Midwest Geological Sequestration Consortium

Illinois Basin – Decatur Project

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Advanced Energy Technology Initiative
University of Illinois – Illinois State Geological Survey

18 August 2015 – Pittsburgh, PA

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

PRAIRIE RESEARCH INSTITUTE

CCS in Decatur, IL USA

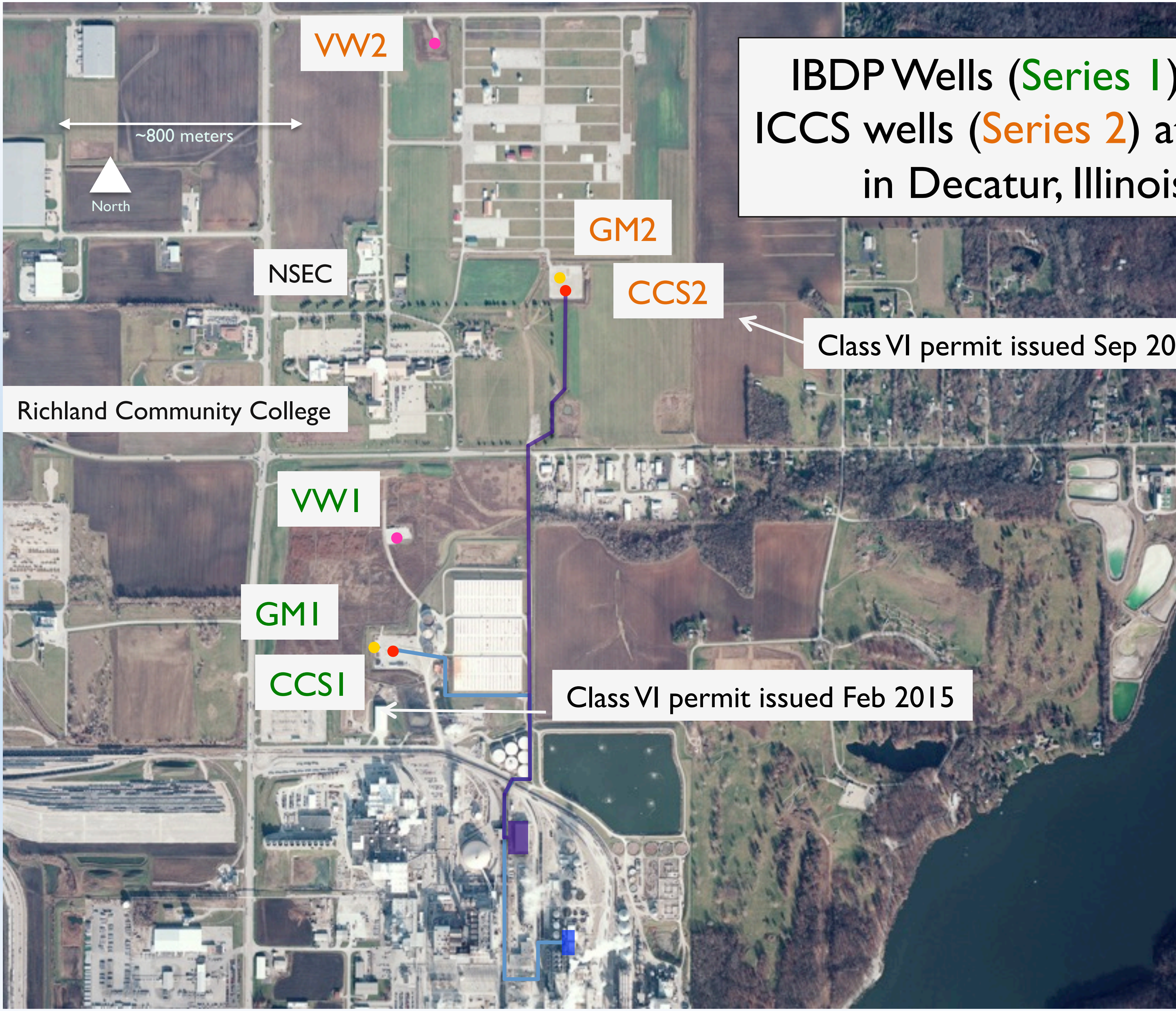
Illinois Basin – Decatur Project

- Large-scale demonstration
- Volume: 1 million tonnes
- Injection period: 3 years
- Injection rate: 1,000 tonnes/d
- Compression capacity: 1,100 tonnes/day
- Status: Post-injection monitoring

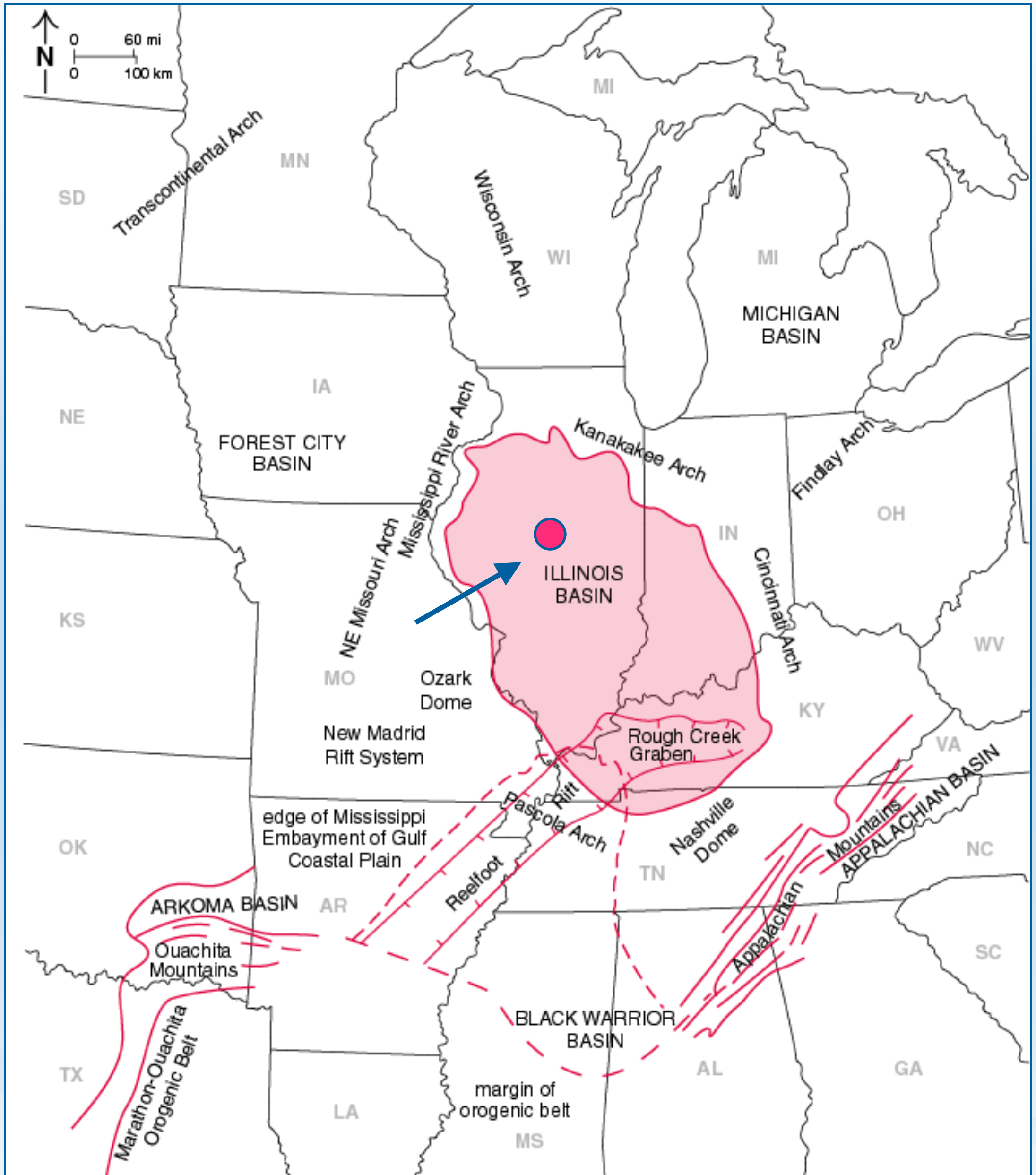
Illinois Industrial CCS Project

- Industrial-scale
- Volume: 5 million tonnes
- Injection period: 3 years
- Injection rate: 3,000 tons/d
- Compression capacity: 2,200 tonnes/day
- Status: Pre-injection monitoring

