



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

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Director, Advanced Energy Technology Initiative  
University of Illinois, USA



**ILLINOIS STATE  
GEOLOGICAL SURVEY**  
PRAIRIE RESEARCH INSTITUTE

CSLF Rome, Italy  
18 April 2013





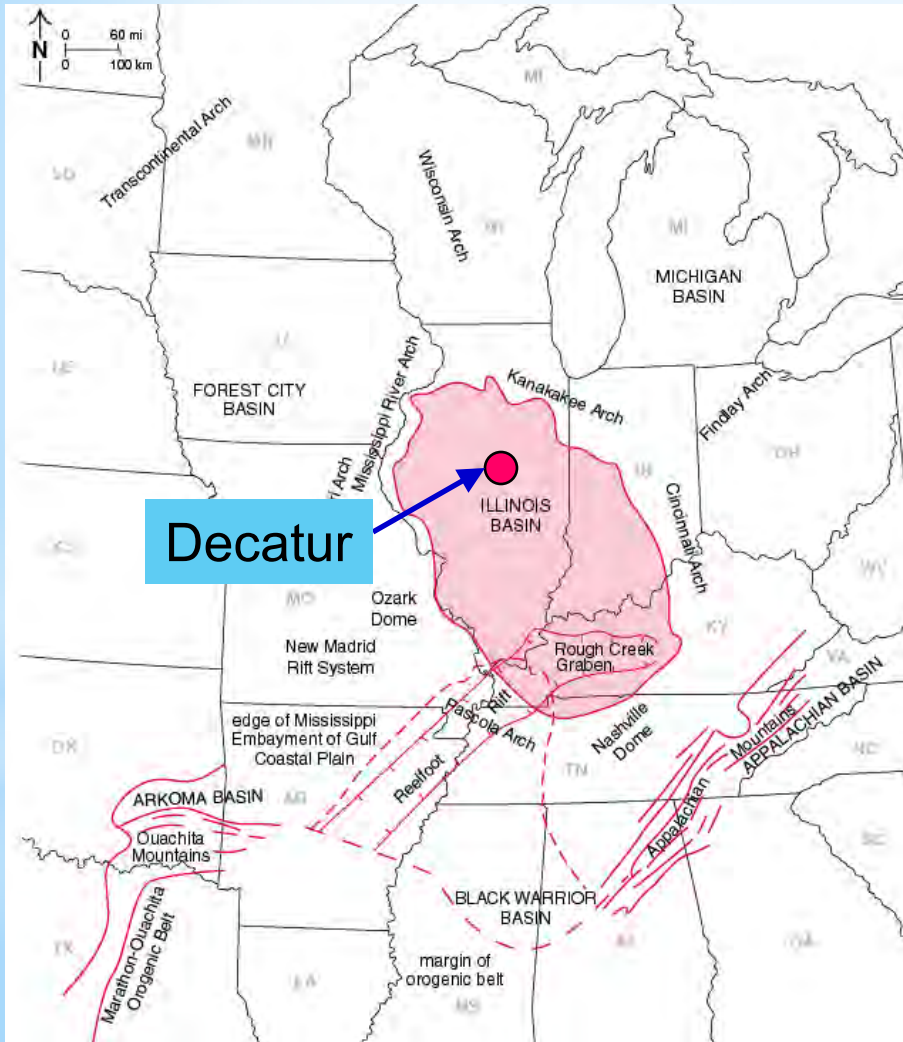
## Acknowledgements

- 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

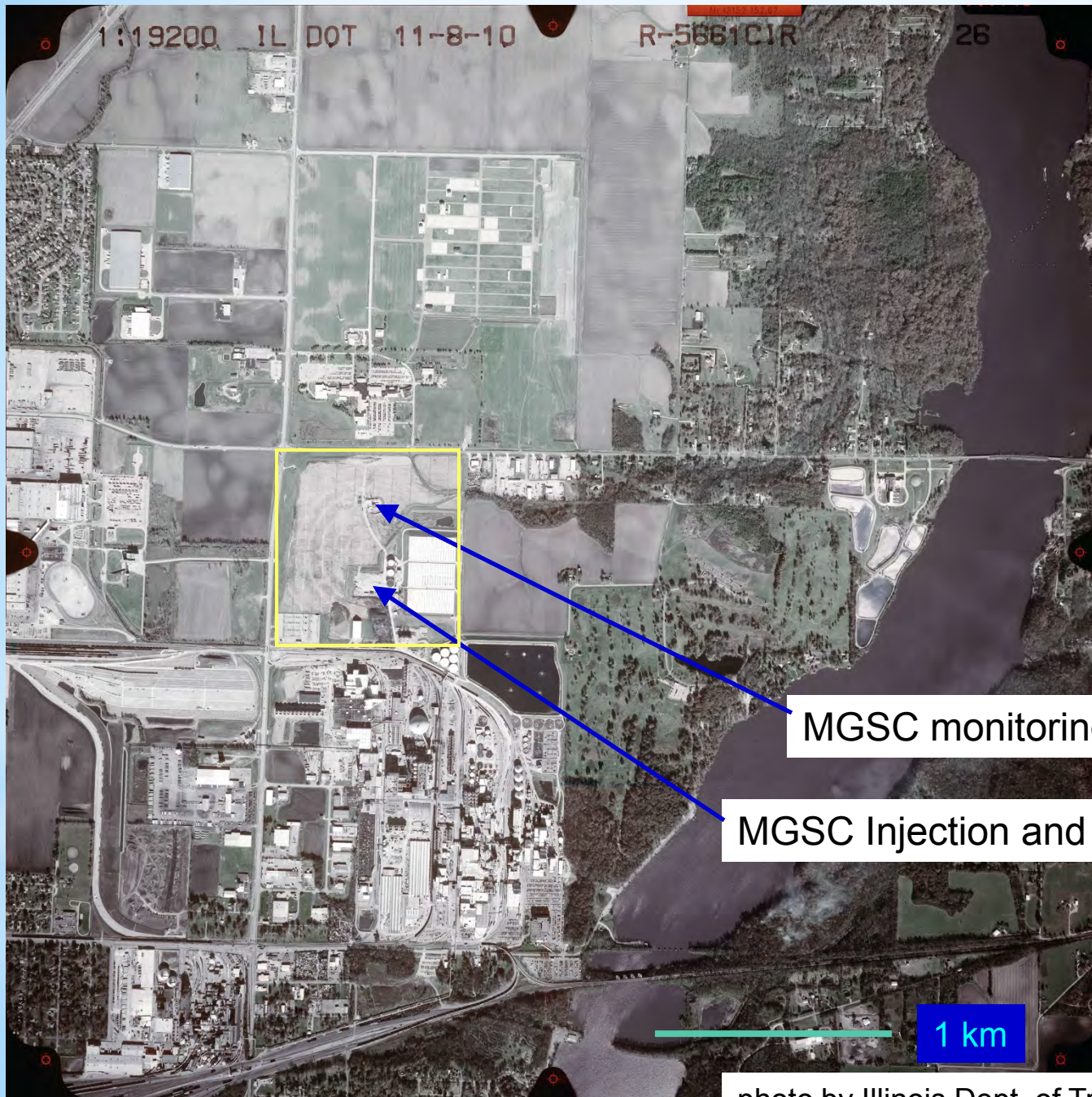


# Illinois Basin – Decatur Project Scope



A collaboration of the Midwest Geological Sequestration Consortium, the Archer Daniels Midland Company (ADM), Schlumberger Carbon Services, and other subcontractors to inject 1 million metric tons of anthropogenic carbon dioxide at a depth of 7,000 +/- ft (2,000 +/- m) to test **geological carbon sequestration in a saline reservoir** at a site in Decatur, IL





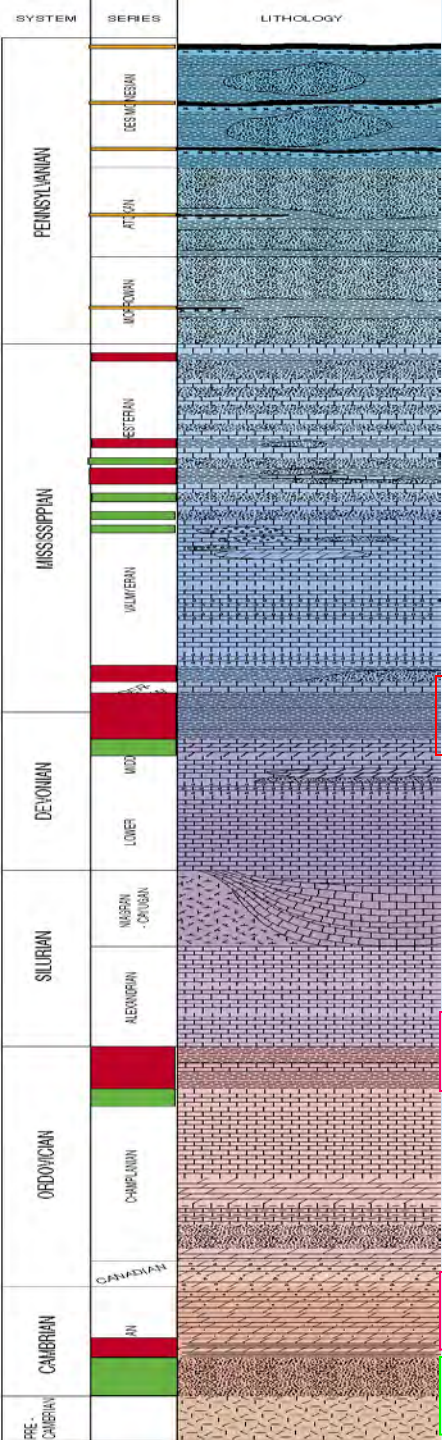
**MGSC  
Illinois  
Basin-  
Decatur  
Project  
(IBDP) Site**

MGSC monitoring well

MGSC Injection and geophone wells

1 km





# 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

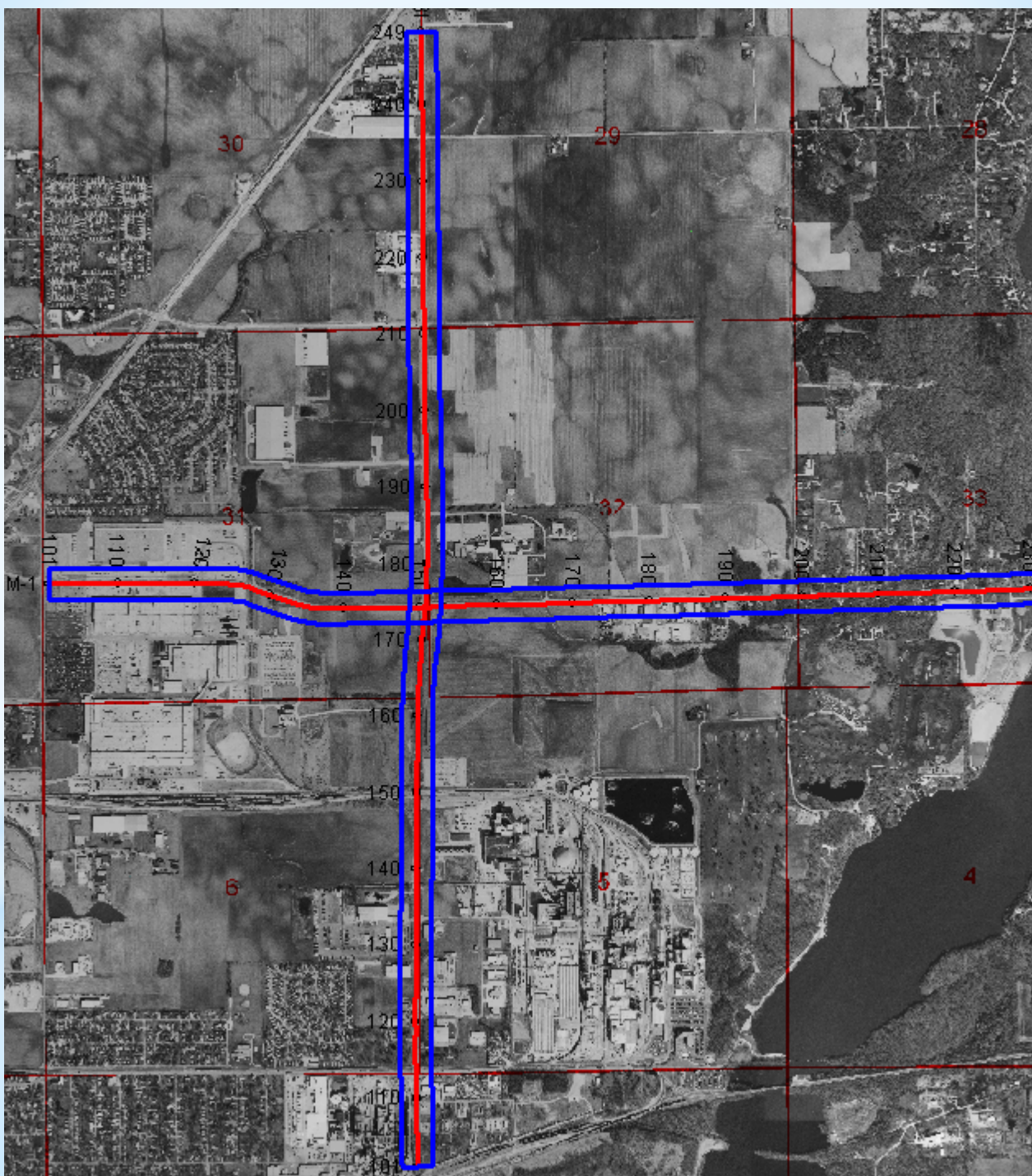
**New Albany (Seal)**

**Maquoketa (Seal)**

**Eau Claire Shale (Seal)**

**Mount Simon Sandstone (Sink)**

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





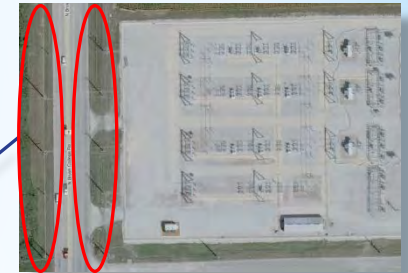
# Acquisition Challenges: Noise



Thick concrete surface creating source generated noise



Road traffic noise due to tractor trailers visiting ADM plant.



