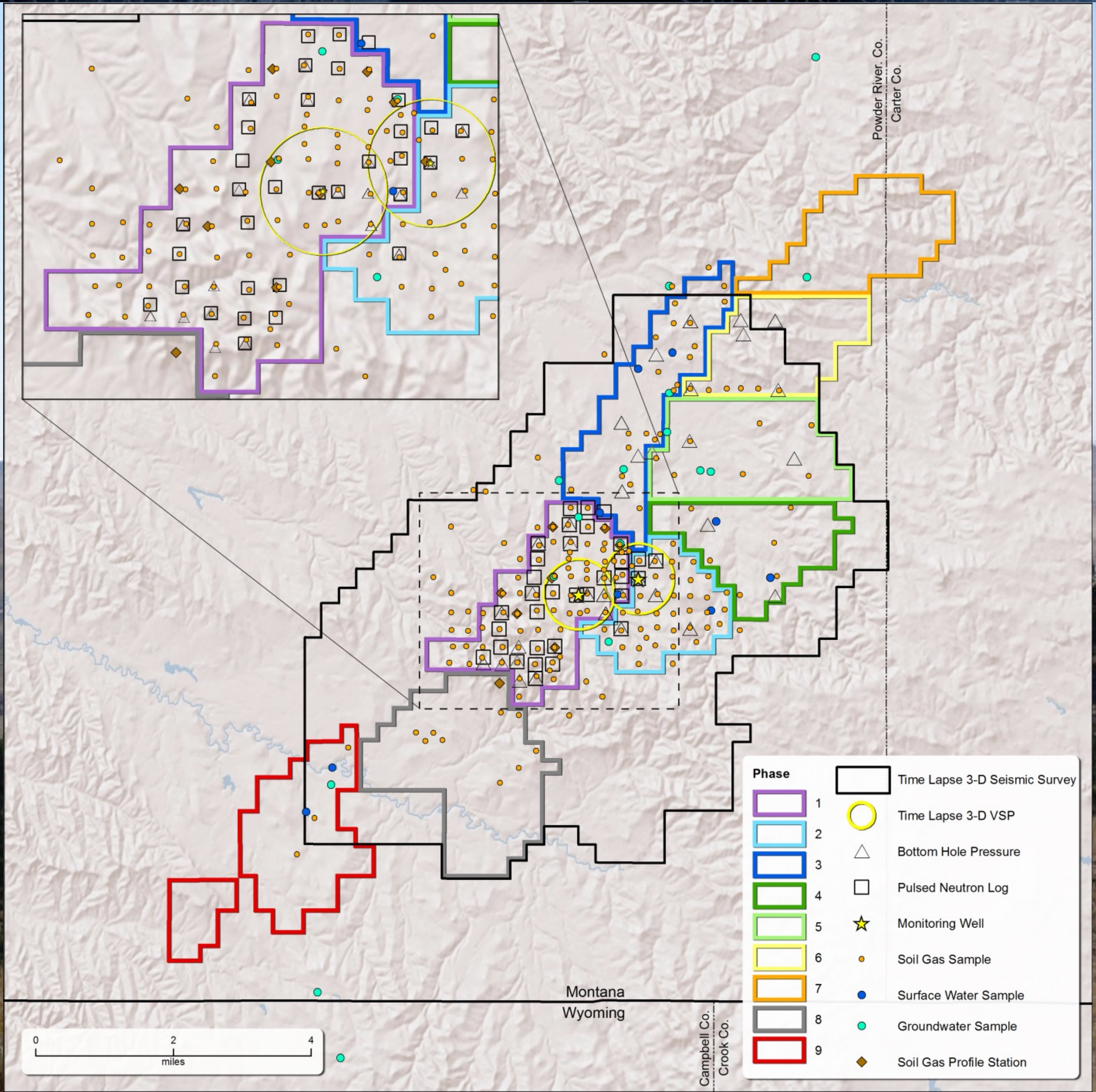
PCOR Partnership Objectives

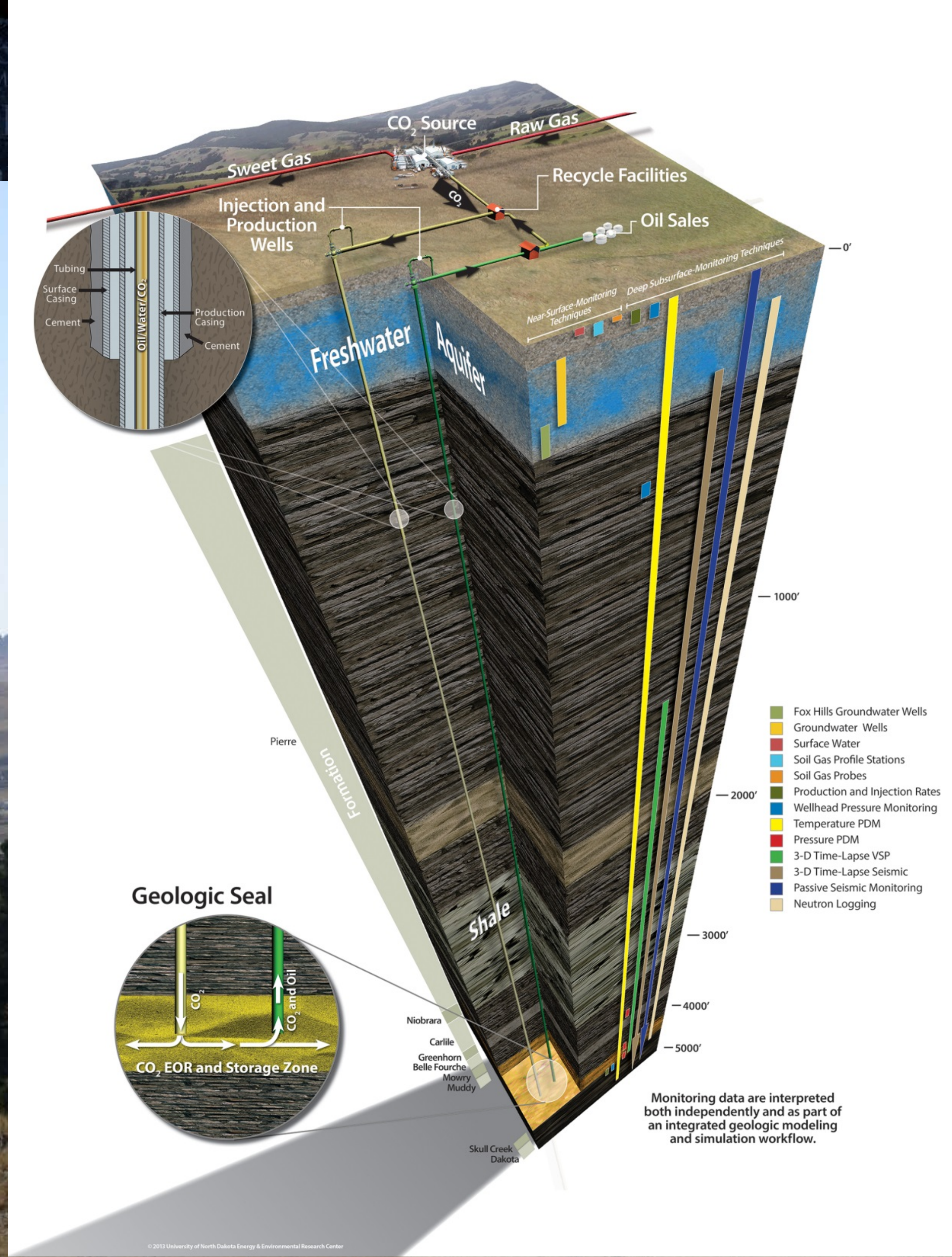
- Safely and permanently achieve carbon dioxide (CO_2) storage on a commercial scale in conjunction with enhanced oil recovery (EOR).
- Demonstrate that oil-bearing formations are viable sinks with significant storage capacity to help meet near-term U.S. objectives.
- Establish monitoring, verification, and accounting (MVA) methods to safely and effectively monitor commercial-scale simultaneous CO_2 EOR and CO_2 storage projects.
- Utilize the commercial 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 relationship between the CO_2 EOR process and long-term storage of CO_2.

Bell Creek CO_2 Storage Study



Monitoring Locations




