Midwest Geological Sequestration Consortium

Lessons Learned from the Illinois Basin – Decatur Project: Integration of Deep Saline CO_2 Storage into the Value Change

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The Midwest Geological Sequestration Consortium (MGSC) is a collaboration led by the geological surveys of Illinois, Indiana, and Kentucky, USA

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*Mark of Schlumberger

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Acknowledgements

ILLINOIS
INDUSTRIAL CARBON
CAPTURE & STORAGE

The Industrial Carbon Capture and Storage (ICCS) project is administered by the U.S. Department of Energy's Office of Fossil Energy and managed by the National Energy Technology Laboratory (award number DE-FE-0001547) and by a cost share agreement with the Archer Daniels Midland Company, University of Illinois, Schlumberger Carbon Services, and Richland Community College.

This ICCS project received DOE funding from the American Recovery and Reinvestment Act of 2009 ($141.4 million).

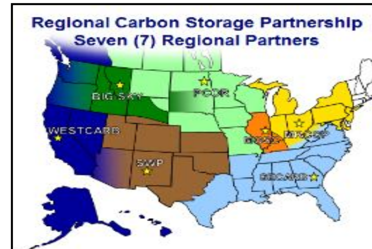
ADM - Decatur CCS Projects

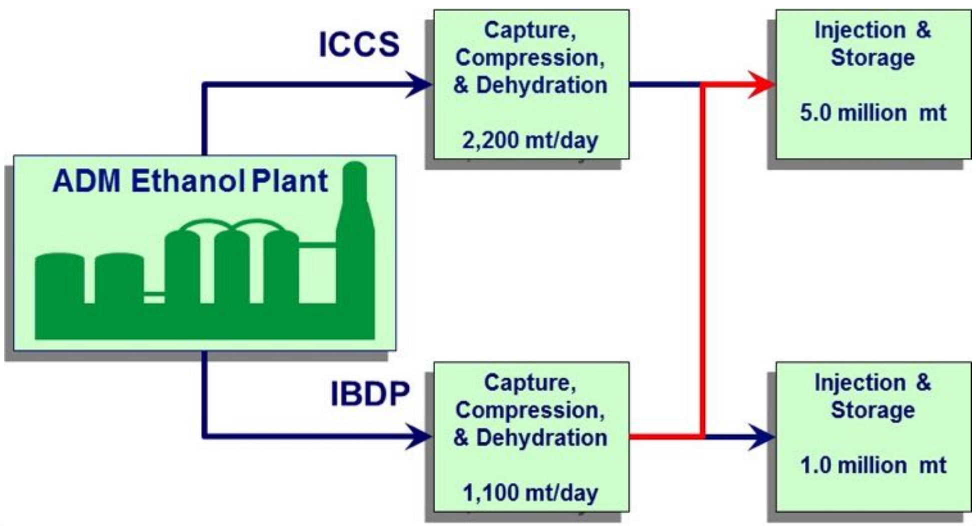
Illinois Basin - Decatur Project

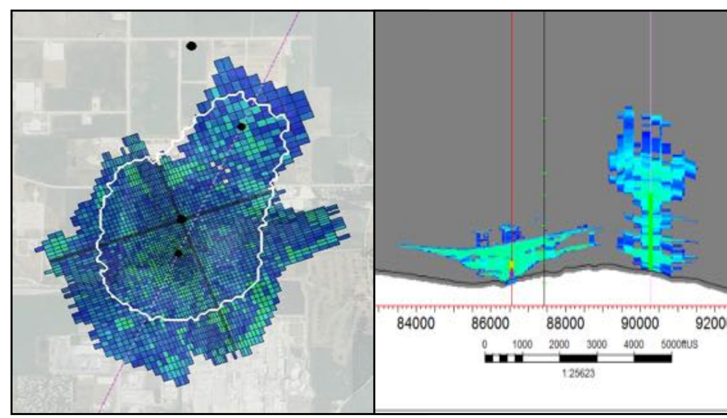
- *Large scale geologic test to inject 1.0 million mt of CO_2 over a three year period (1,000 MT/ day).*

Illinois Industrial CCS Project

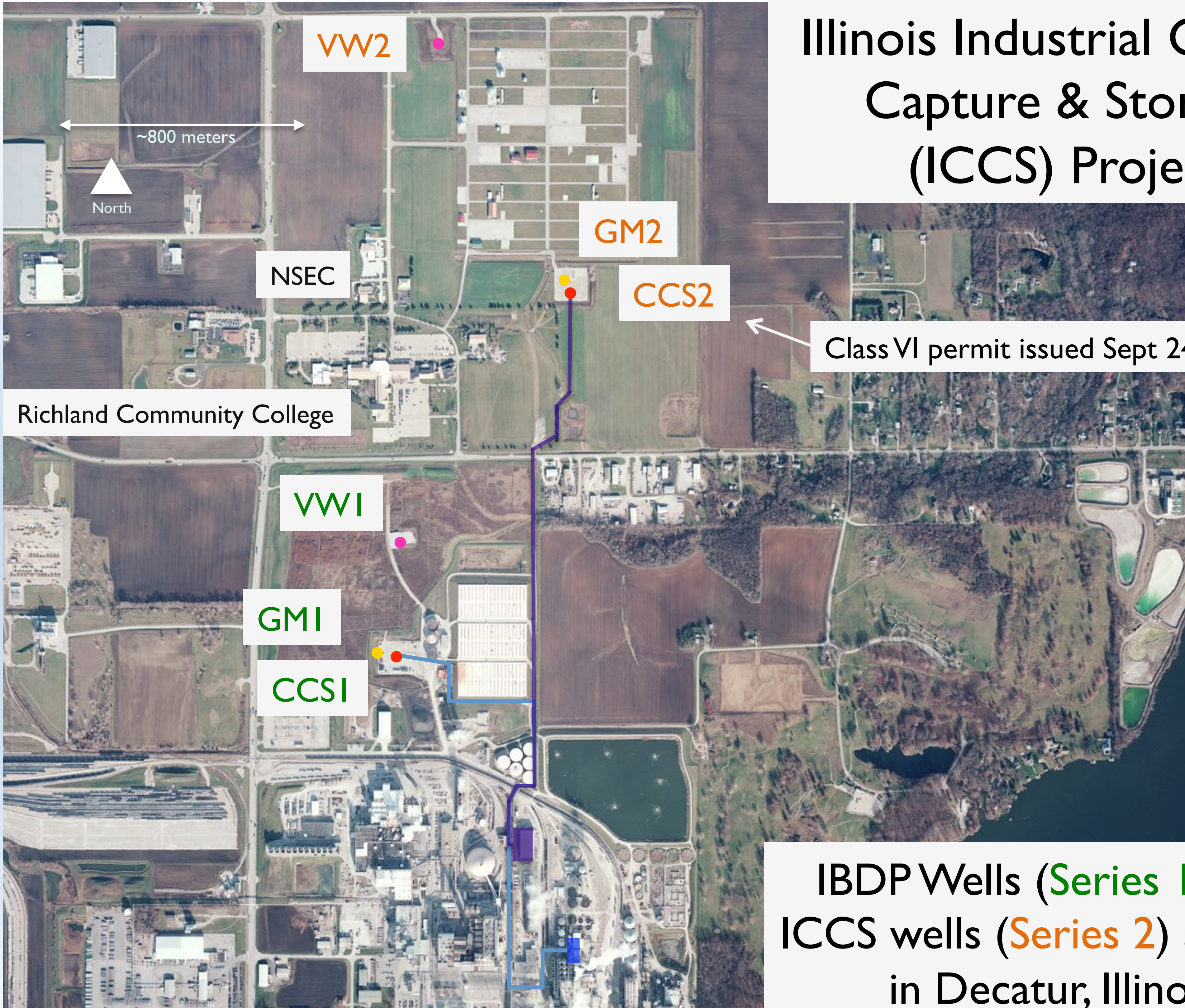
- *Target & demonstrate advanced CCS technologies at industrial scale facilities.*
- *Inject and store 1.0 million mt CO_2 per year (3,000 tons/day).*
- *Study the interaction of two separate plumes.*