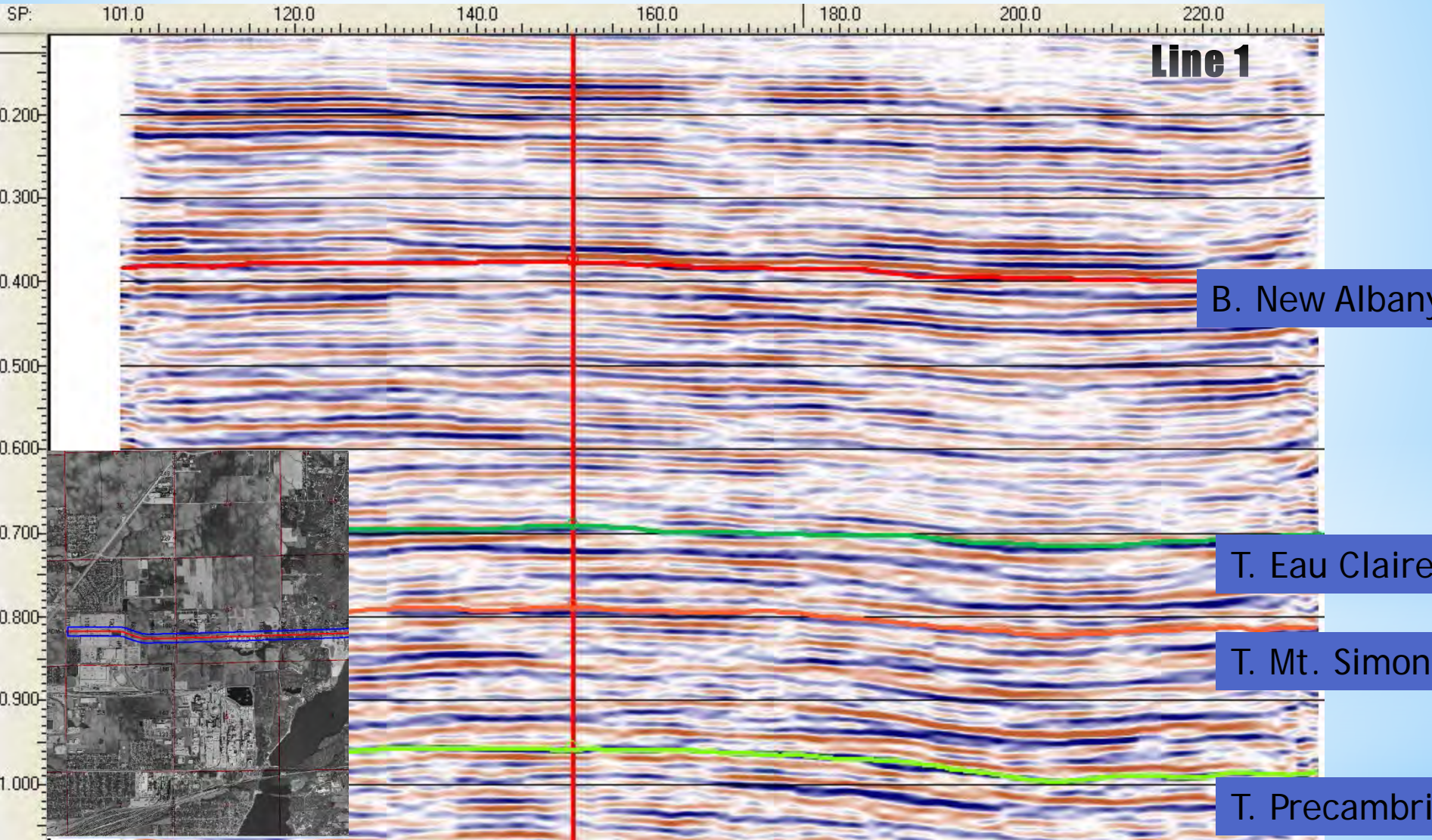
Electrical noise from power lines and 60Hz transformer plant



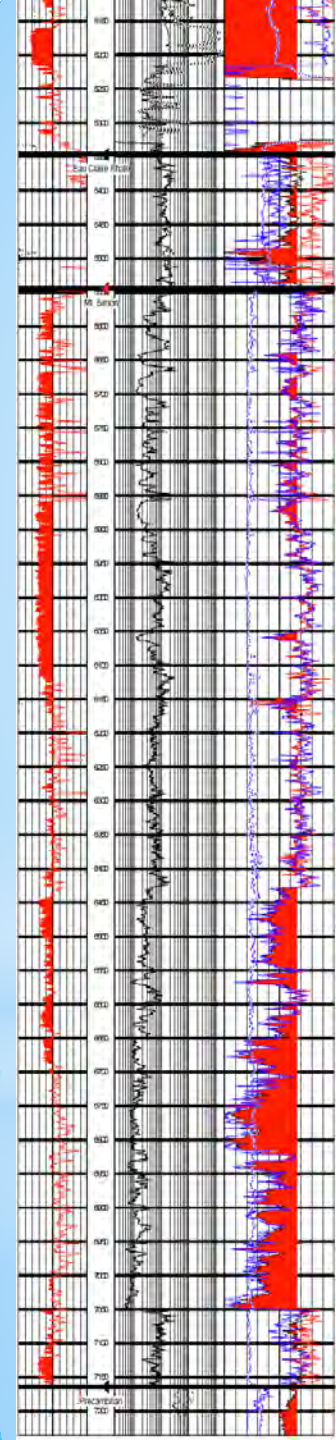
Plant Related Noise from ADM plant



# Correlate Horizons From a well 75 km to the South







Eau Claire Shale

Upper Mt. Simon

Middle Mt. Simon

Lower Mt. Simon

Injection Interval



5,455

SLB Carbon Services  
ADM Verification Well 1

Core 6

1.0  
0.1  
0.2  
0.3  
0.4  
0.5  
0.6  
0.7  
0.8  
0.9  
1.0  
1.1  
1.2  
1.3  
1.4  
1.5  
1.6  
1.7  
1.8  
1.9  
2.0