CO2 Source
Raw Gas
Sweet Gas
CO2
Recycle Facilities
Injection and Production Wells
Oil Sales
Tubing
Surface Casing
Cement
Oil/Water/CO2
Production Casing
Cement
Near-Surface-Monitoring Techniques
Deep Subsurface-Monitoring Techniques
0′
Freshwater
Aquifer
1000′
2000′
3000′
4000′
5000′
Pierre
Formation
Shale
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
Geologic Seal
CO2
CO2 and Oil
CO2 EOR and Storage Zone
Niobrara
Carlile
Greenhorn
Belle Fourche
Mowry
Muddy
Skull Creek
Dakota
Monitoring data are interpreted both independently and as part of an integrated geologic modeling and simulation workflow.
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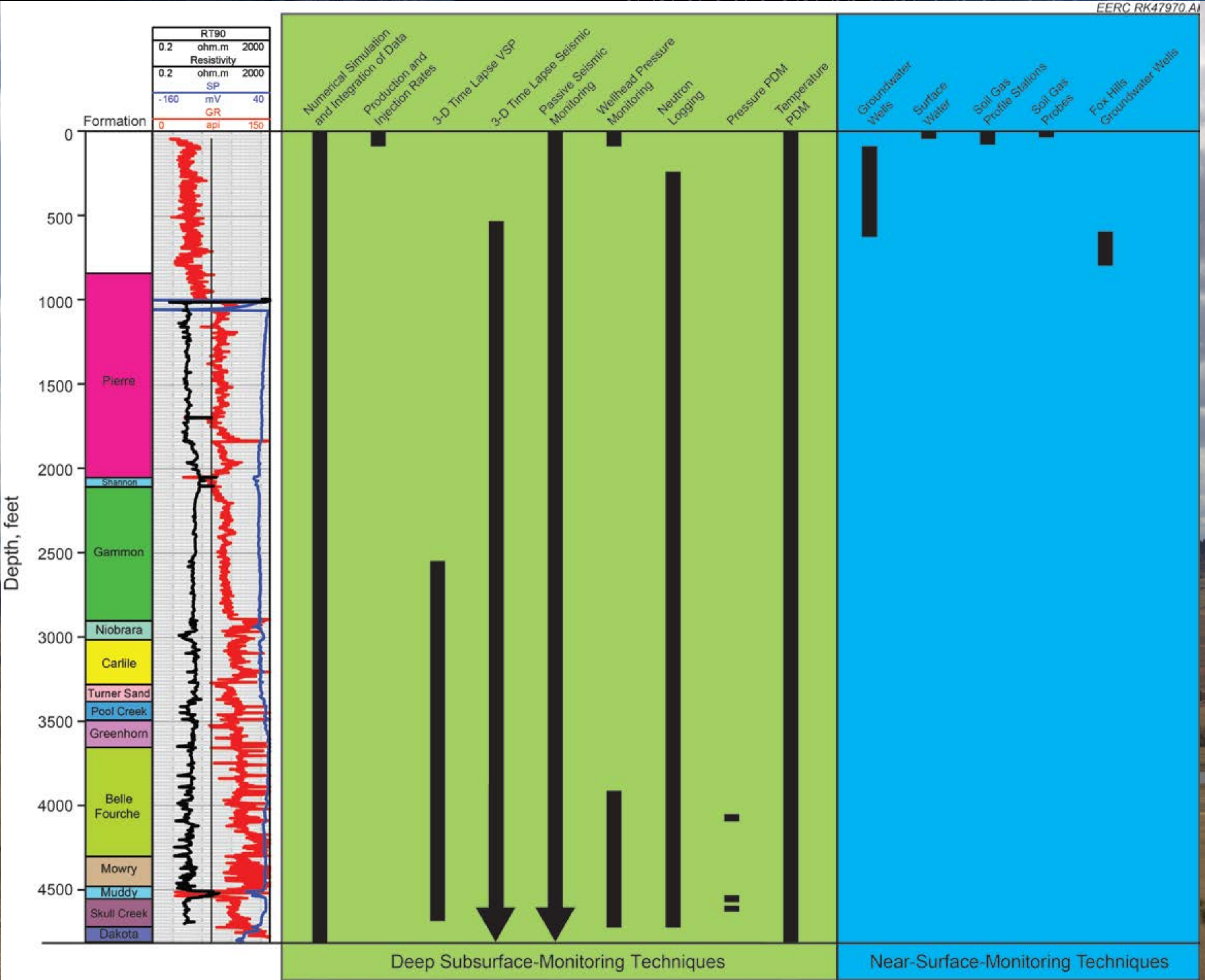
Monitoring Techniques