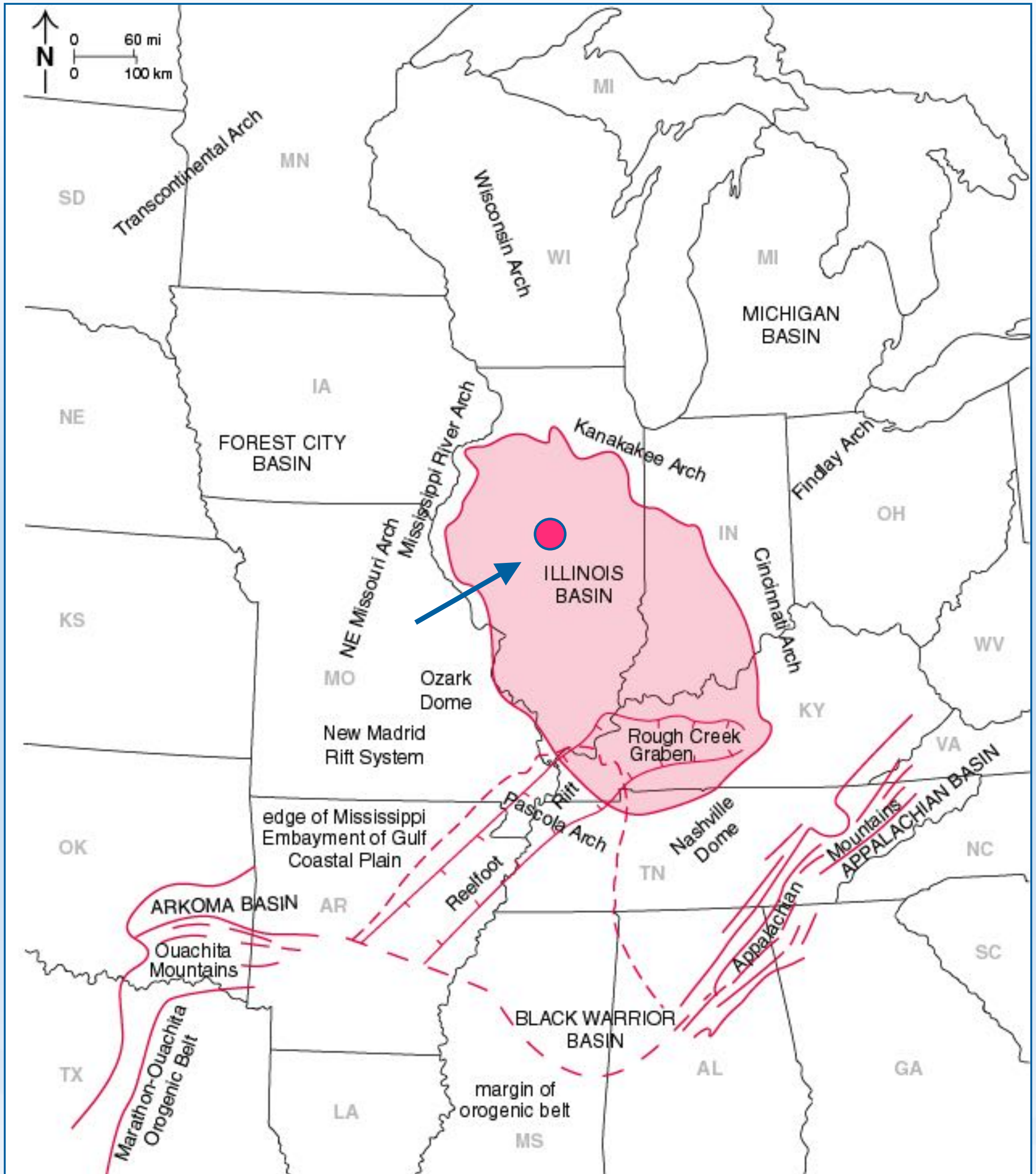


Illinois Industrial Carbon Capture & Storage (ICCS) Project



IBDP Wells (Series 1) and ICCS wells (Series 2) at ADM in Decatur, Illinois

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

- Prove injectivity and capacity
- Demonstrate security of injection zone
- Contribution to best practices

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

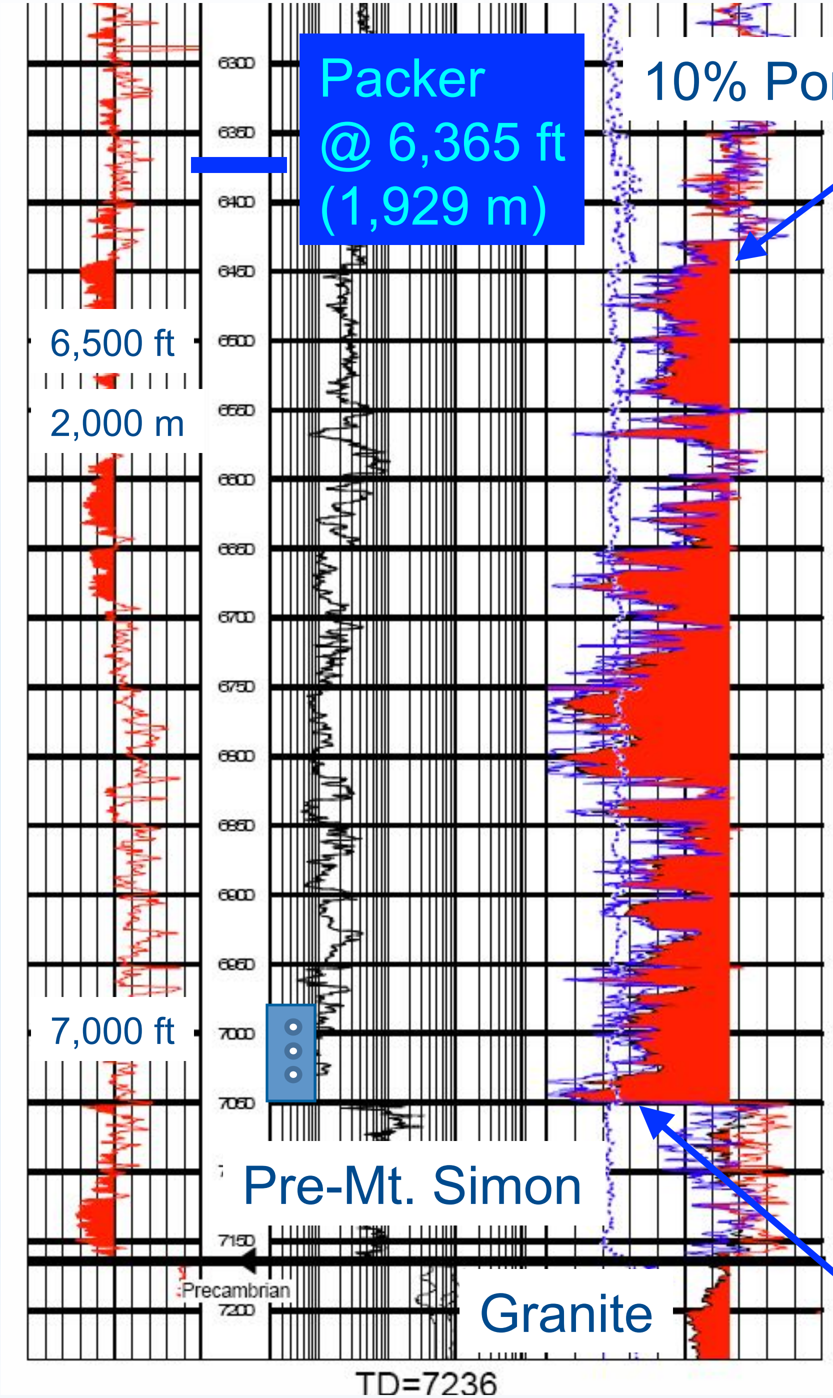
A Dehydration/ compression facility location
B Pipeline route (1.9 km)
C Injection well site
D Verification/ monitoring well site
E Geophone well