5455

5457

5450

5461

5465

PS  
12

5458

5458

5460

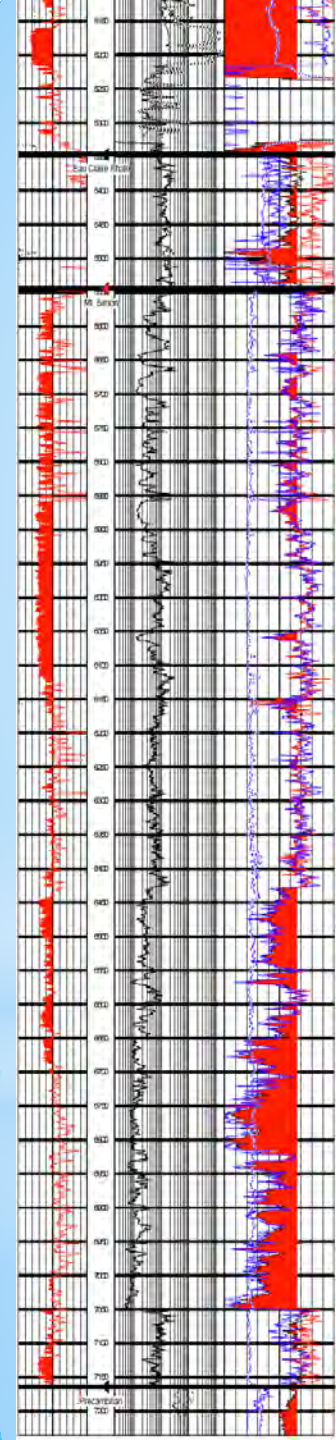
5462

5464

5,465







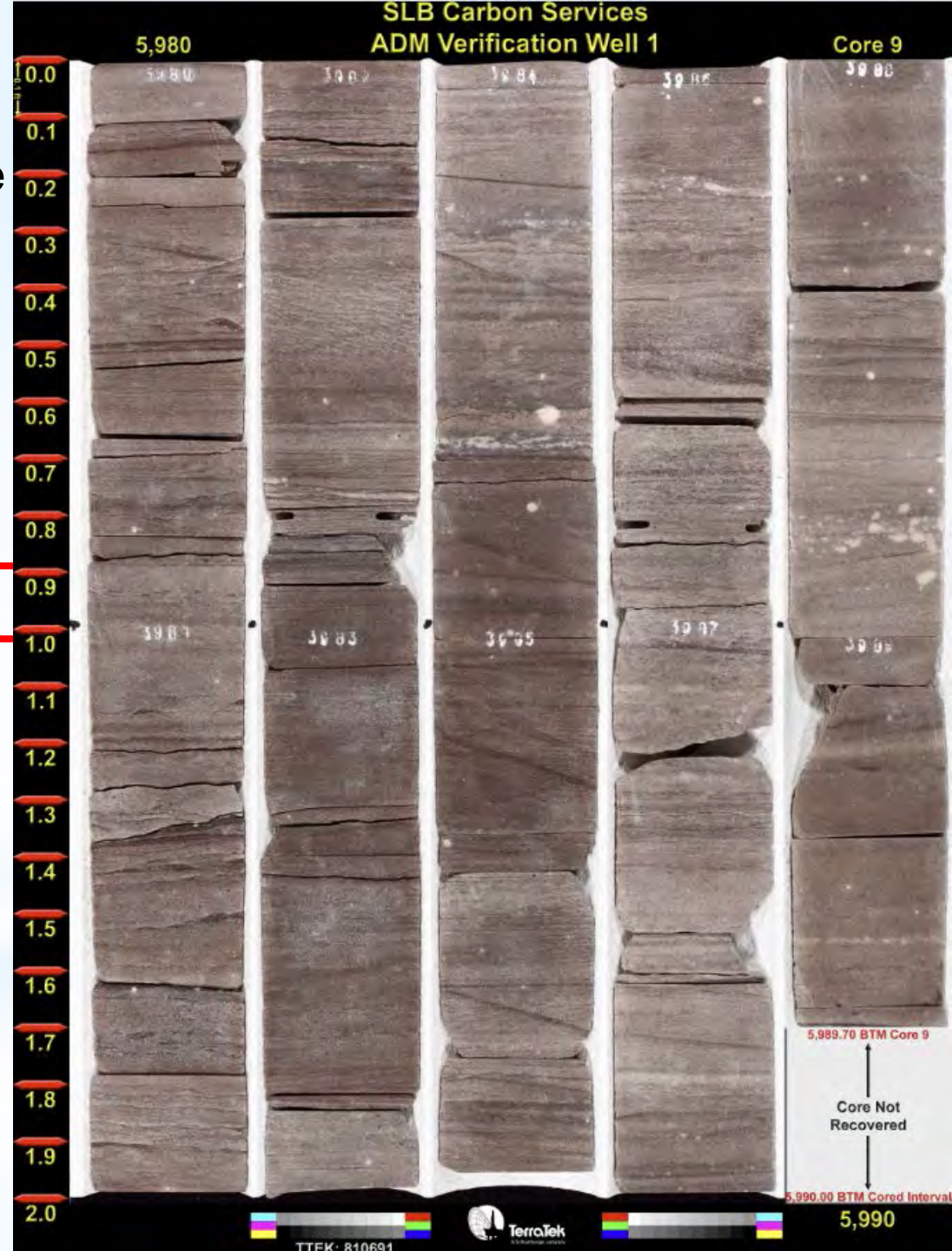
Eau Claire Shale

Upper Mt. Simon

Middle Mt. Simon

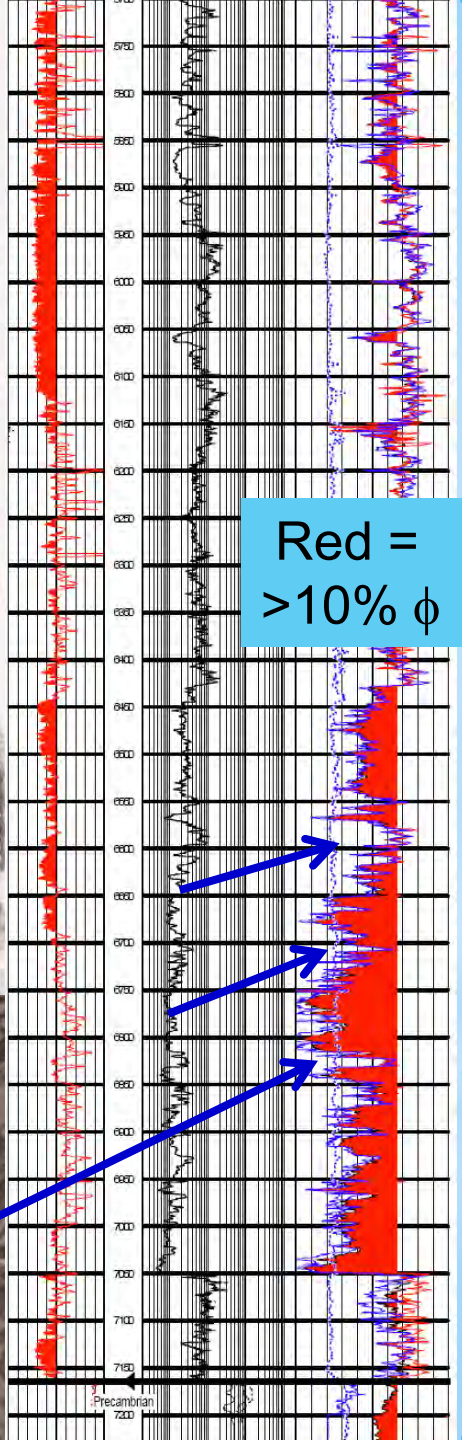
Lower Mt. Simon

Injection Interval





# Mount Simon Depositional Analogue: Brahmaputra River System

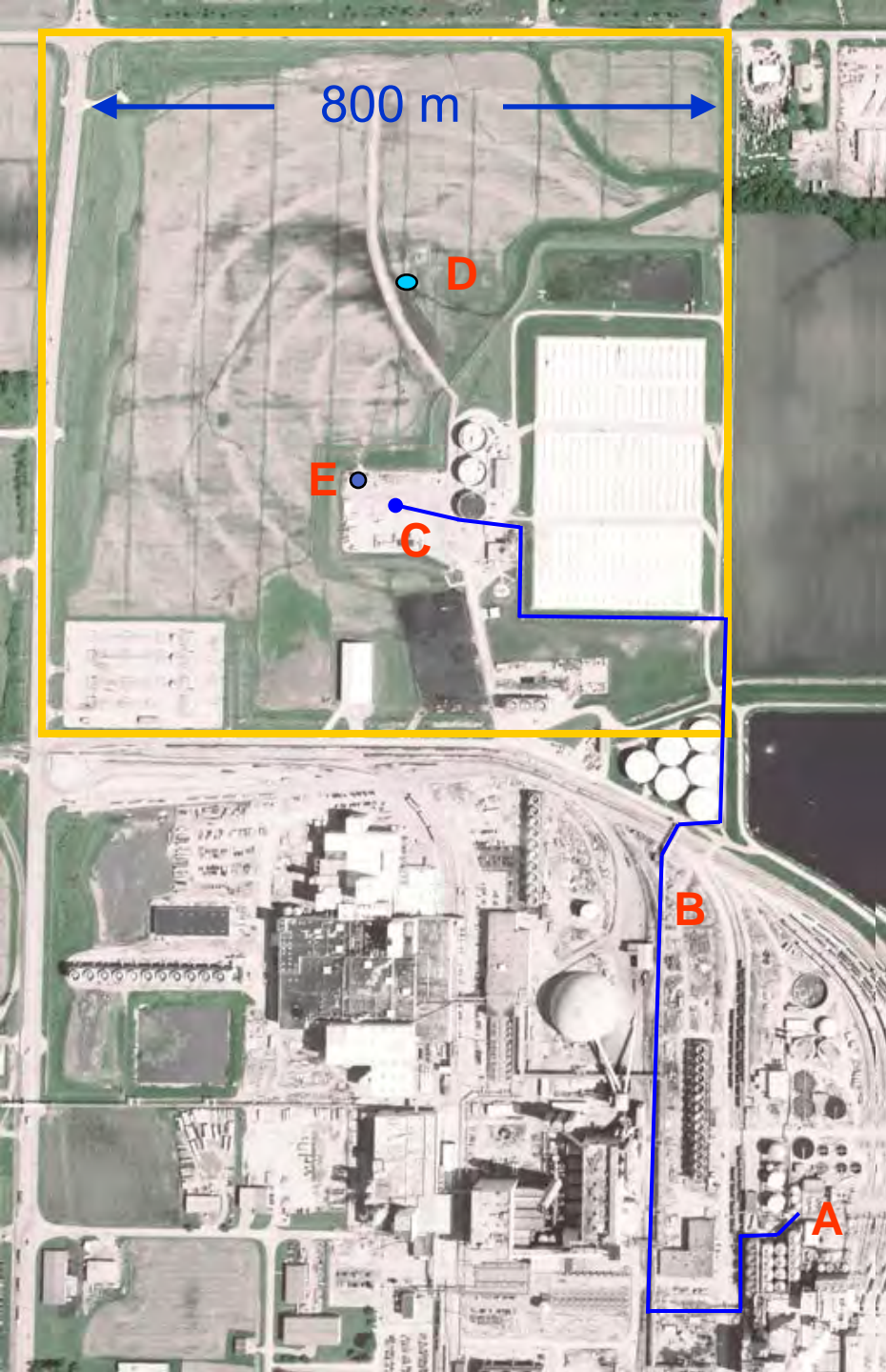


Sand-rich but low porosity/perm layers



# 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  
(15 April 2013):  
453,144 tonnes

# IBDP Environmental Monitoring Framework

## Near Surface

Atmosphere

Soil/vadose zone

Shallow groundwater

Eddy covariance

Meteorological conditions

Ambient CO<sub>2</sub> for HHS

Tunable diode laser for CO<sub>2</sub>

CIR aerial imagery

InSAR and GPS

Soil gases

Soil CO<sub>2</sub> flux

Tunable diode laser for CO<sub>2</sub>

Geophysical surveys

Geochemical sampling

P/T monitoring

## Deep Subsurface

Above seal

Injection zone

Geophysical surveys

Geochemical sampling

P/T monitoring

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





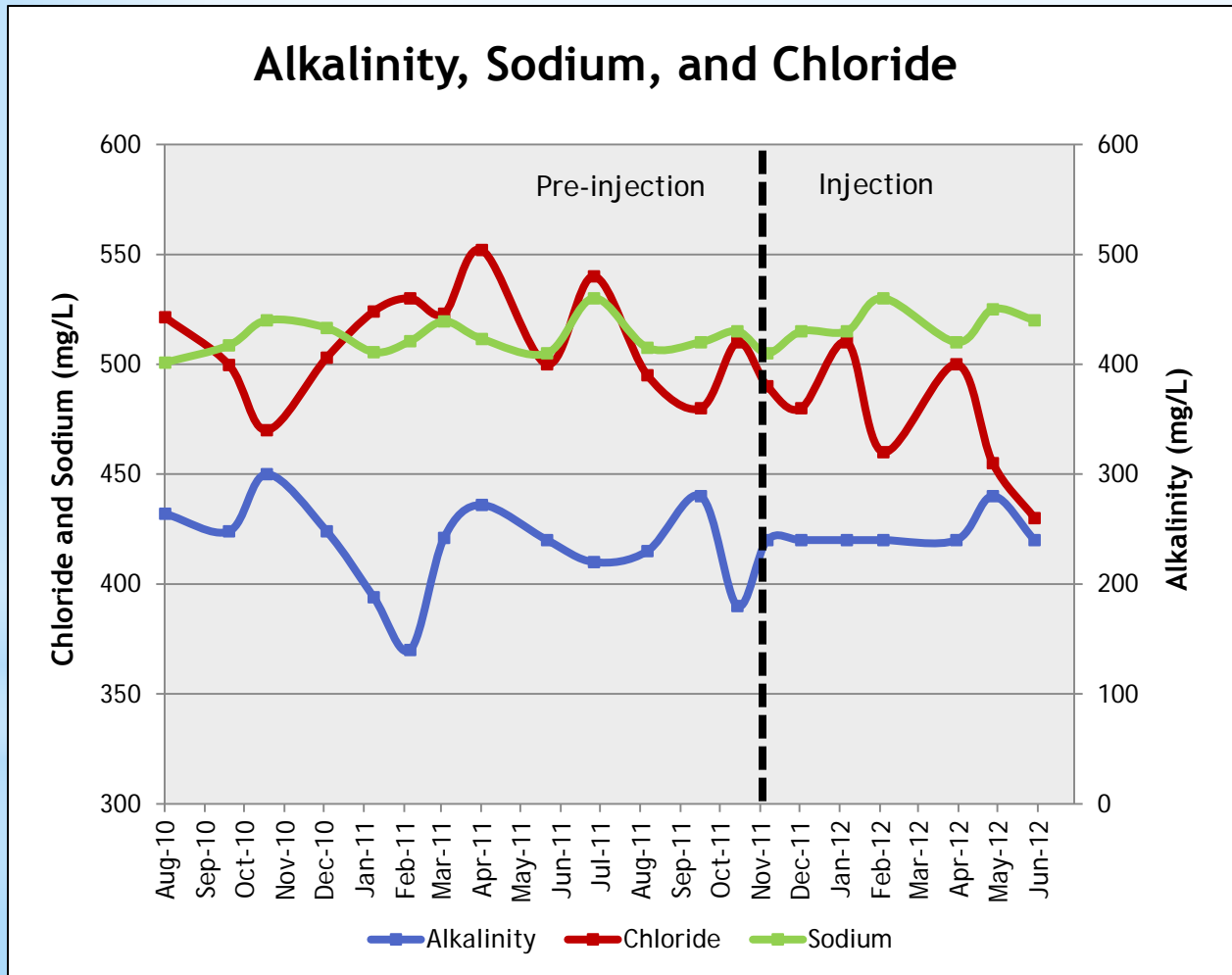
# Shallow Groundwater Network

- 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,  $\text{NH}_3$ , C and O isotopes, TOC, and TIC