Deep Subsurface MVA Goals

The goal of the deep subsurface MVA program is to effectively monitor and track the movement of injected CO_2 and reservoir fluids in the deep subsurface in order to evaluate storage efficiency, demonstrate safe and effective storage, identify fluid migration pathways, and determine the fate of injected CO_2.

"Utilize economical technologies which provide high value to both the CO_2 storage and EOR components of the project where possible and have minimal impact to commercial EOR operations."

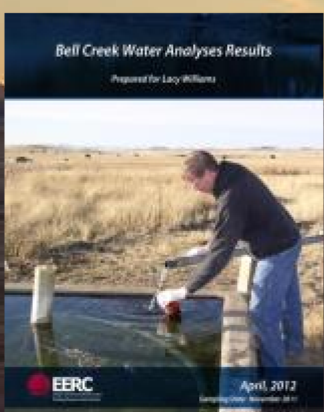
Near-Surface MVA Goals

The purpose of the near-surface-monitoring program is twofold:

1) To establish baseline conditions for naturally occurring CO_2 levels present in surface water, soil, and shallow groundwater aquifers in the vicinity of the carbon storage formation.
2) To provide a source of data to show that surface environments remain unaffected by fluid or gas migration and to identify the source and quantify the impact of an out-of-zone migration event should it occur.

Lessons Learned

- Keys to success
  - Integrated approach to MVA, risk assessment, characterization, modeling, and simulation.
  - Strong industry partnerships.
  - Public engagement and landowner relations.
  - Adequate planning and contingency plans during drilling and monitoring operations.
  - Communication
    - ♦ Providing clear objectives to service providers and stakeholders.



Contact Information

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Charlie Gorecki, Senior Research Manager
PCOR Partnership Program Manager
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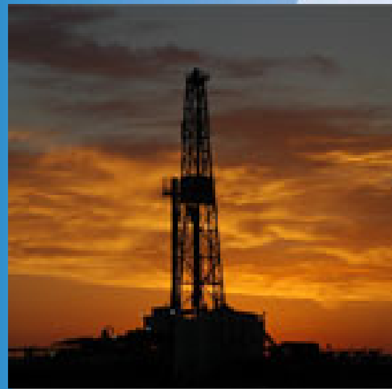

Commercial & Experimental Monitoring at SECARB's Anthropogenic Test Site

George J. Koperna, Jr. , VP

Advanced Resources International, Inc.

Carbon Storage R&D Project Review Meeting
21 August 2013, Pittsburgh, PA

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Acknowledgement

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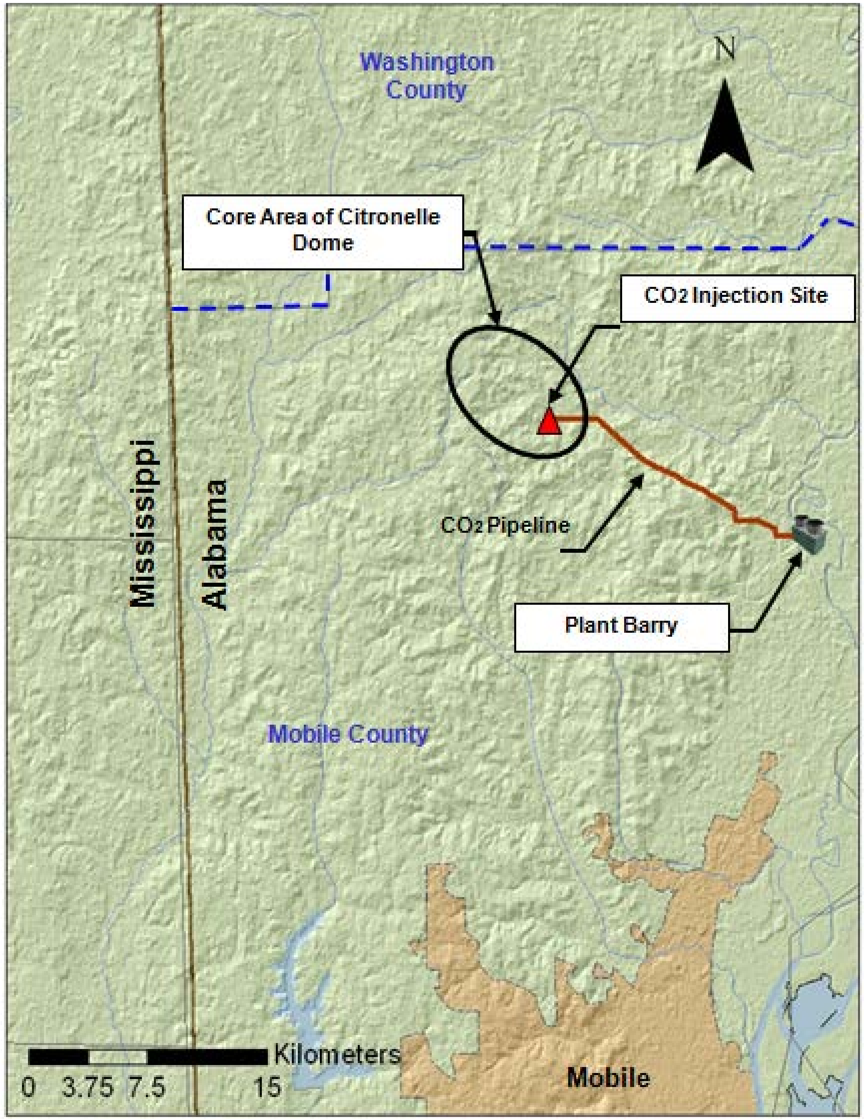
Storage Overview