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



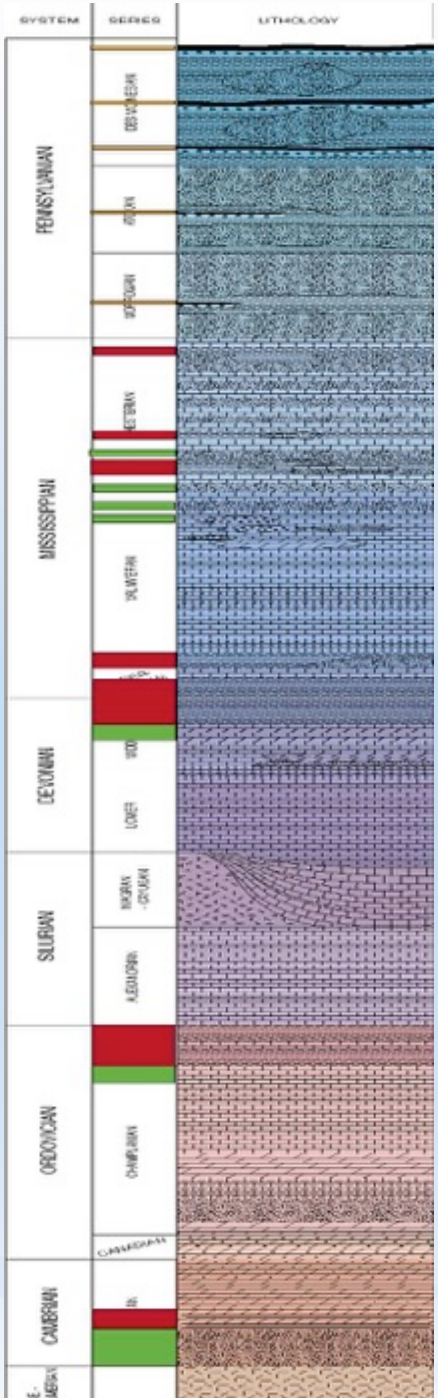
Illinois Basin – Decatur Project Scope



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 Stratigraphic Column



Pennsylvanian coal seams

New Albany Shale

back-up seals

Maquoketa Shale

St. Peter Sandstone

Eau Claire Shale — seal

Mt. Simon Sandstone — reservoir

Mount Simon Storage Capacity:
11 (E=0.4%) to 150 (E=5.5%) billion metric tons

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 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

Current Affairs

- MGSC undergoing transition:
  - Shift in leadership
  - Shift in project personnel
  - Shift from operations to post-injection monitoring
  - Shift to knowledge and data sharing
  - Preparations for final activities

- MGSC BP5 focus:
  - Outreach (integrate STEP)
  - Post-injection monitoring and modeling
  - Project Assessment
    - Evaluation, data analysis, knowledge sharing, capacity building
    - Participate in national and international technology transfer
  - Post-test Site Planning

Post-Injection Activities

- 3D Surface Seismic Survey – January 2015
  - Processing nearly complete
- Post-injection VSP, permit interim period – January 2015
  - Working to improve comparisons between repeat VSPs
- Post-injection near surface monitoring
  - Moving from injection monitoring to reduced program
- Knowledge and data sharing best practices
  - Publications
  - National and international research collaborations
  - Collective data sets
  - Teaching data sets

Aligning Knowledge and Data Sharing Opportunities

Working to Align Data Sharing Goals and Achieve Success

Vetting Data

- Complete 3D seismic processing
- Review data
- Verify data against previous data sets
- Ground-truthing

Integrating Data

- Microseismic data dependent upon 3D surface seismic
- Research underway in multiple projects
- Publications being prepared

Defining Research Questions

- What are best practices for releasing and managing data sharing?
- Can VSP data be improved?
- Are models accurately reflecting observed activity?

Preparing Data for Release

- Vetting data
- Defining data sets
- Ensuring quality
- Maintaining integrity

Data Sharing

- Planned research release
- Coincide with publication release
- Align with larger initiatives

Data Sharing as Best Practices

Outcome: Stakeholder engagement strategy that resonates with the Public

- Began public engagement early
- Made public engagement a priority
- Created, evaluated, and refined communications plan
- Integrated public engagement into project management
- Made sufficient investment in time and resources
- Understood and consulted community
- Maintained flexibility and diligence

Research Q&A for Science & Society

- How do you know the CO_2 is staying where you put it?
- What happens in the event of earthquakes?
  - Induced seismicity
  - Fracture and catastrophic release of stored CO_2
- Where does formation water go when CO_2 is injected?
  - Increased pressure
- Does CO_2 injection fracture rocks during injection?
- What are long-term implications of project?
- Who is liable if something goes wrong with the project?
- How do you know it is safe?

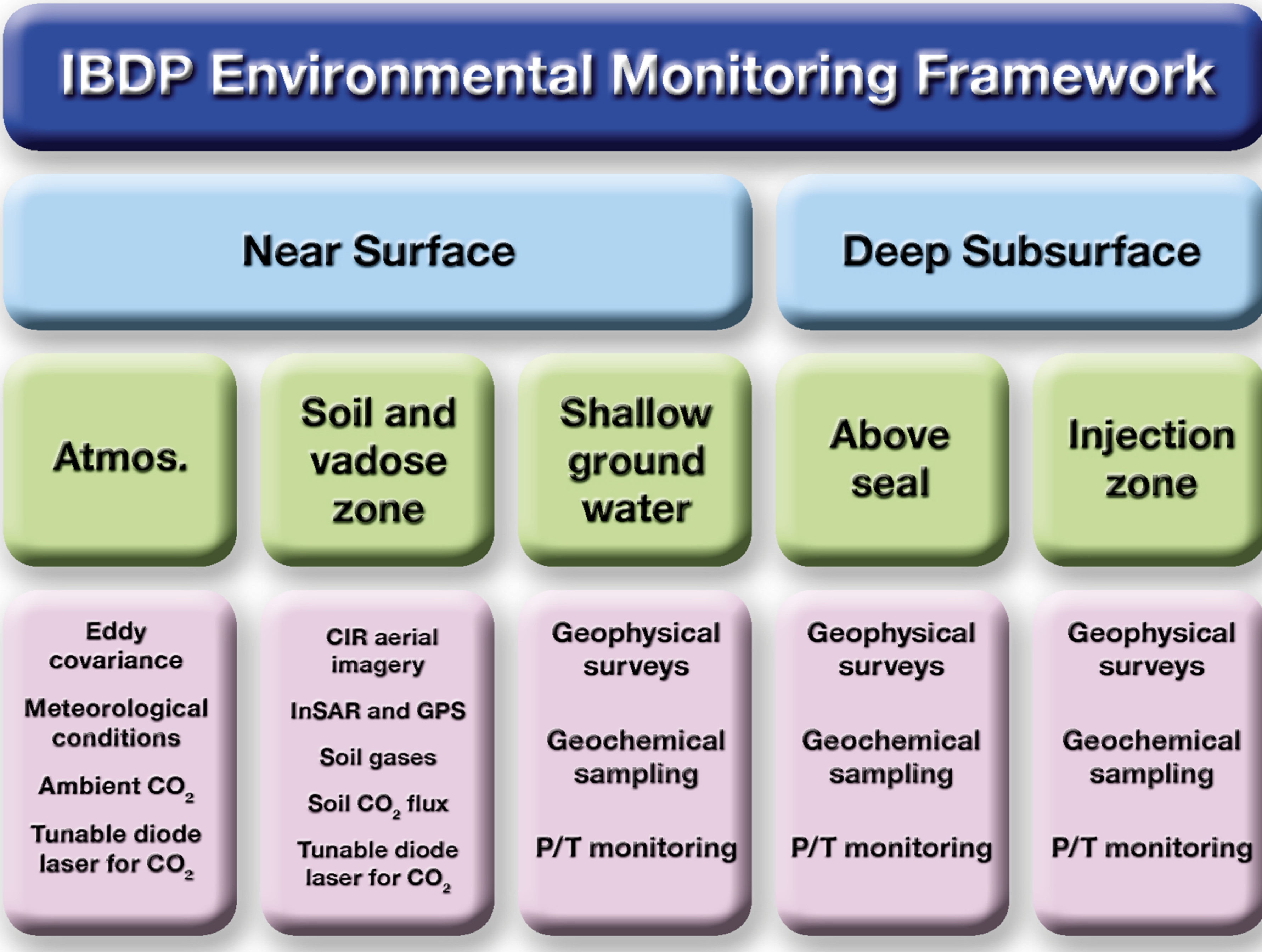
Outcome: We Better Understand Longitudinal Risk Profile of Carbon Capture and Storage Workflow

- Discussion and evaluation in plenary sessions preferable to breakout sessions. Led to fully involving experts, wider range of views and, greater discussion.
- Risk profile can change significantly over time and must be continually reviewed.
- Self-rating of expertise level led greater understanding of where expert views diverged from well-informed non-experts.
- Scenarios with very high worst-case severities must be treated differently from scenarios whose high risk results from higher likelihood.