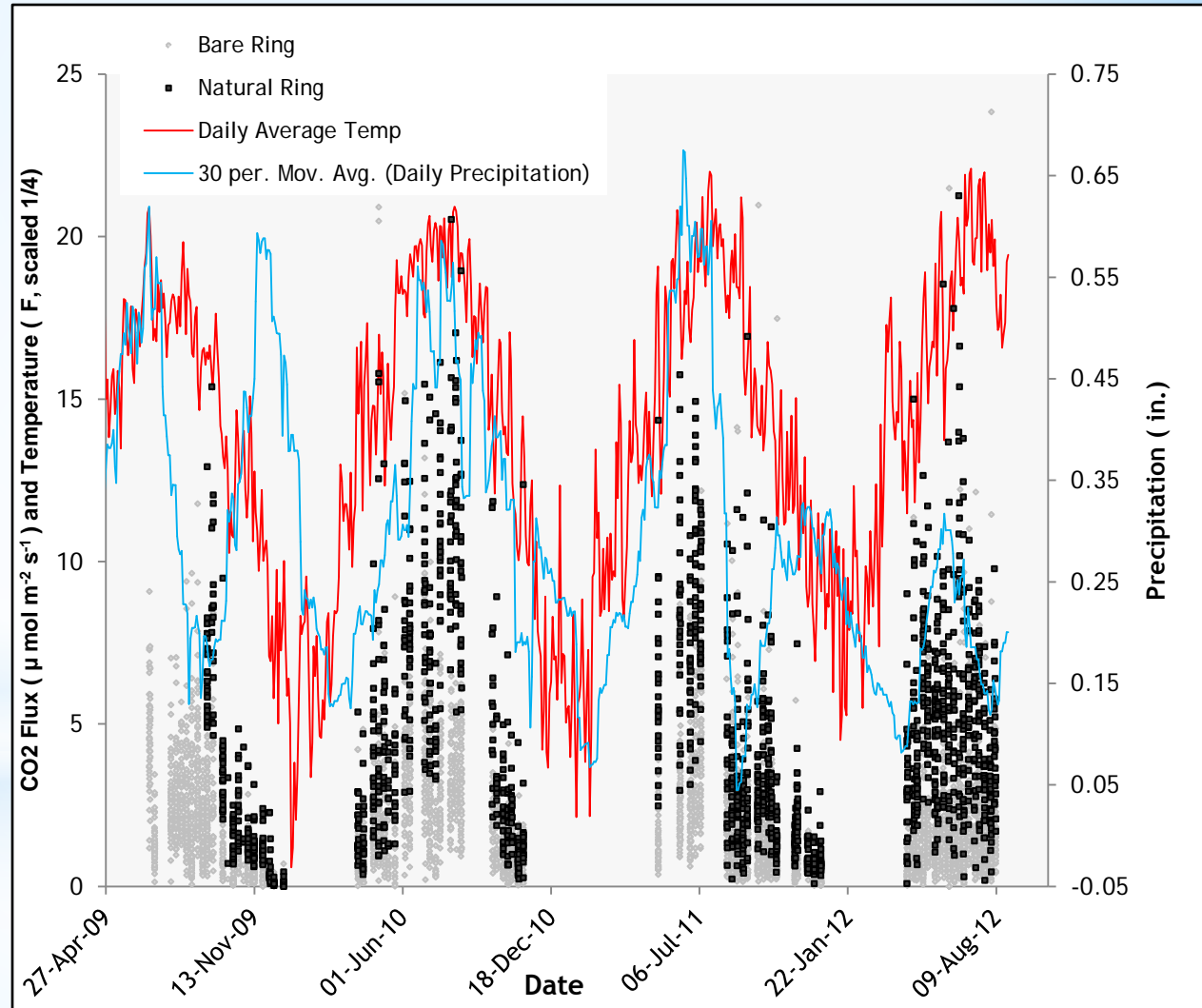
# Generally Consistent Trends



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

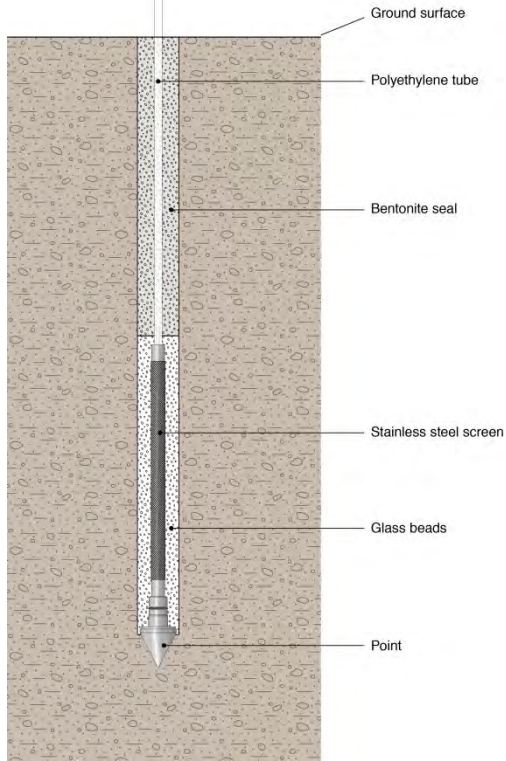
# Soil Flux Monitoring

- 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

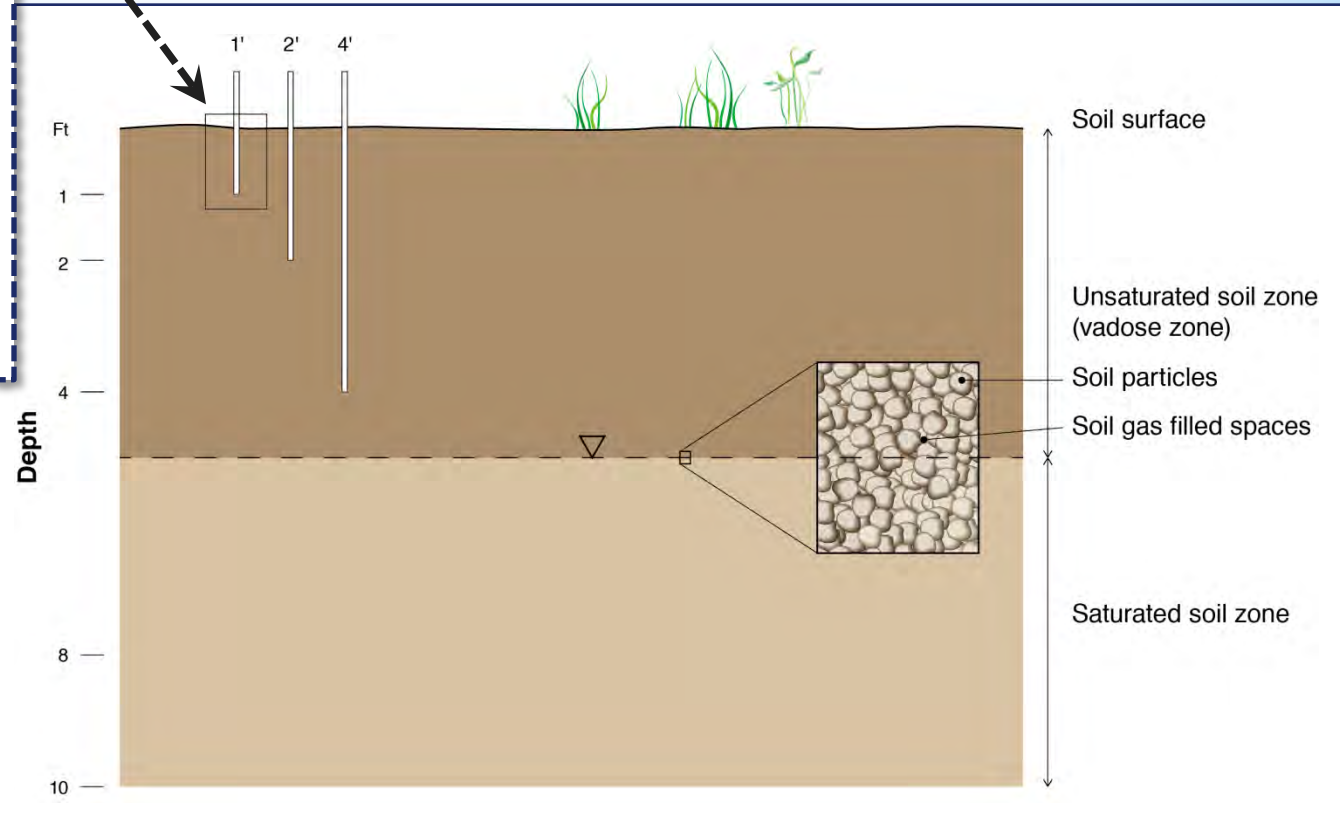




# Soil Gas Installations

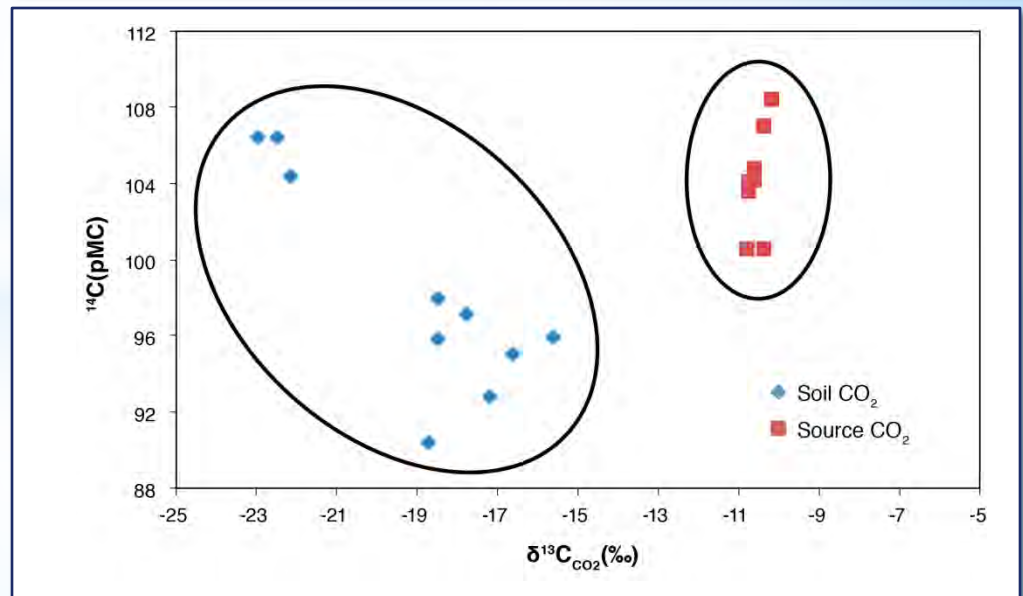
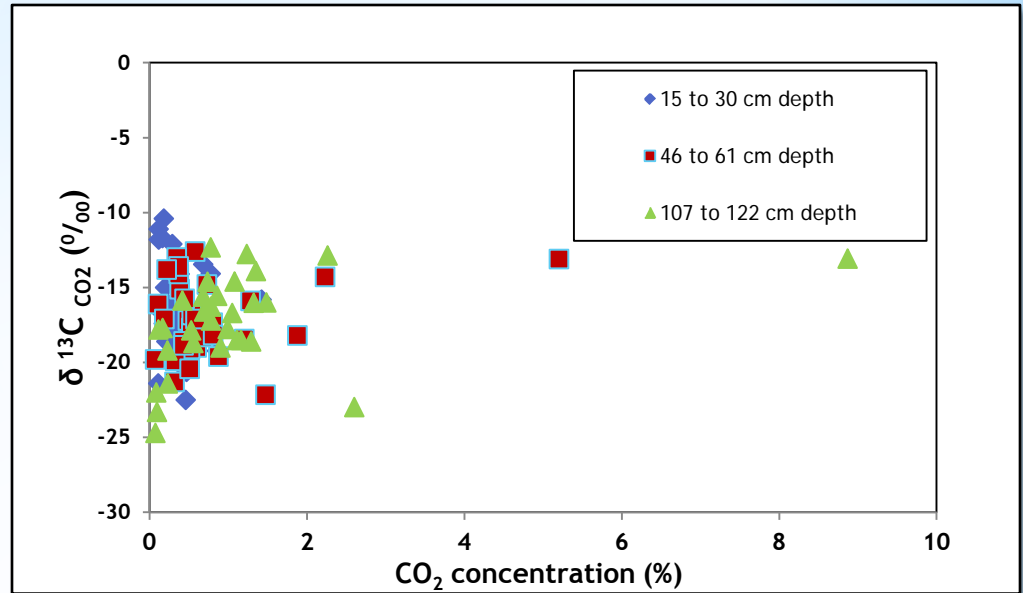


Detail View



# Soil Gas Characterization

- Quarterly data collection began Summer 2011
- Analyzed for CO<sub>2</sub>, N<sub>2</sub>, Ar + O<sub>2</sub>, light hydrocarbons (C<sub>1</sub> to C<sub>6</sub>),  $\delta^{13}\text{C}_{\text{CO}_2}$ , and <sup>14</sup>C
- Biogenic activity consumes O<sub>2</sub> and generally CO<sub>2</sub> concentrations increase with depth
- Range of  $\delta^{13}\text{C}_{\text{CO}_2}$  in soil: -10 to -25 per mil
- Distinct signatures of soil CO<sub>2</sub> and source CO<sub>2</sub>





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

Satellite interferometry

# Surface Environmental Monitoring

No atmospheric releases

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

A photograph of an eddy covariance air monitoring station in a field. The station consists of two tall towers with various sensors and instruments attached. The ground is covered in green grass.

