



Site Characterization and Development of a Monitoring Plan at a 1-million Tonne CCS Demonstration: Decatur, Illinois USA

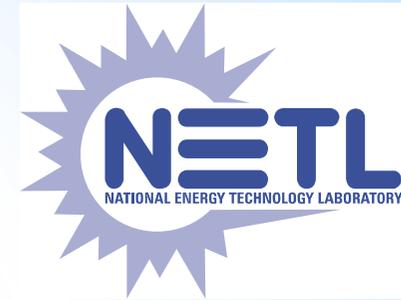
Robert J. Finley, Principal Investigator
Midwest Geological Sequestration Consortium
Director, Advanced Energy Technology Initiative
University of Illinois, USA



**ILLINOIS STATE
GEOLOGICAL SURVEY**
PRAIRIE RESEARCH INSTITUTE

RITE Tokyo, Japan
24 January 2013





Acknowledgements

- The Midwest Geological Sequestration Consortium is funded by the U.S. Department of Energy through the National Energy Technology Laboratory (NETL) via the Regional Carbon Sequestration Partnership Program (contract number DE-FC26-05NT42588) and by a cost share agreement with the Illinois Department of Commerce and Economic Opportunity, Office of Coal Development through the Illinois Clean Coal Institute.
 - The Midwest Geological Sequestration Consortium (MGSC) is a collaboration led by the geological surveys of Illinois, Indiana, and Kentucky
 - Landmark Graphics software via University Donation Program and Petrel* E&P software platform via Schlumberger Carbon Services are gratefully acknowledged
- *Mark of Schlumberger



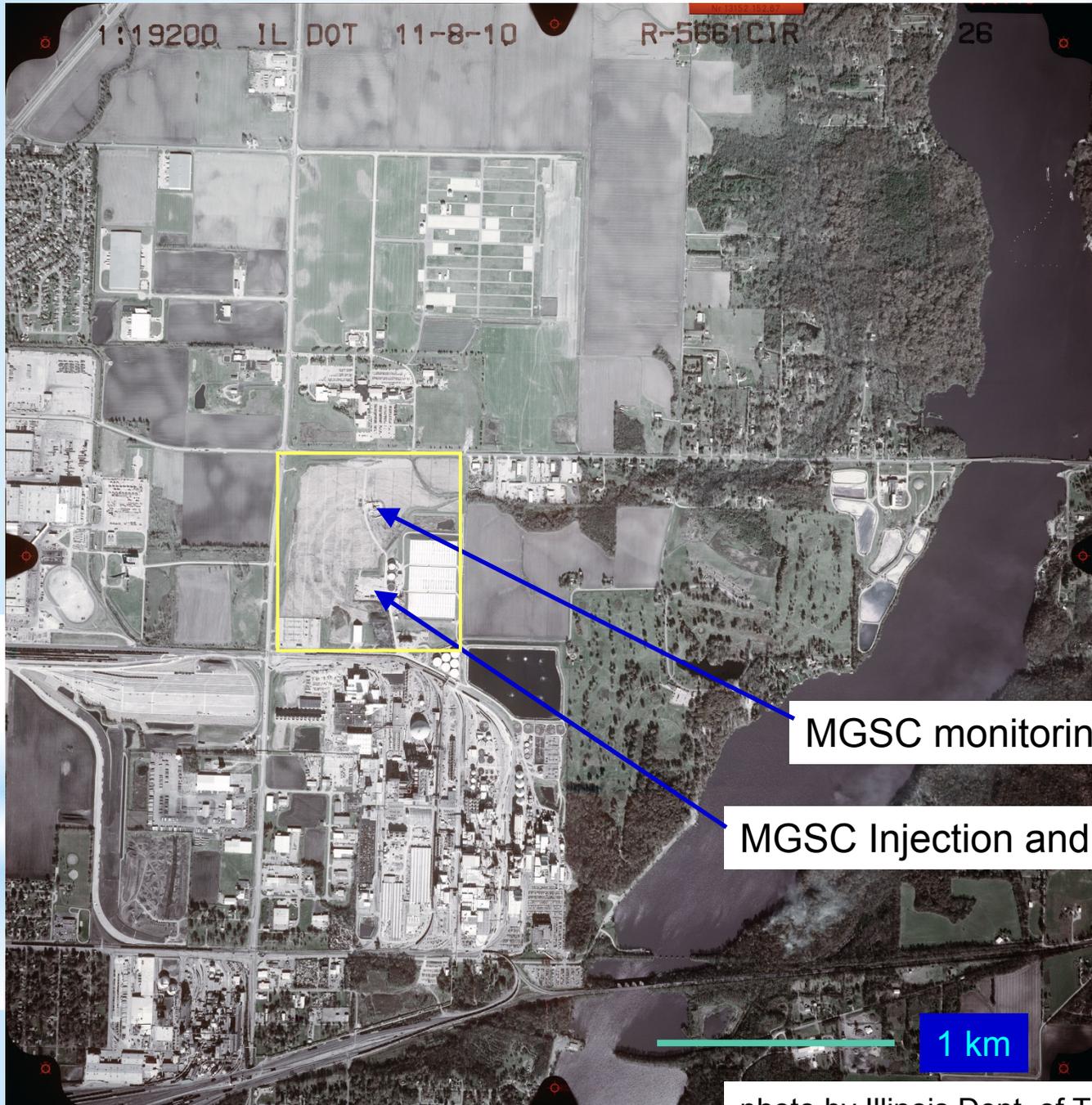
Objectives of Presentation

- Provide a basic workflow for Site Selection and Characterization
 - How to decrease uncertainty and reduce project risk
- Demonstrate development of a monitoring plan
- Present results to date of monitoring plan implementation

Workflow

- Basin Analysis
- Site (prospect) selection
- Site delineation
- Site development and implementation of monitoring
 - Injection of 1,000 metric tons per day, 2011-2014
- Ongoing monitoring during and after injection

**MGSC
Illinois
Basin-
Decatur
Project
(IBDP) Site**



MGSC monitoring well

MGSC Injection and geophone wells

1 km

photo by Illinois Dept. of Transportation, 8 November 2010

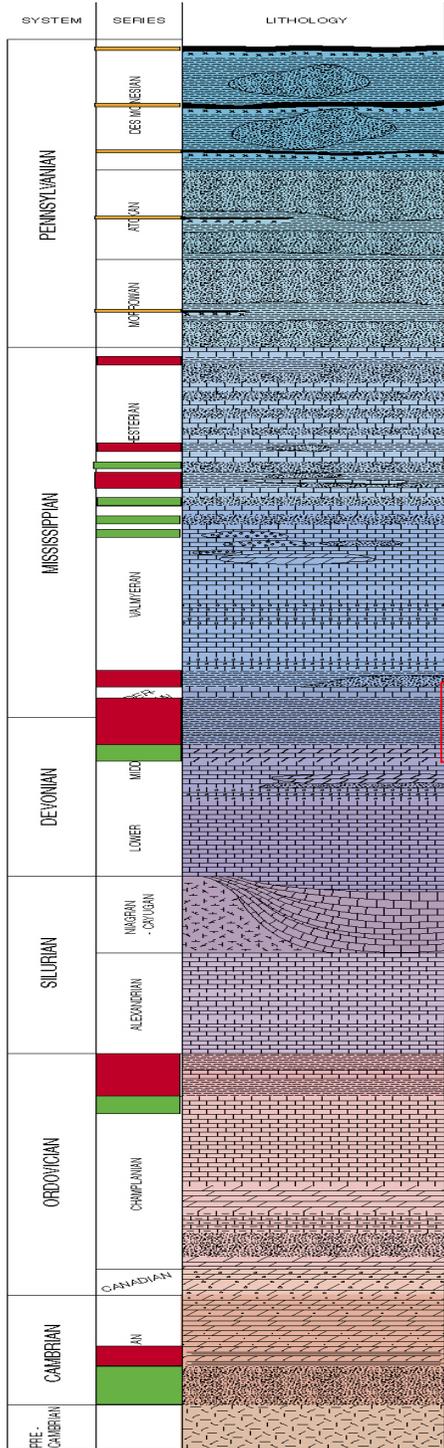
Regional Geology

Use Existing Well and Seismic Data

Illinois Basin Stratigraphic Column Showing Seals and Sinks

Upper Mt. Simon used extensively for natural gas storage

Mt. Simon is overlain by three thick impermeable shales and numerous thinner shale-rich strata



New Albany (Seal)

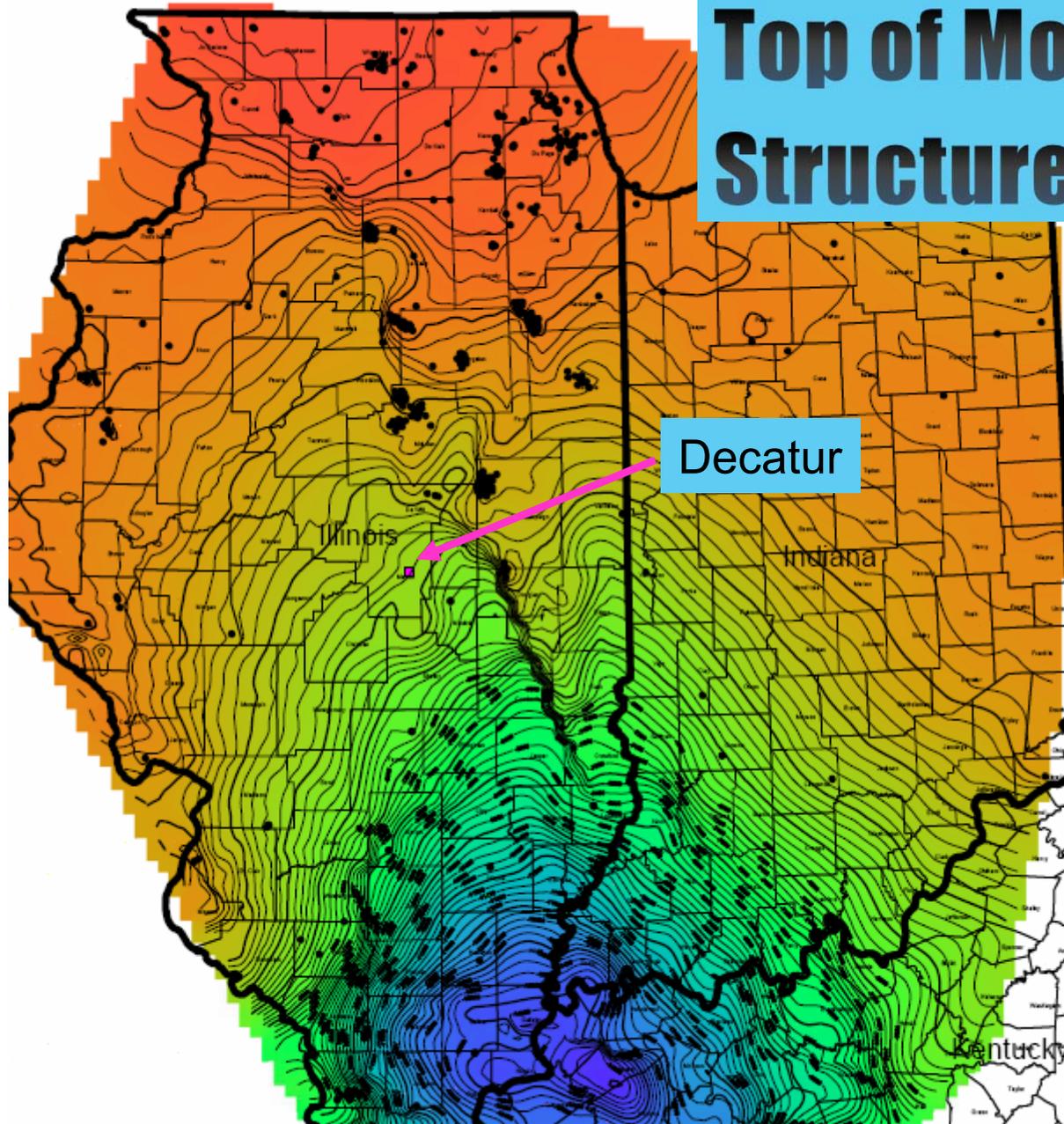
Maquoketa (Seal)

Eau Claire Shale (Seal)

Mount Simon Sandstone (Sink)