Operational Injection: 17 November 2011

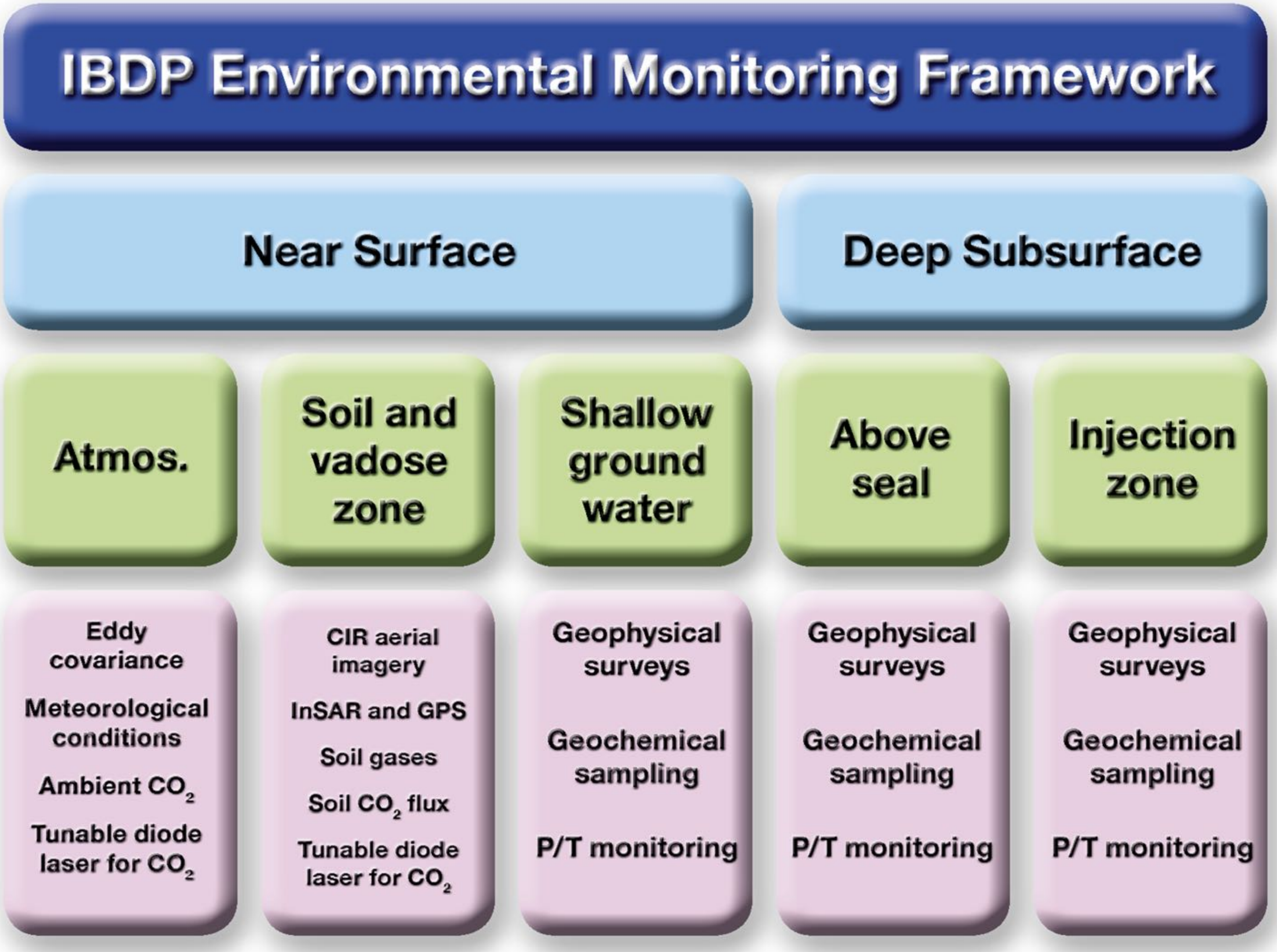
- IBDP fully operational 24/7
- IBDP is the first 1 million tonne carbon capture and storage project from a biofuel facility in the US
- Injection completed November 2014
- Intensive post-injection monitoring under MGSC through 2017

Total Injection
(26 November 2014):
999, 215 tonnes

Injection Well Completion 2009



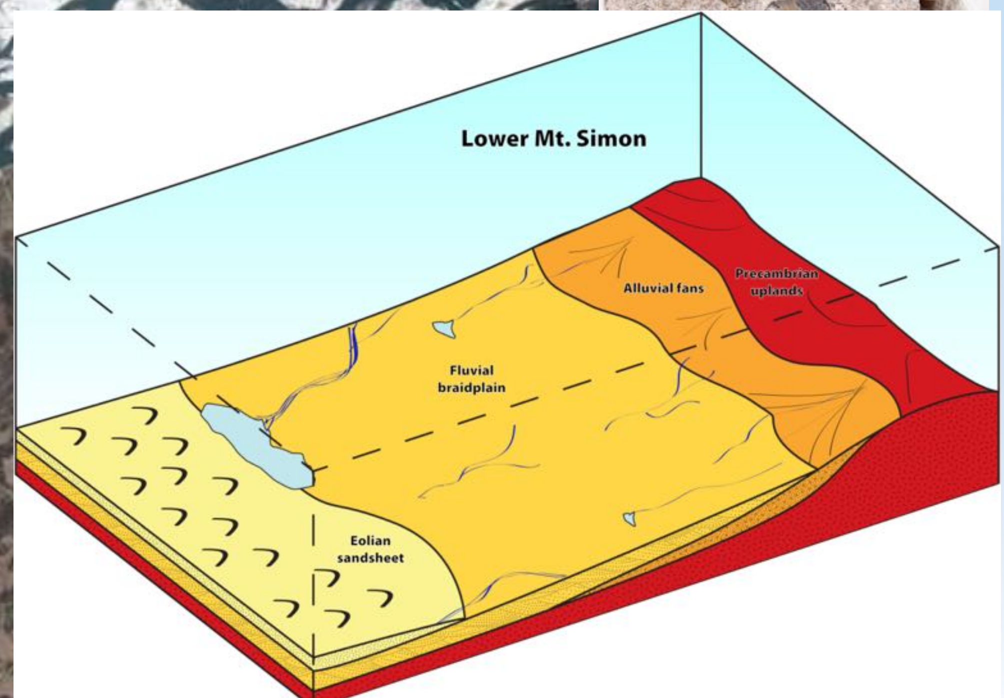
Perforations: 6,985 -7,015; 7,025 - 7,050
55 ft (16.7 m) open interval