Project Schedule and Milestones

The CO_2 capture unit at Alabama Power's (Southern Co.) Plant Barry became **operational in 3Q 2011.**

A newly built 12 mile CO_2 pipeline from Plant Barry to the Citronelle Dome **completed in 4Q 2011.**

A characterization well was drilled in **1Q 2011 to confirmed geology.**

Injection wells were drilled in **3Q 2011**.

100k – 300k metric tons of CO_2 will be injected into a saline formation **began 3Q 2012.**

3 years of post-injection monitoring.

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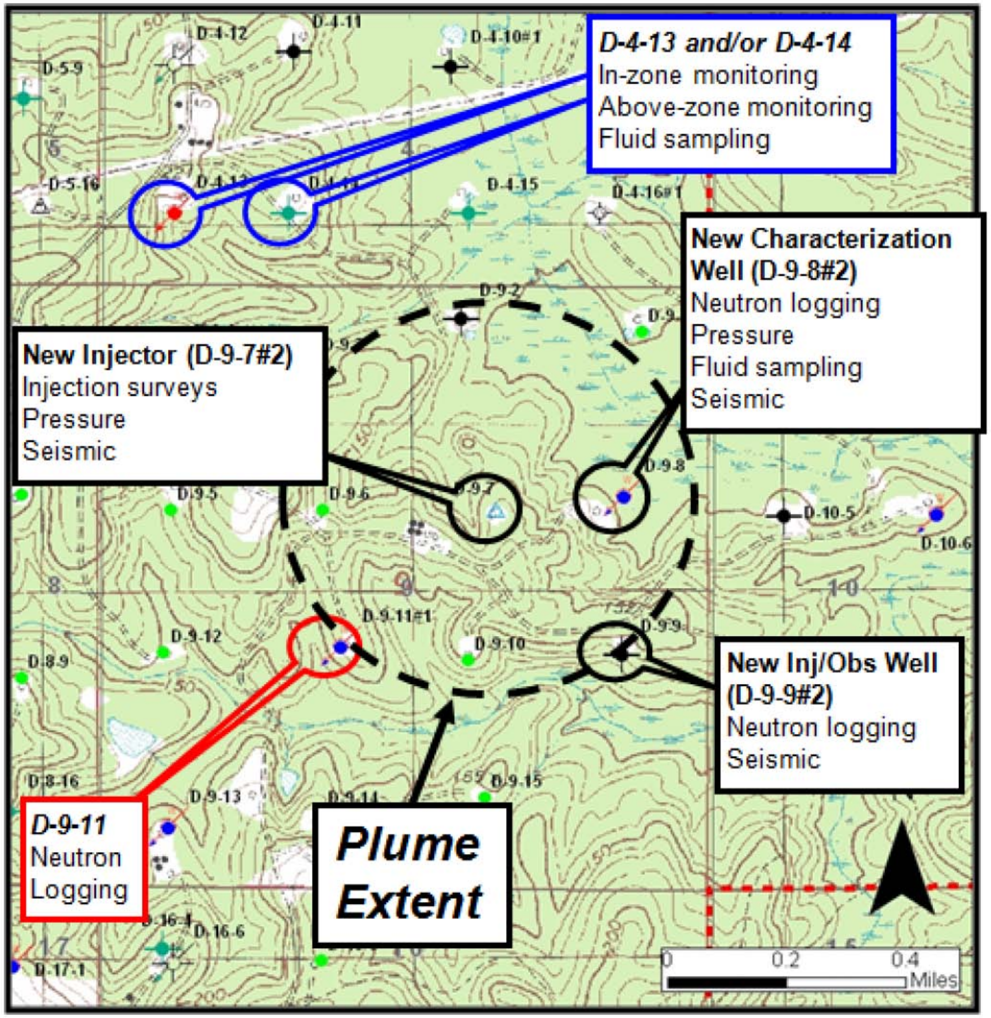
MVA Sample Locations



- One Injector (D-9-7 #2)
- Two deep Observation wells (D-9-8 #2 & D-9-9 #2)
- Two in-zone & above zone Monitoring wells (D-4-13 & D-4-14)
- One PNC logging well (D-9-11)
- Twelve soil flux monitoring stations

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Design of MBM for Citronelle

Tools Deployed with MBM:

- Discrete Pressure & Temperature (2 Quartz Gauges)
- Distributed Temperature Sensing (DTS) with Heater (Heat-Pulse)
- Fluid Sampling (U-tube)
- Seismic monitoring 18 clamping geophones
- Distributed Acoustic Sensing (DAS)

The Citronelle MBM Improvement over Cranfield = Flatpack and Geophone Cable (one line deployment vs. 7)