- Potential Seal
- Potential Sink
- Coal Bed
- Potential Sink and Seal

Top of Mount Simon Structure



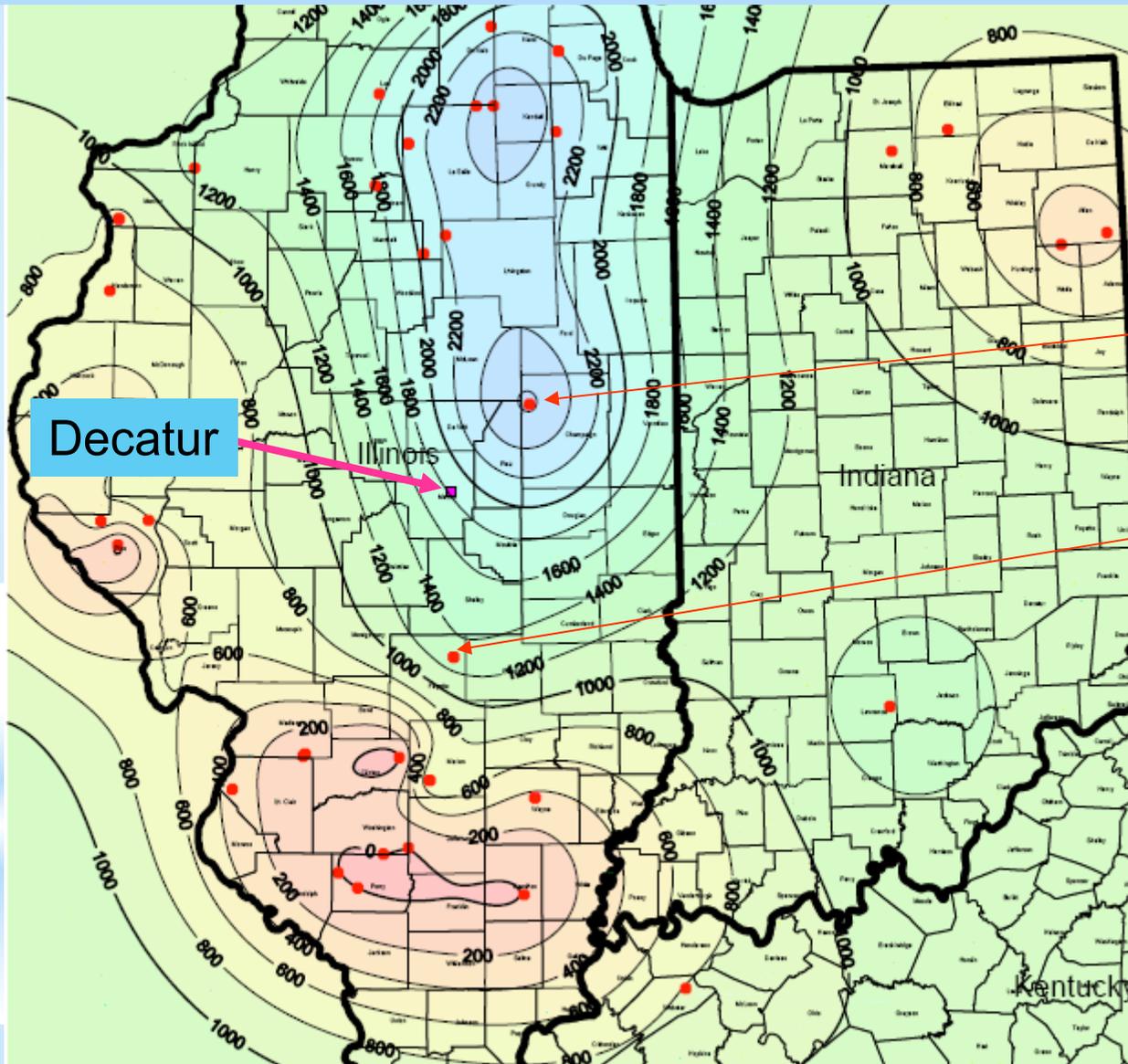
Decatur

At Decatur the top of the Mount Simon is 1,698 m measured depth

Nearest Mount Simon well is 30 km to the southeast



Thickness of the Mount Simon Sandstone



Hinton #7
penetrated 793 m
(2600 ft) of Mount
Simon

Wells with
Precambrian
granite

Preliminary Seismic Reflection Survey

2D Lines for a First Assessment

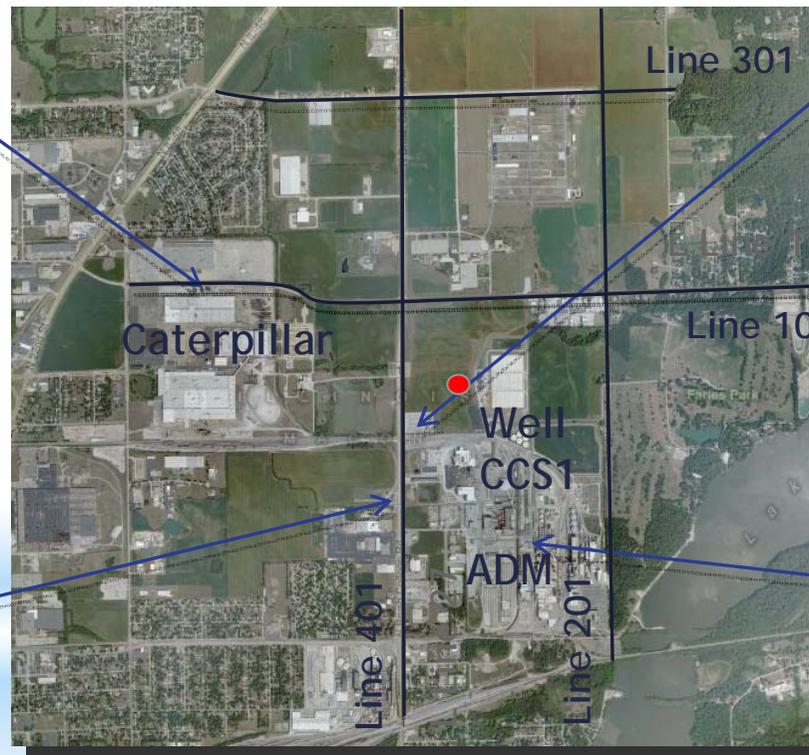
Acquisition Challenges: Noise



Thick concrete surface creating source generated noise



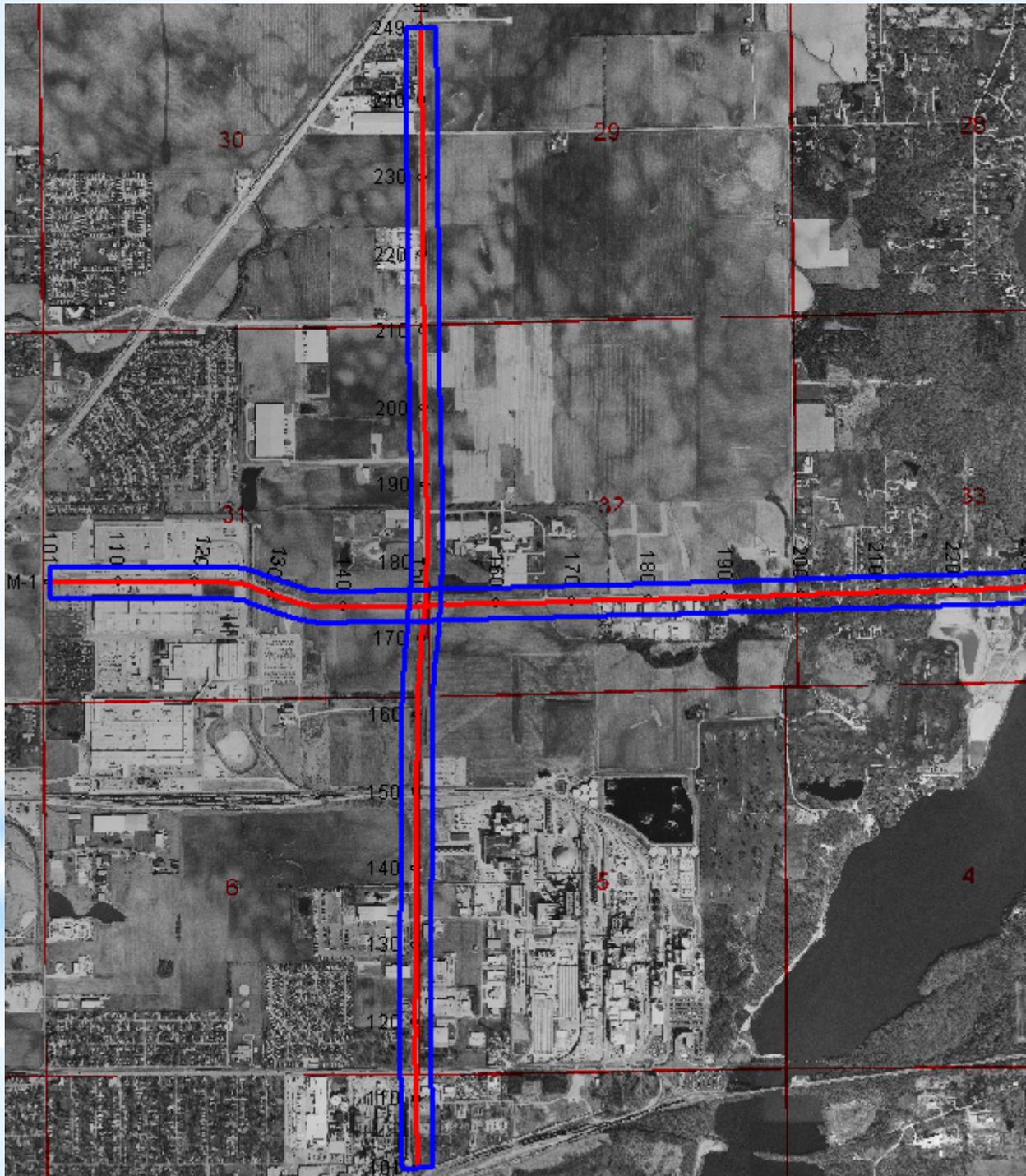
Road traffic noise due to tractor trailers visiting ADM plant.



Electrical noise from power lines and 60Hz transformer plant



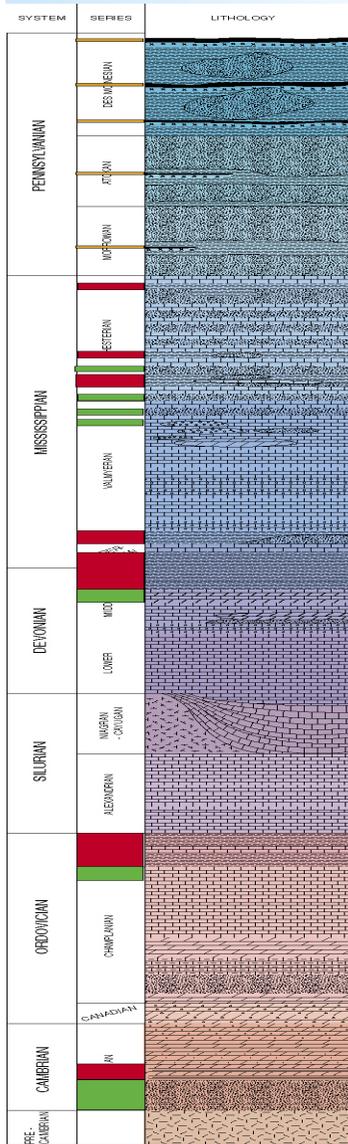
Plant Related Noise from ADM plant



Seismic Interpretation Results

Results of First 2D Assessment
Help Prepare for Drilling Injection Well

Mt. Simon Sandstone Structure Before Seismic

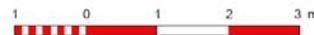
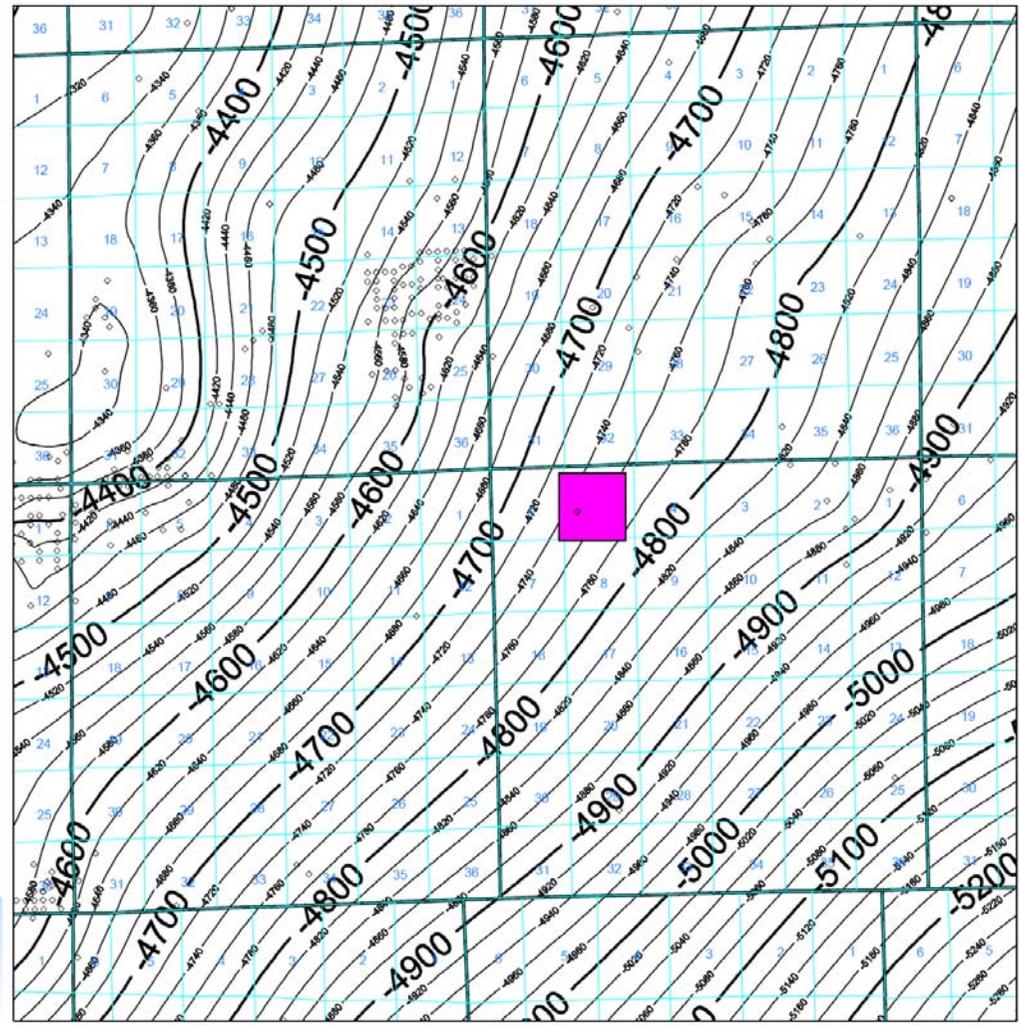


**New Albany
(Seal)**

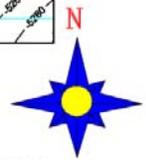
**Maquoketa
(Seal)**

Eau Claire (Seal)

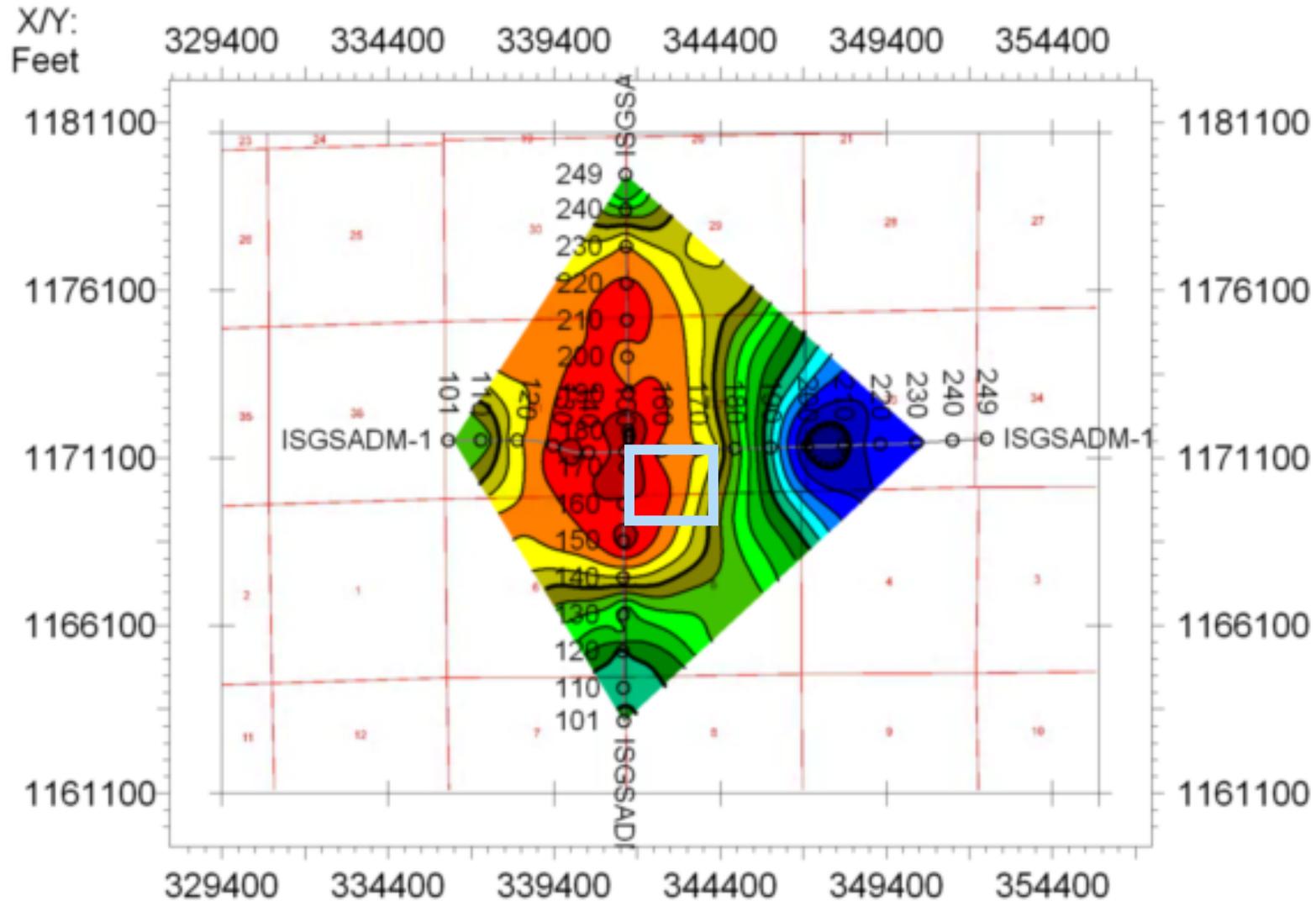
Mt. Simon Sandstone (Sink)



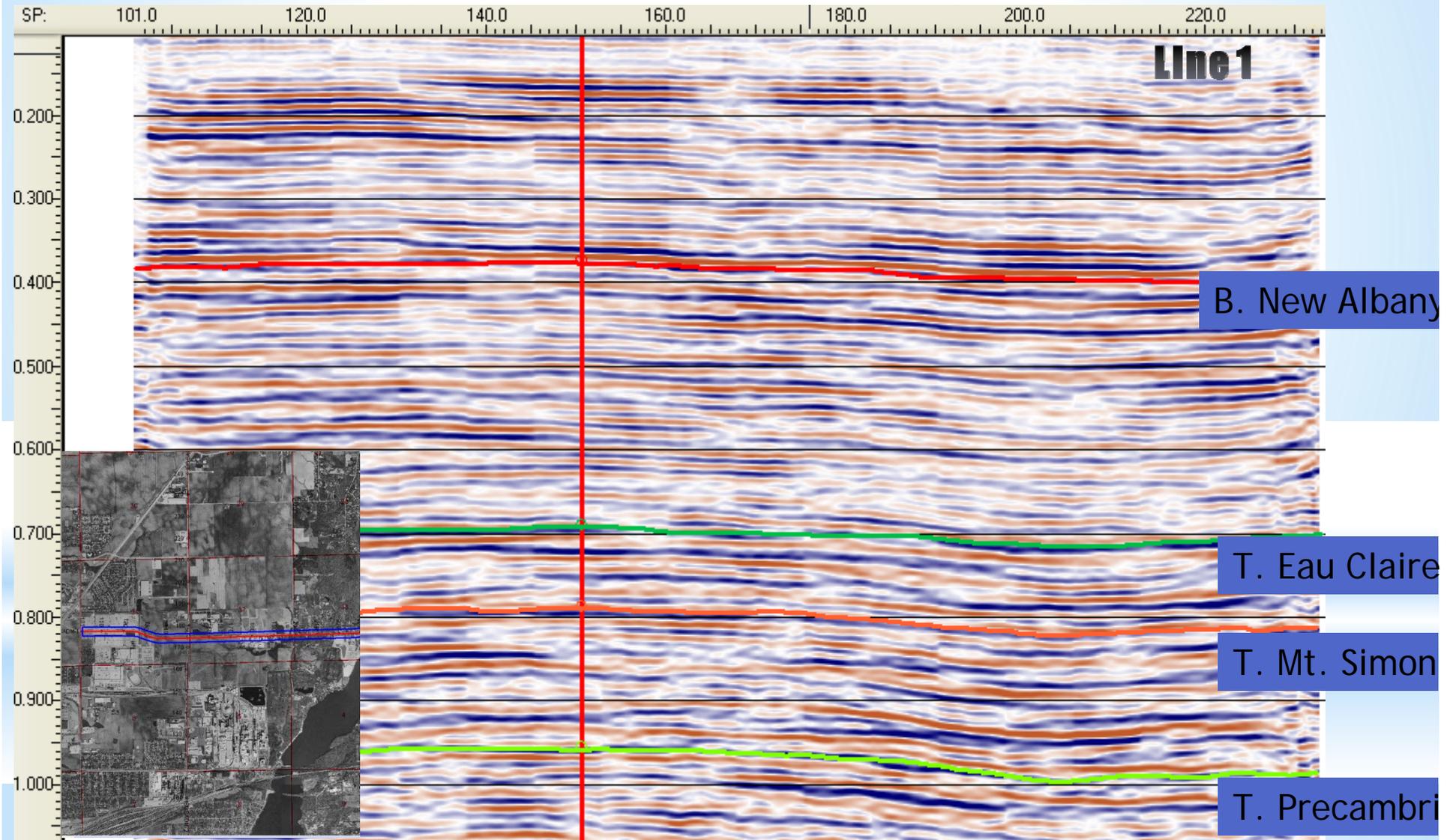
Top Mt. Simon Structure
(conformalbe mapping from
the Eau Claire Structure)