IBDP Environmental Monitoring Framework
Near Surface
Deep Subsurface
Atmos.
Soil and vadose zone
Shallow ground water
Above seal
Injection zone
Eddy covariance
Meteorological conditions
Ambient CO_2
Tunable diode laser for CO_2
CIR aerial imagery
InSAR and GPS
Soil gases
Soil CO_2 flux
Tunable diode laser for CO_2
Geophysical surveys
Geochemical sampling
P/T monitoring
Geophysical surveys
Geochemical sampling
P/T monitoring
Geophysical surveys
Geochemical sampling
P/T monitoring

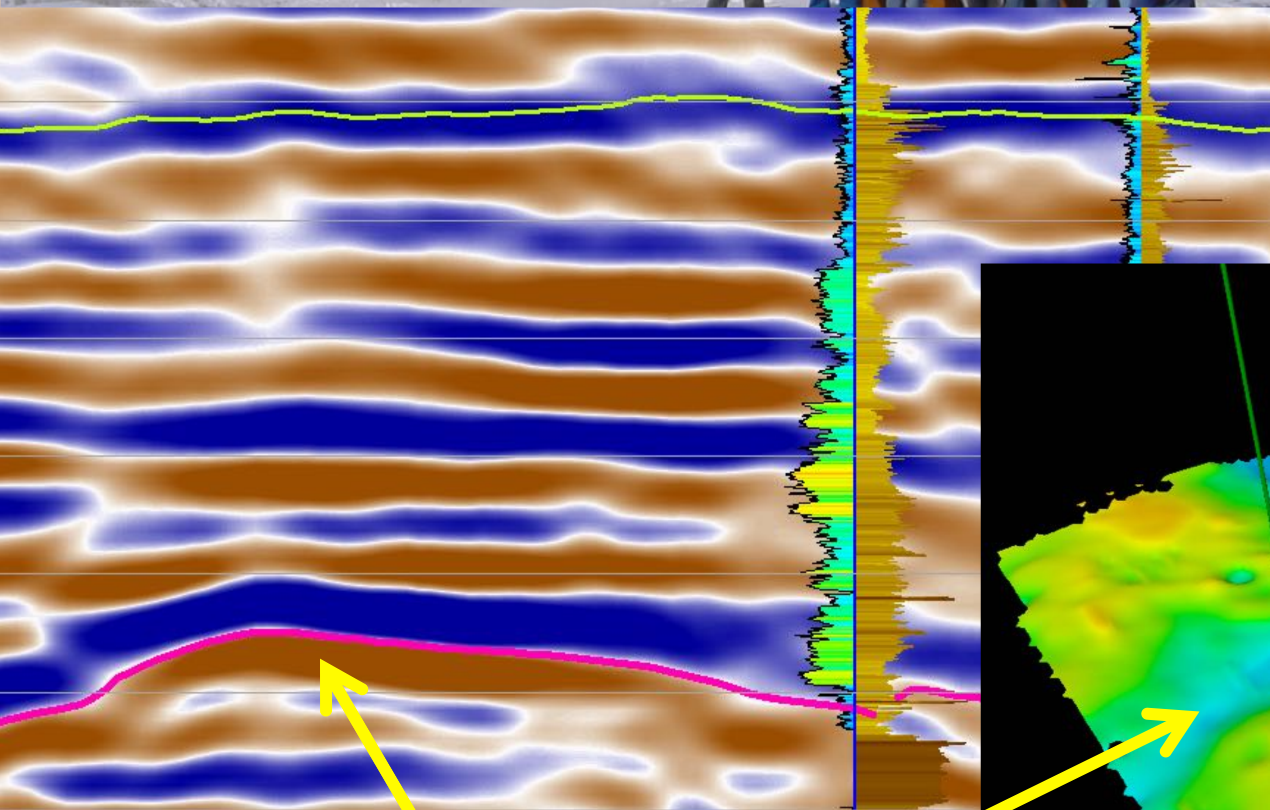
Outcome: We Better Understand Depositional and Diagenetic History of a Major Storage Resource

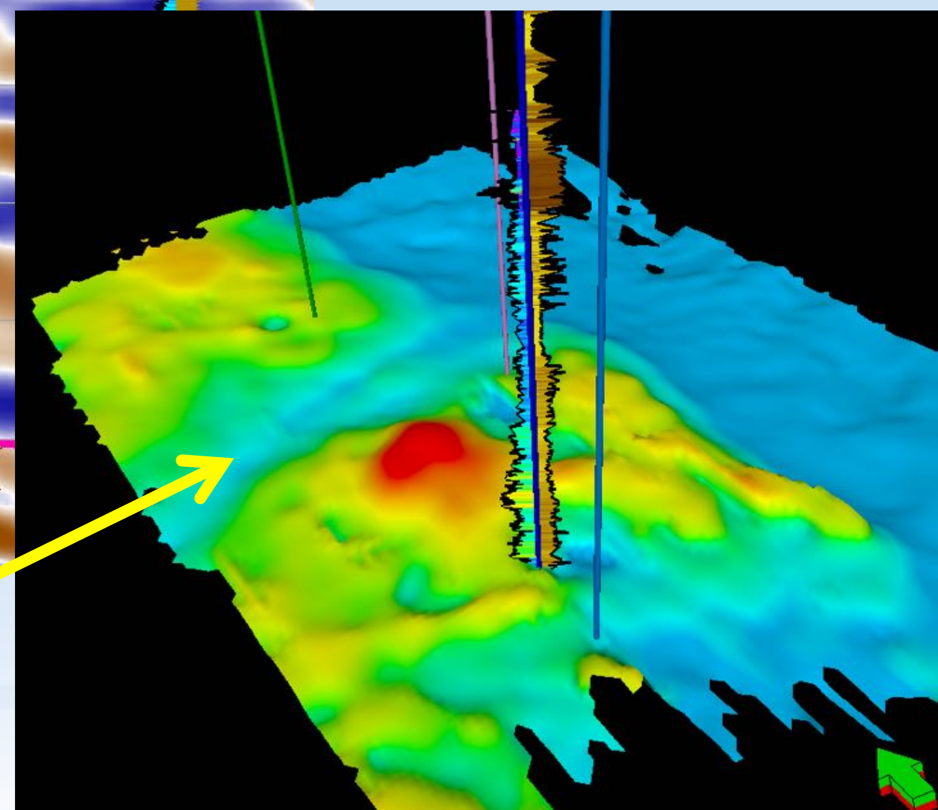
- At 500 m in total thickness at Decatur, the Mount Simon Sandstone has been shown to be a substantial storage resource meeting criteria of injectability and storage capacity
- Storage capacity of 11 (P_{90}) to 150 (P_{10}) billion metric tons have been assessed for the entire Illinois Basin
- Intervals of tens of meters of exceptional reservoir quality in the Lower Mount Simon show a combination of primary and secondary porosity in a sand-rich fluvial system
- Original depositional units are well-connected as flow units based on pressure response in the injection and verification wells