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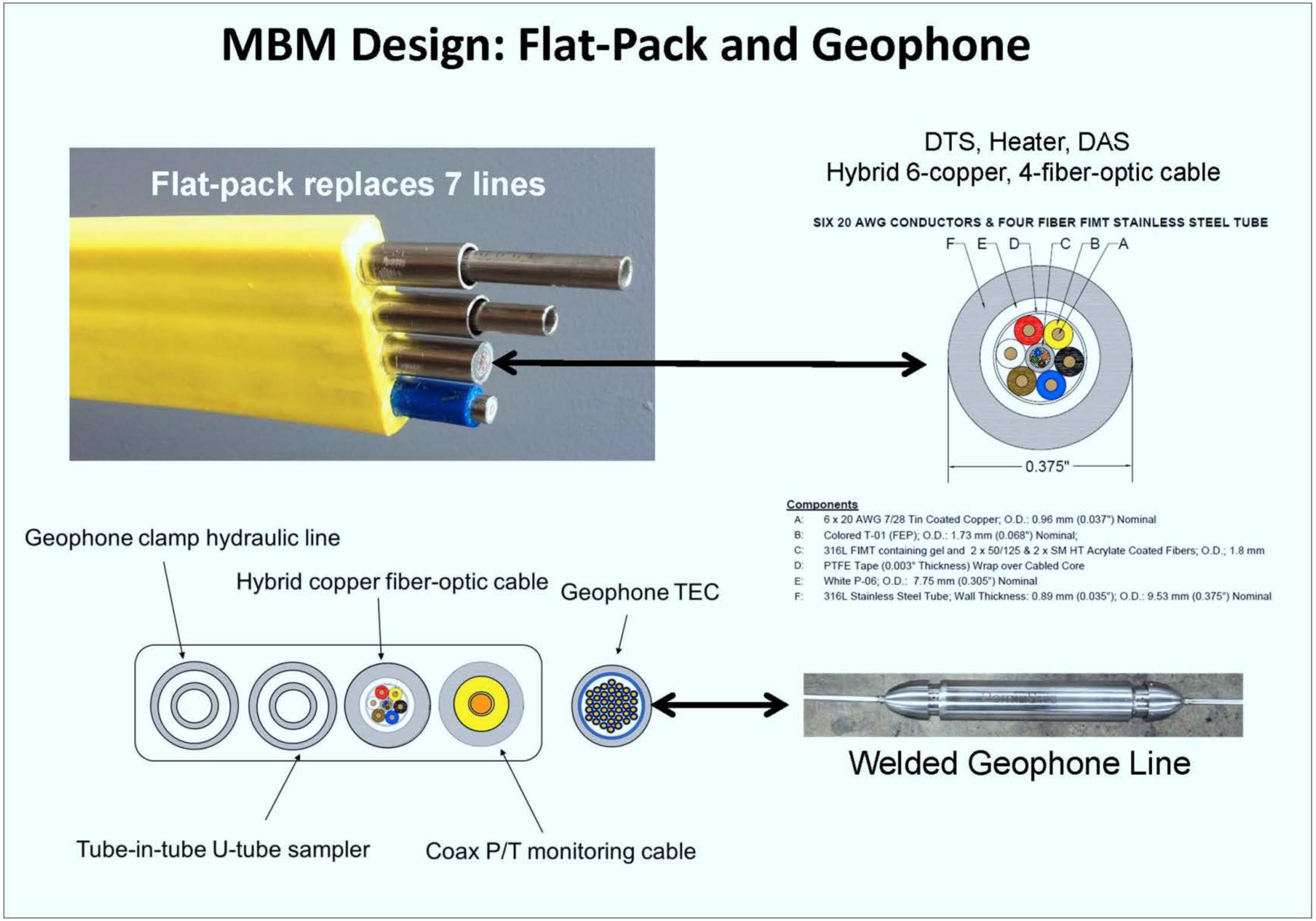
MBM Design: Flat-Pack and Geophone



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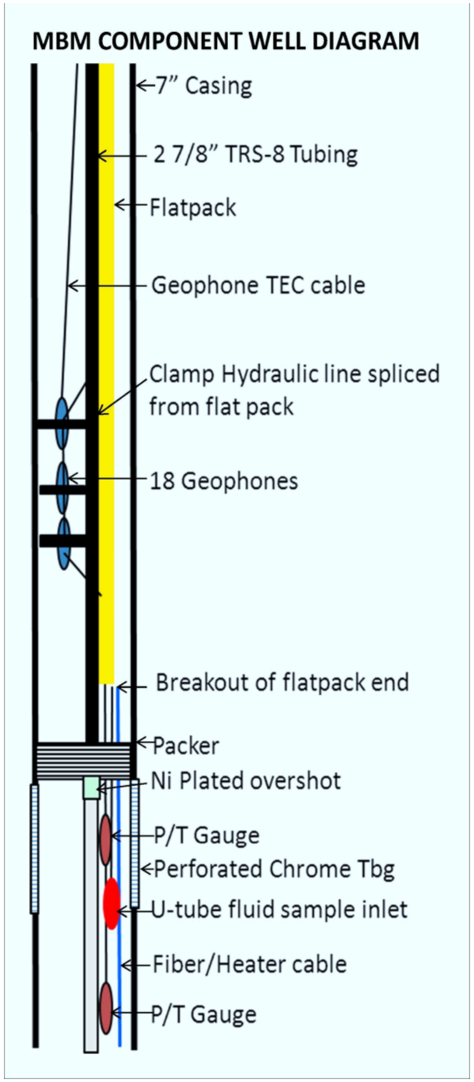
Deployment of MBM



Tubing Deployment allows for wireline access:

- 4-element flatpack
- 18-level Geophone cable
  - ✓ Hydraulic clamps for Geophones
  - ✓ Clamp in tubing/casing annulus
- Dual mandrel hydraulic packer
- Non-rotating overshot connection for coupling to 450’ bottom assembly
- Avoids splices at packer

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Deployment of MBM

RUN-IN DATA

- Bundling 7 control lines in a polypropylene-jacketed flatpack
- Non-rotating off-center overshot to couple the uphole, dual-mandrel hydroset packer assembly
- Packer landed at ~9,400 feet (2,865 m)
- Completion depth was 9,850 feet (3,002 m)
- Required four – 24 hour-a-day operations to install.

