An Evaluation of the Carbon Sequestration Potential of the Cambro-Ordovician Strata of the Illinois and Michigan Basins

Cooperative Agreement Number: DE-FE0002068

Hannes E. Leetaru

University of Illinois

U.S. Department of Energy
National Energy Technology Laboratory
Strategic Center for Coal's
FY13 Carbon Storage Peer Review
August, 2013

Presentation Outline

- Project Overview
  - Goals and Objectives
  - Benefits of Program
  - Scope of Work
- Accomplishments
- Summary
- Backup Material

Benefit to the Program

- Program goals.
  - Reduce storage risk by documenting the uncertainties related to natural fractures, injectivity, and geochemical interactions for the St. Peter and Knox strata.
- Project benefits statement.
  - At the successful conclusion of this project we expect to delineate potential new geologic intervals for carbon storage in Illinois, Indiana, Michigan, and Western Kentucky, which will enhance the North American carbon storage resource potential.
  - Support the DOE Program initiative to develop BPMs for site selection, characterization, site operations, and closure practices.

Project Overview: Goals and Objectives

- This Cambro-Ordovician project will highlight areas of high risk and low risk for carbon storage in the St. Peter and Knox strata in the Illinois and Michigan Basins.
- Develop a Best Practices Manual will show the methodology for reducing storage risks
- Show how seismic reflection data can be used to delineate high and low risk areas
- Study seals and reservoirs for faulting and fracture risk (geomechanical studies), as well as their interactivity and reactions with CO_2 in the presence of brine (geochemical studies).