Mount Simon Depositional Analogue: Brahmaputra River System



3D Seismic Defines Reservoir



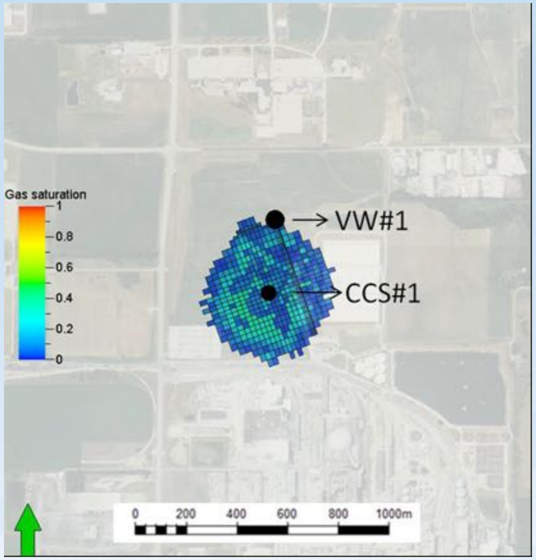


Eroded Precambrian surface

from Leetaru, ISGS

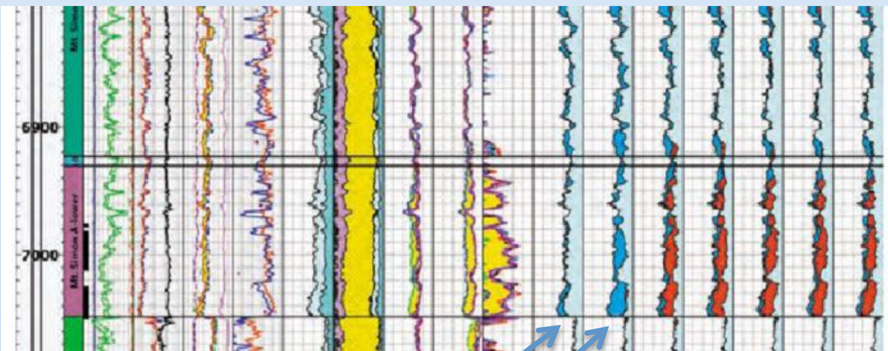
Outcome: We Better Understand Reservoir Fluid Distribution and Impacts of Heterogeneity on Pressure

- Pulsed neutron logs (Schlumberger RST* Log) help estimate the depth, thickness and saturation of CO_2 around injection and verification wells and arrival time at verification well
- CO_2 reached verification well in March 2012 in Zone 3 and July 2012 in Zone 2, much sooner than expected
- Revised reservoir simulation, including permeability distribution, was calibrated to CO_2 arrival at VW1
- Pressure distribution in lower Mt. Simon shows rapid in-zone response to injection variations

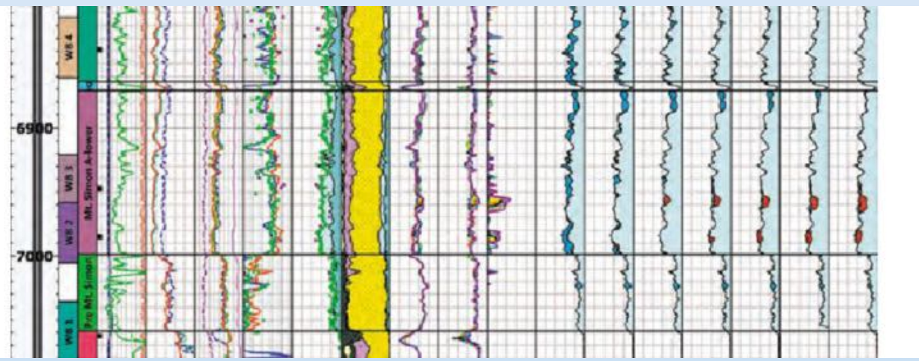


Repeat Pulsed Neutron* Logging has Defined CO_2 Distribution at the Injection and Observation Wells

CCS1



VW1

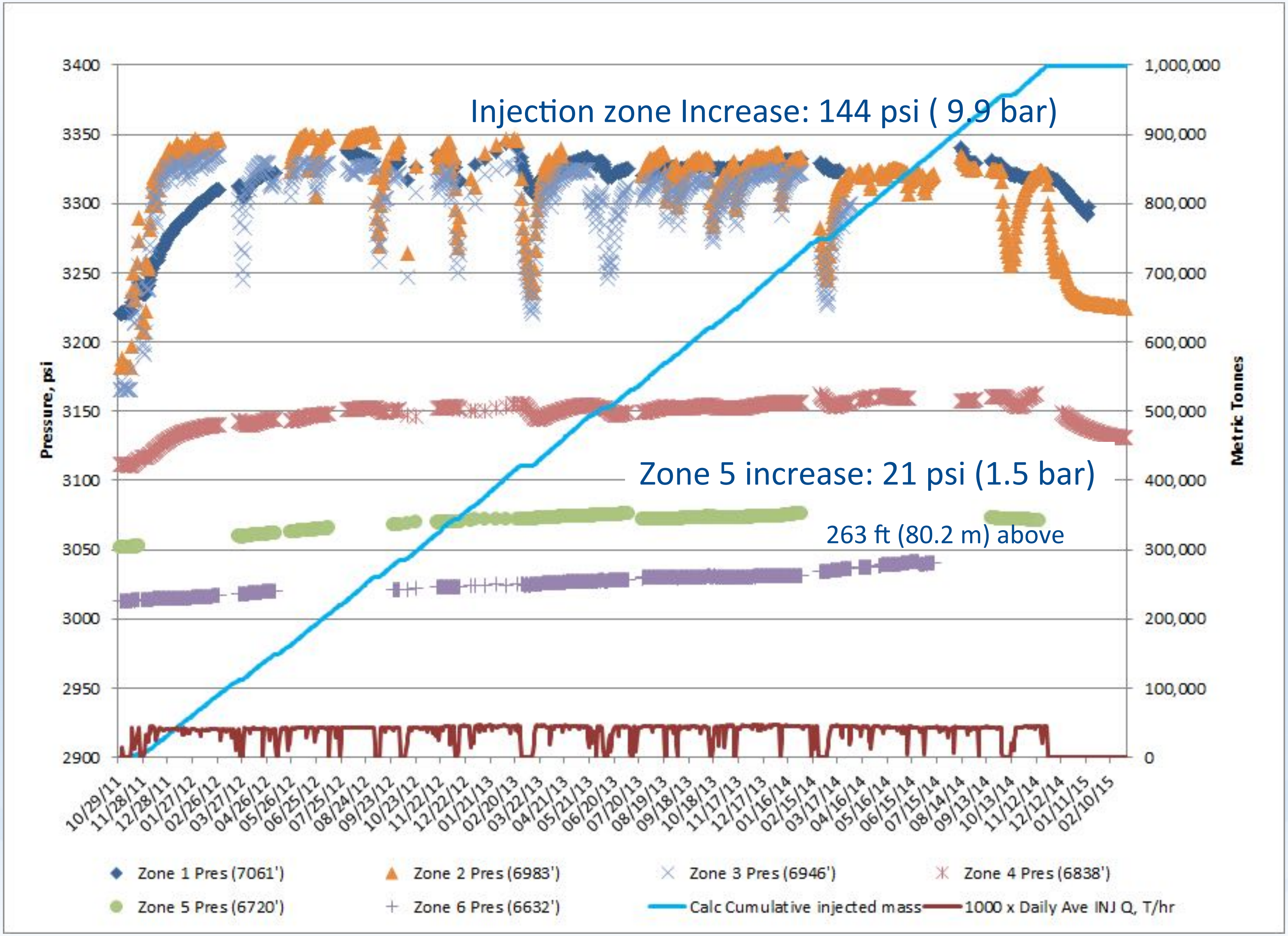


Pre-injection

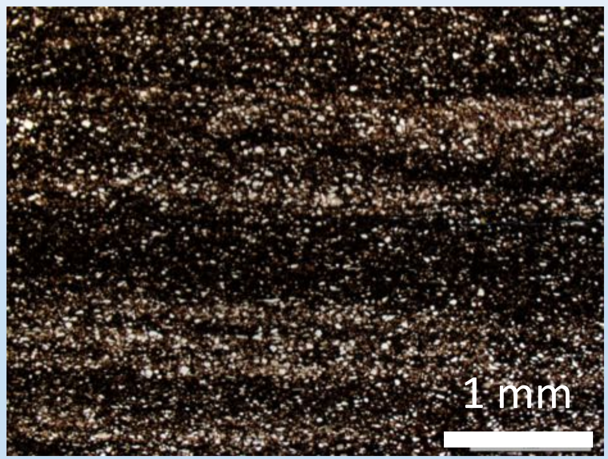
Five post-injection logging runs: March, July, and November 2012; July 2013; July 2014