Eddy covariance air monitoring

# IBDP Environmental Monitoring Framework

## Near Surface

**Atmosphere**

Eddy covariance

Meteorological conditions

Ambient CO<sub>2</sub> for HHS

Tunable diode laser for CO<sub>2</sub>

**Soil/vadose zone**

CIR aerial imagery

InSAR and GPS

Soil gases

Soil CO<sub>2</sub> flux

Tunable diode laser for CO<sub>2</sub>

**Shallow groundwater**

Geophysical surveys

Geochemical sampling

P/T monitoring

## Deep Subsurface

**Above seal**

Geophysical surveys

Geochemical sampling

P/T monitoring

**Injection zone**

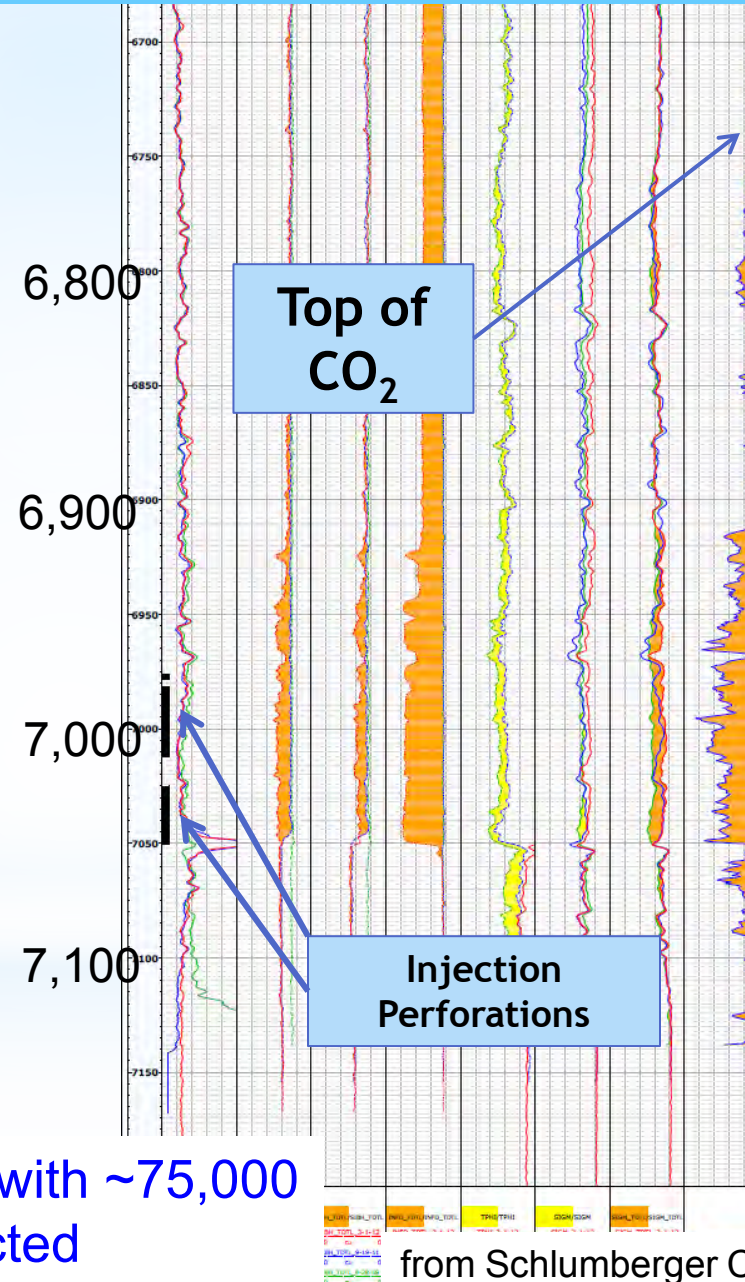
Geophysical surveys

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

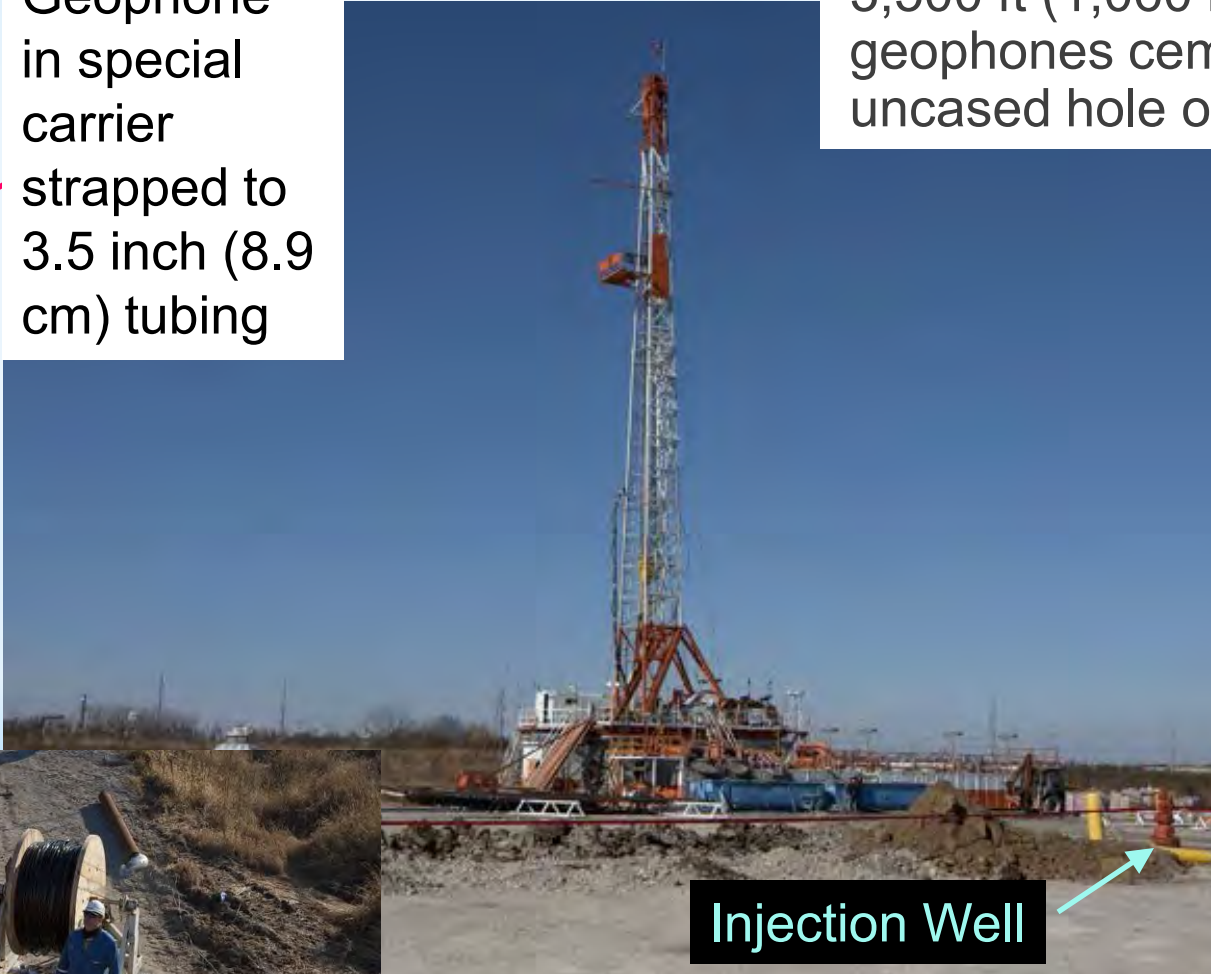
from Schlumberger Carbon Services

# Geophone Well Completed November 2009

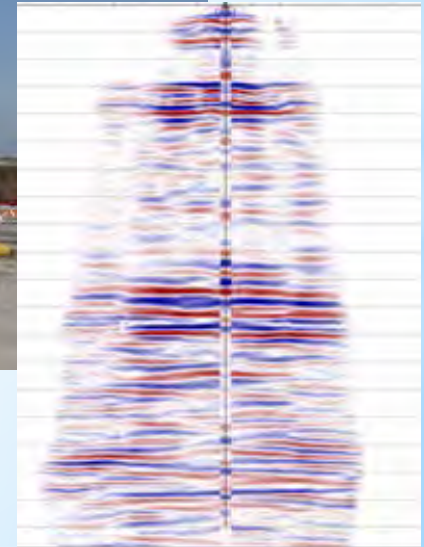


Geophone  
in special  
carrier  
strapped to  
3.5 inch (8.9  
cm) tubing

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 Schlumberger



# Westbay Installation and Sampling



June-August 2011

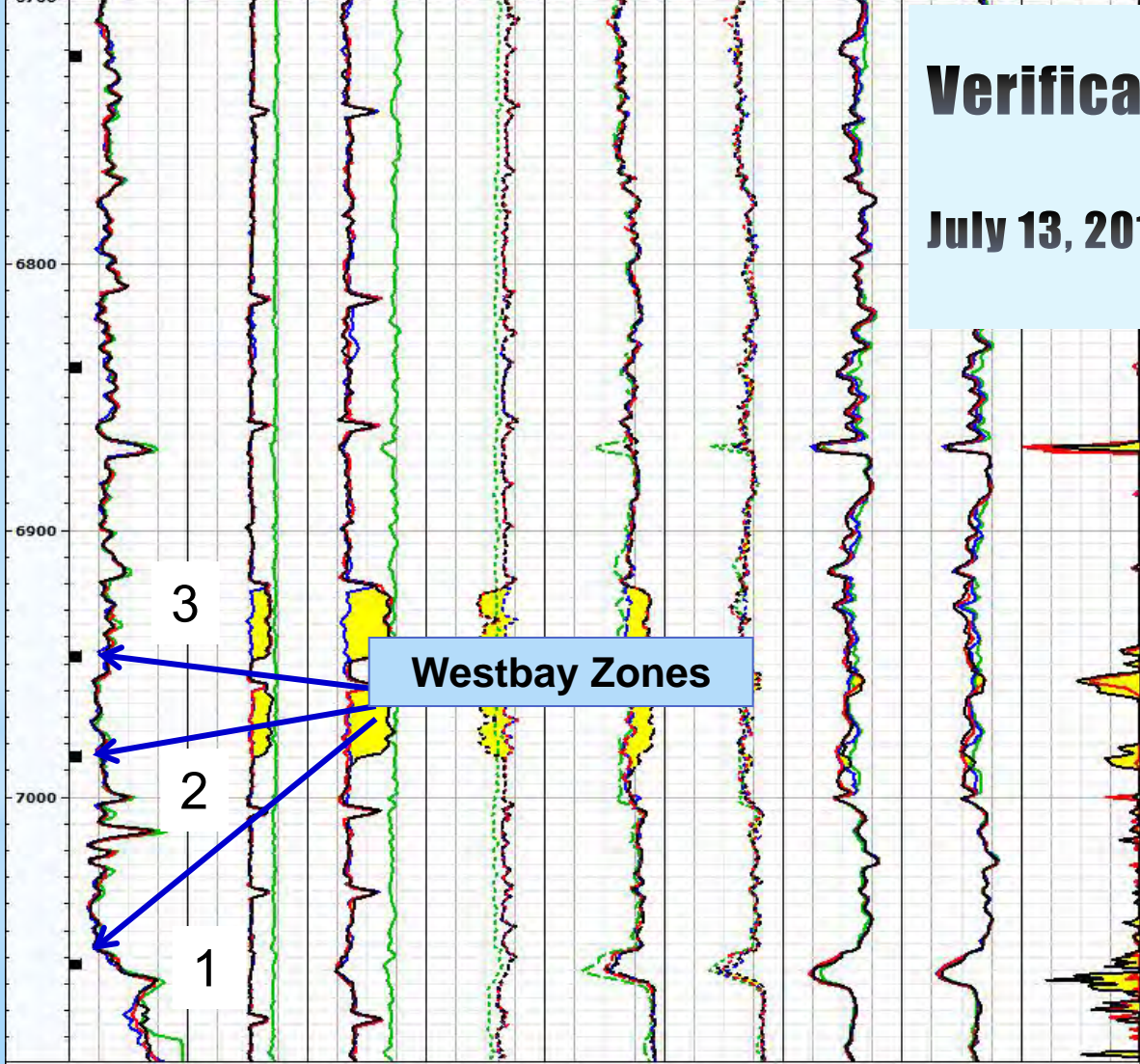


# Water Quality Comparison

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 <sup>-</sup> (mg/L)	170	36,900	120,000
Br <sup>-</sup> (mg/L)	1	180	680
Alkalinity (mg/L)	380	130	80
Na <sup>+</sup> (mg/L)	140	17,200	50,000
Ca <sup>2+</sup> (mg/L)	100	5,200	19,000
K <sup>+</sup> (mg/L)	1	520	1,700
Mg <sup>2+</sup> (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)

Reference 1000	Perfs		SBNA_FIL		SIBH_TDTL		INFO_TDTL		TPHL		PHIC		SIGM		SIGM_TDTL		DeltaSw
	Perfs	SBNA_FIL	SIBH_TDTL	INFO_TDTL	TPHL	PHIC	SIGM	SIGM_TDTL									
0	gAPI 150	200 cu 0	200 cu 0	1000 1/s 0	0.6 m3/m3 0	0.6 m3/m3 0	60 cu 0	60 cu 0									
0	GR_3-12	SBNA_FIL_3-12	SIBH_TDTL_3-12	INFO_TDTL_3-12	TPHL_3-12	PHIC_3-12	SIGM_3-12	SIGM_TDTL_3-12									DeltaSw_7-12
0	gAPI 150	200 cu 0	200 cu 0	1000 1/s 0	0.6 m3/m3 0	0.6 m3/m3 0	60 cu 0	60 cu 0									
0	GR_9-11	SBNA_FIL_9-11	SIBH_TDTL_9-11	INFO_TDTL_9-11	TPHL_9-11	PHIC_9-11	SIGM_9-11	SIGM_TDTL_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 m3/m3 0	60 cu 0	60 cu 0									
0	GR_3-11	SBNA_FIL_3-11	SIBH_TDTL_3-11	INFO_TDTL_3-11	TPHL_3-11	PHIC_3-11	SIGM_3-11	SIGM_TDTL_3-11									DeltaSw_3-12
0	gAPI 150	200 cu 0	200 cu 0	1500 1/s 0	0.6 m3/m3 0	0.6 m3/m3 0	60 cu 0	60 cu 0									
0	gAPI 150	200 cu 0	200 cu 0	1500 1/s 0	0.6 m3/m3 0	0.6 m3/m3 0	60 cu 0	60 cu 0									-1 v/v 0



# Verification Well RST Logging

July 13, 2012

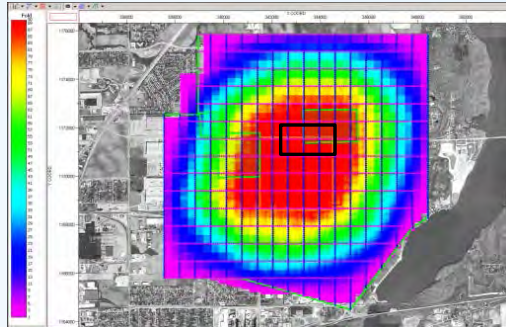
CO<sub>2</sub> in Reservoir

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

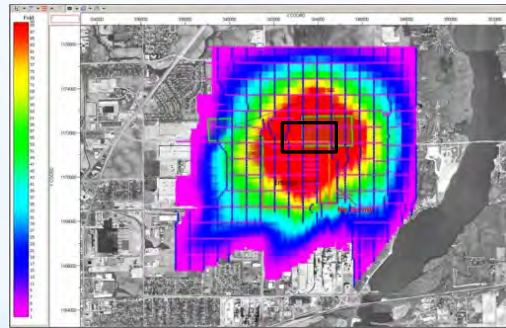


# 3D Acquisition Challenges: Design Iterations and Fold Coverage

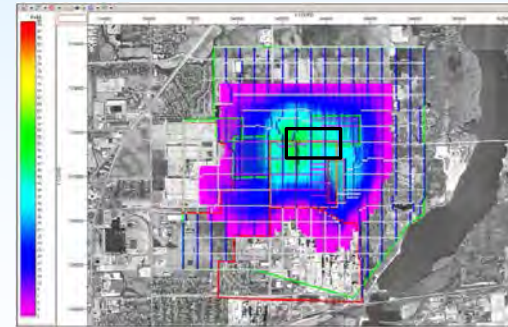
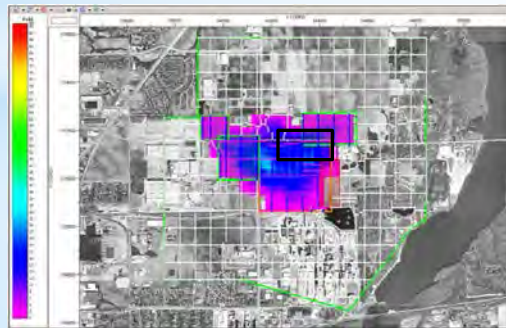
Ideal design



Ideal design with planned offsets

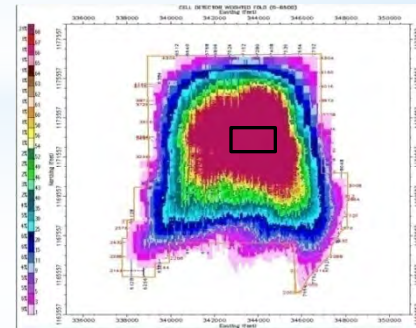
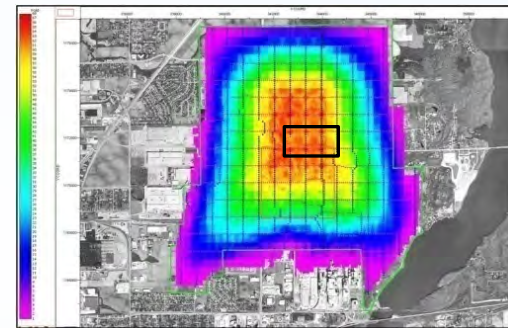


Access to known permitted areas only.