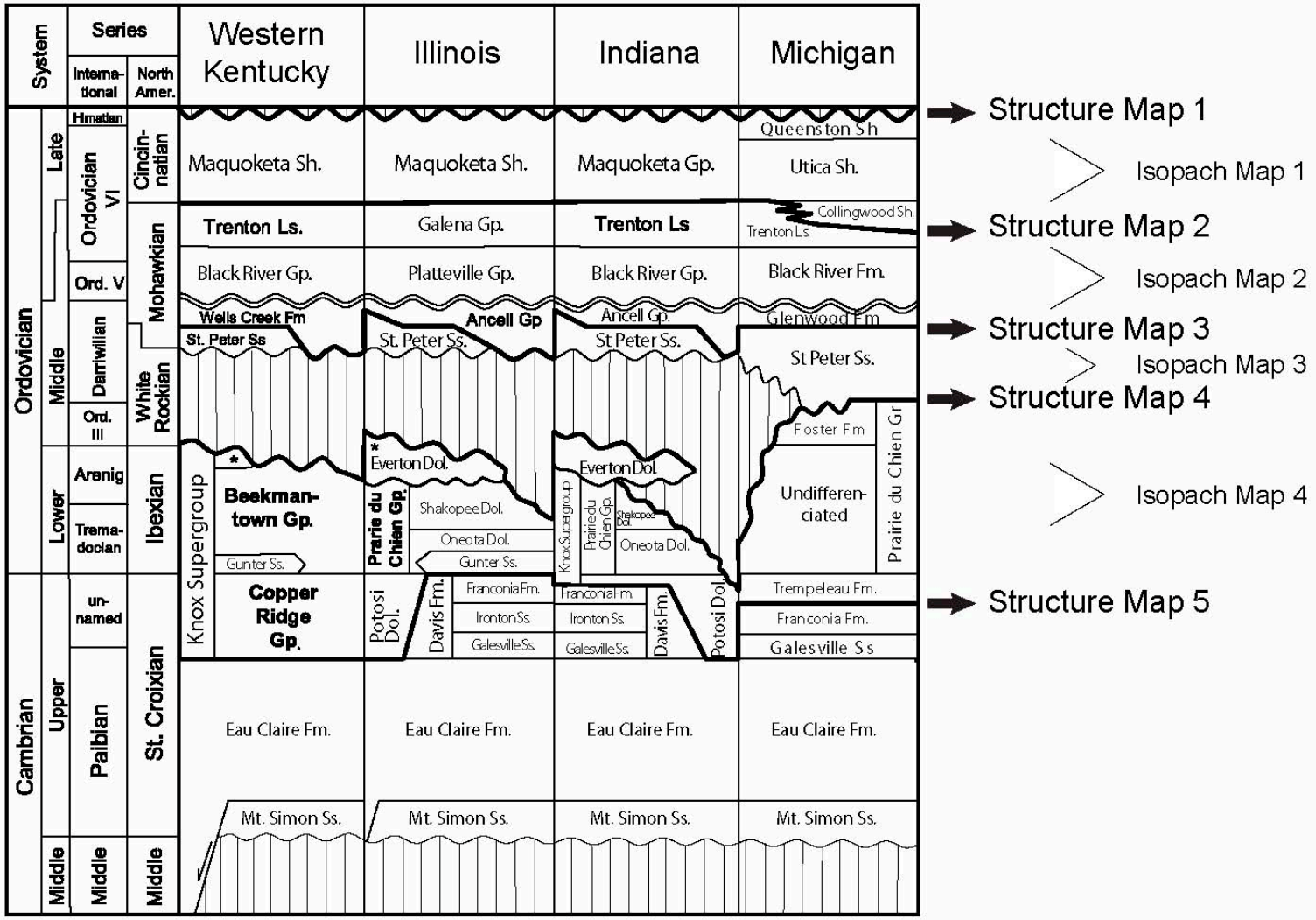
Project Overview: Goals and Objectives

- Reservoir simulation of commercial injection into St. Peter and Knox to show carbon storage potential
- Perform CO_2 injection test in an existing well in Hancock County, Kentucky to evaluate injectivity of the Knox sandstone.
- Develop regional CO_2 storage resource estimates for the Knox and St. Peters for use in future version of DOE's North American CO_2 Storage Resource Atlas.

Partners

- Illinois State Geological Survey
- Western Michigan University
- Indiana Geological Survey
- Kentucky Geological Survey
- Schlumberger Carbon Services
- Brigham Young University

Stratigraphic Column



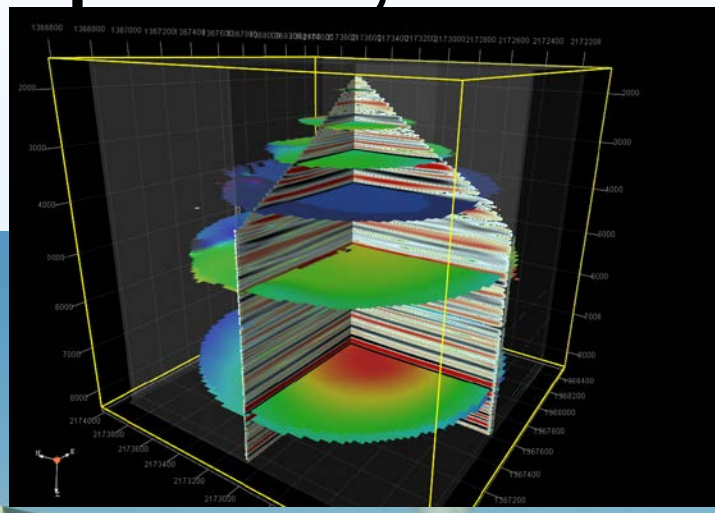
Task 3 – Site Evaluation

- Evaluate reservoirs and seals for Cambro-Ordovician section in Illinois Basin
  - Injected CO_2 into Knox at Hancock, Kentucky
    - Results summarized in DOE Topical Report
  - Acquired core from Knox and Maquoketa at Decatur, Illinois
    - Results on website www.knoxstp.com

Reservoir Injectivity Testing in the Knox

- Design the injectivity test
- Perform the injection test, collecting pressure and temperature data
- Abandon the well as required by the U.S. Environmental Protection Agency and remediate the wellsite
- Pressure transient analysis performed