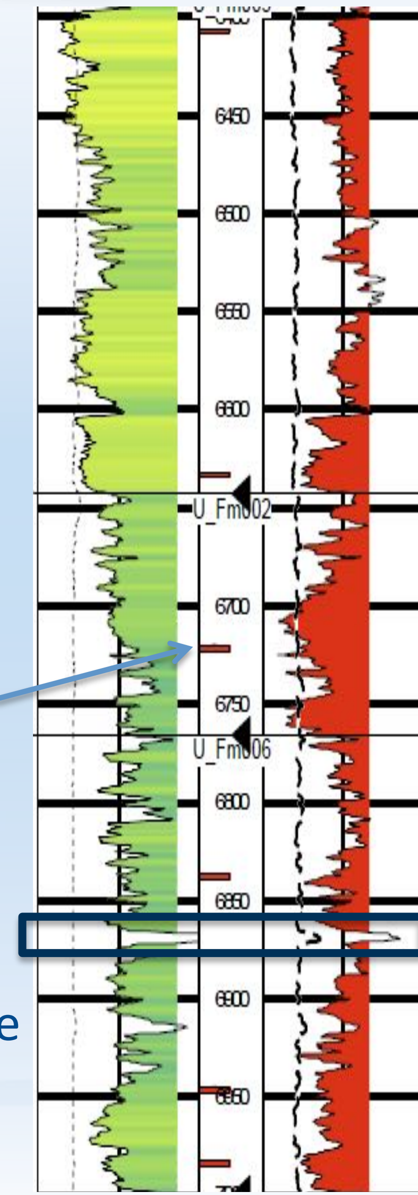
*Schlumberger Reservoir Saturation Tool (RST)

Westbay* Pressure Monitoring Output – 28 February 2015



Mudstone Baffle Between Injection Zones





6,863-6,863.25

Porosity: 1.5%

K_v: <0.01 mD

K_h: 4.13 mD in siltstone laminae

Three 3D Vertical Seismic Profiles Acquired

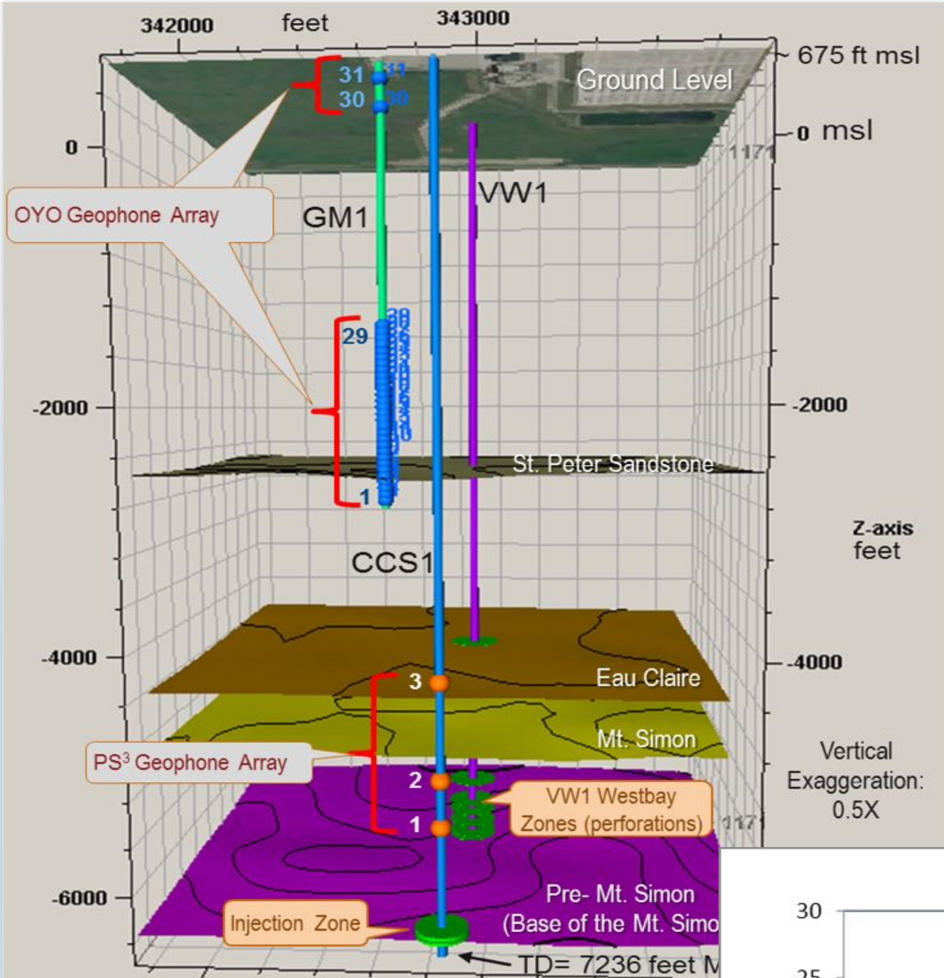
3D VSP Survey Name	Survey Date	Ground Conditions	Vibrator Sweep	Repeated Shots	Volume of CO_2 Injected
Baseline 1 (B1)	January 2010	Wet	2 – 100 Hz		
Baseline 2 (B2)	April 2011	Dry	8 – 120 Hz		0
Monitor 1 (M1)	February 2012	Frozen dry	8 – 120 Hz	467	~74,000 tonnes
Monitor 2 (M2)	April 2013	Damp	8 – 120 Hz	385	~433,000 tonnes
Monitor 3 (M3)	February 2014	Frozen	8 – 120 Hz	384	~730,000 tonnes

from Schlumberger Carbon Services

Outcome: Microseismic Activity Has Supported Insight Into Reservoir Pressure Distribution