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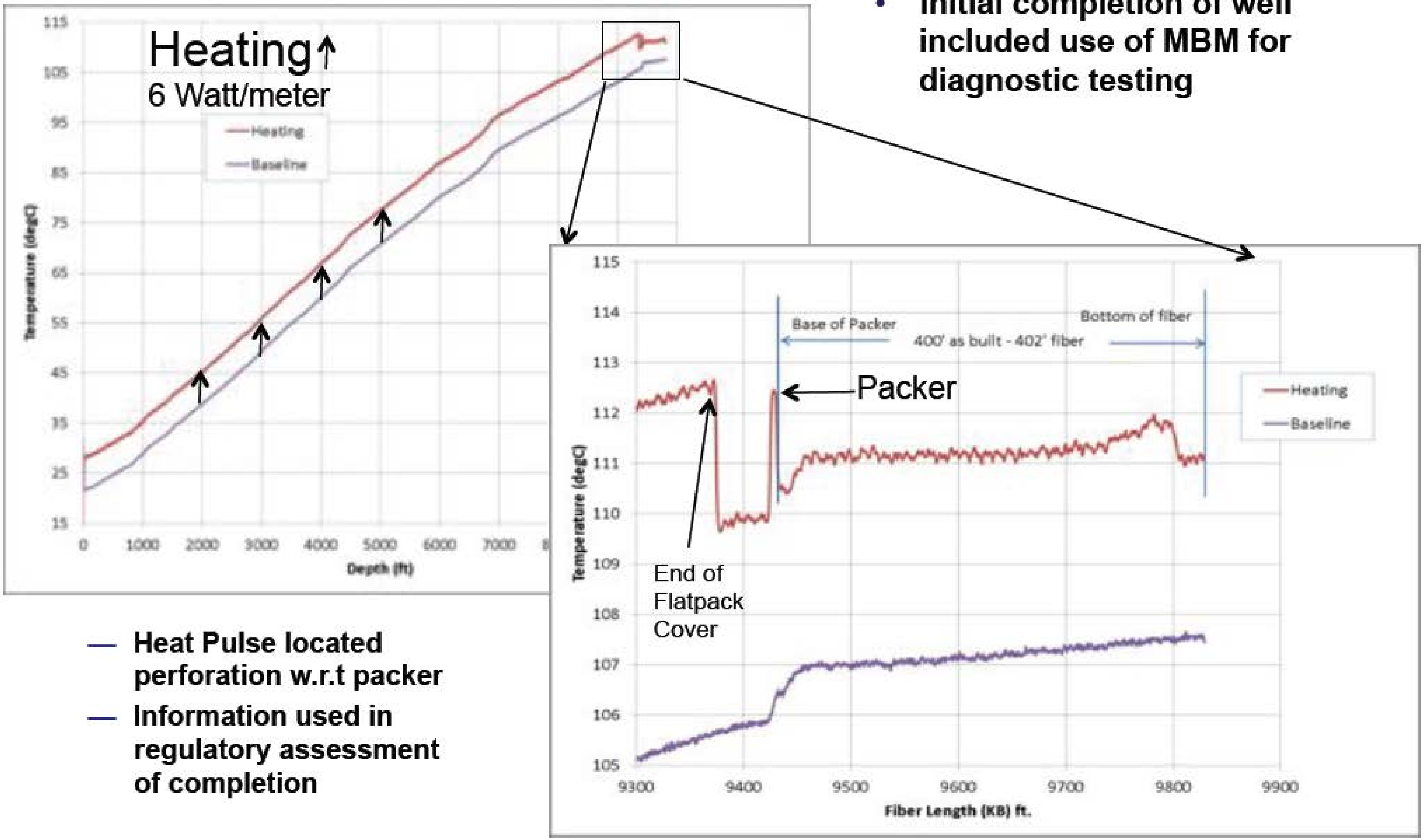
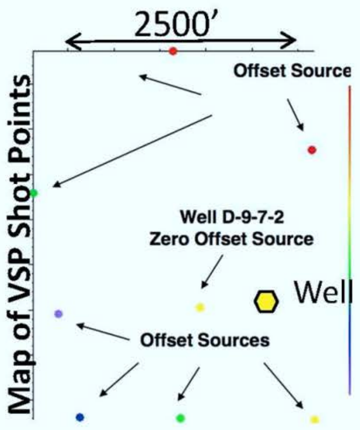
Diagnostic Testing – Heat Pulse



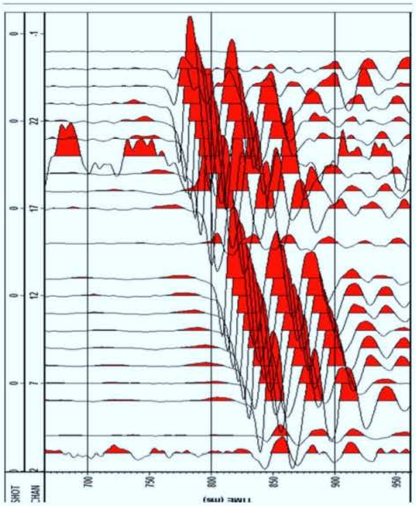
- **Initial completion of well included use of MBM for diagnostic testing**