CO_2 injection test Knox sandstone, Sept. 20-21, 2010



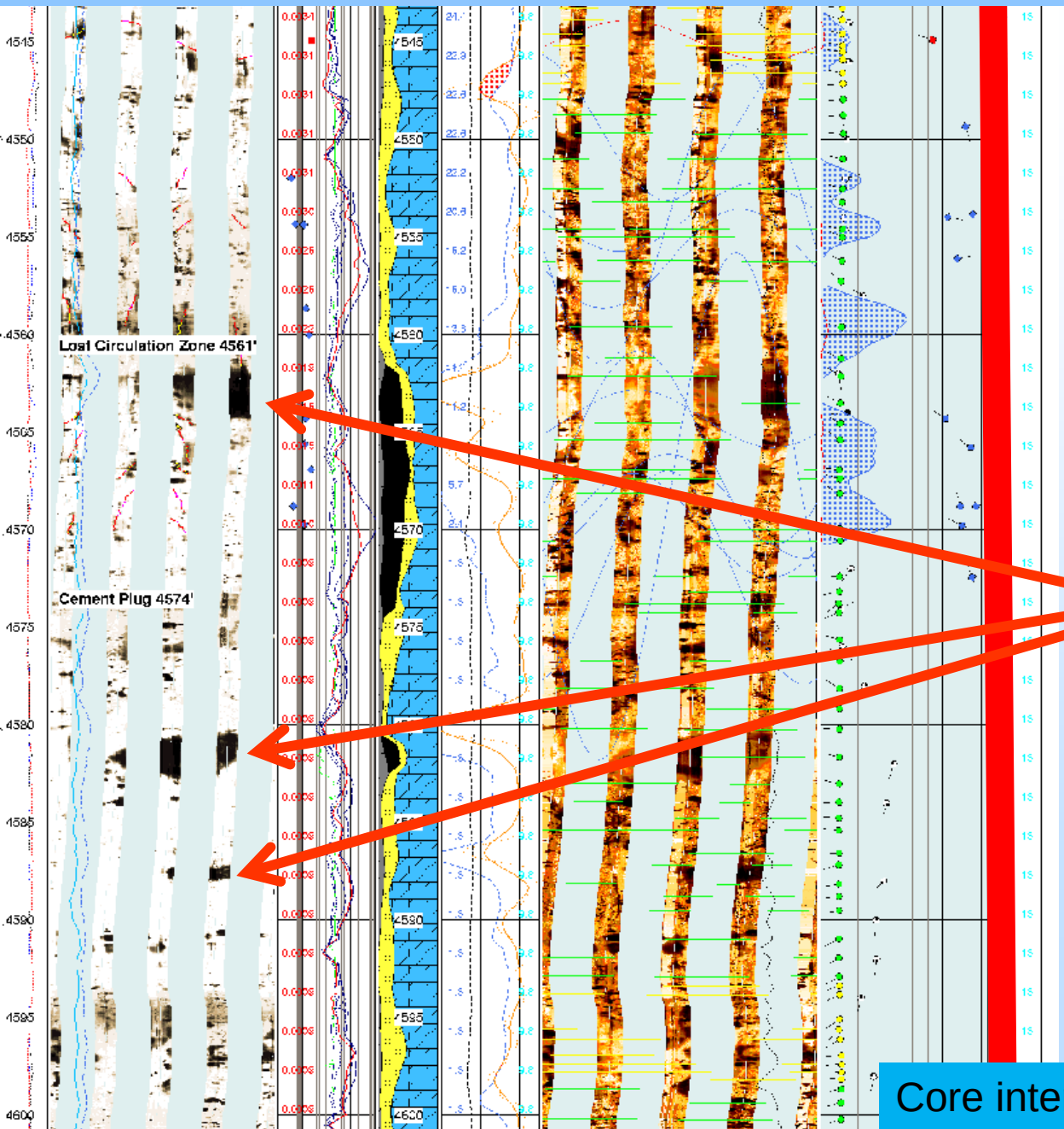
Open-hole interval 5,038 – 5,268 ft

- 367 tonnes CO_2
- 3 bbl per minute
- 1,000 psi wellhead
- 2,538 psi final bottom hole pressure

Results of Blan Well Test

- CO_2 storage well comparable to the Marvin Blan No. 1 would require approximately 103 surface hectares to store 1 million tonnes of CO_2.