Top of Mount Simon Reflector from 2D Seismic

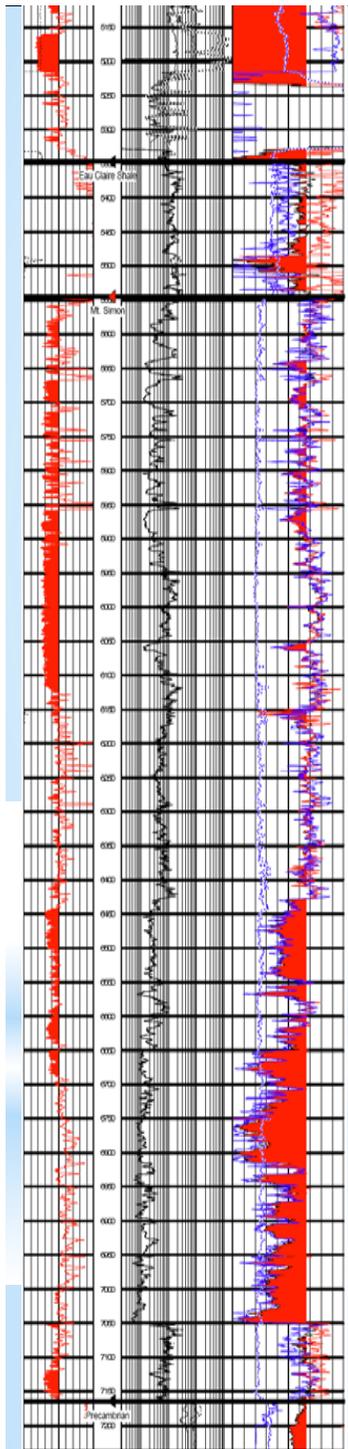


Correlate Horizons From a well 75 km to the South



Geology

Predictions and New Interpretations



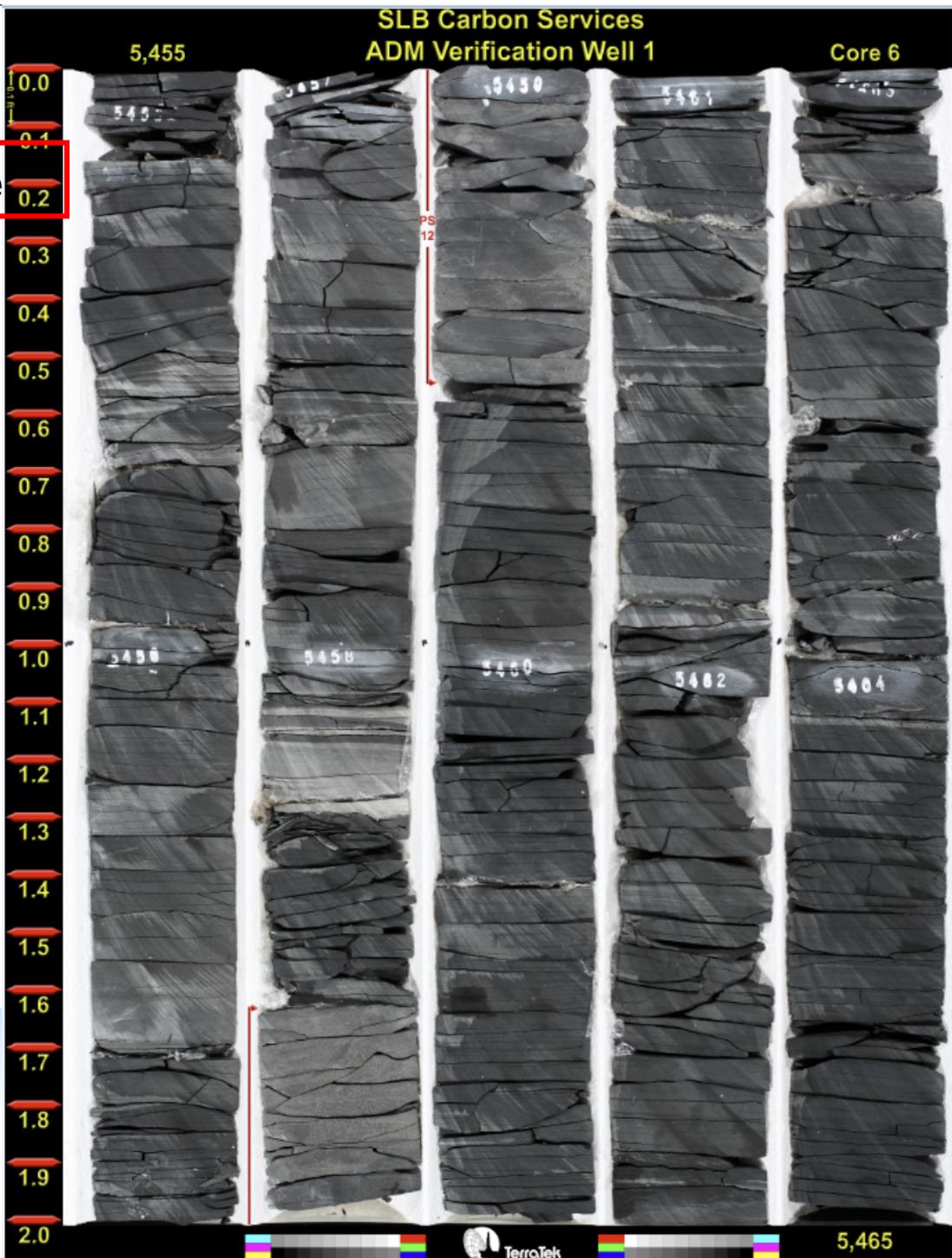
Eau Claire Shale

Upper Mt. Simon

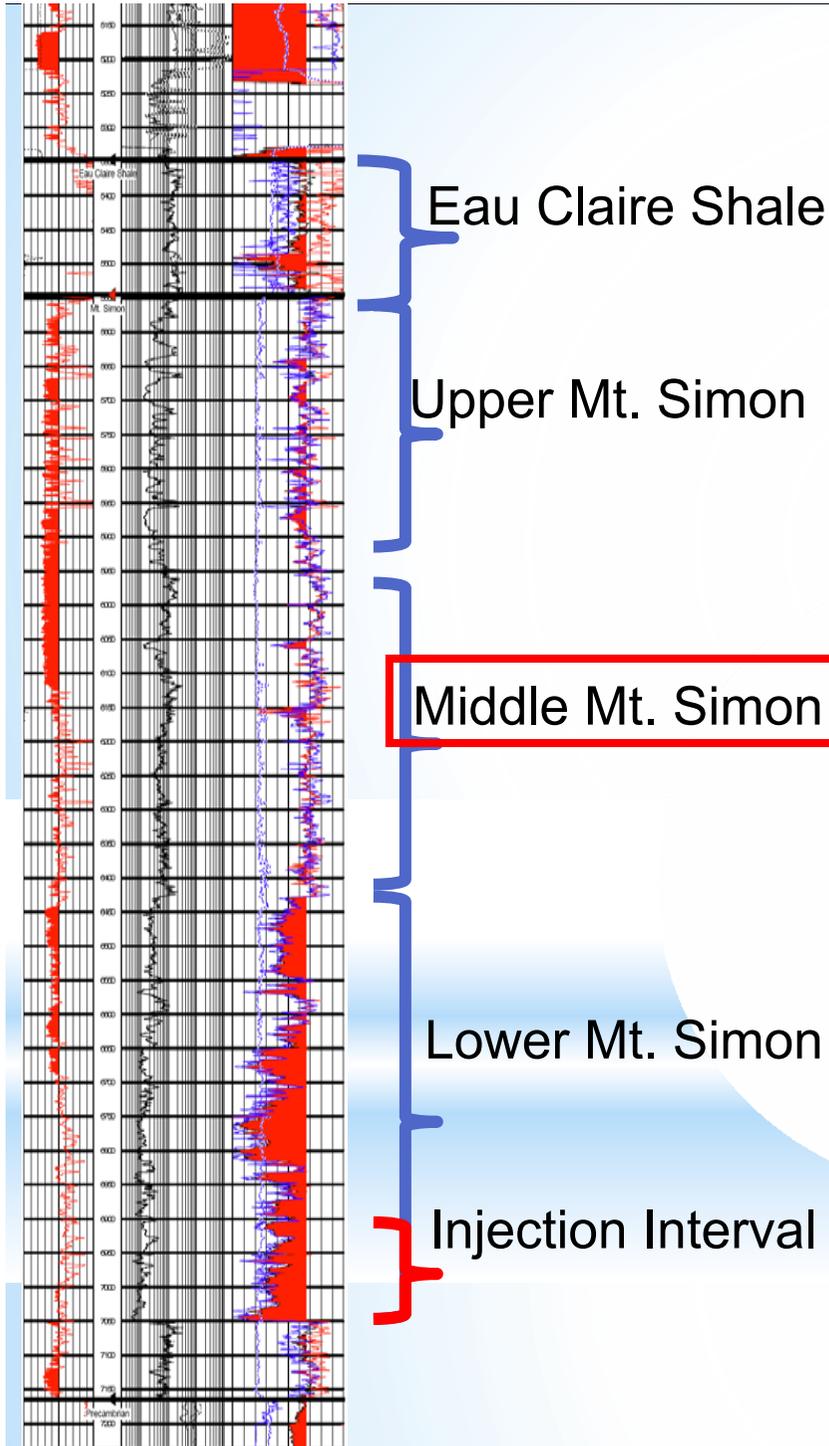
Middle Mt. Simon

Lower Mt. Simon

Injection Interval



SLB Carbon Services
ADM Verification Well 1



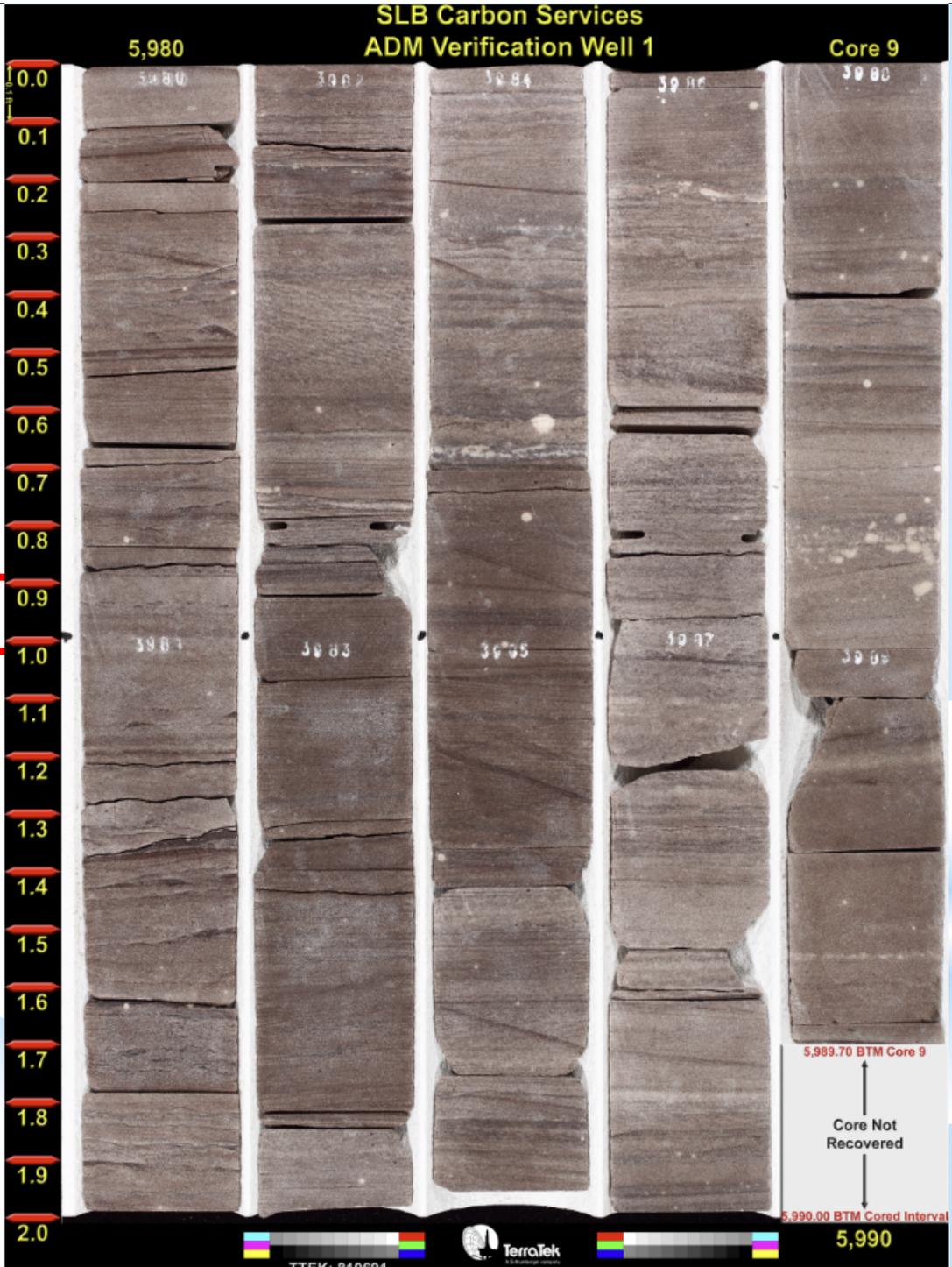
Eau Claire Shale

Upper Mt. Simon

Middle Mt. Simon

Lower Mt. Simon

Injection Interval



Core 9

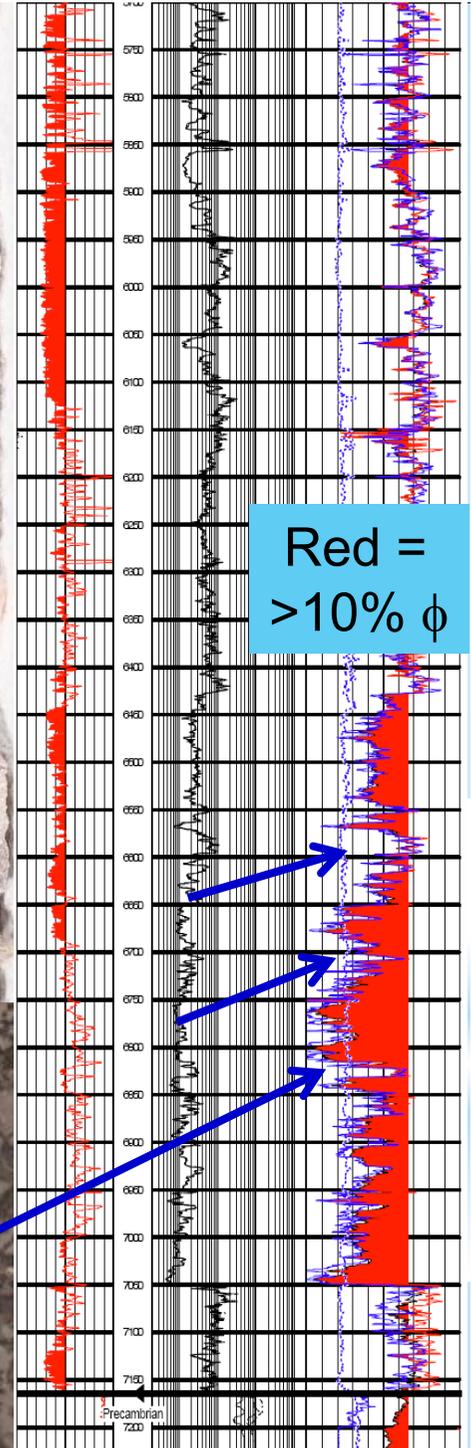
5,989.70 BTM Core 9

Core Not Recovered

5,990.00 BTM Cored Interval

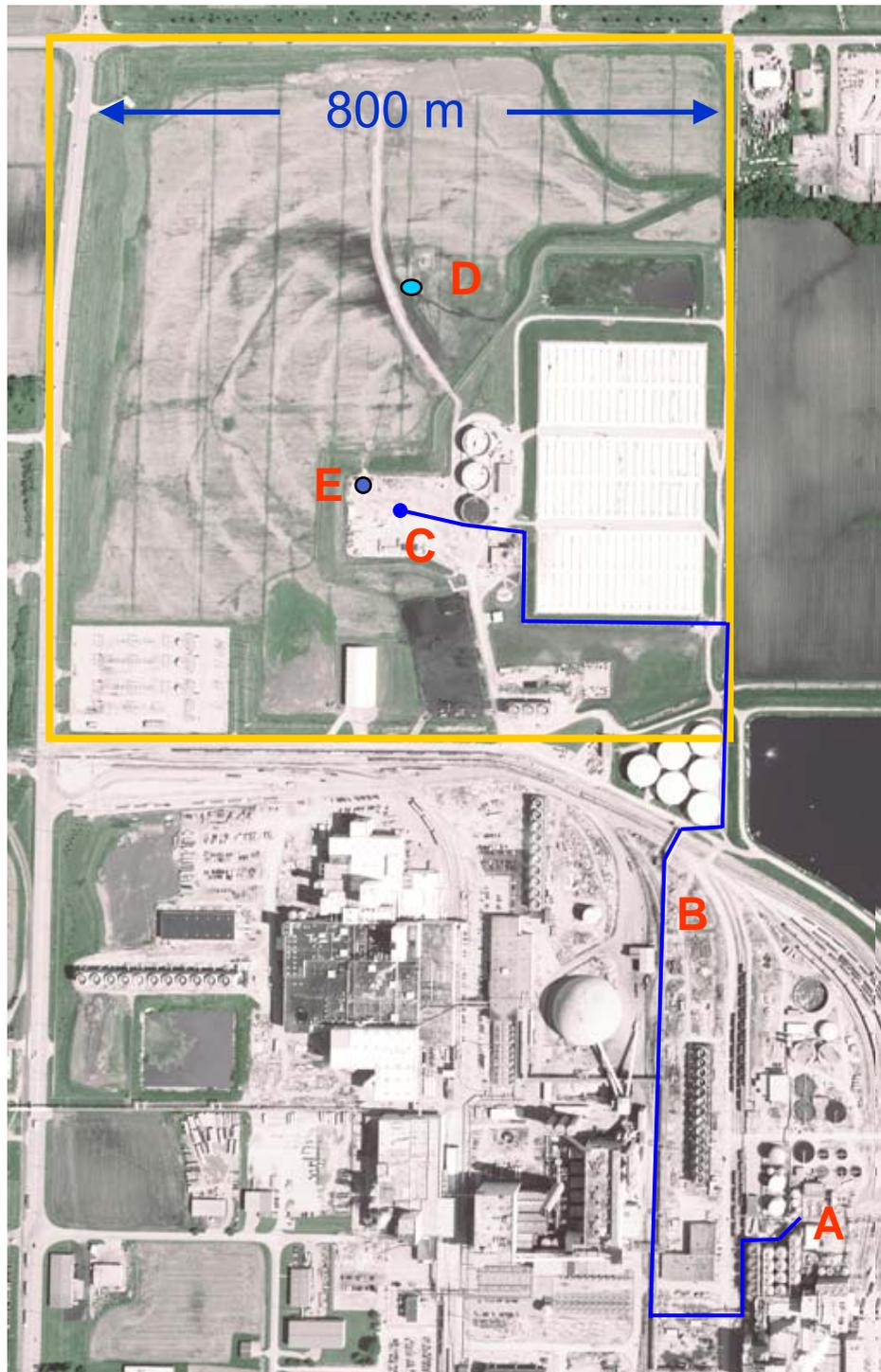
5,990

Mount Simon Depositional Analogue: Brahmaputra River System



Sand-rich but low porosity/perm layers

Project Installation



Illinois Basin – Decatur Project Site (on ADM industrial site)

- A** Dehydration/ compression facility location
- B** Pipeline route (1.9 km)
- C** Injection well site
- D** Verification/ monitoring well site
- E** Geophone well



Operational Injection: 17 November 2011

- **IBDP** fully operational 24/7
- **IBDP** is the first 1 million tonne carbon capture and storage project from a biofuel facility in the US
- Injection through fall 2014
- Intensive post-injection monitoring under MGSC through fall 2017

Cumulative Injection
(18 January 2013):
378,450 tonnes

Project Monitoring Plan