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

Final design

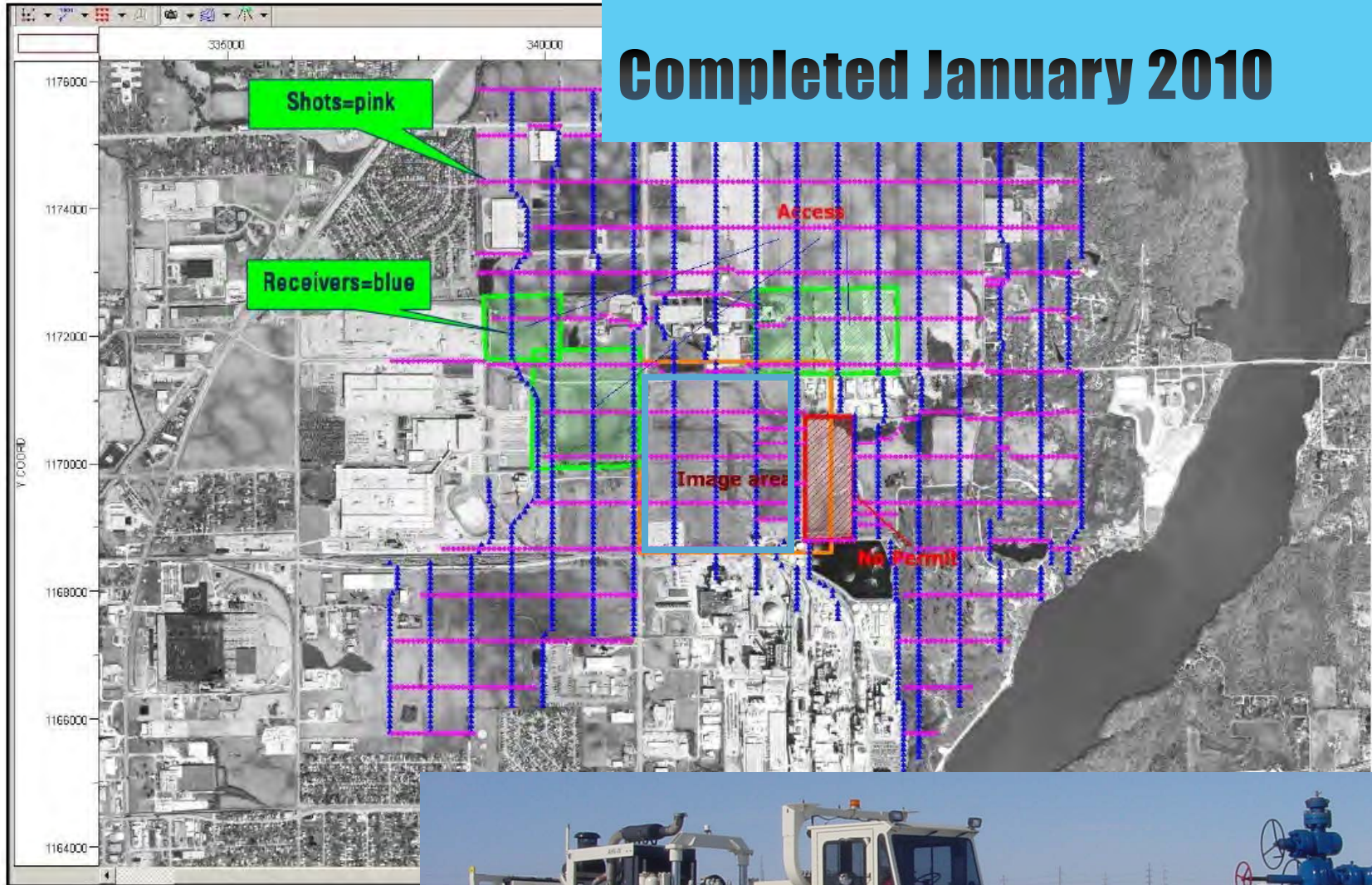


Acquired data



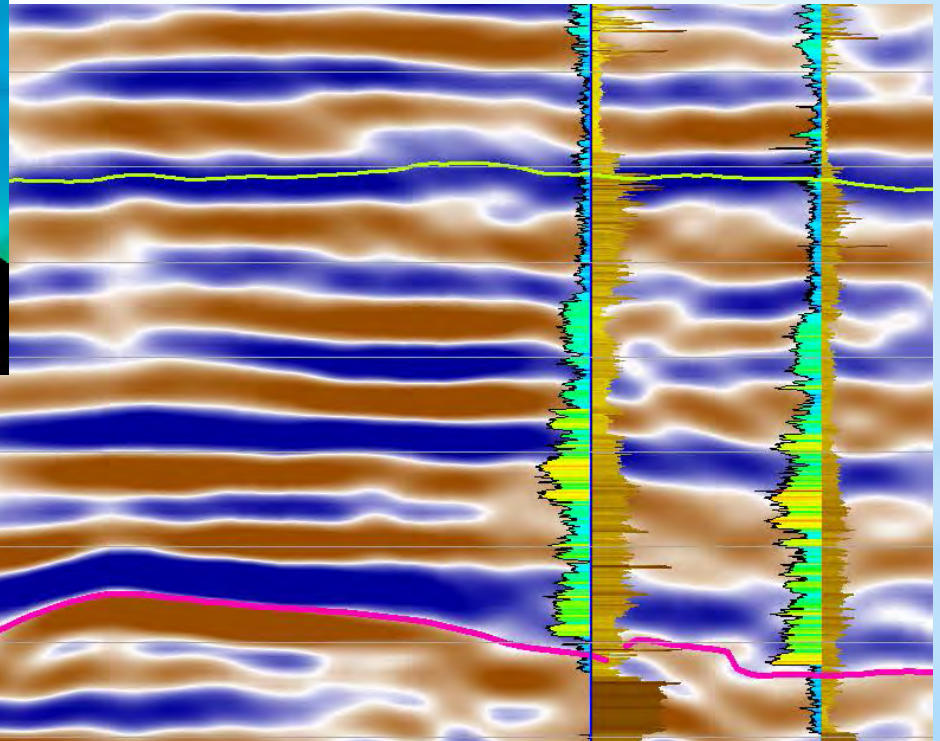
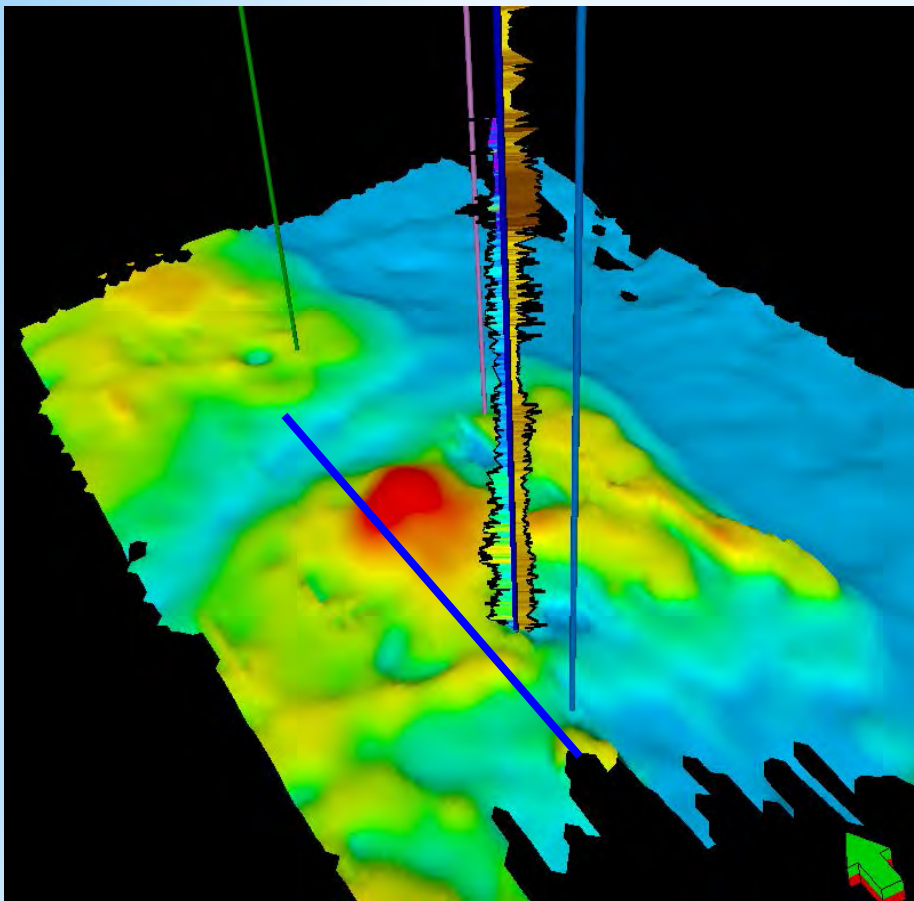
# Baseline 3D Geophysical Survey

Completed January 2010





# 3D Seismic Reveals Precambrian Topography

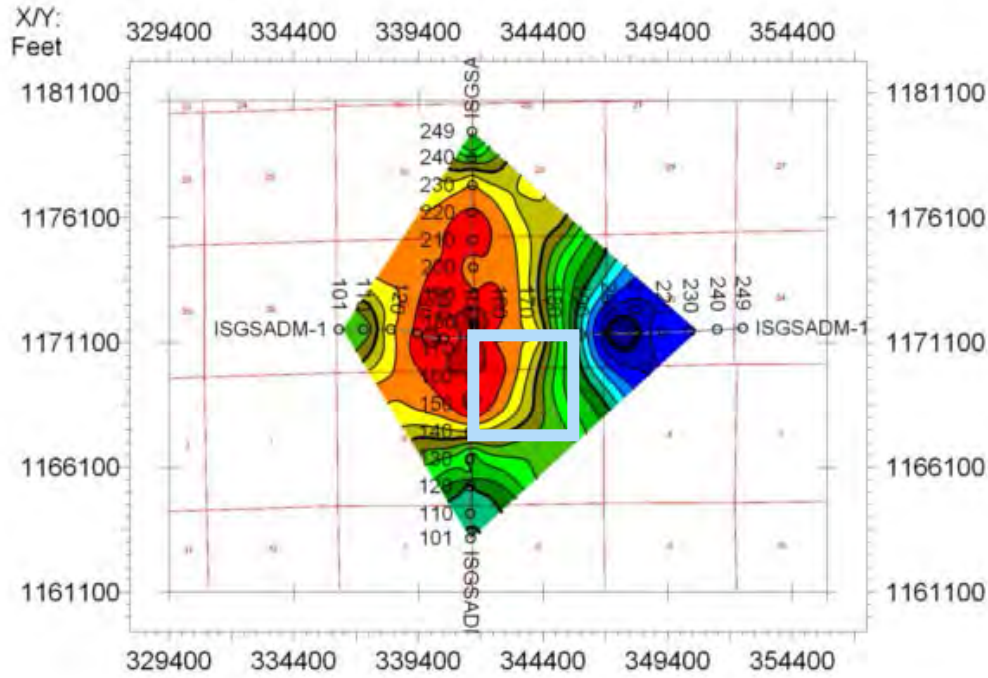


from Leetaru, ISGS

Valley eroded into  
Precambrian

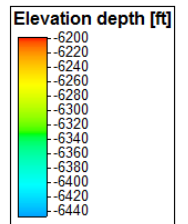
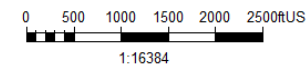
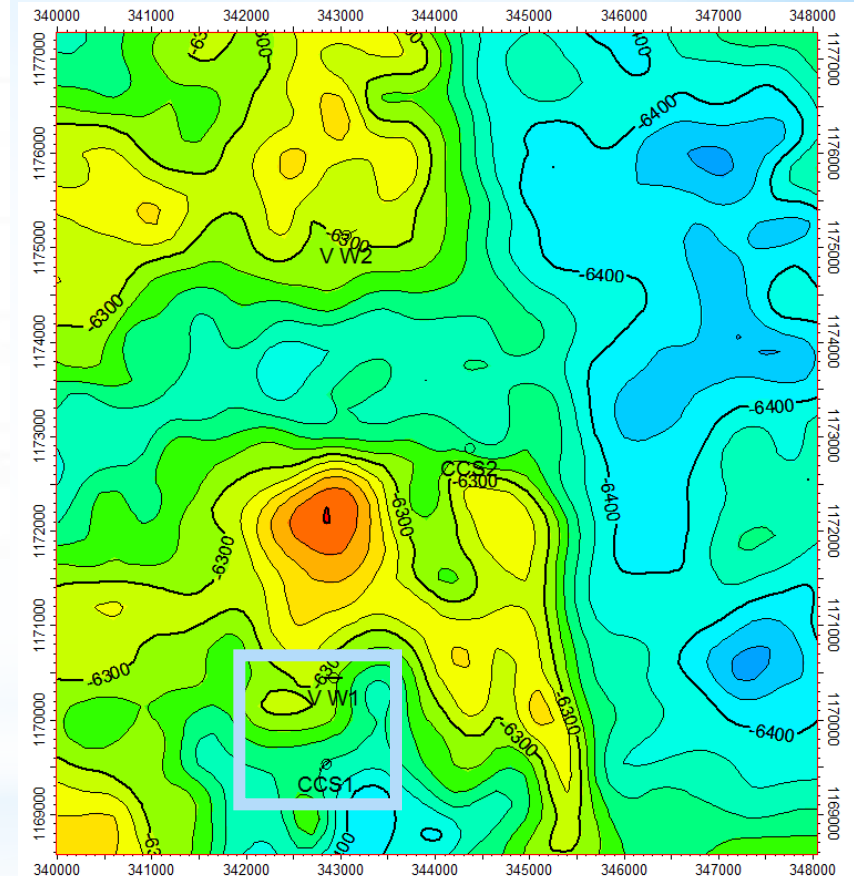
Precambrian structural high