Illinois Basin – Decatur Project Workflow

- Regional Characterization
- Site assessment
- Outreach and public engagement
- Permitting and building the IBDP test site
- Collect and analyze key monitoring baseline data
- Injection, monitoring, and modeling
- Post-injection monitoring, modeling, and analysis
- Research collaborations, knowledge sharing

Completed On-going Current activities Upcoming activities


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

IBDP Risk Assessment and Project Uncertainties

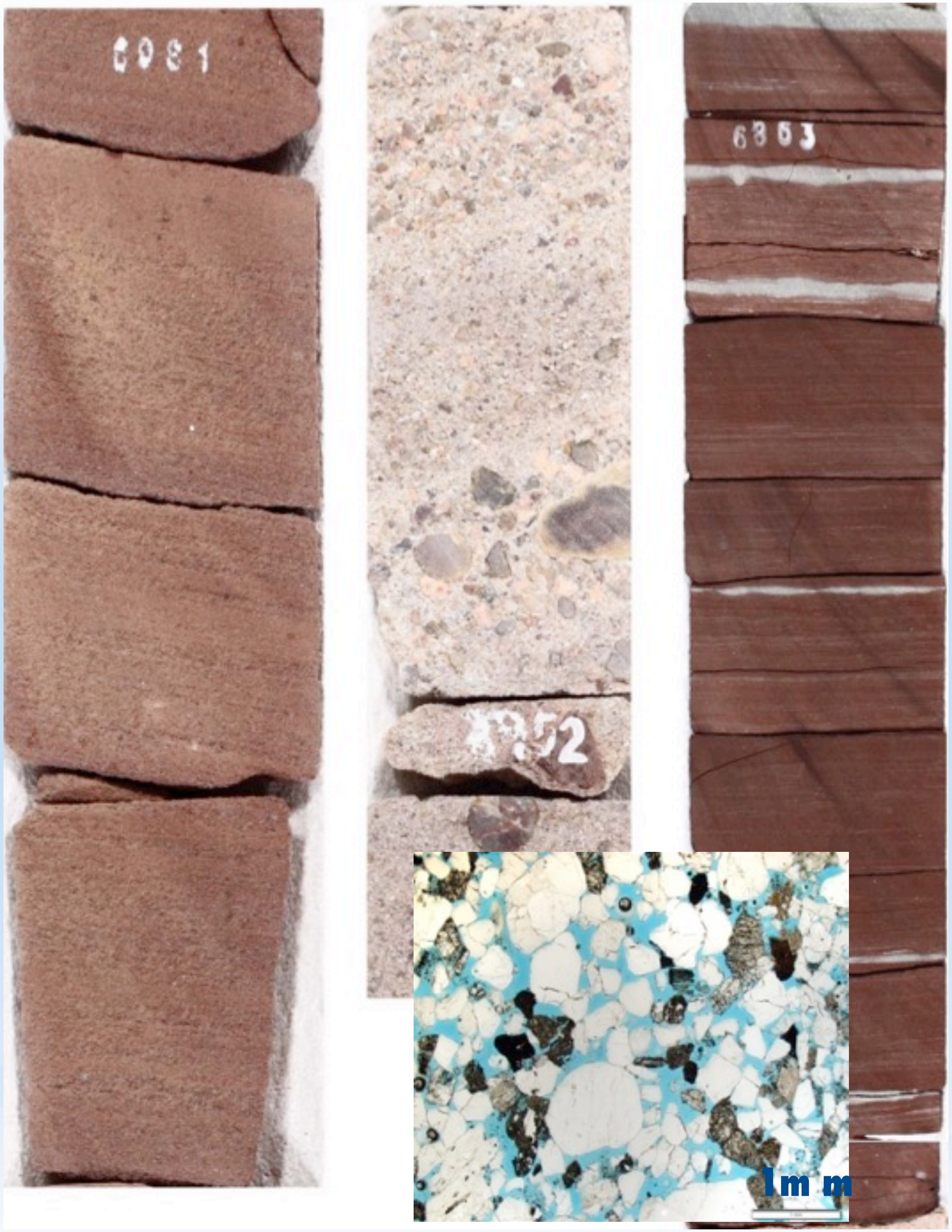
Geologic Uncertainty
Operational Uncertainty
Regulatory Uncertainty
Social Uncertainty

Regulatory Uncertainty

Change in Scope
Long-term Funding
Challenges in Knowledge Sharing
Complacency Potential
Institutional Memory Loss

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

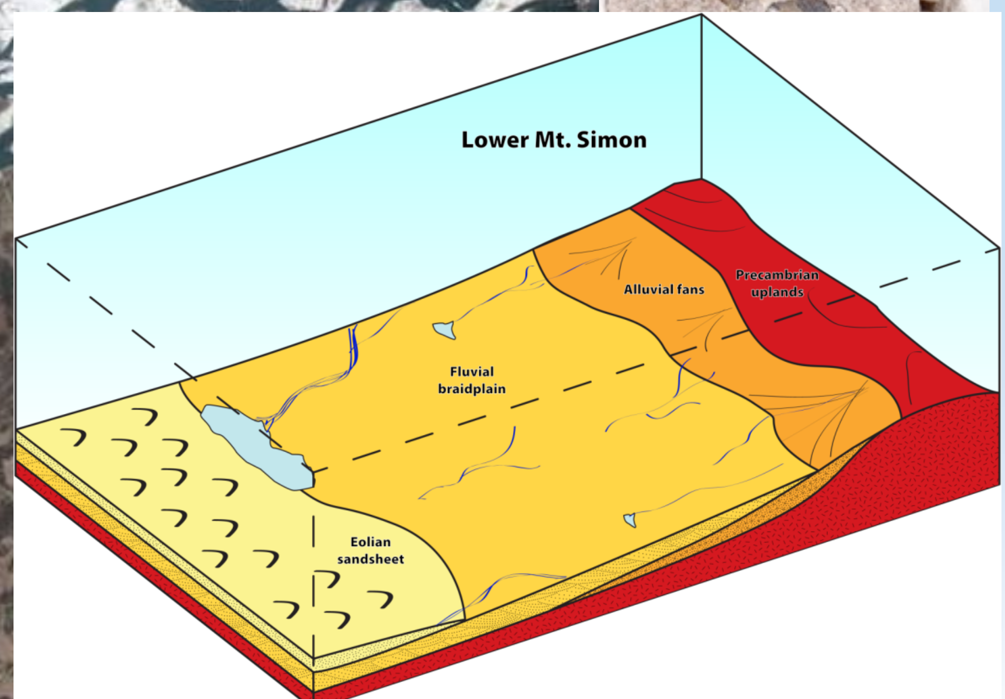


Lower Mt. Simon Fluvial Deposits

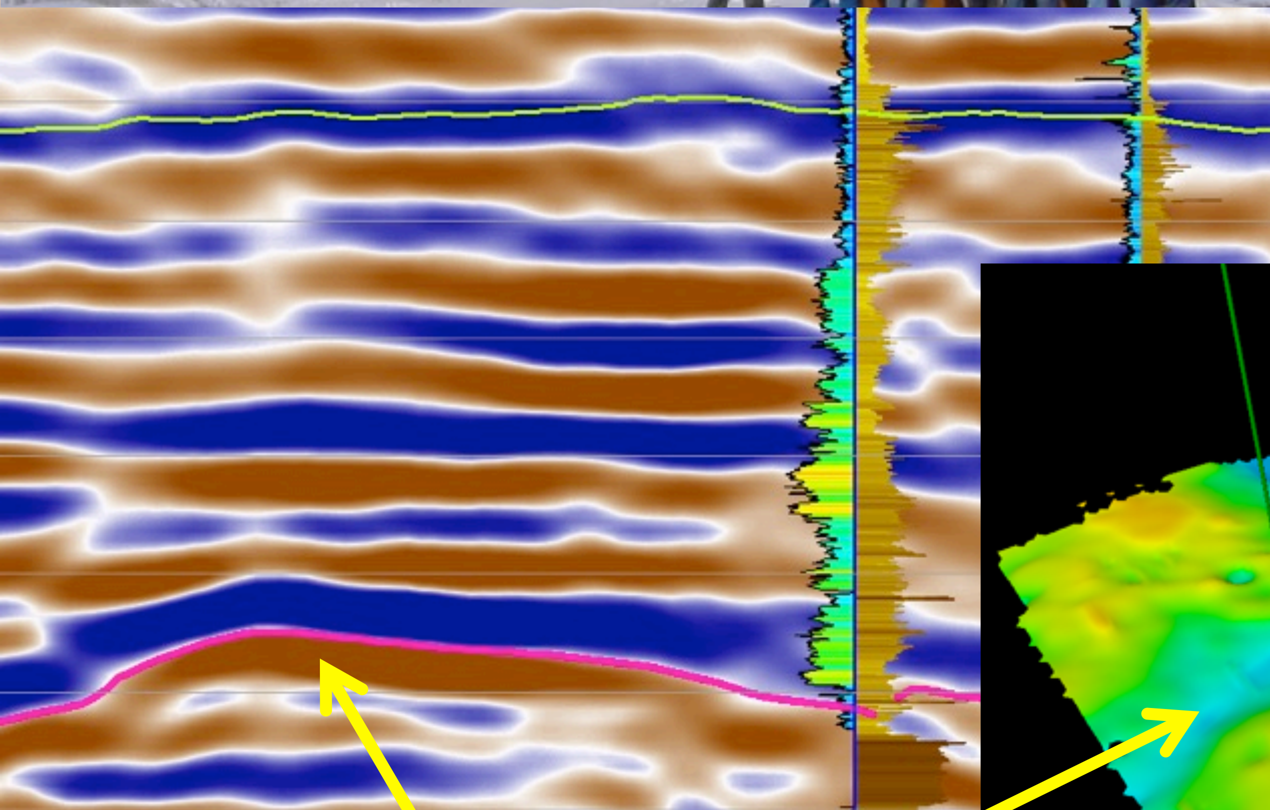
- Braid Plain and alluvial fan deposits; poorly to mod. sorted, cross-bedded sandstone to pebble conglomerate. Porosity up to 30% and 500mD permeability
- Fluvial flood plain and playa deposits; planar and ripple laminated mudstones and siltstones. Tight and impermeable