Develop and Implement

IBDP Environmental Monitoring Framework

Near Surface

Atmosphere

Eddy covariance
Meteorological conditions
Ambient CO₂ for HHS
Tunable diode laser for CO₂

Soil/vadose zone

CIR aerial imagery
InSAR and GPS
Soil gases
Soil CO₂ flux
Tunable diode laser for CO₂

Shallow groundwater

Geophysical surveys
Geochemical sampling
P/T monitoring

Deep Subsurface

Above seal

Geophysical surveys
Geochemical sampling
P/T monitoring

Injection zone

Geophysical surveys
Geochemical sampling
P/T monitoring

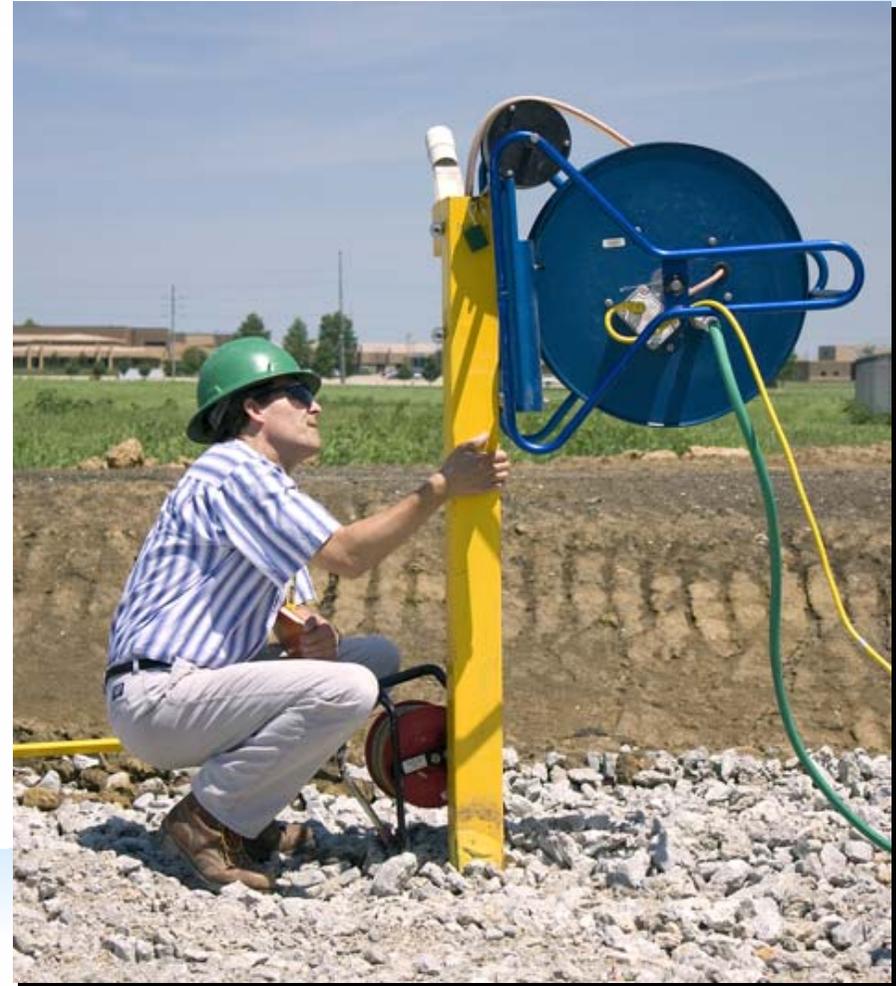


Near-Surface Monitoring Locations

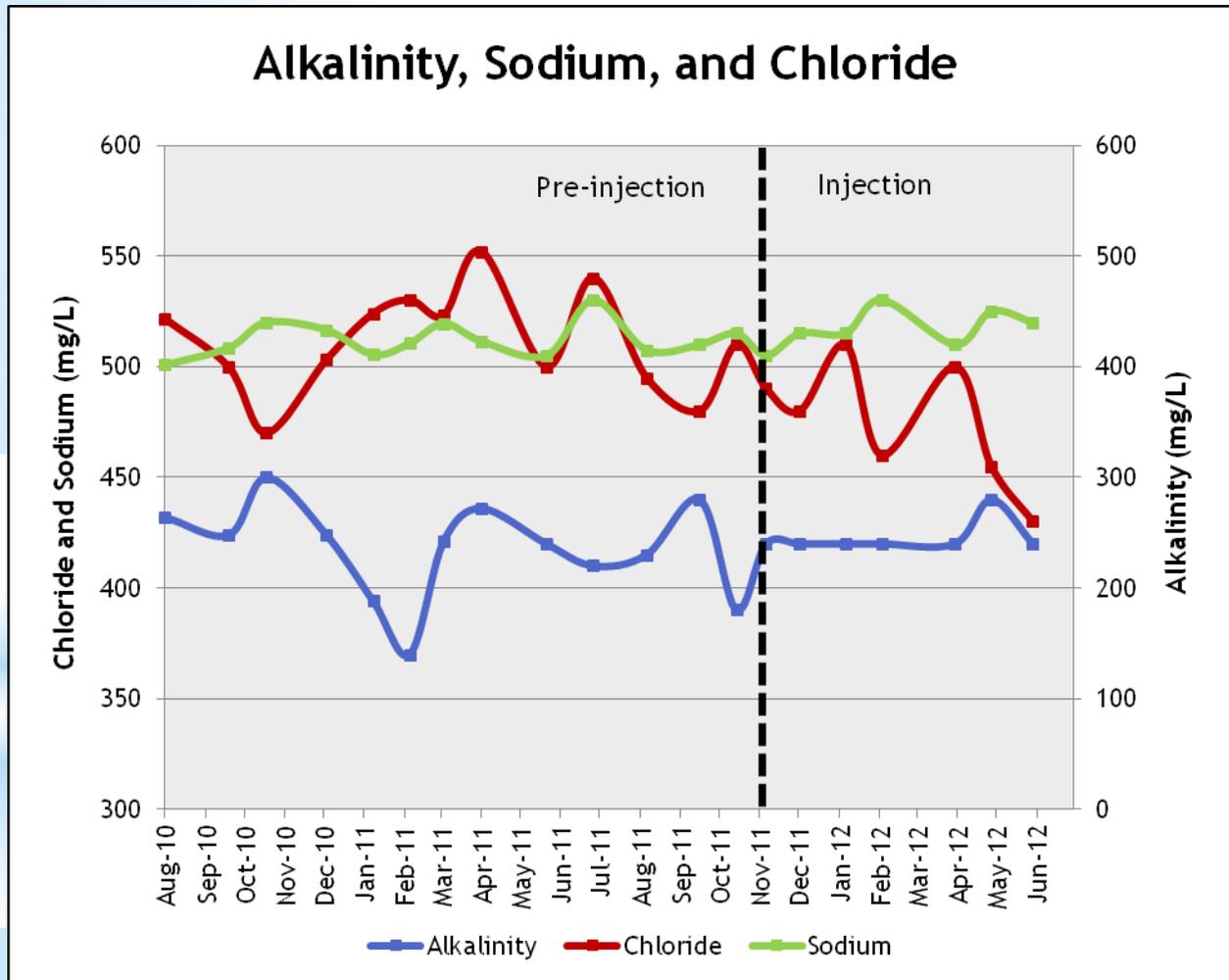
- 17 groundwater wells, 4 permit-required
- 110 soil flux rings
- 21 InSAR reflectors
- 1 air monitoring site

Shallow Groundwater Network

- Installed 17 wells at 11 locations between Fall 2008 and Spring 2010
 - Well depths: 30 to 300 feet (9 to 91m)
- Monthly sampling began in March 2009
- Analyzed for anions, cations, alkalinity, TDS, NH_3 , C and O isotopes, TOC, and TIC



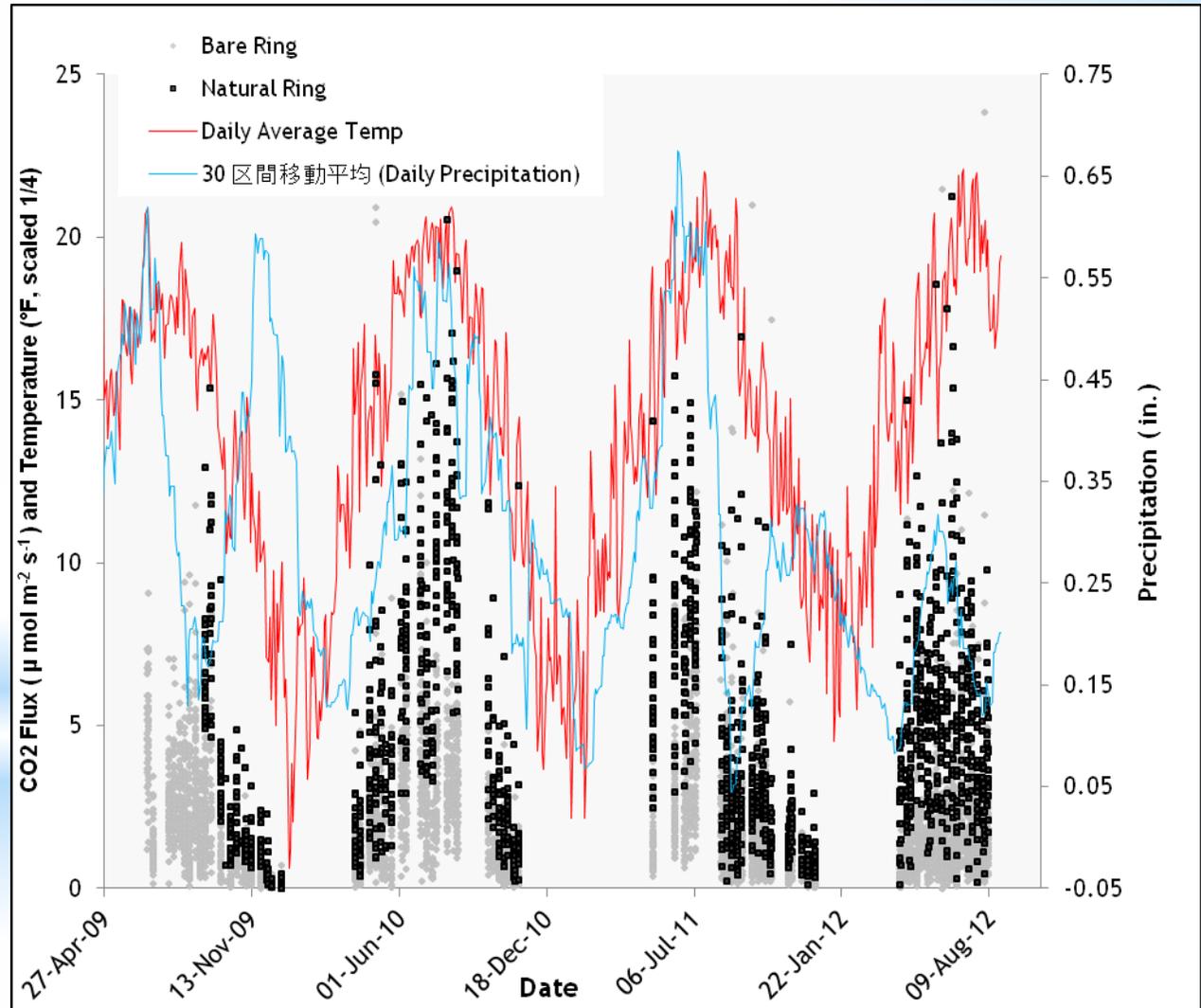
Generally Consistent Trends



- Well G104
- Note injection period data are generally consistent with preinjection data
- Chloride decreasing

Soil Flux Monitoring

- Network of 100+ rings
- Ecosystem flux estimation, atmospheric modeling, and leak detection
- Weekly point data collection began Summer 2009
- 30-minute data from multiplexer to define diurnal variability