# Top of Mount Simon Structure



2D in Time

# Comparison of 2D and 3D Seismic



# Base Mount Simon Structure

from Leetaru, ISGS

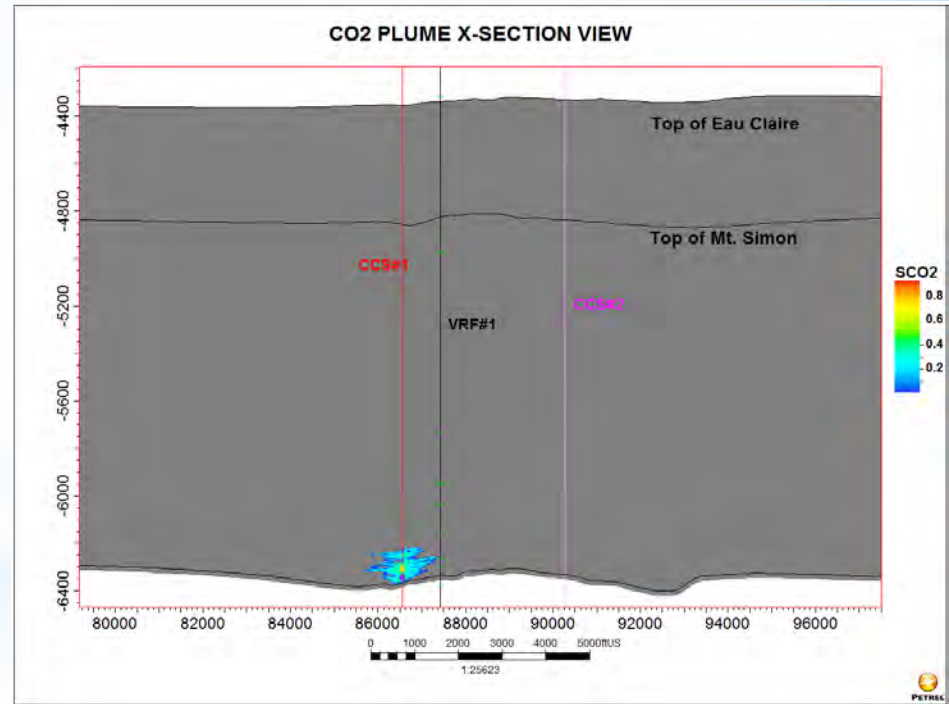
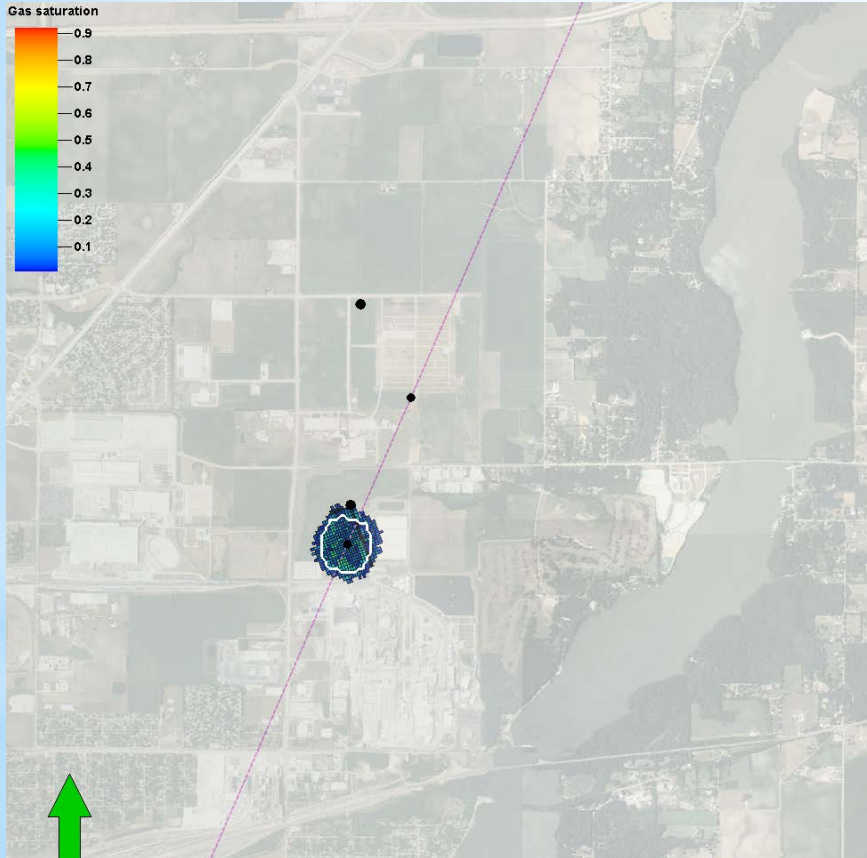
3D in Depth (ft)



# Reservoir Simulation: CO<sub>2</sub> Plume & Pressure Pulse Evolution

March 2012

- 32 x 32 km Eclipse\* reservoir model
- ~ 3 million grid cells
- variable cell dimensions

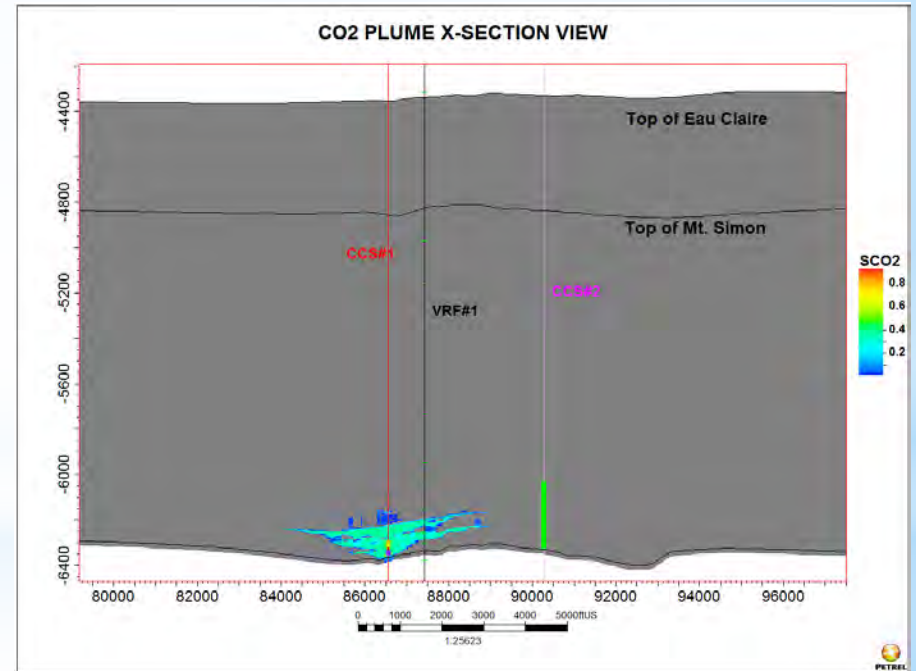
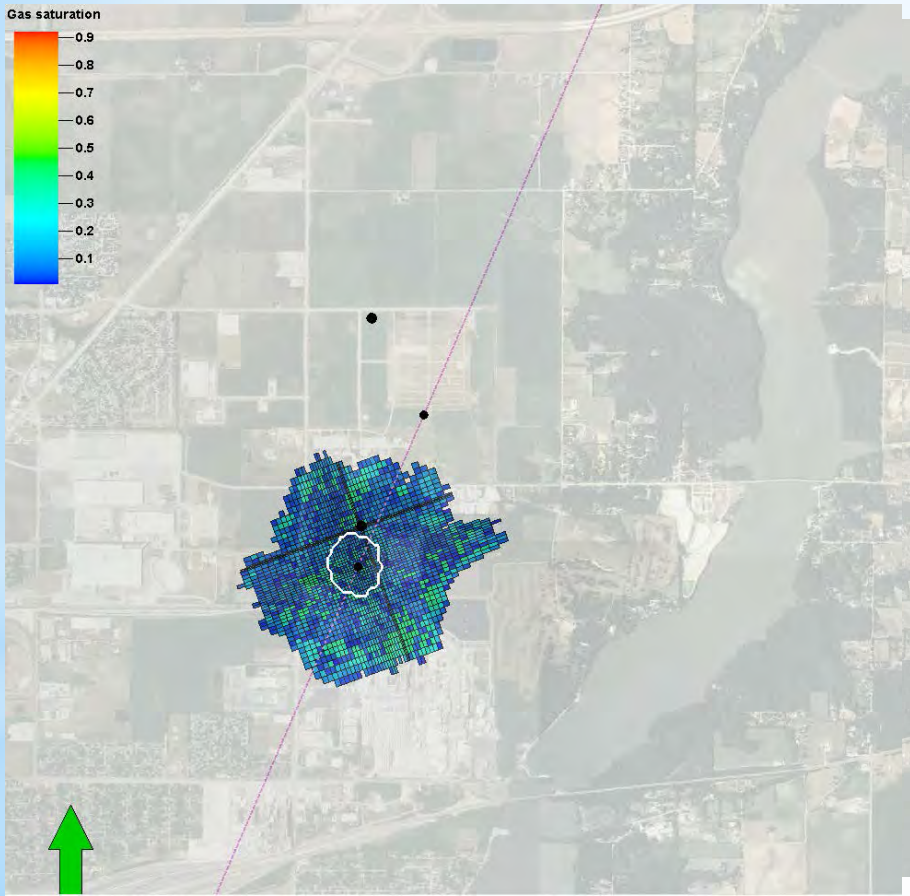