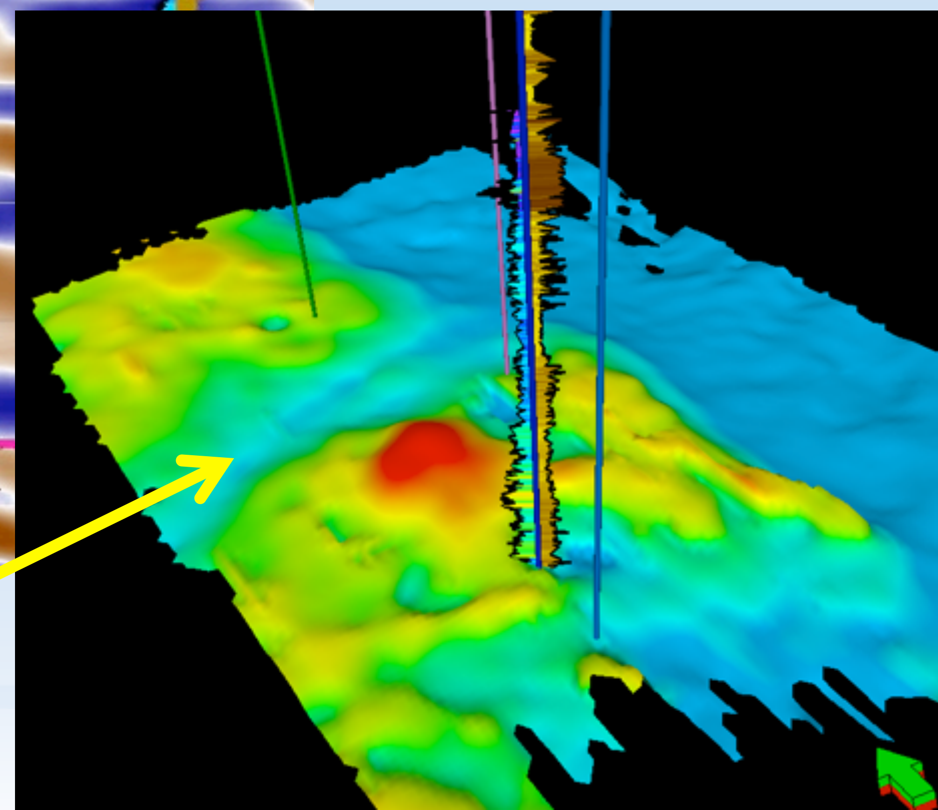
from Freiburg, ISGS

Mount Simon Depositional Analogue: Brahmaputra River System



3D Seismic Defines Reservoir



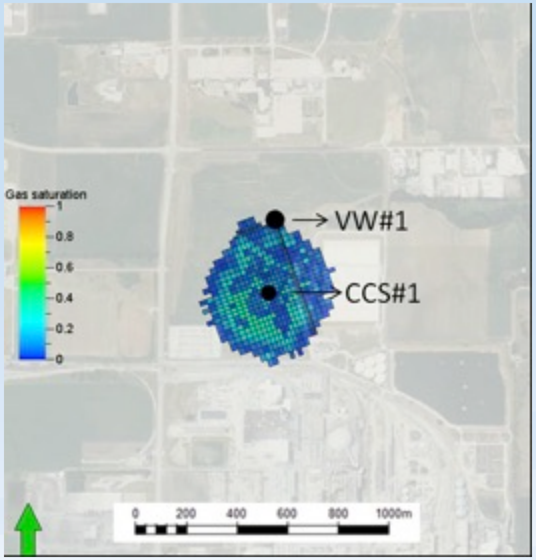


Eroded Precambrian surface

from Leetaru, ISGS

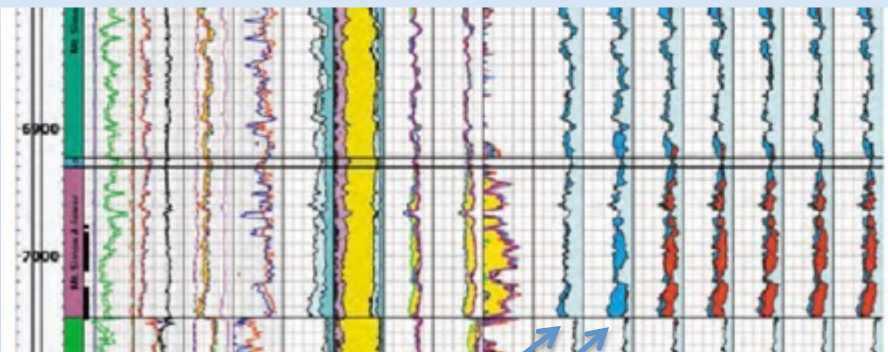
Outcome: We Better Understand Reservoir Fluid Distribution and Impacts of Heterogeneity on Pressure

- 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

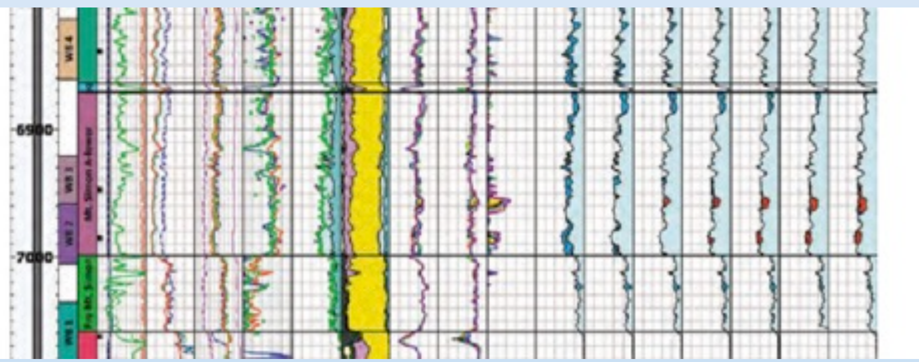


Repeat Pulsed Neutron* Logging has Defined CO_2 Distribution at the Injection and Observation Wells