Soil Gas Installations

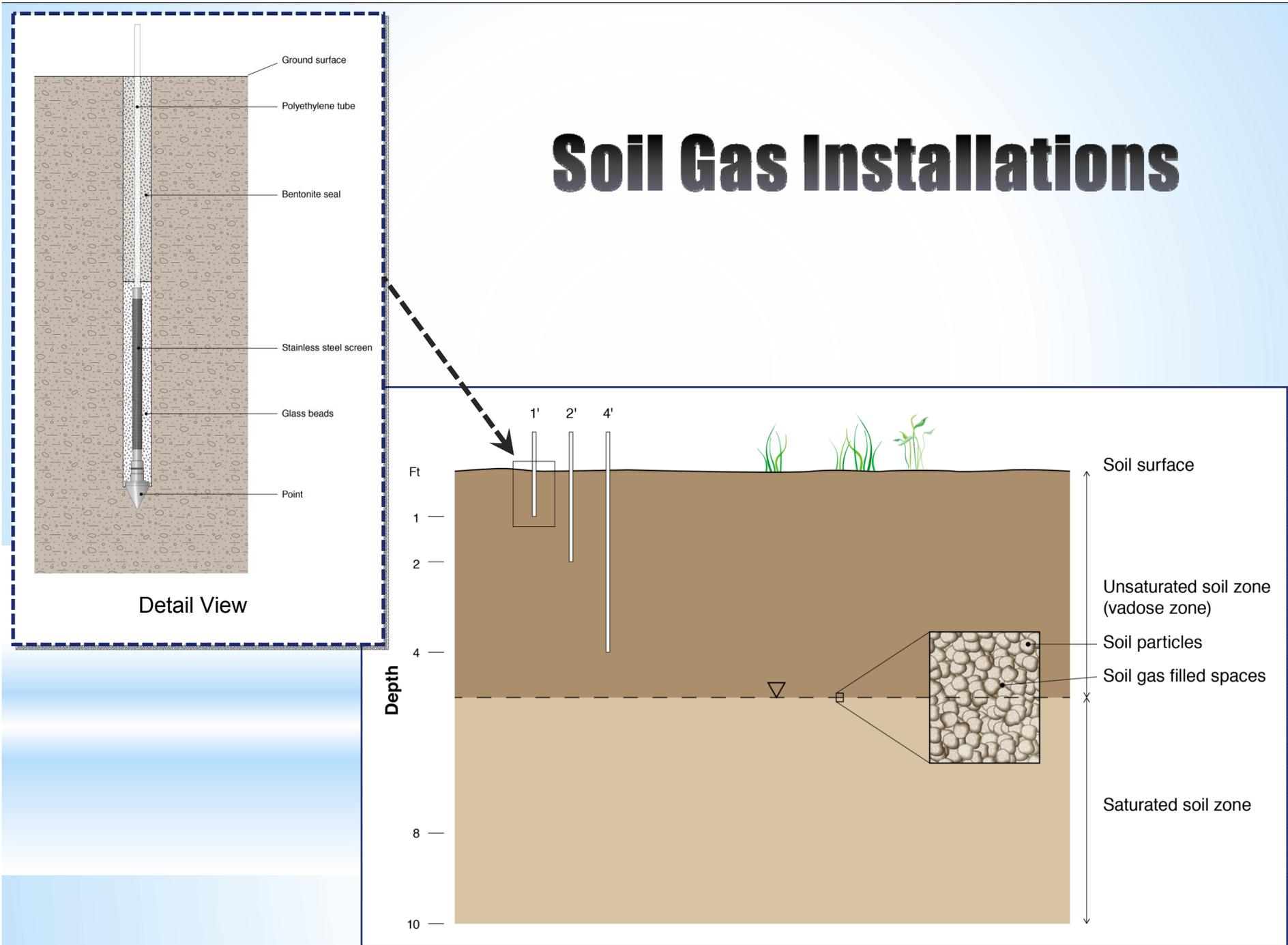
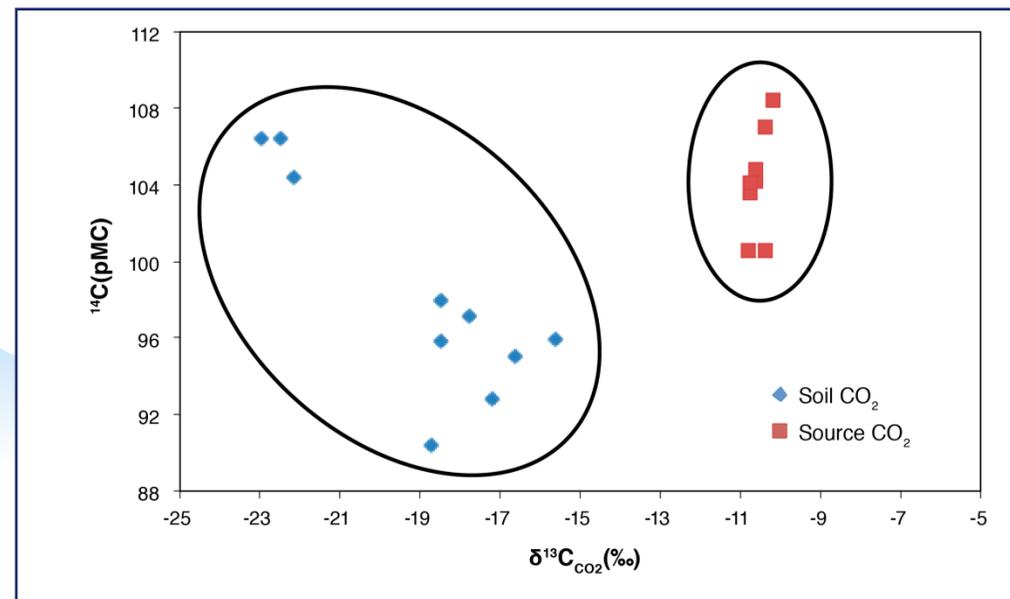
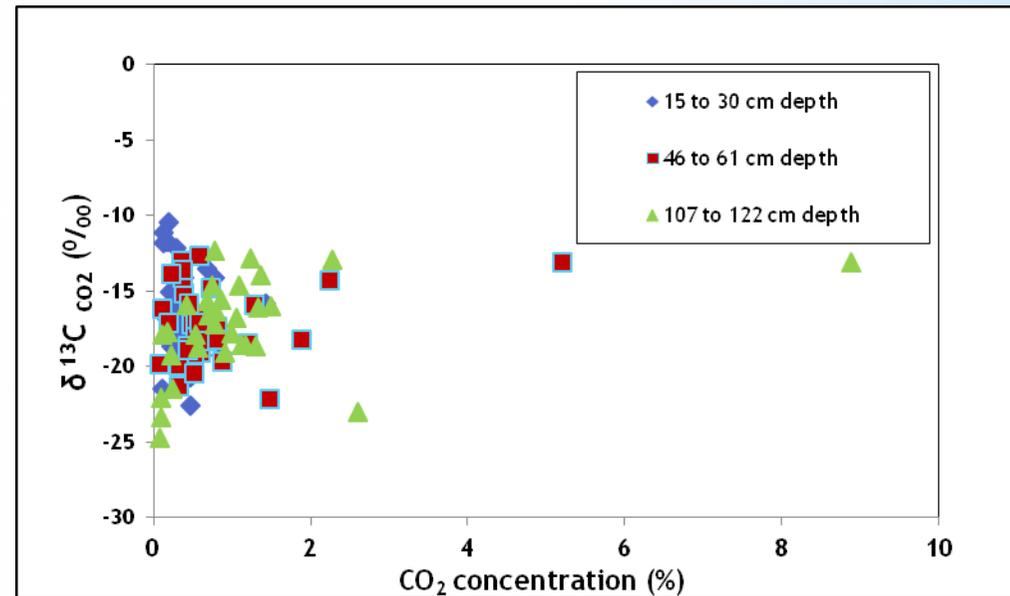


Figure Source: Daniel Byers (ISGS)

Soil Gas Characterization

- Quarterly data collection began Summer 2011
- Analyzed for CO₂, N₂, Ar + O₂, light hydrocarbons (C₁ to C₆), $\delta^{13}\text{C}_{\text{CO}_2}$, and ¹⁴C
- Biogenic activity consumes O₂ and generally CO₂ concentrations increase with depth
- Range of $\delta^{13}\text{C}_{\text{CO}_2}$ in soil: -10 to -25 per mil
- Distinct signatures of soil CO₂ and source CO₂





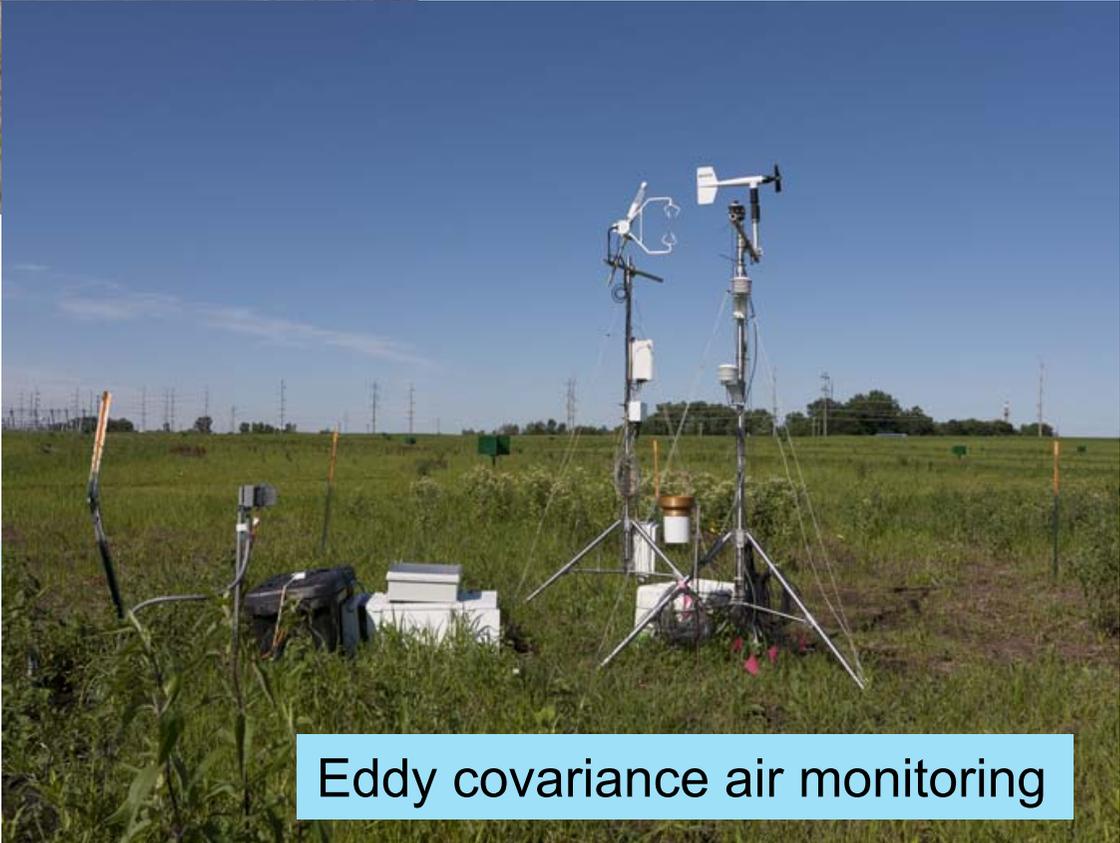
Satellite interferometry

The image shows a field with several green rectangular markers on poles, used for satellite interferometry monitoring. In the background, there are industrial buildings and power lines.

Surface Environmental Monitoring

No atmospheric releases

No surface deformation
as of August 2012 with
~ 250,000 tonnes injected



Eddy covariance air monitoring

The image shows an eddy covariance air monitoring station in a field. It consists of two tall towers with various sensors and instruments attached. The ground is covered with green grass and some equipment is visible in the foreground.

IBDP Environmental Monitoring Framework

Near Surface

Atmosphere

Eddy covariance
Meteorological conditions
Ambient CO₂ for HHS
Tunable diode laser for CO₂

Soil/vadose zone

CIR aerial imagery
InSAR and GPS
Soil gases
Soil CO₂ flux
Tunable diode laser for CO₂

Shallow groundwater

Geophysical surveys
Geochemical sampling
P/T monitoring

Deep Subsurface

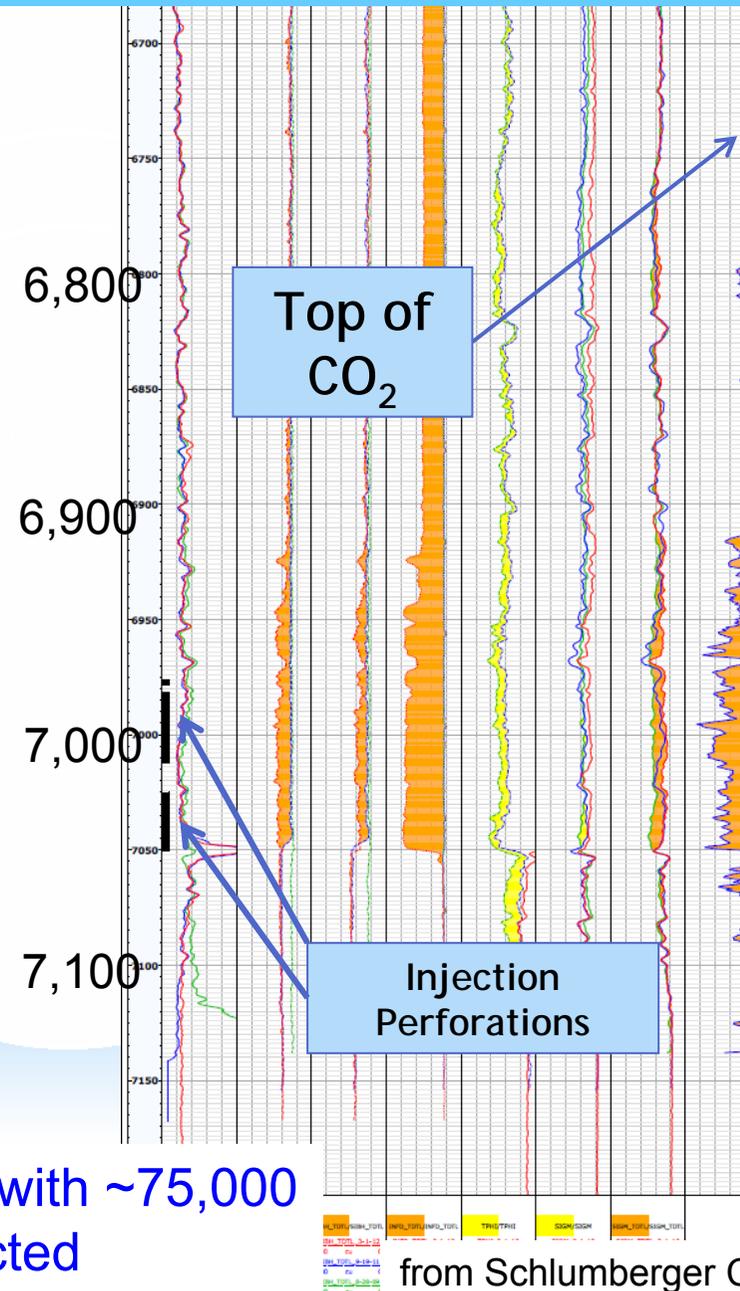
Above seal

Geophysical surveys
Geochemical sampling
P/T monitoring

Injection zone

Geophysical surveys
Geochemical sampling
P/T monitoring

Injection Well Drilled to 2,190 m (7,230 ft) (2009)



RST*
reservoir
saturation
tool
Log

Logged March 1, 2012 with ~75,000 tonnes metric tons injected

*Mark of Schlumberger

from Schlumberger Carbon Services

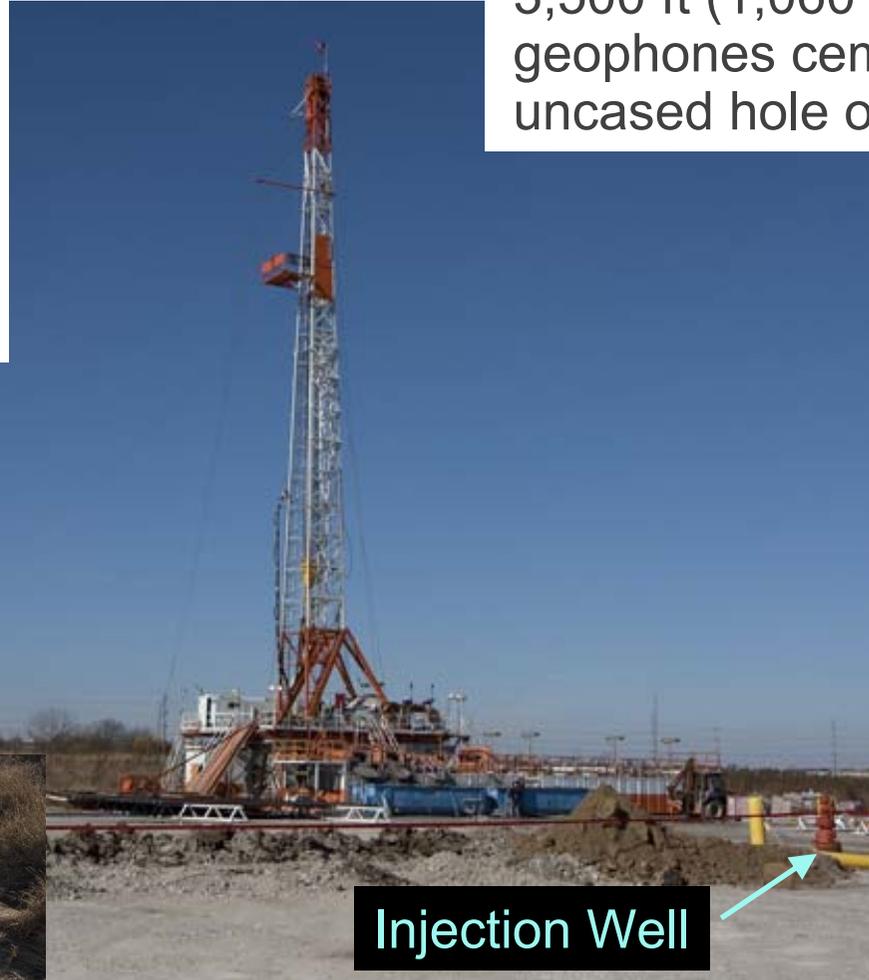
Geophone Well Completed November 2009



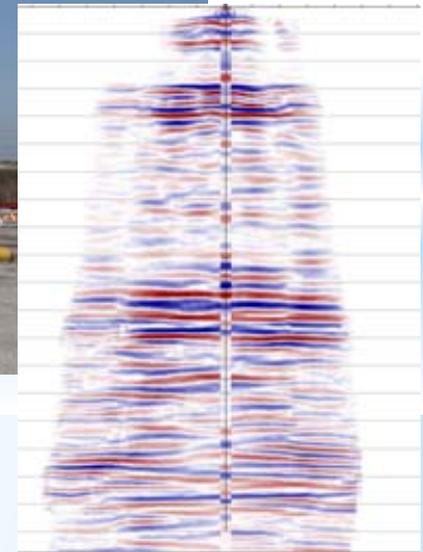
Geophone in special carrier strapped to 3.5 inch (8.9 cm) tubing