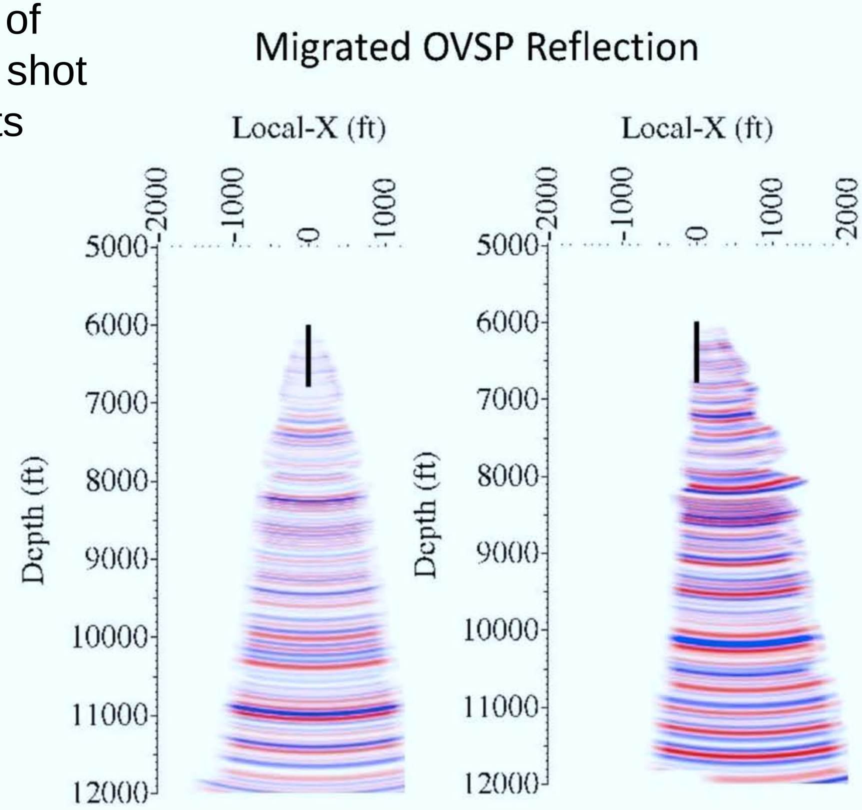
- **Heat Pulse located perforation w.r.t packer**
- **Information used in regulatory assessment of completion**

MBM Geophone Array: Baseline VSP, OVSP and Walkaway



Map of VSP shot points





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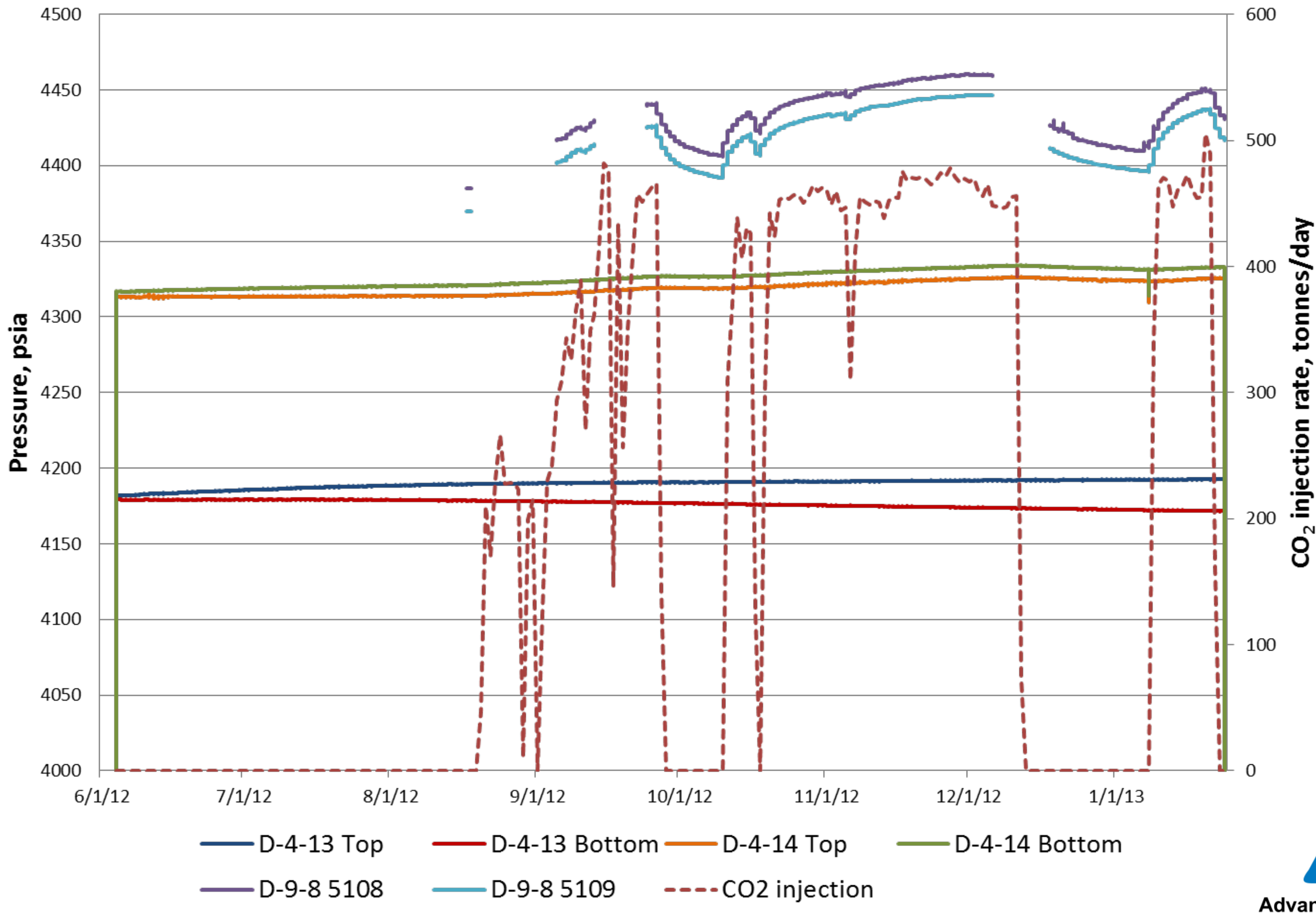
Pressure & Injection Rate Response