CCS1



VW1

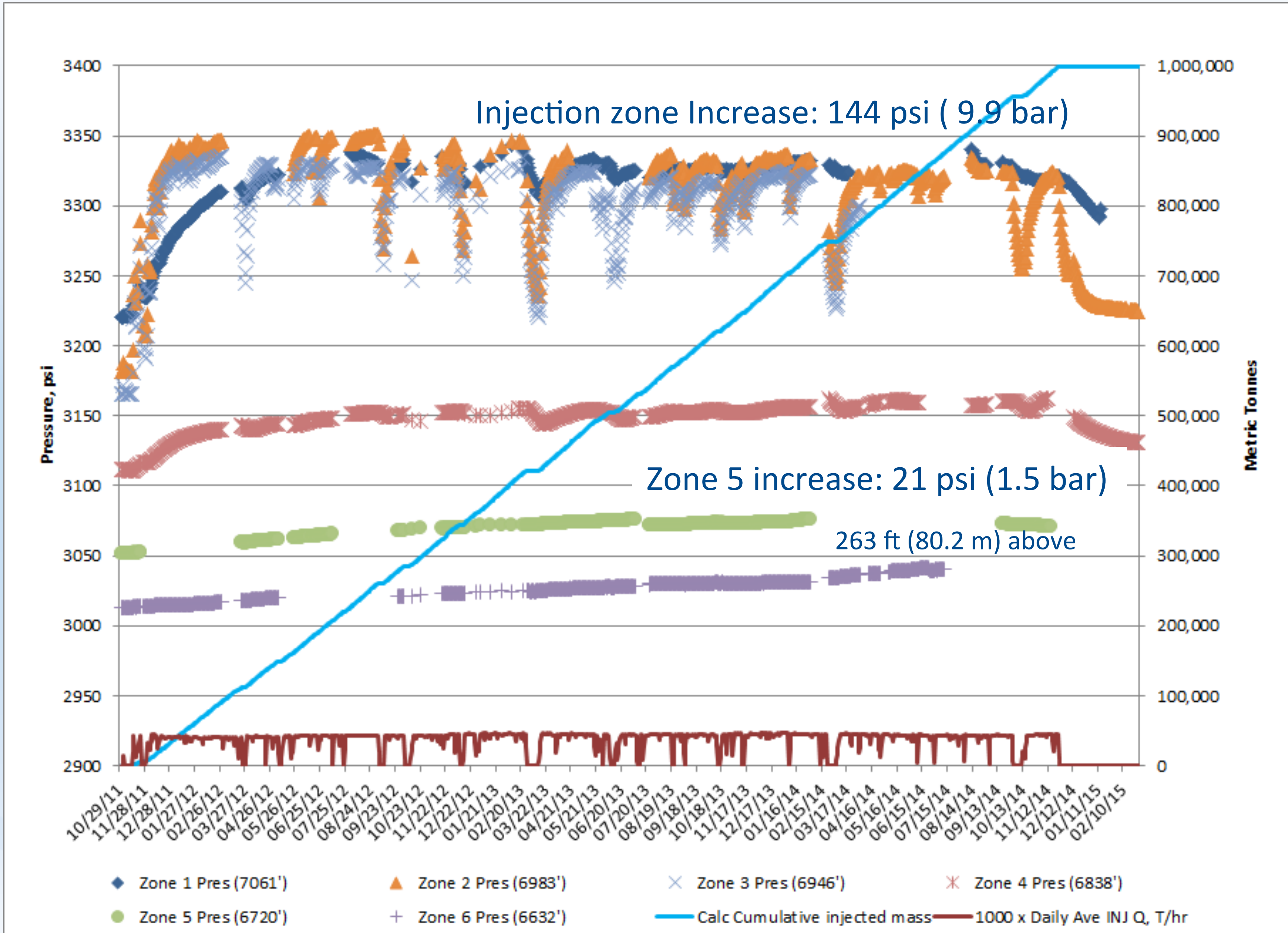


Pre-injection

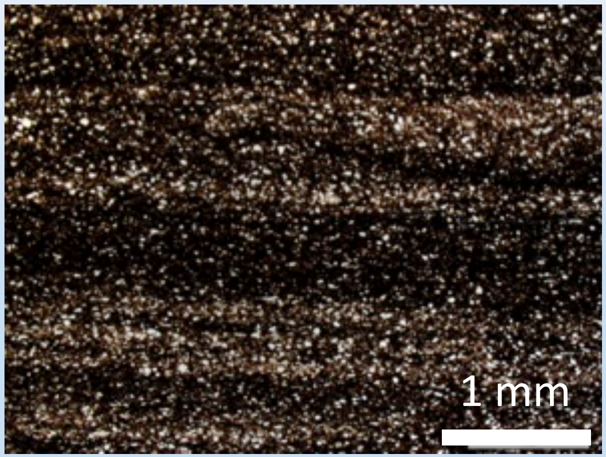
Five post-injection logging runs: March, July, and November 2012; July 2013; July 2014

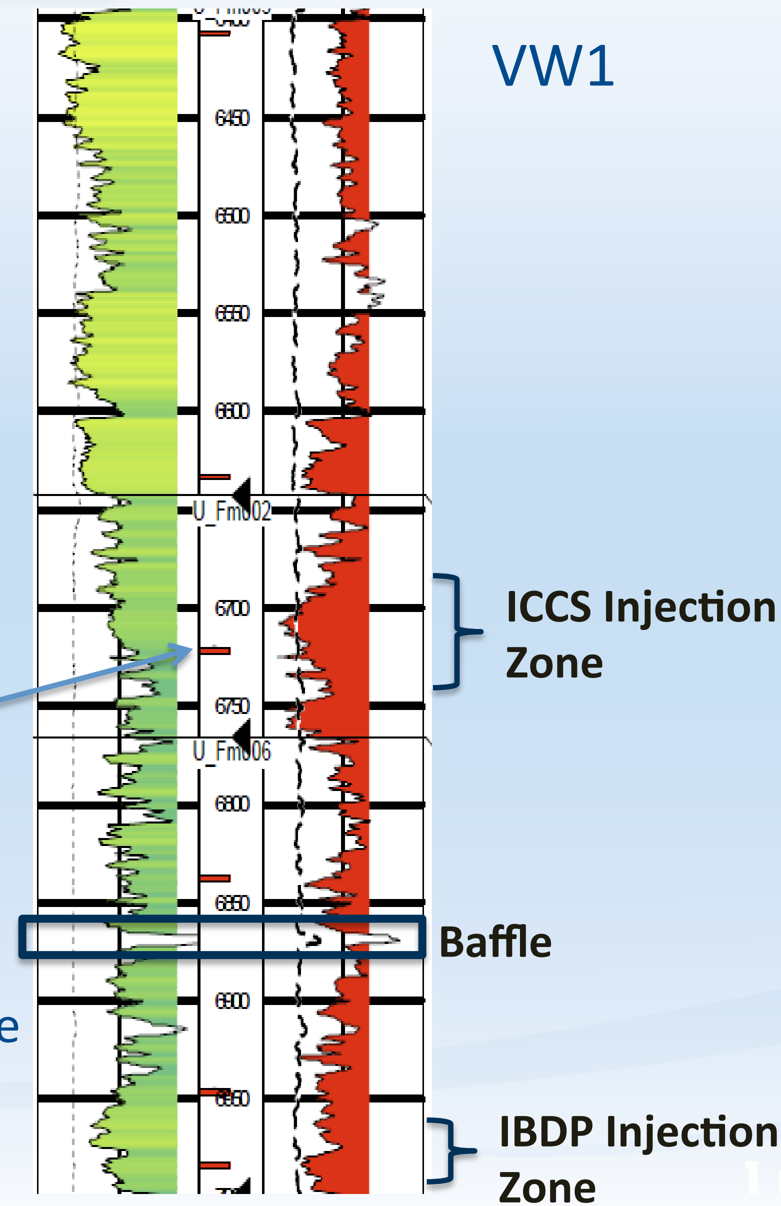
*Schlumberger Reservoir Saturation Tool (RST)