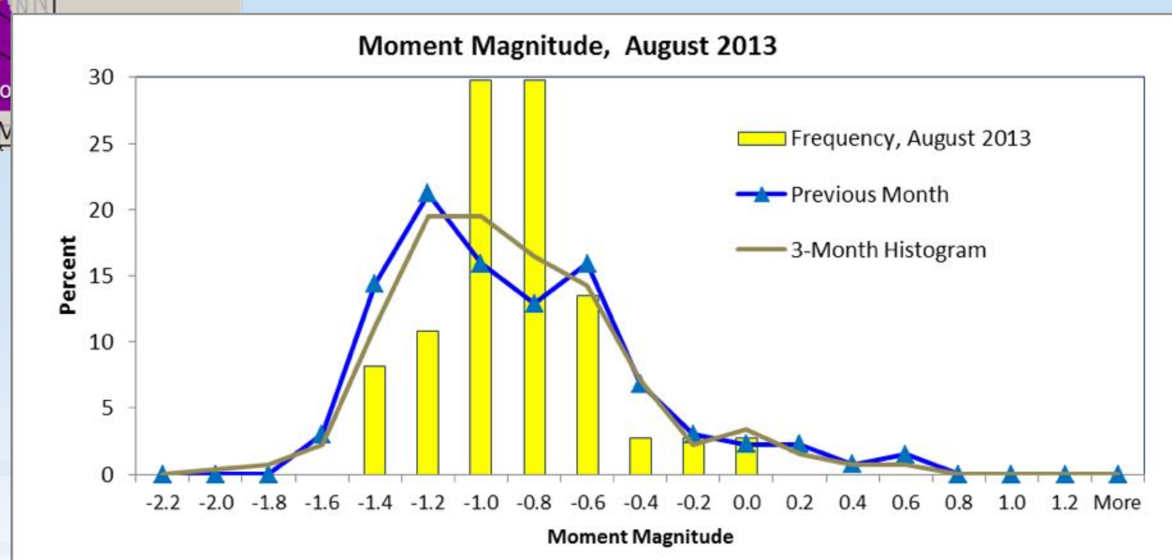
- Microseismic activity started only after injection began at site
- Clusters north of injection well first to occur and lie over Precambrian topography that may have localized planes of weakness due to compaction
- Cluster orientation consistent with northeast principal stress direction
- No pre-existing fault planes seen in 3D seismic
- Timing of events ties to pressure propagation
- Most events are in the pre-Mt. Simon and Precambrian basement; none are above the lower Mt. Simon

Microseismic Events Began in January 2012



- June-August 2013: average 89 located events/month
- Mean moment magnitude = -0.98
- Max. event for three months: +0.25

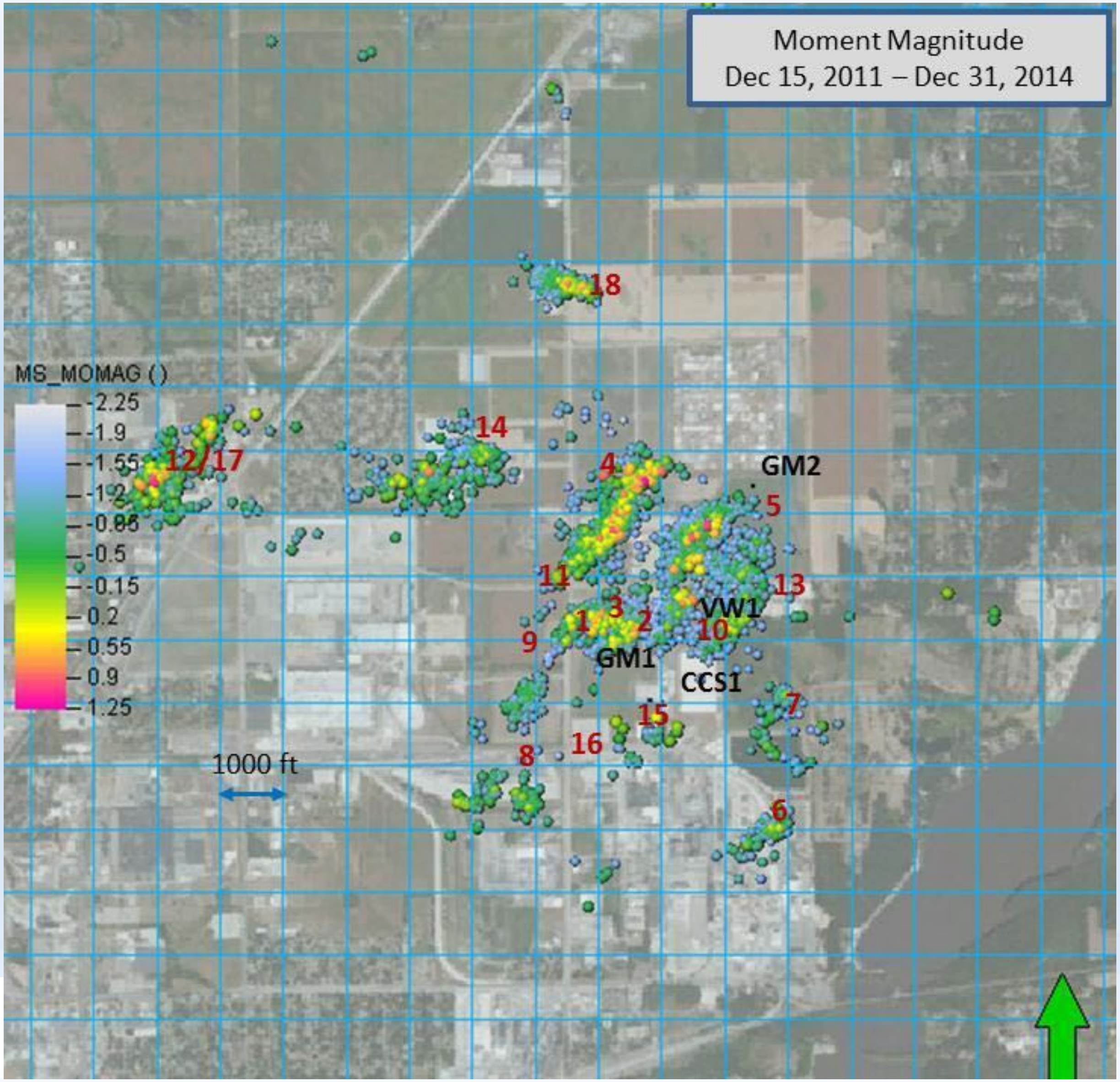
- Recent max event = +1.02 in September 2013