3,500 ft (1,060 m) well with 31 geophones cemented into uncased hole on tubing string



Injection Well



Westbay System First-in-the-World Deployment at 2,200 m+ for Eleven Sampling Levels

Nine Sampling Levels In the
Mount Simon Sandstone

Two Sampling Levels
Above the Eau Claire Shale

Two Fluid Sample Sets
Collected Preinjection

November 2010

P port

sampling
port



Westbay multilevel groundwater characterization and monitoring system is a mark of S

Westbay Installation and Sampling



June-August 2011

Water Quality Comparison

| Constituent | Shallow Groundwater | Ironton-Galesville | Mt. Simon (injection formation) |
|-------------------------|---------------------|--------------------|---------------------------------|
| Conductivity (mS/cm) | 1.5 | 80 | 170 |
| TDS (mg/L) | 1,000 | 65,600 | 190,000 |
| Cl ⁻ (mg/L) | 170 | 36,900 | 120,000 |
| Br ⁻ (mg/L) | 1 | 180 | 680 |
| Alkalinity (mg/L) | 380 | 130 | 80 |
| Na ⁺ (mg/L) | 140 | 17,200 | 50,000 |
| Ca ²⁺ (mg/L) | 100 | 5,200 | 19,000 |
| K ⁺ (mg/L) | 1 | 520 | 1,700 |
| Mg ²⁺ (mg/L) | 50 | 950 | 1,800 |
| pH (units) | 7.2 | 6.9 | 5.9 |

- Shallow groundwater (16 well average)
- Ironton-Galesville (2 zone average; swab only)
- Mt. Simon (9 zone average)

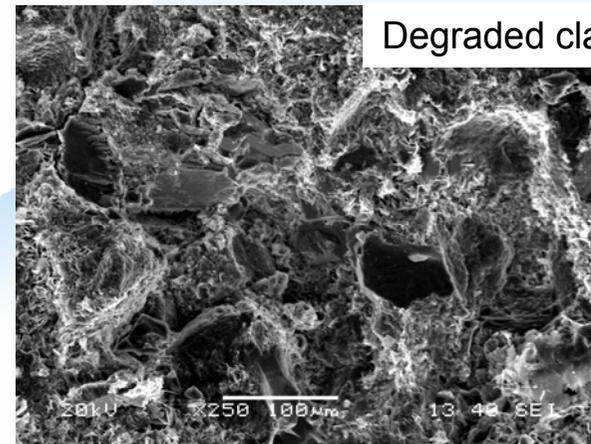
Extensive Core Recovery in Verification Well Included Samples for Reactivity Analysis



Rock Samples and Synthetic Brine Reacted Over 3-9 Months

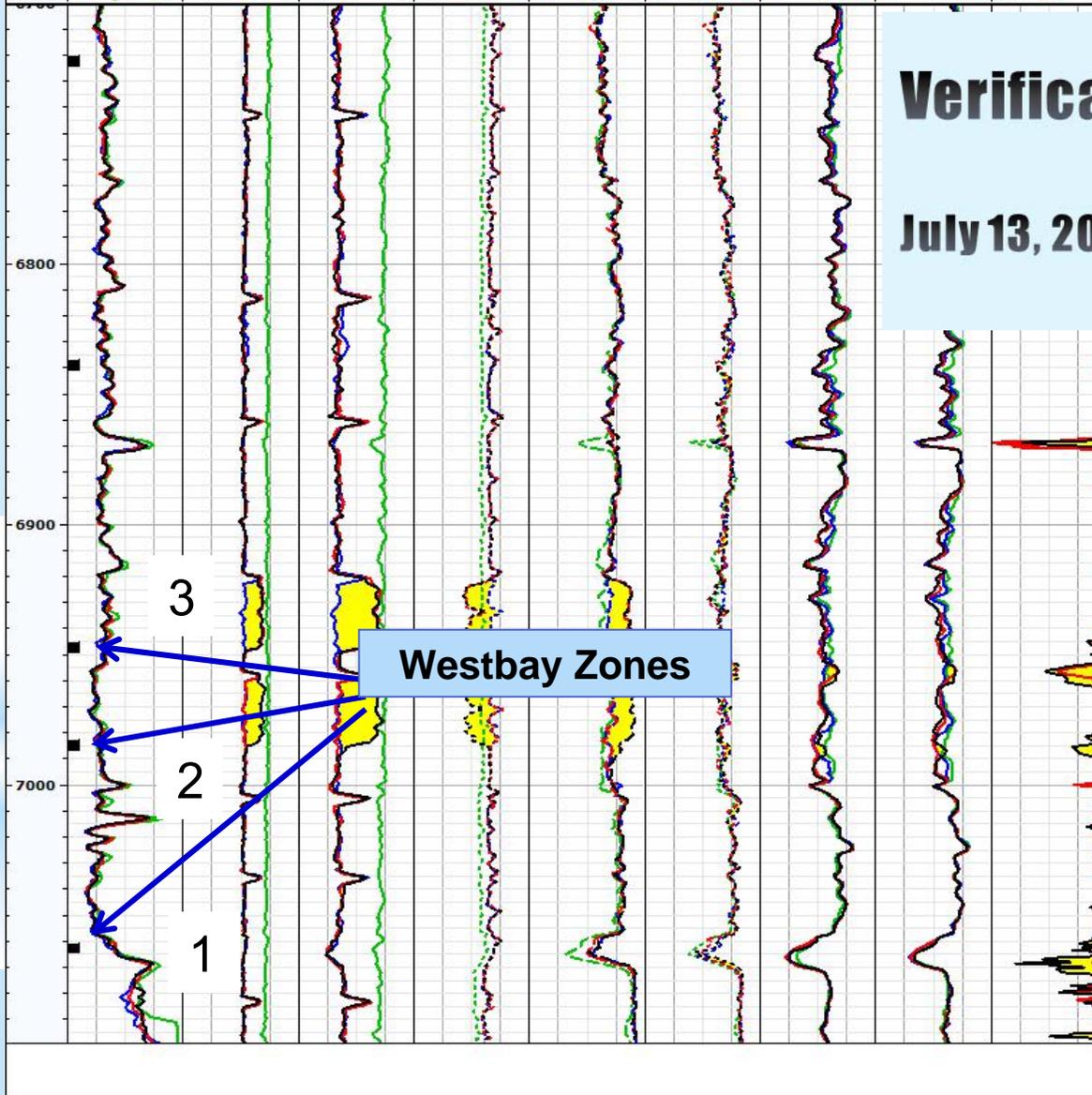


from Yoksoulian, 2011



Degraded clay minerals

| | | Perfs | | | | | | | | | | | | | |
|---------------------------|----------|-------------------|----------------|---------------------|----------------|---------------------|---------------|---------------------|----------------|---------------------|-------|---------------------|--|---------------------|--|
| | | FIL_7-12/SBNA_FIL | | TOTL_7-12/SIBH_TOTL | | INFO_9-11/INFO_TOTL | | TPHL_7-12/TPHL_9-11 | | PHIC_7-12/PHIC_9-11 | | SIGM_7-12/SIGM_9-11 | | TOTL_7-12/SIGM_TOTL | |
| Reference (ft 2000) | 0 | GR_7-12 | SBNA_FIL_7-12 | SIBH_TOTL_7-12 | INFO_TOTL_7-12 | TPHL_7-12 | PHIC_7-12 | SIGM_7-12 | SIGM_TOTL_7-12 | | | | | | |
| | 0 | gAPI 150 | 200 cu 0 | 200 cu 0 | 1000 1/s 0 | 0.6 m3/m3 0 | 0.6 ft3/ft3 0 | 60 cu 0 | 60 cu 0 | | | | | | |
| | 0 | GR_3-12 | SBNA_FIL_3-12 | SIBH_TOTL_3-12 | INFO_TOTL_3-12 | TPHL_3-12 | PHIC_3-12 | SIGM_3-12 | SIGM_TOTL_3-12 | | | | | | |
| | 0 | gAPI 150 | 200 cu 0 | 200 cu 0 | 1000 1/s 0 | 0.6 m3/m3 0 | 0.6 ft3/ft3 0 | 60 cu 0 | 60 cu 0 | DeltaSw_7-12 | | | | | |
| | 0 | GR_9-11 | SBNA_FIL_9-11 | SIBH_TOTL_9-11 | INFO_TOTL_9-11 | TPHL_9-11 | PHIC_9-11 | SIGM_9-11 | SIGM_TOTL_9-11 | DeltaSw_7-12 | | | | | |
| | 0 | gAPI 150 | 200 cu 0 | 200 cu 0 | 1000 1/s 0 | 0.6 m3/m3 0 | 0.6 ft3/ft3 0 | 60 cu 0 | 60 cu 0 | -1 | | | | | |
| 0 | GR_3-11 | SBNA_FIL_3-11 | SIBH_TOTL_3-11 | INFO_TOTL_3-11 | TPHL_3-11 | PHIC_3-11 | SIGM_3-11 | SIGM_TOTL_3-11 | DeltaSw_3-12 | | | | | | |
| 0 | gAPI 150 | 200 cu 0 | 200 cu 0 | 1000 1/s 0 | 0.6 m3/m3 0 | 0.6 ft3/ft3 0 | 60 cu 0 | 60 cu 0 | -1 | | v/v 0 | | | | |



Verification Well RST Logging

July 13, 2012

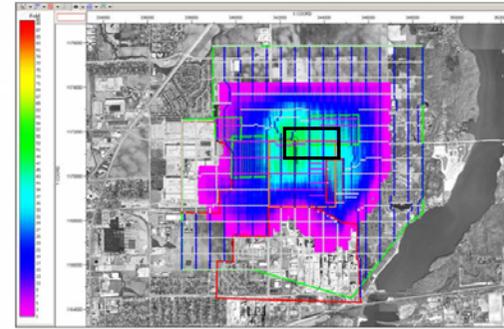
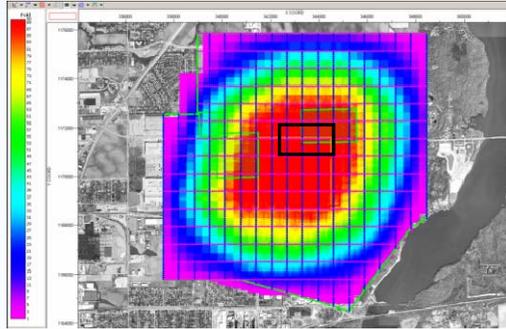
CO₂ in Reservoir

Westbay Zones 2 and 3 equivalent to lower and upper perforations, respectively

from Schlumberger Carbon Services

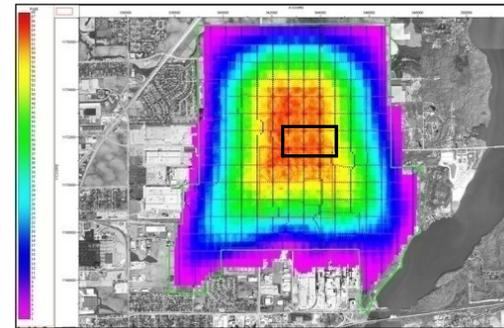
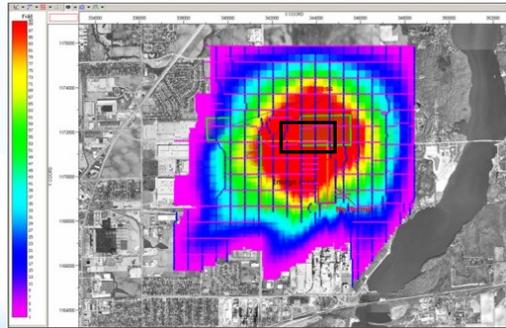
3D Acquisition Challenges: Design Iterations and Fold Coverage

Ideal design



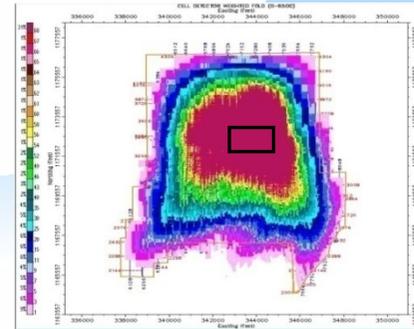
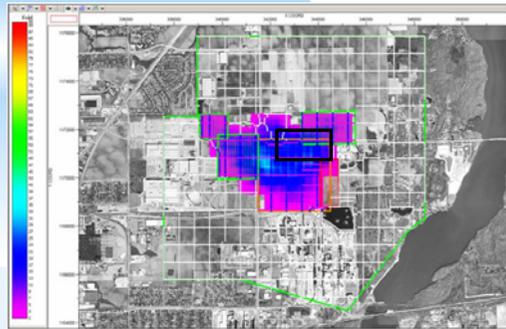
Case of shots in permitted areas only. Receiver locations relatively unrestricted

Ideal design with planned offsets



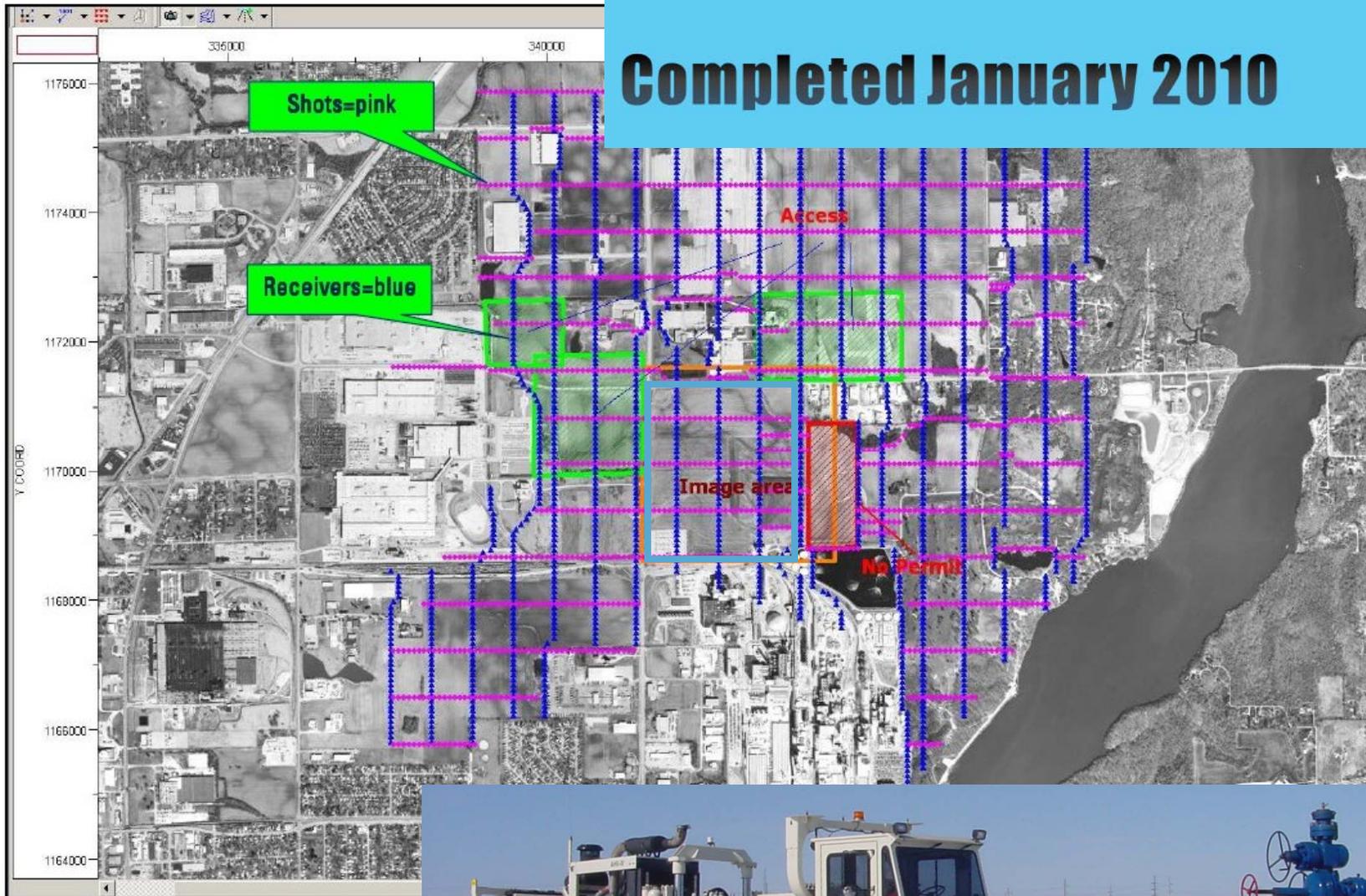
Final design

Access to known permitted areas only.