Westbay* Pressure Monitoring Output – 28 February 2015



Mudstone Baffle Between Injection Zones





6,863-6,863.25

Porosity: 1.5%

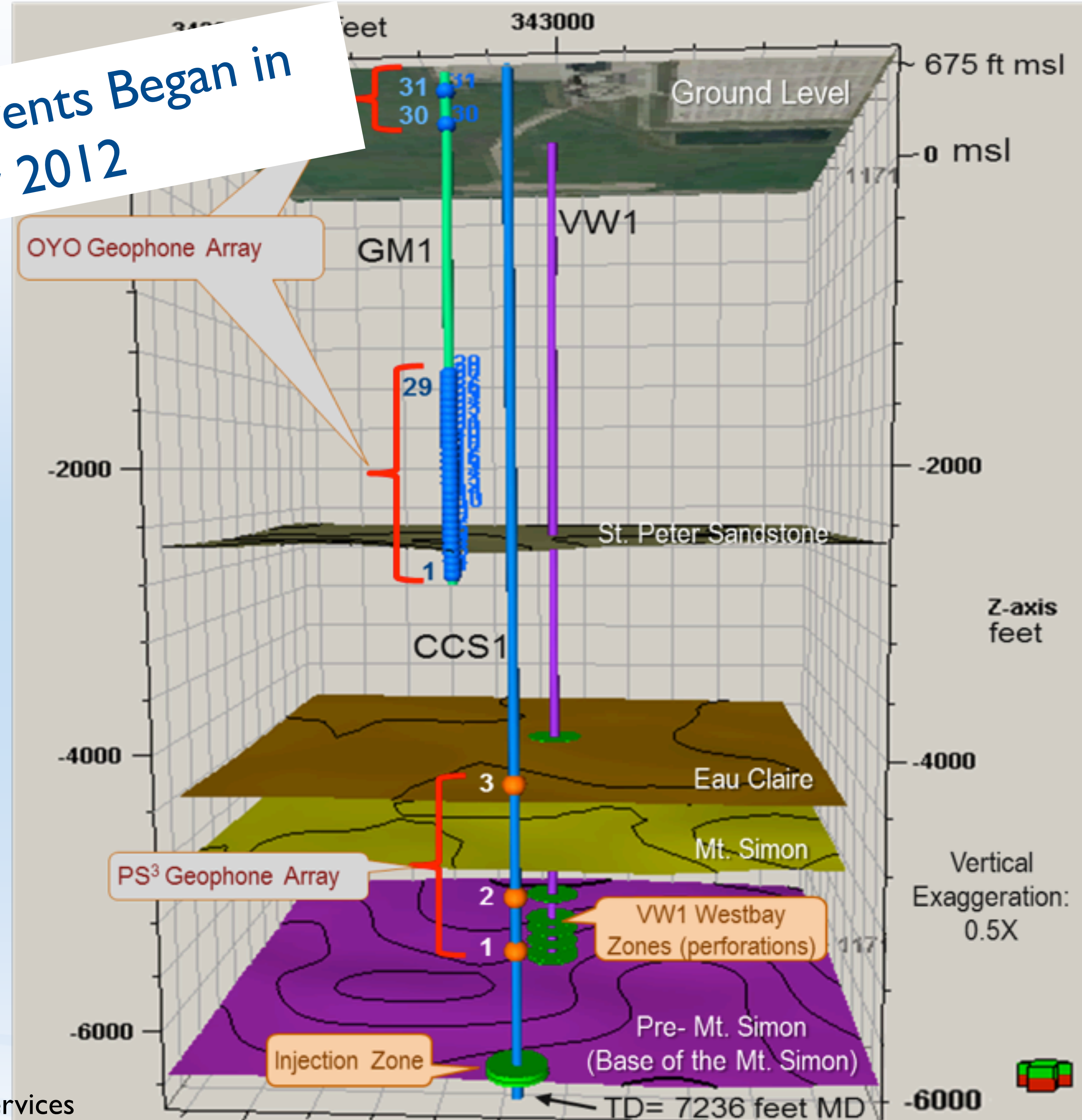
K_v: <0.01 mD

K_h: 4.13 mD in siltstone laminae

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

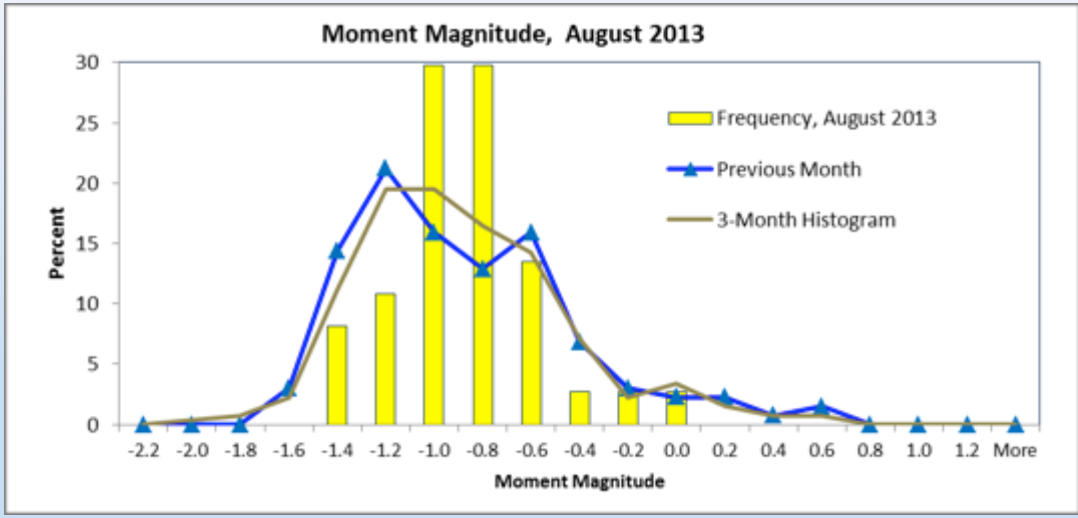
Microseismic Events Began in January 2012



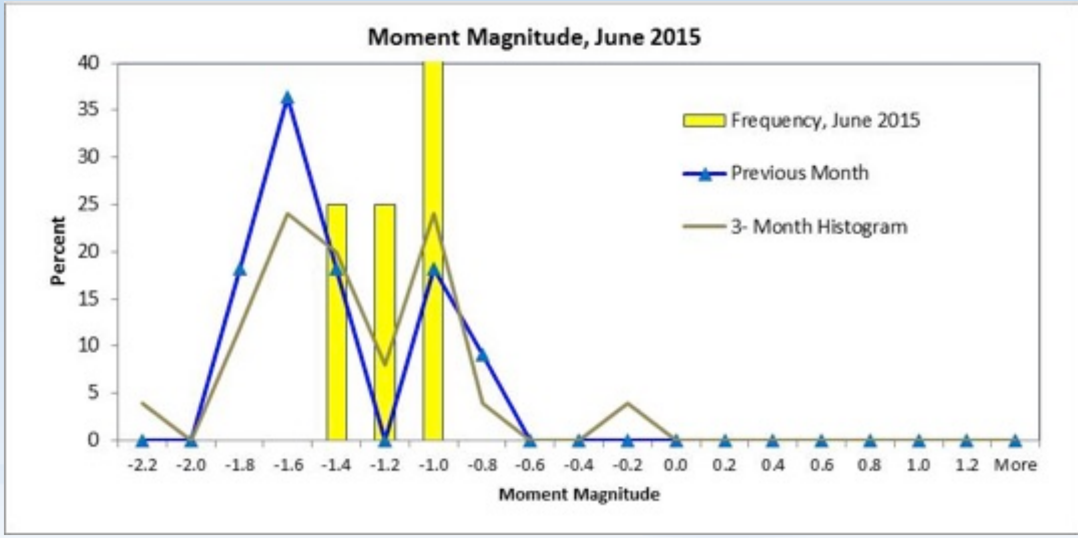
from Schlumberger Carbon Services

Maximum event = +1.02 in September 2013

- Jun-Aug 2013 (avg) = 89 located events/month
- Mean moment magnitude: -0.98
- Max. event for three months: +0.25

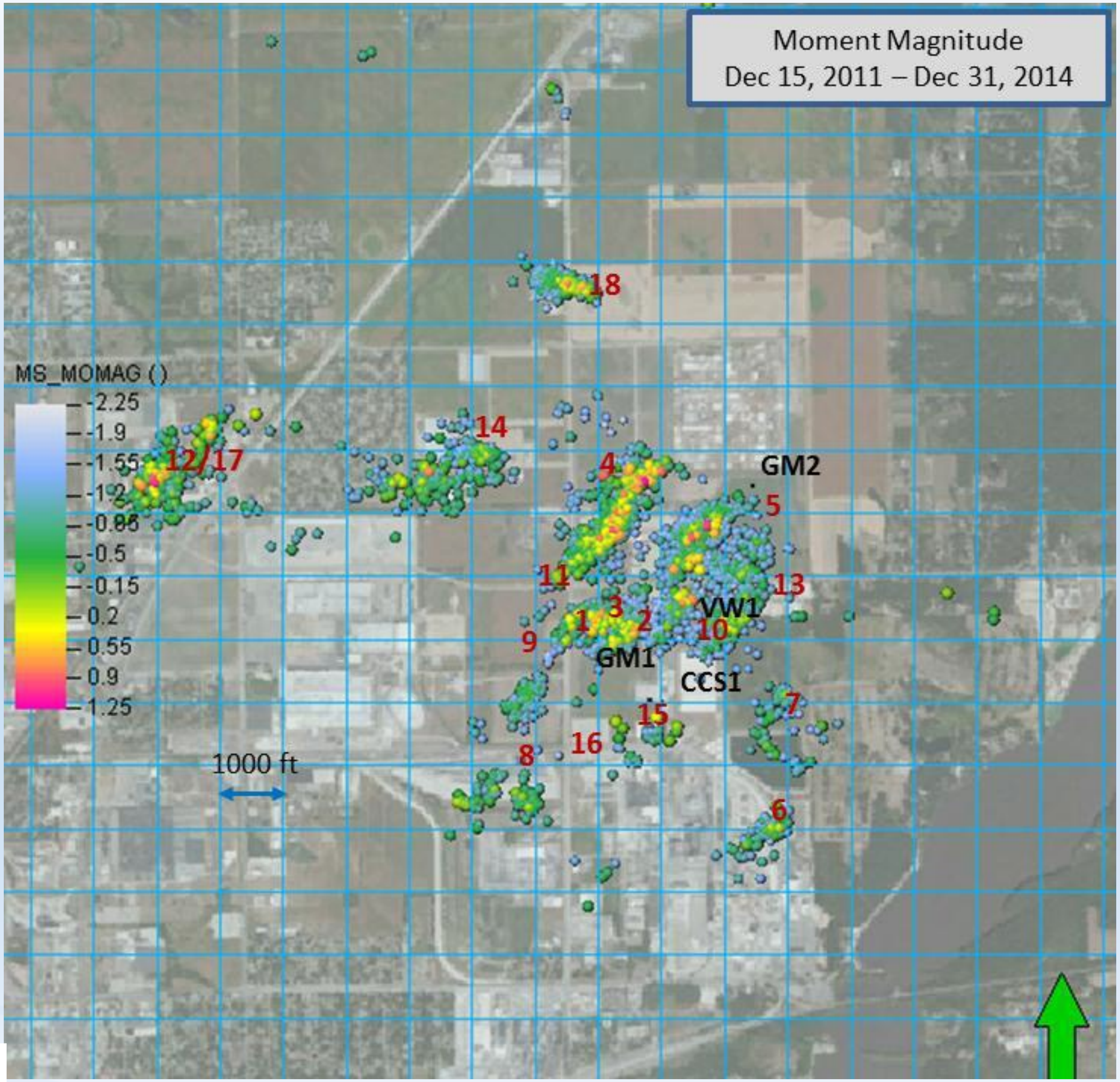


- Jun 2015: 12 detected events
  4 located events
- Mean moment magnitude: -1.23
- Max. event for three months: -0.2