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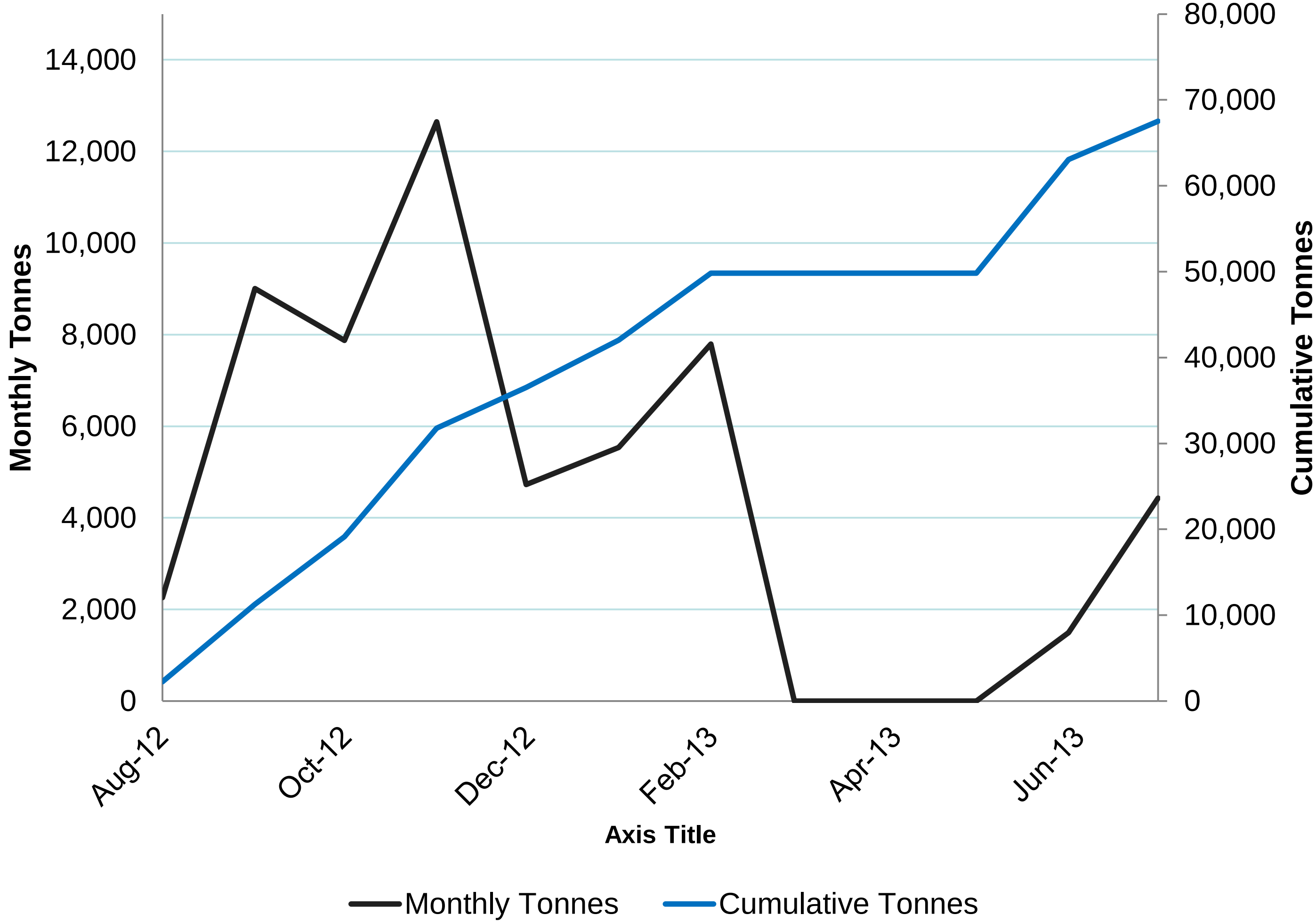
CO_2 Injection



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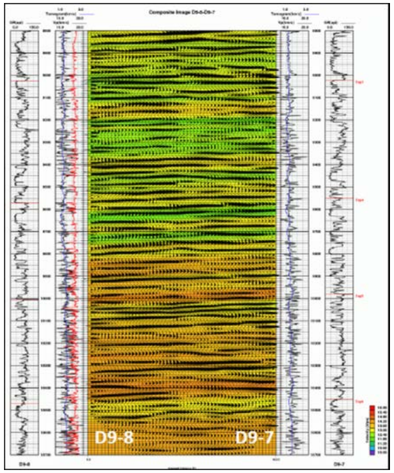
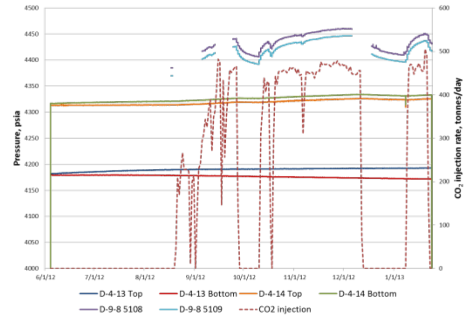
Lessons Learned

- **Time and cost reductions, but not yet commercial**
- **Data, data, and more data**
- **MVA systems can impact injection and vice versa**
- **We have a good capacity, injectivity, and no apparent formation damage**





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Thank you

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