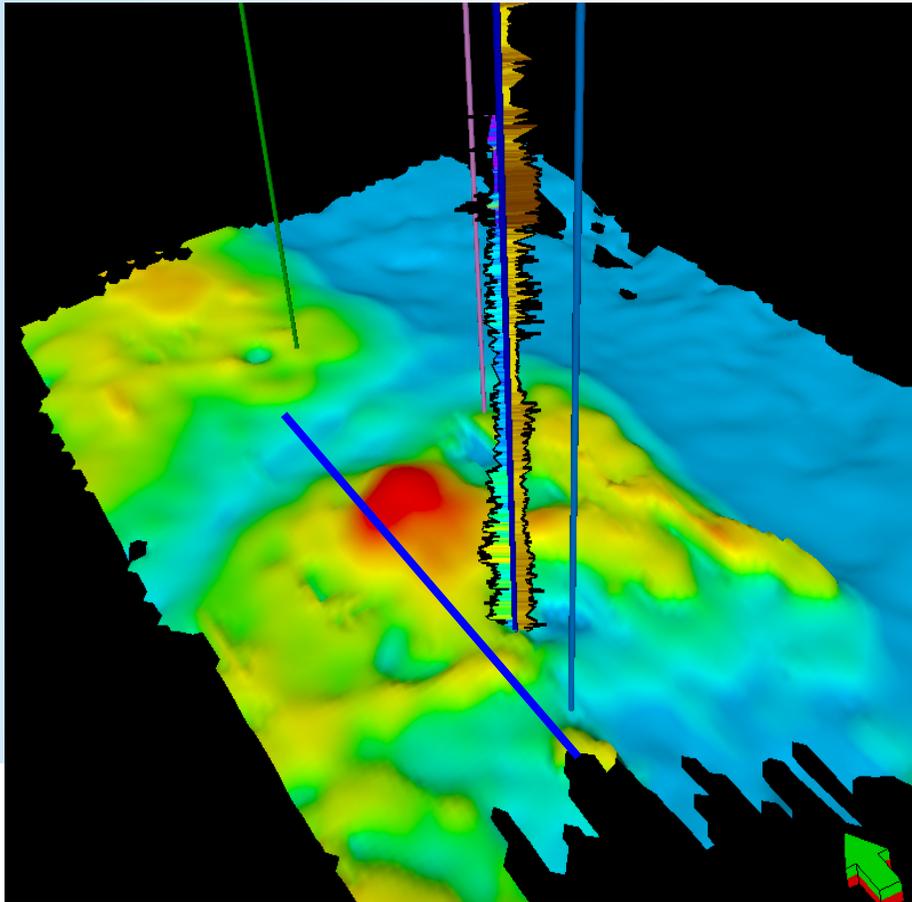


Acquired data

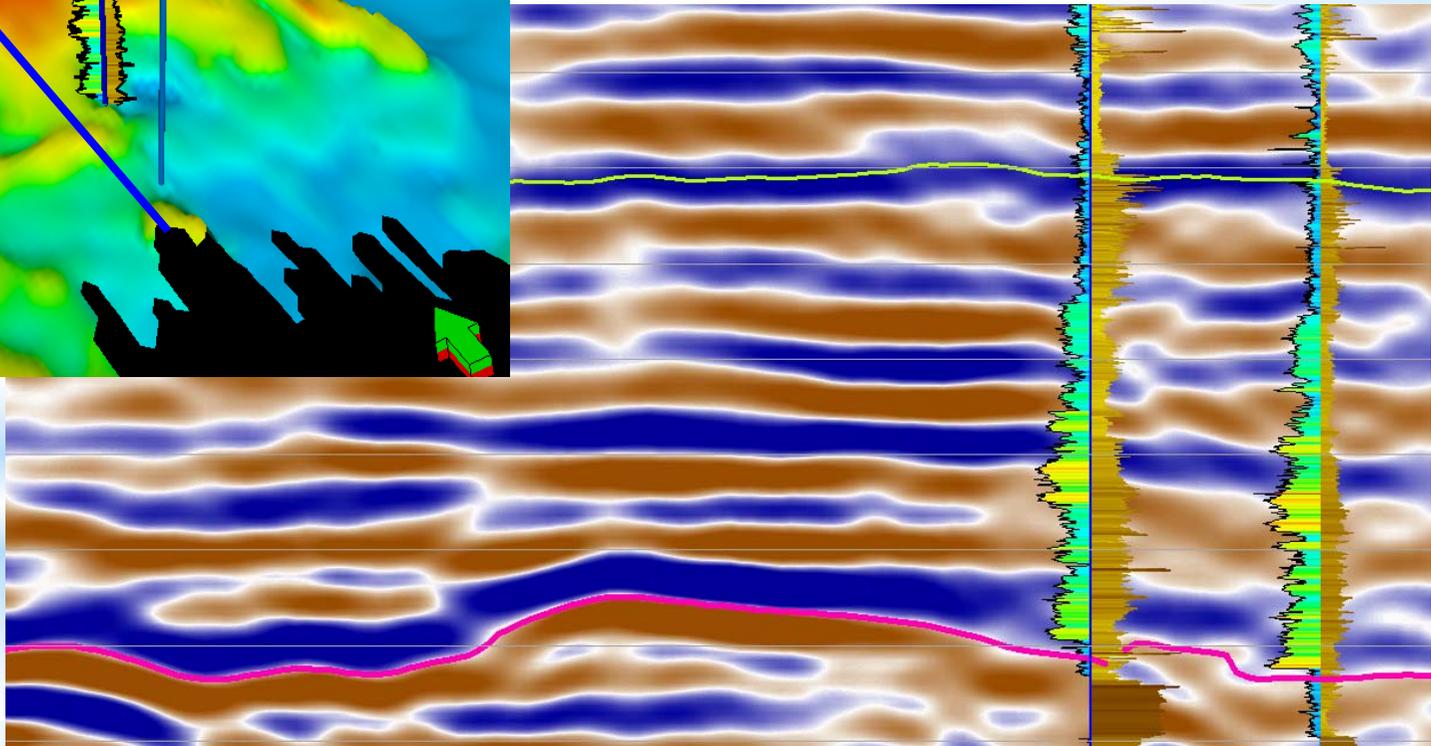
Baseline 3D Geophysical Survey Completed January 2010



3D Seismic Reveals Precambrian Topography



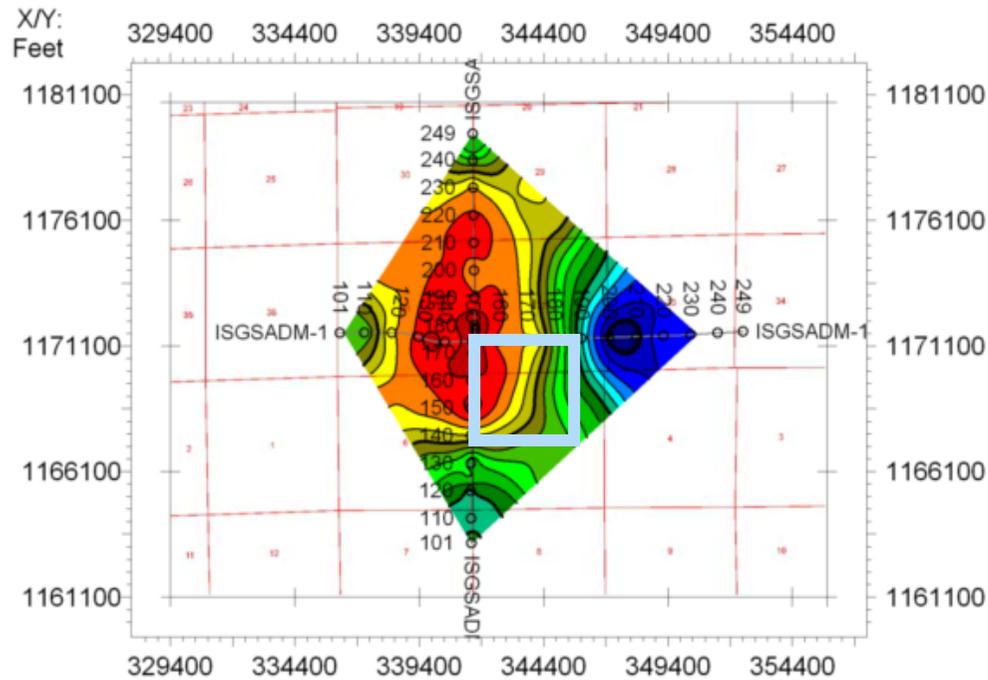
from Leetaru, ISGS



Valley eroded into
Precambrian

Precambrian structural high

Top of Mount Simon Structure

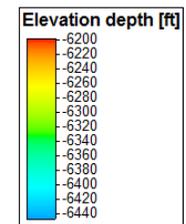
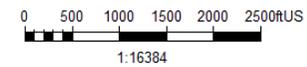
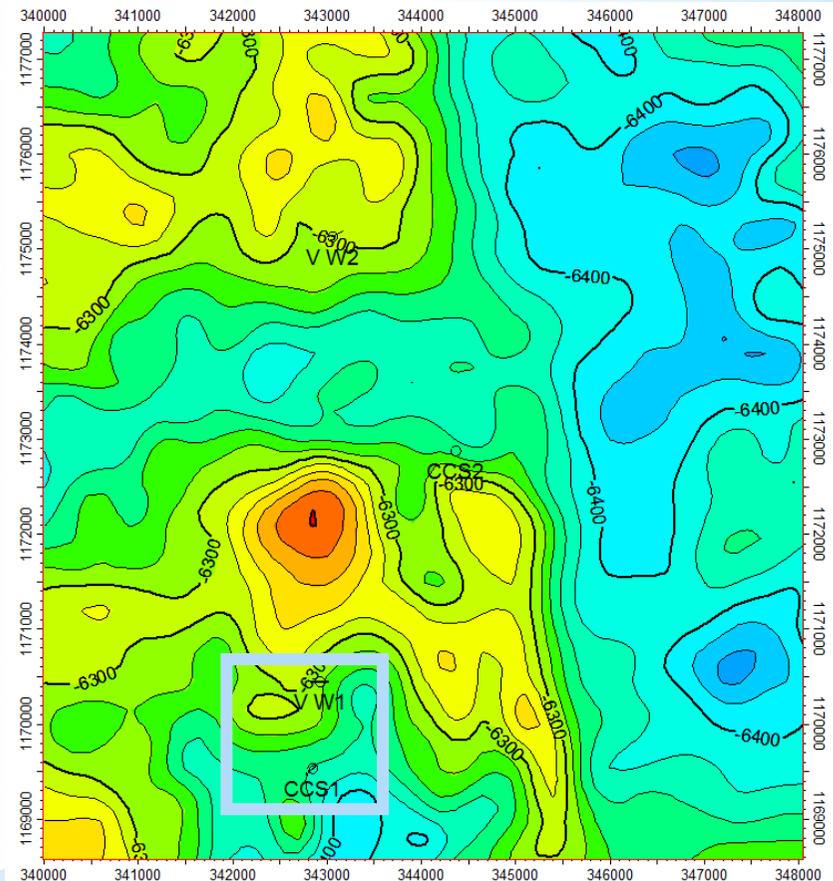