from Schlumberger Carbon Services

Microseismic Cluster Activity: Cluster Locations in Relation to Surface Features



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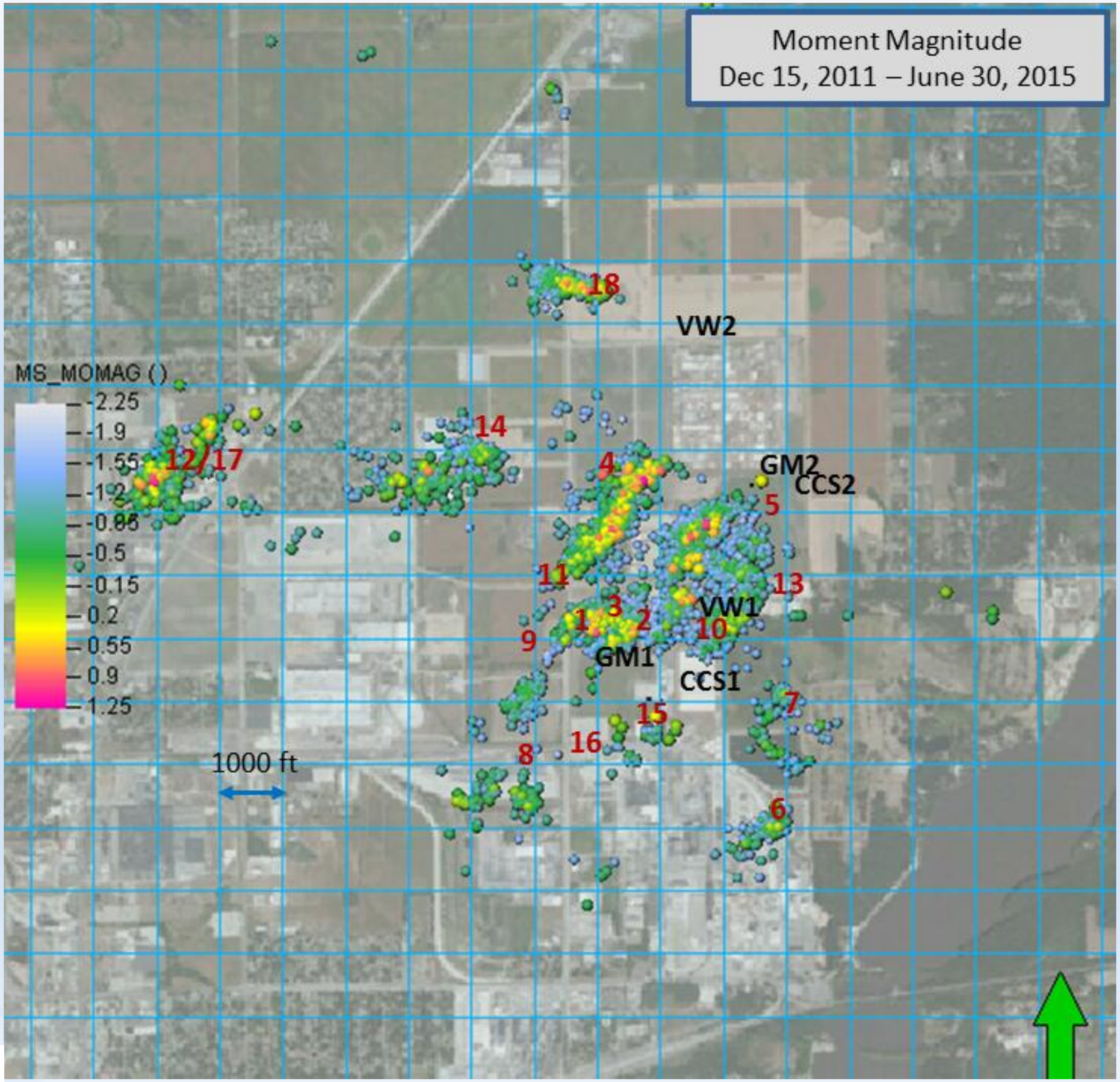

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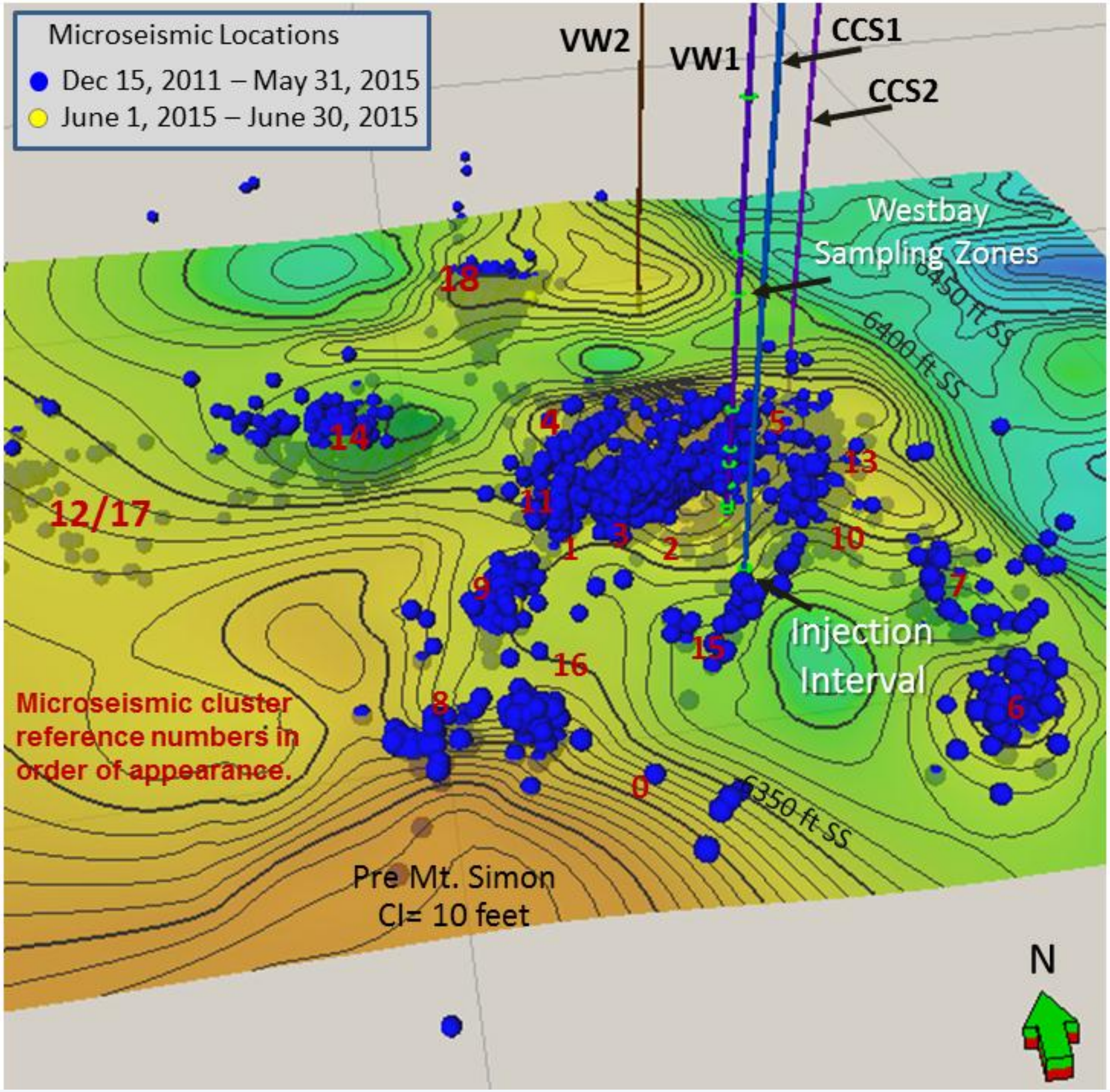
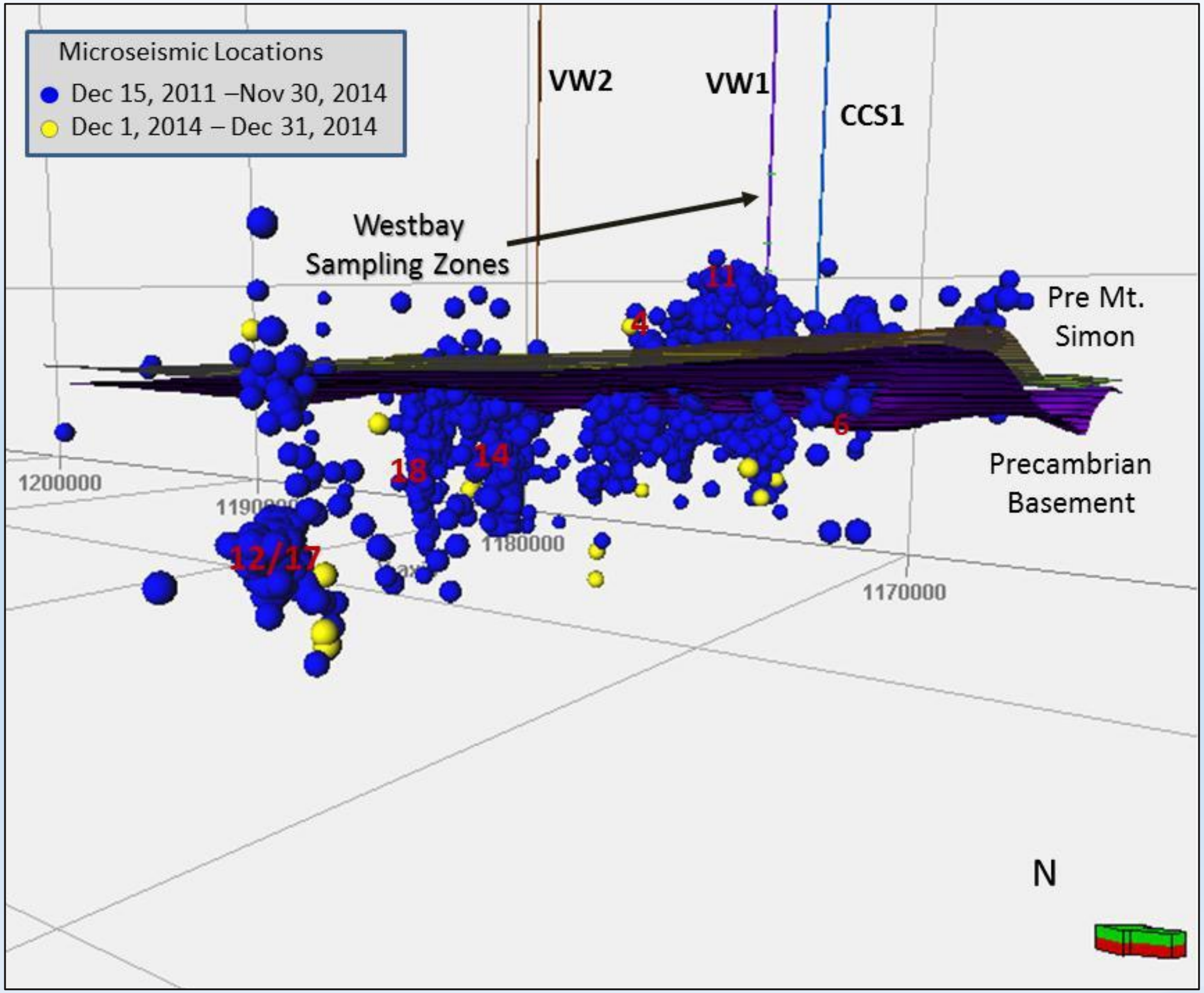