\*Mark of Schlumberger

from Schlumberger Carbon Ser

# CO<sub>2</sub> Plume & Pressure Pulse Evolution

2014

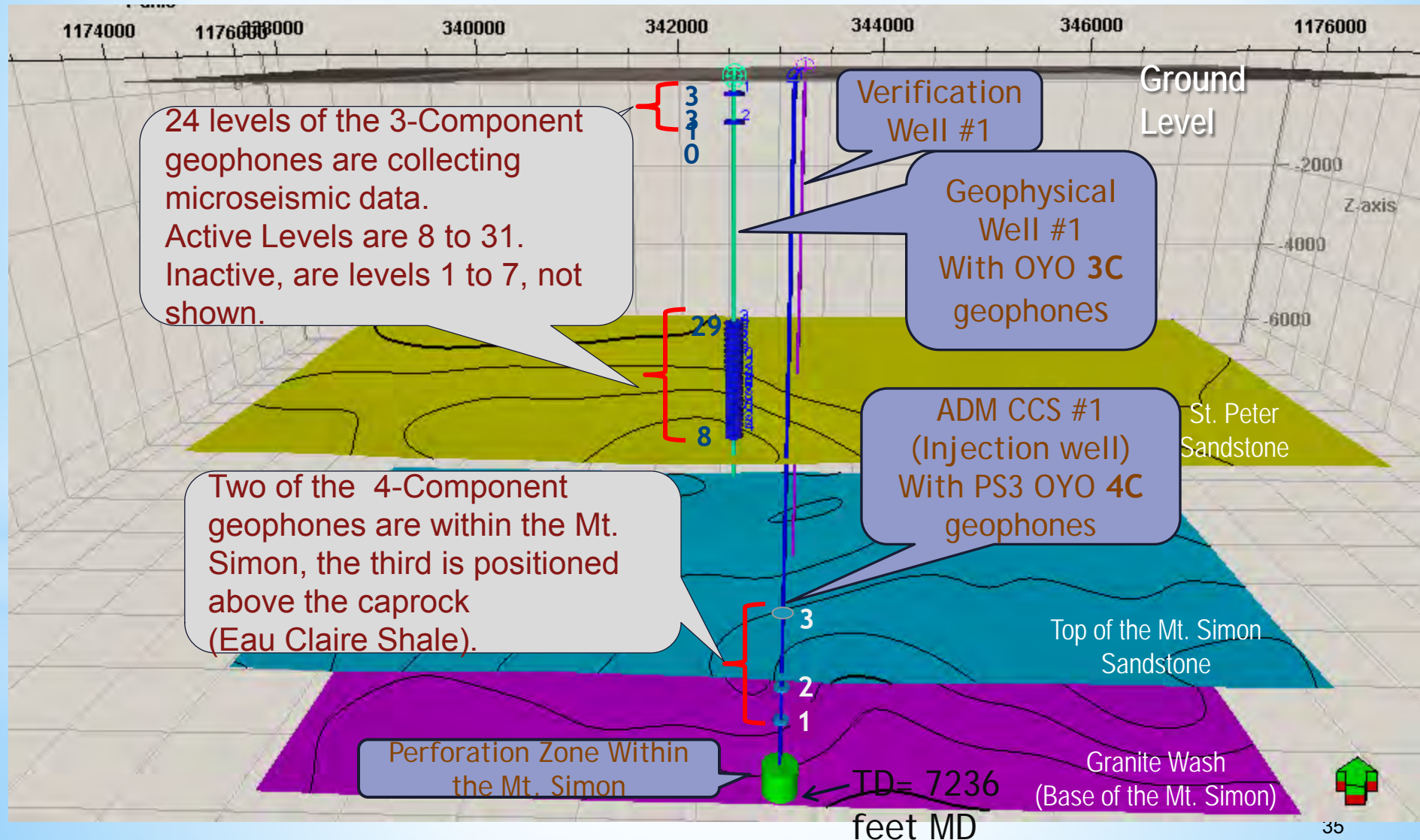


from Schlumberger Carbon Ser

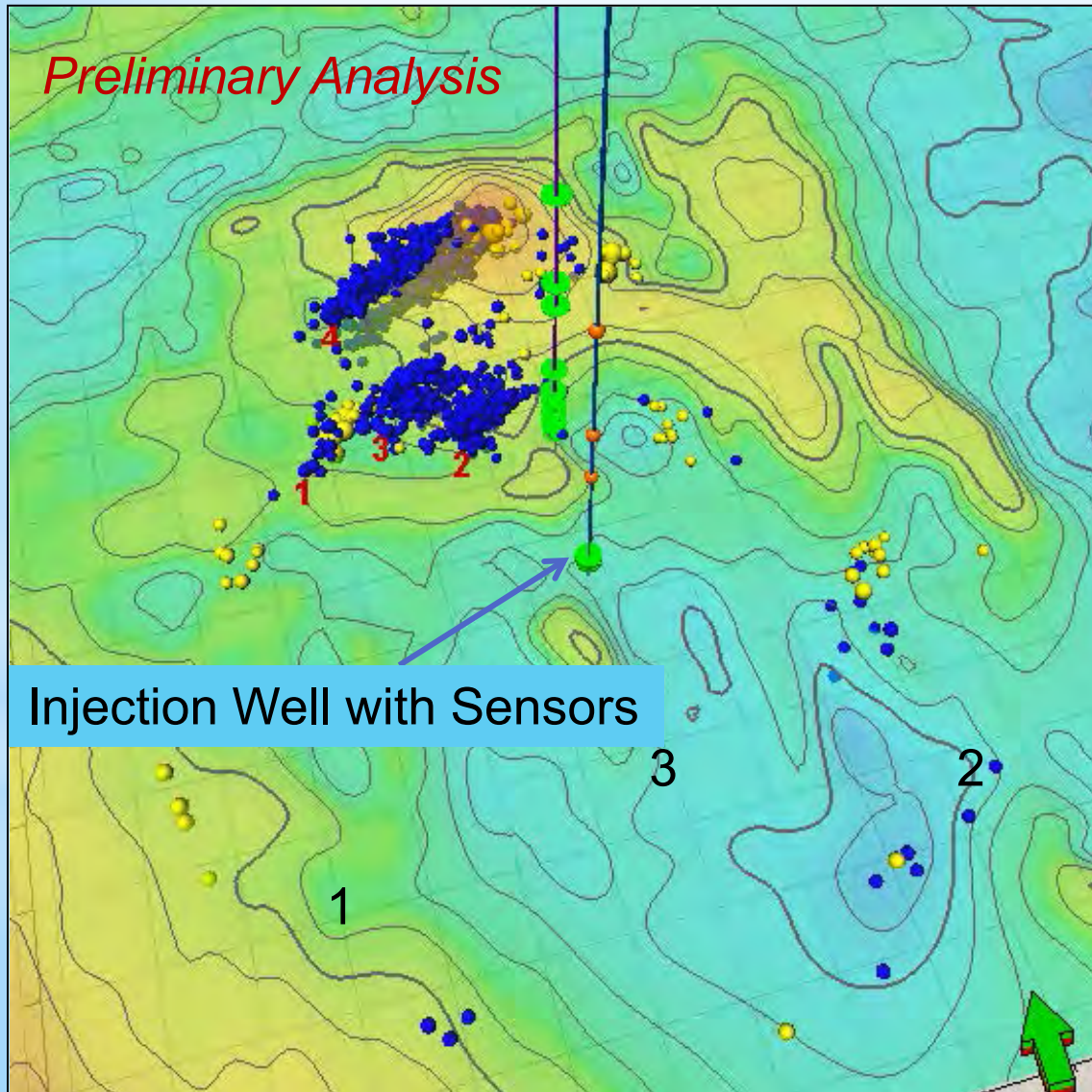


# Geophones, wells, and reservoir details

From Schlumberger  
Carbon Services



# Microseismic Events Recorded NW of Verification Well



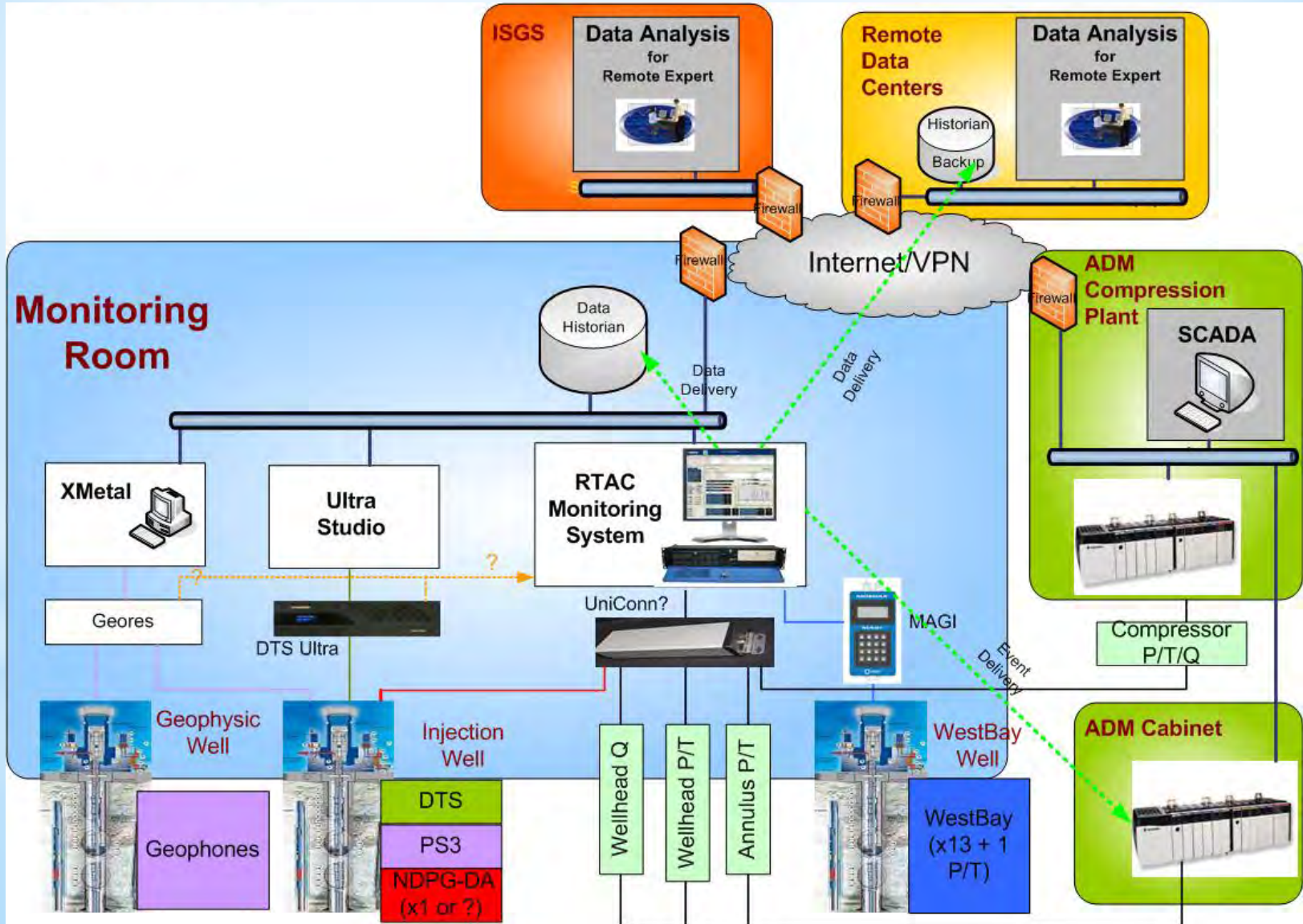
- Four component geophones deployed in injection well adequate to monitor activity
- Microseismic events clustered mainly in four groups NW of verification well
- Events predominately in minus 0.5 to minus 2.0 magnitude
- Event clusters elongated roughly parallel to basinal  $\sigma_1$  direction

from Schlumberger Carbon Services



# Data Collection System

from Schlumberger Carbon Services





# Data Collection System - System Screenshot

Schlumberger  
Carbon Services

## Illinois Basin - Decatur Project

V3.5

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**Alarms**

2012-08-07 15:40:40	DTS	Reference coil average temperature	High
2012-08-06 15:41:33	vWestbay	Probe #6 Comm. Status	Faulty
2012-08-05 08:47:46	MICRO	Injection well L2 C2 status	Suspicious
2012-08-05 08:47:46	MICRO	Geophysics well L5 C3 status	Suspicious
2012-08-05 08:47:46	MICRO	Geophysics well L2 C1 status	Suspicious

**Events**

2012-08-05 19:02:51	RTAC	RTAC Alarms and Events is OK	End of event
2012-08-05 19:02:21	RTAC	RTAC Alarms and Events is down	Start of event
2012-08-05 00:01:55	RTAC	RTAC Alarms and Events is OK	End of event
2012-08-05 00:01:25	RTAC	RTAC Alarms and Events is down	Start of event
2012-08-02 13:40:53	RTAC	Log in Illinois Basin - Decatur Project project	OPERATOR (OPERATORS)

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**Illinois Basin - Decatur Project - Decatur specific tags**

**Analog Inputs**

Atmos press	14.7	psia
Atmos temp	95.0	°F

**Verification well**

Analog Inputs

Annulus press	26.0	psig
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Westbay

P#13 (tubing) press	2,292.6	psia
---------------------	---------	------

P#12 press	2,072.9	psia
P#11 press	2,116.5	psia
P#10 (QAQC) press	2,432.0	psia
P#6 press	-1000.0	psia
P#6 temp	-1,768.	°F
P#2 press	3,347.1	psia
P#2 temp	122.5	°F

**Injection well**

Analog Inputs

WH injection press	1356.0	psig
WH injection temp	98.9	°F
WH annulus press	615.5	psig
Press Mtn: tank level	41.1	%

Geophones

Z#10 avg temp	108.7	°F
Z#8 avg temp	121.9	°F
Z#6 avg temp	127.7	°F
Z#4 avg temp	129.6	°F
Z#2 avg temp	130.9	°F

Dowhole P/T gauge

Press	3321.7	psig
Temp	131.3	°F

**Geophysics well**

Geophones

**CO2 compressing unit**

ADM PLC

Injection flow rate	42.5	t/h
Injected mass	234,500	t

**CO2 venting unit**

ADM PLC

Vented flow rate	0.0	t/h
------------------	-----	-----

**ADM control room**

Digital Outputs 1-8 ● Modbus Slave RTU ●  
 Digital Outputs 9-16 ● RTAC system health ●

**Injection monitoring room**

Analog Inputs

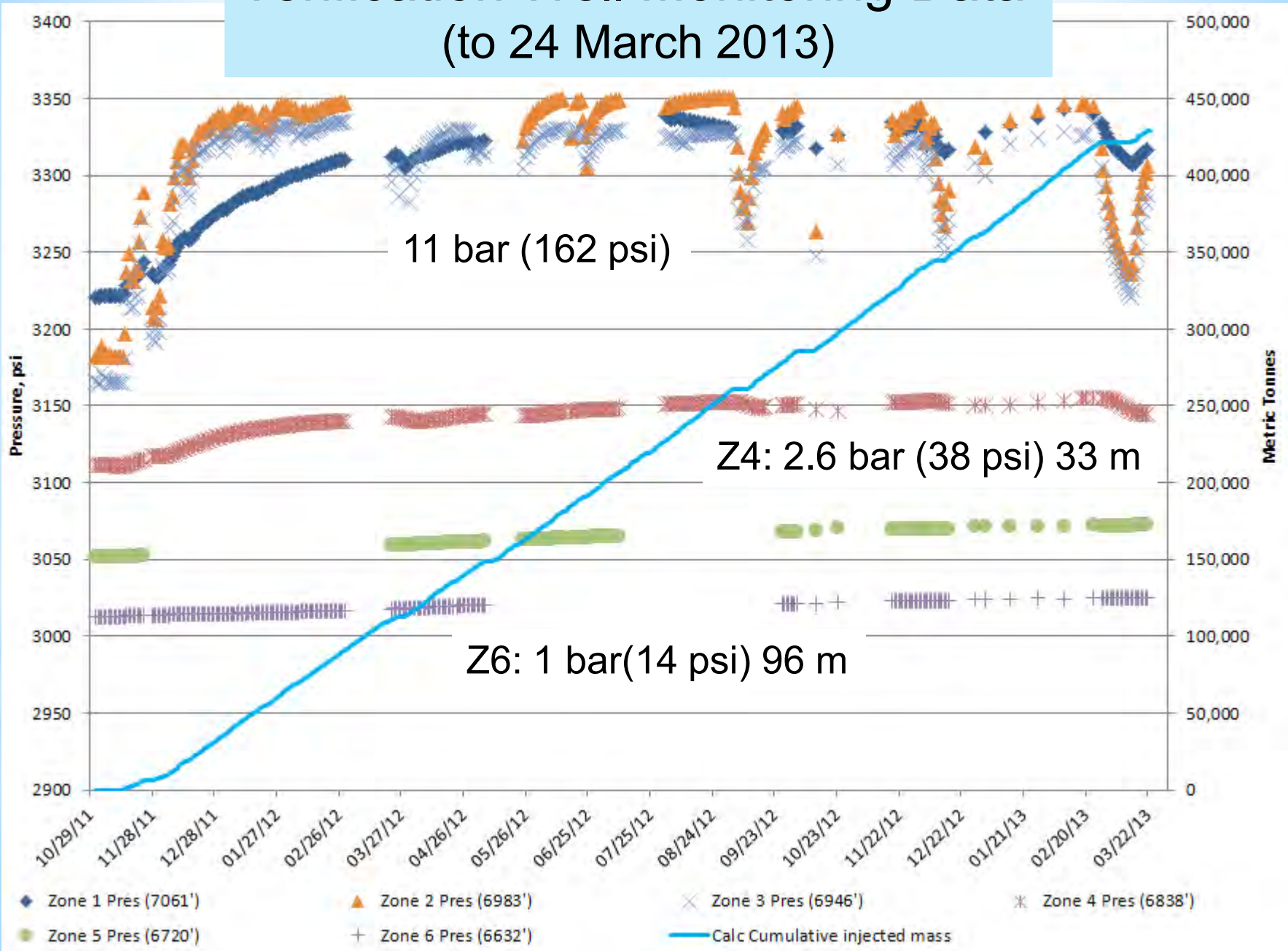
Temp	76.7	°F
------	------	----

OPERATOR (OPERATORS) | 8/7/2012 4: M

From Schlumberger Carbon Services



# Verification Well Monitoring Data (to 24 March 2013)



# Key Operational Results – IBDP Year One

- Mount Simon Sandstone reservoir is accepting CO<sub>2</sub> 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 shot in 4-5 April 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 453,000+ tonnes injected, CO<sub>2</sub> remains in lowermost Mt. Simon; internal reservoir heterogeneity affecting CO<sub>2</sub> distribution





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