2D in Time

Base Mount Simon Structure

from Leetaru, ISGS

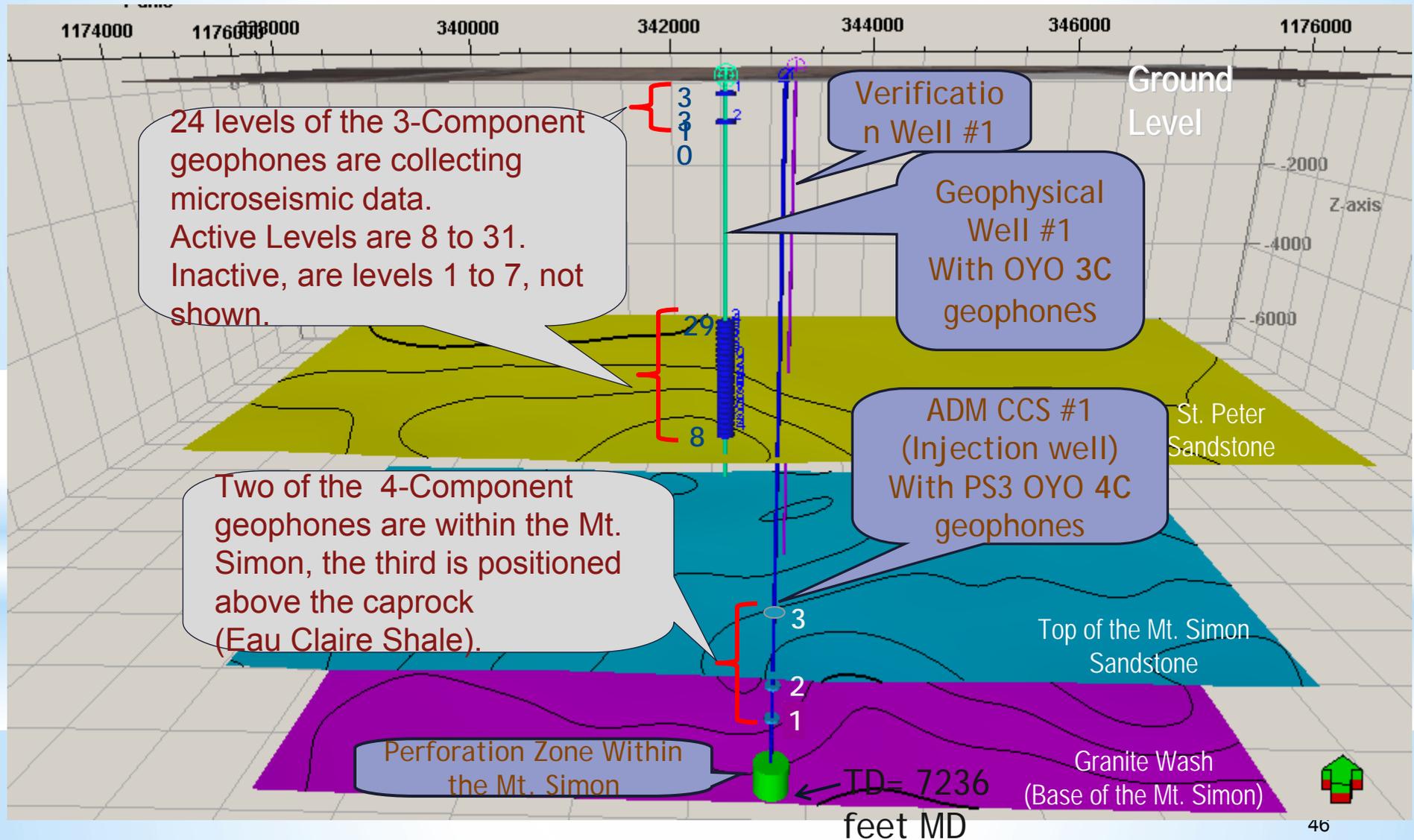
Comparison of 2D and 3D Seismic



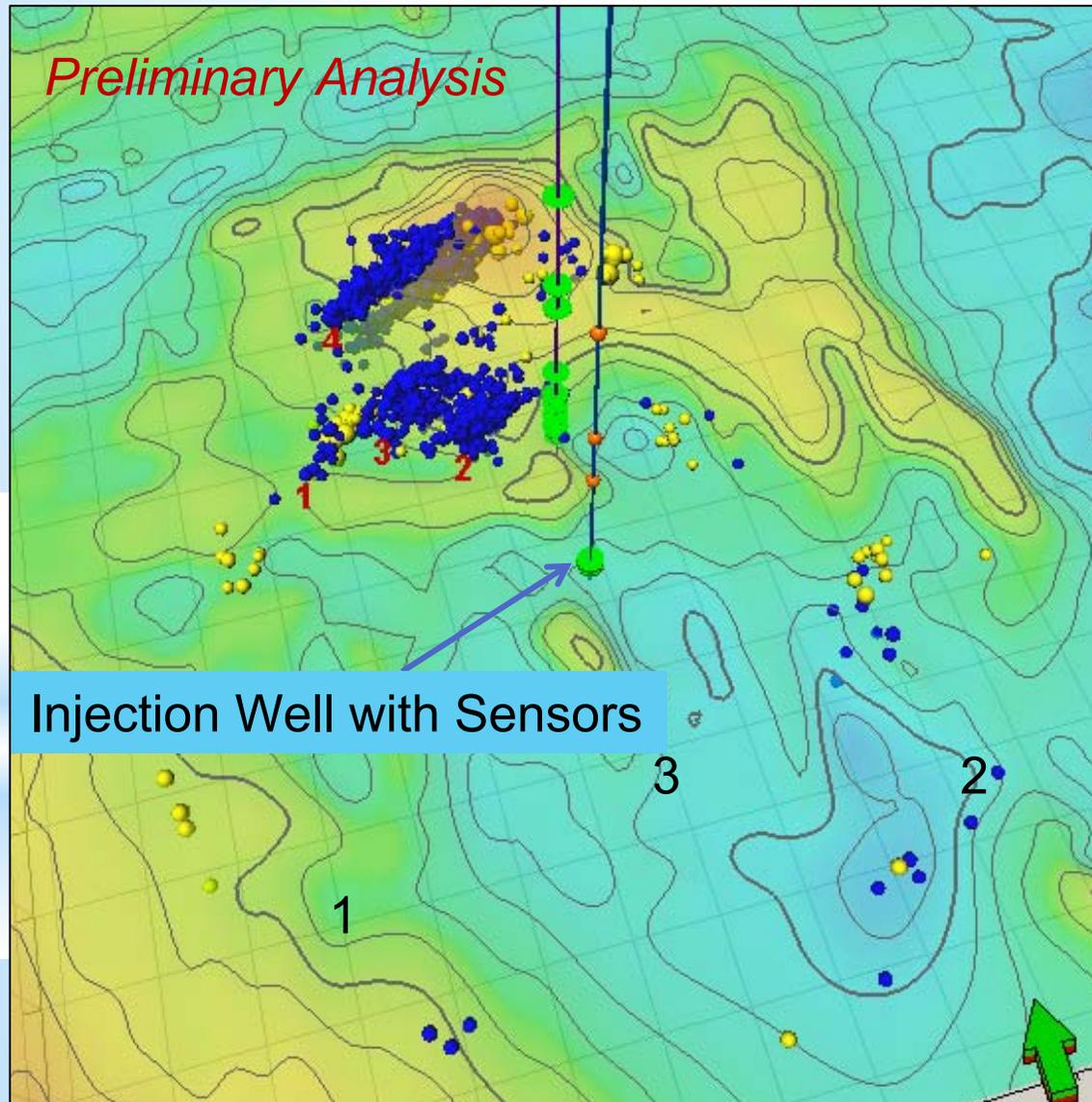
3D in Depth (ft)

Geophones, wells, and reservoir details

From Schlumberger
Carbon Services



Microseismic Events Recorded NW of Verification Well

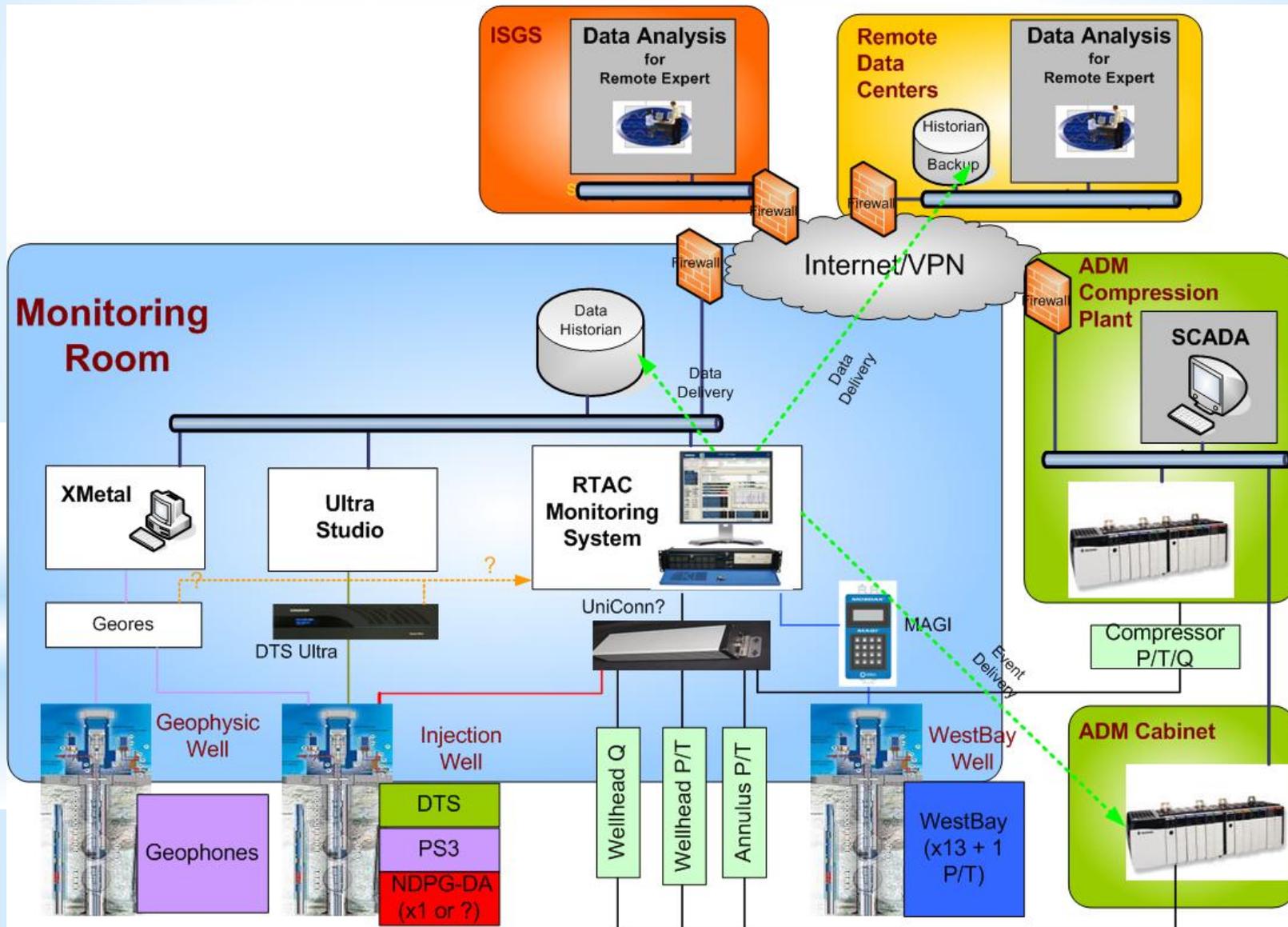


- Four component geophones deployed in injection well adequate to monitor activity
- Microseismic events clustered mainly in four groups NW of verification well
- Events predominately in minus 2 to minus 3.5 magnitude
- Event clusters elongated roughly parallel to basinal σ_1 direction

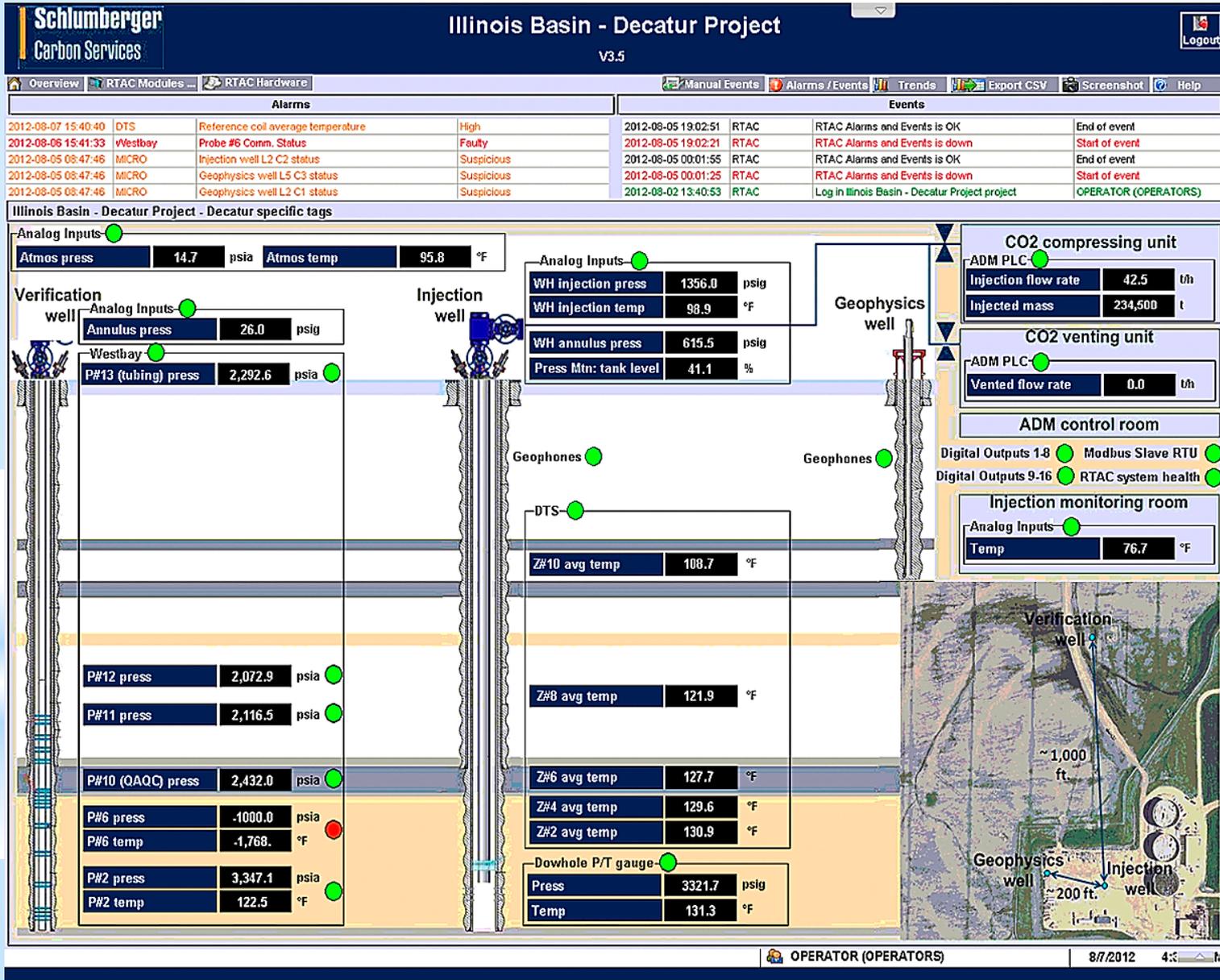
from Schlumberger Carbon Services

Data Collection System

from Schlumberger Carbon Services



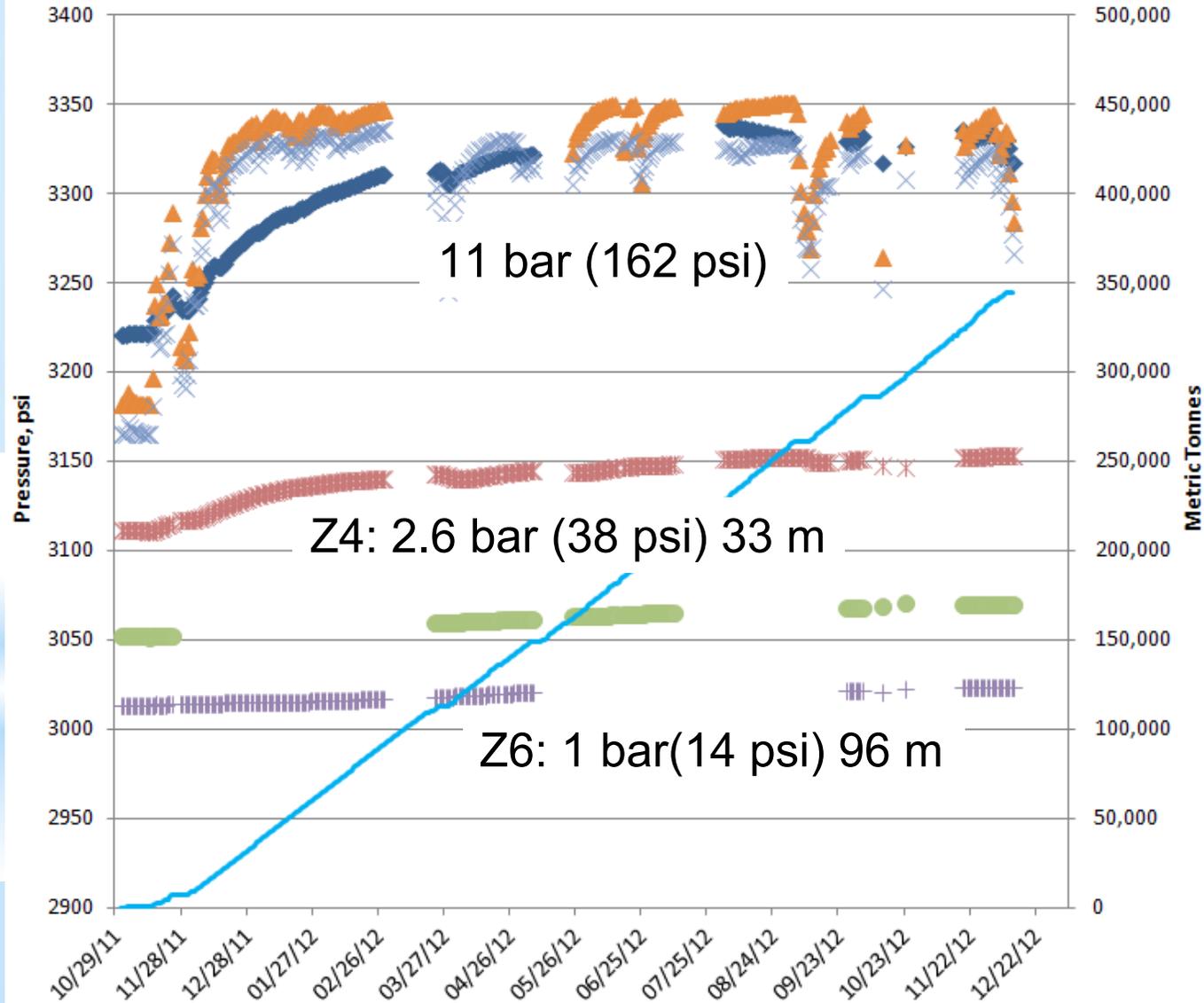
Data Collection System - System Screenshot



From
Schlumberger
Carbon
Services

Verification Well Monitoring Data

Plotted pressure data is based on averages for each day.



CCS#1 Perforated Zone Summary

| Zone # | Top | Bot |
|--------|--------|--------|
| 2 | 6982.0 | 7012.0 |
| 1 | 7025.0 | 7050.0 |

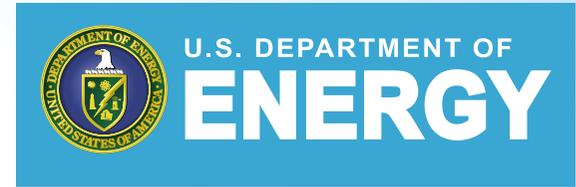
VW1 Perforated Zone Summary

| Zone # | Top | Bot |
|--------|--------|--------|
| 11 | 4917.5 | 4920.5 |
| 10 | 5000.7 | 5003.7 |
| 9 | 5653.8 | 5557.3 |
| 8 | 5840.4 | 5843.9 |
| 7 | 6416.2 | 6419.7 |
| 6 | 6632.3 | 6635.8 |
| 5 | 6720.3 | 6723.8 |
| 4 | 6837.1 | 6840.6 |
| 3 | 6945.6 | 6949.1 |
| 2 | 6983.0 | 6985.5 |
| 1 | 7061.2 | 7064.2 |

- ◆ Zone 1 Pres (7061')
- ▲ Zone 2 Pres (6983')
- × Zone 3 Pres (6946')
- ✕ Zone 4 Pres (6838')
- Zone 5 Pres (6720')
- + Zone 6 Pres (6632')
- Calc Cumulative injected mass

Key Operational Results – IBDP Year One

- Mount Simon Sandstone reservoir is accepting CO₂ more easily than expected resulting in quicker detection at verification well
- Upward plume growth limited by reservoir permeability stratification, as modeled, and confirmed by pressure observations
- Resulting plume believed thinner than expected and was not definitively detected with a 3D vertical seismic profile at 75,000 tonnes cumulative injection in March 2012; new survey due in January-February 2013
- Mt. Simon 200,000 ppm brine is more corrosive than expected, leading to corrosion of verification well cabling and need to replace corrosion inhibitor in well sooner than expected
- With 378,000 tonnes injected, CO₂ remains in lowermost Mt. Simon; internal reservoir heterogeneity affecting CO₂ distribution



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