Microseismic Cluster Activity: Relationship to Basement Structure

from Schlumberger Carbon Services

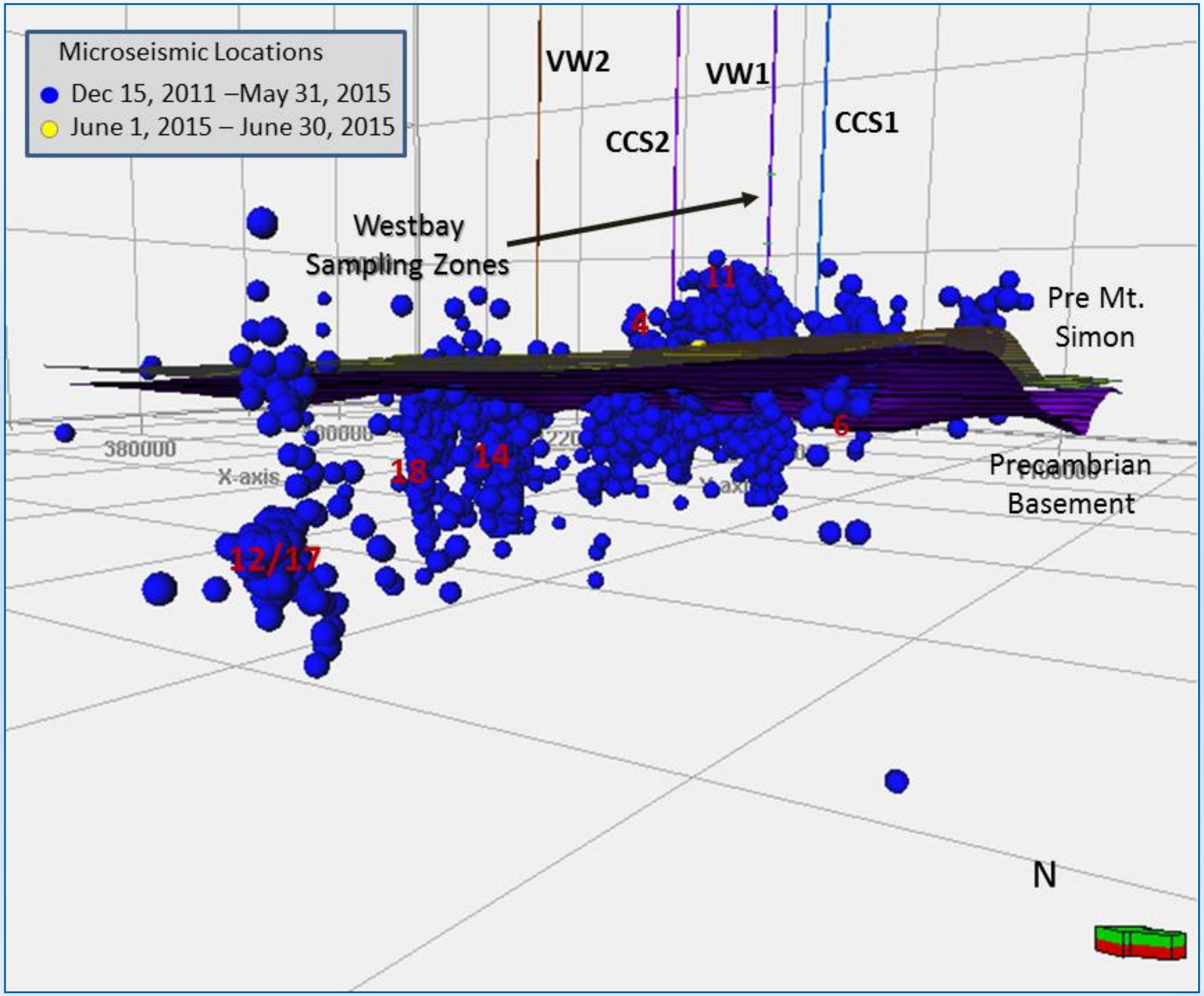
Microseismic events in relation to stratigraphy



Majority of events are in the pre Mt Simon and Precambrian

from Schlumberger Carbon Services

Microseismic events in relation to stratigraphy



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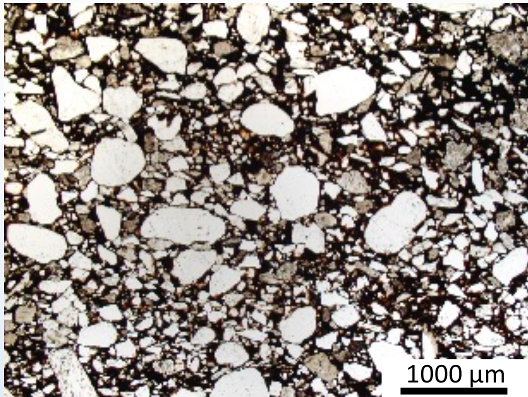


Pre-Mt. Simon Sandstone

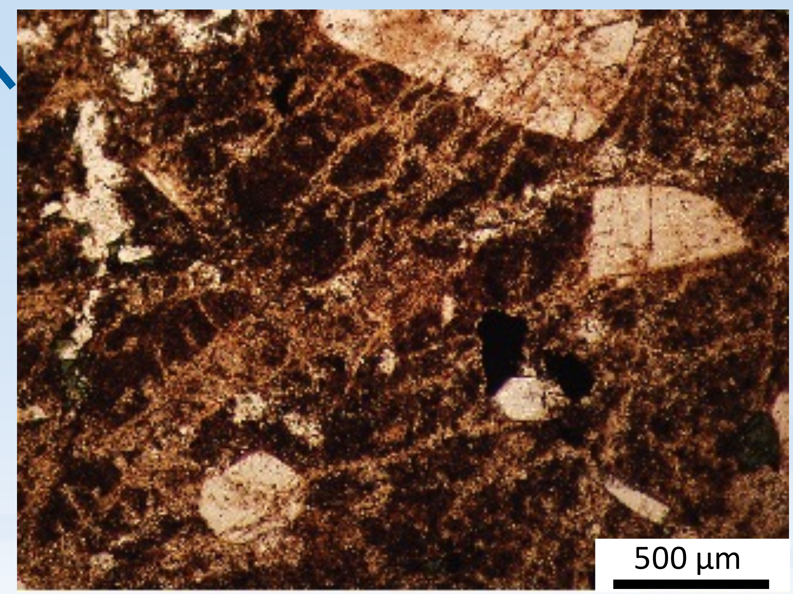
- Unconformable contact with Mt. Simon
- Sandstones and pebble conglomerates. Porosity <8% and perm. <1md.
- Bioturbation throughout suggesting marine environment and dating Pre-Mt. Simon at Cambrian

from Freiburg, ISGS

Precambrian Basement

- Upper Basement is Rhyolite
- Distinct Weathering Profile. Fractured
- Dated at 1.45 Ga

from Freiburg, ISGS



Outcome: Successful permitting of UIC wells for two projects provides precedent for future projects

- Proactively engage regulators
  - Engage early
  - Familiarize yourself with regulatory time clock
- Expect technical collaboration between USEPA and applicant
- USEPA focused on making technical, risk-based permitting decisions
- Modeling should be discussed in detail with USEPA prior to development and verification
- Start early
- Seek out examples (publicly available)
- Provide balance of information – detail important, but can distract
- Remain flexible

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

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

Midwest Geological Sequestration Consortium

Publication Plan – 2015 to 2016 (subject to change)

- International Journal of Greenhouse Gas Control:
  - Special Volume
  - 4 papers on microseismic research at IBDP
  - Publish Q1 or Q2 of 2016
- American Geophysical Union:
  - Geophysical Monitoring for Geologic Sequestration of Carbon Dioxide
  - 2 book chapters
    - Microseismic Monitoring, Event Location, and Focal Mechanisms: A Case Study of the Illinois Basin – Decatur Project
    - Seismic Data Integration for Site Characterization and Monitoring.
- Pre-Cambrian Basin Geology
- Illinois Basin Tectonic Regime
- Open file reports

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