December 2014:
- Peak frequency at -1.2
- Peak MM at -0.05

from Schlumberger Carbon Services

Microseismic Cluster Activity: Cluster Locations in Relation to Surface Features



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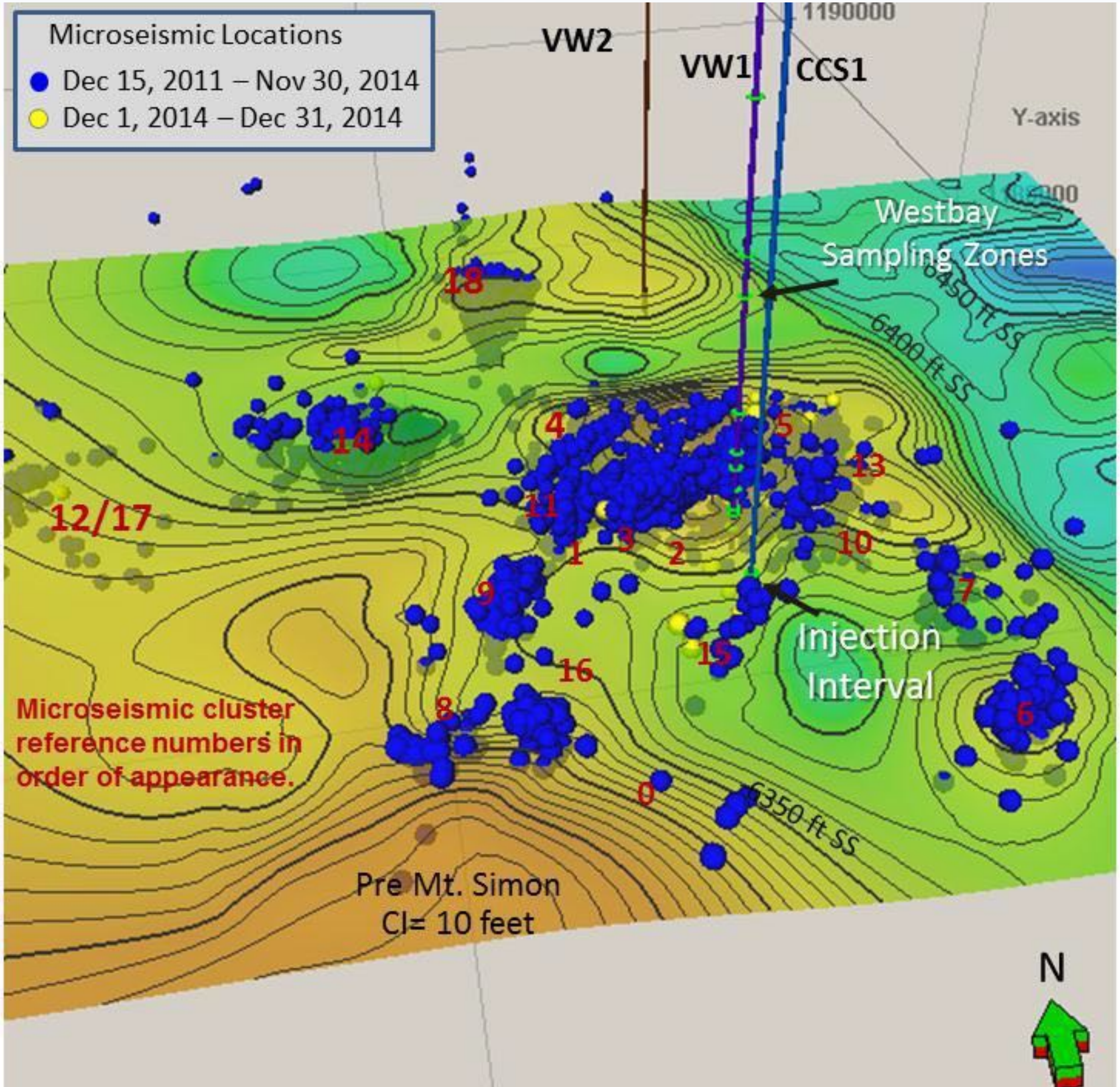

Microseismic Cluster Activity: Relationship to Basement Structure

from Schlumberger
Carbon Services

Key Operational Results – IBDP at Completion of Injection

- Mount Simon Sandstone reservoir accepted CO_2 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 detected with a 3D vertical seismic profile until April 2013
- Mt. Simon 200,000 ppm brine is more corrosive than expected
- With 999,215 tonnes injected, CO_2 remains in lowermost Mt. Simon; internal reservoir heterogeneity affecting CO_2 distribution
- No CO_2 leakage or adverse impacts detected to date
- Second project (ICCS) will add opportunity to monitor two plumes

CCS1 Transition from IEPA Class I to USEPA Class VI

- Injection period covered under IEPA Class I
- Post injection site care covered under USEPA Class VI
  - CCS1 becomes monitoring well for CCS2
  - Direct ground water quality monitoring
  - Indirect ground water quality monitoring
  - Mechanical integrity testing (MIT)
  - Plume monitoring
  - Seismic monitoring
  - Pressure-front monitoring
- Interim phase between end of IBDP/CCS1 injection and start of CCS2 injection

Direct Ground Water Monitoring Above Eau Claire

- Formations:
  - Quaternary and/or Pennsylvanian
  - St. Peter
  - Ironton-Galesville
- Activity:
  - Fluid sampling
  - Distributed temperature sensing (DTS)
  - Pressure/temperature monitoring (SP and IG)
- Wells: Shallow groundwater, CCS1, CCS2, GM2, VW1, and VW2
- Frequency (changes over time):
  - Interim period
  - CCS2 injection phase
  - CCS2 post-injection phase

Final Steps: Demonstration of Non-Endangerment

At end of PISC period:

- Operator submits a demonstration of non-endangerment of USDW to UIC Program Director (40 CFR 146.93(b)(2) or (3)
- Based on evaluation of site monitoring data in conjunction with computational model
- Uses site-specific conditions to confirm and demonstrate non-endangerment
- Includes:
  - Summary of existing monitoring data
  - Comparison of monitoring data and model predictions and model documentation
  - Evaluation of CO_2 plume
  - Evaluation of mobilized fluids
  - Evaluation of reservoir pressure
  - Evaluation of potential conduits for fluid movement
  - Evaluation of passive seismic data

MGSC

U.S. DEPARTMENT OF ENERGY

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ADM

Schlumberger Carbon Services

Midwest Geological
Sequestration Consortium
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Photo credits: Daniel Byers

Plume Monitoring

Target Formation	Monitoring Activity	Monitoring Location	Frequency: Interim Period	Frequency: CCS2 Injection Phase	Frequency: CCS2 Post-Injection Phase
Direct Plume Monitoring					
Mt. Simon	Fluid Sampling	VW1	Once	Year 1-3: Annual Year 4-5: None	None
Mt. Simon	Fluid Sampling	VW2	None	Annual	Annual
Indirect Plume Monitoring					
Mt. Simon	Pulse Neutron logging/ RST	VW1 VW2	Once	Year 2, Year 4	Year 1, 3, 5, 7, 10
Mt. Simon	Pulse Neutron logging/ RST	CCS1 CCS2	Once	Year 2, Year 4	Year 1, 3, 5, 7, 10

Seismic Monitoring

Timing		Survey	Extent/Coverage/Resolution
CCS1 Injection Phase	2009	Baseline 3D Surface Seismic Survey	Extent = 2,600 Acres Fold Coverage = 2,000 Acres
	2011	Baseline 3D Surface Seismic Survey	Extent = 2,600 Acres Fold Coverage = 2,000 Acres
	2011	Baseline GM1 3D VSP	Resolution = 30 Acres
	2012	GM1 3D VSP	Resolution = 30 Acres
	2013	GM1 3D VSP	Resolution = 30 Acres
	2014	GM1 3D VSP	Resolution = 30 Acres
CCS1 Post-Injection Phase	2015	Expanded 3D Surface Seismic Survey	Extent = 3,000 Acres Fold Coverage = 2,200 Acres
	2020	Time Lapse Surface Seismic Survey	Extent = 2,000 Acres Fold Coverage = 600 Acres
	2030	Time Lapse Surface Seismic Survey	Extent = 2,000 Acres Fold Coverage = 600 Acres

Pressure-Front Monitoring

Target Formation	Monitoring Activity	Monitoring Location	Frequency: Interim Period	Frequency: CCS2 Injection Phase	Frequency: CCS2 Post-Injection Phase
Mt. Simon	Pressure/ temperature monitoring	VW1	Continuous	Y1-3: Continuous Y 4-5: None	None
		VW2	None	Continuous	Continuous
		CCS1	Continuous	Continuous	Y 1-3: Continuous Y 4-10: Annual
		CCS2	None	Continuous	Y 1-3: Continuous Y 4-10: Annual
Mt. Simon	DTS	CCS1	Continuous	Continuous	Y 1: Continuous Y 2-10: None
		CCS2	None	Continuous	Y 1: Continuous Y 2-10: Annual
Multiple	Passive seismic (detect M 1.0 events)	Borehole & surface seismic stations within AoR	None	Continuous	Continuous