Potosi Lost Circulation Zone



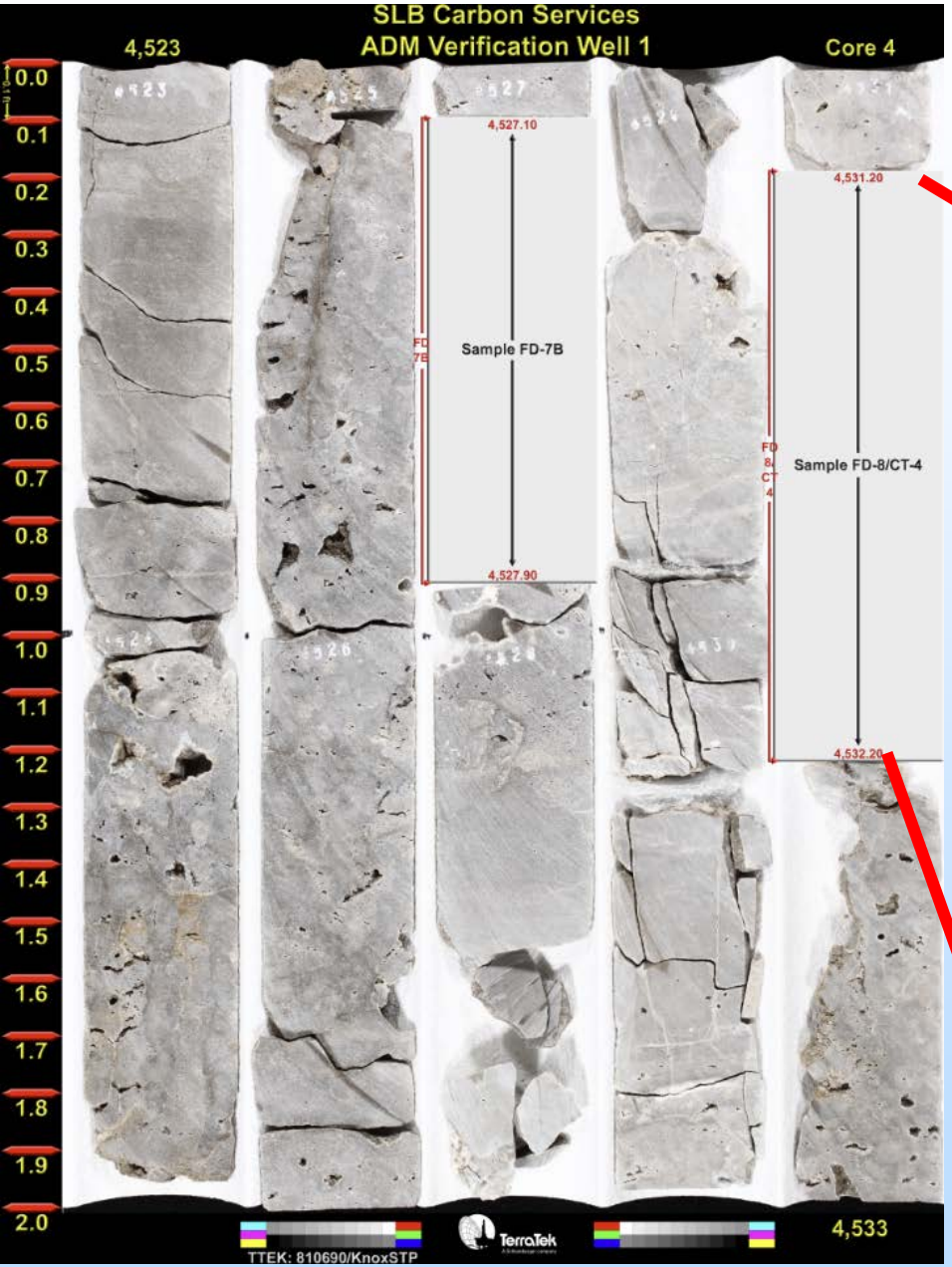
FMI Log
Core interval (4540-4600)
Potosi lost circulation zone

Solution cavities

Core was recovered from Decatur, Illinois

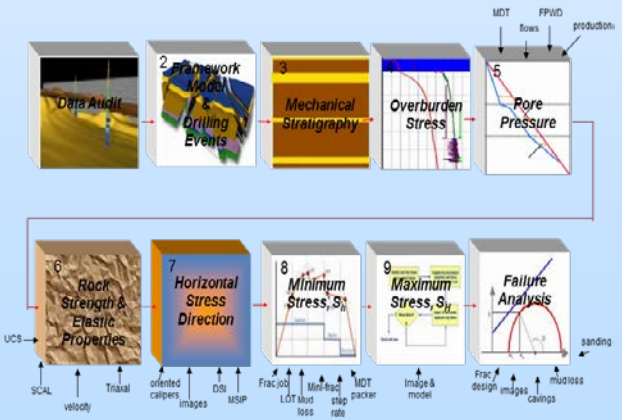
Core interval

Potosi



CT Scan

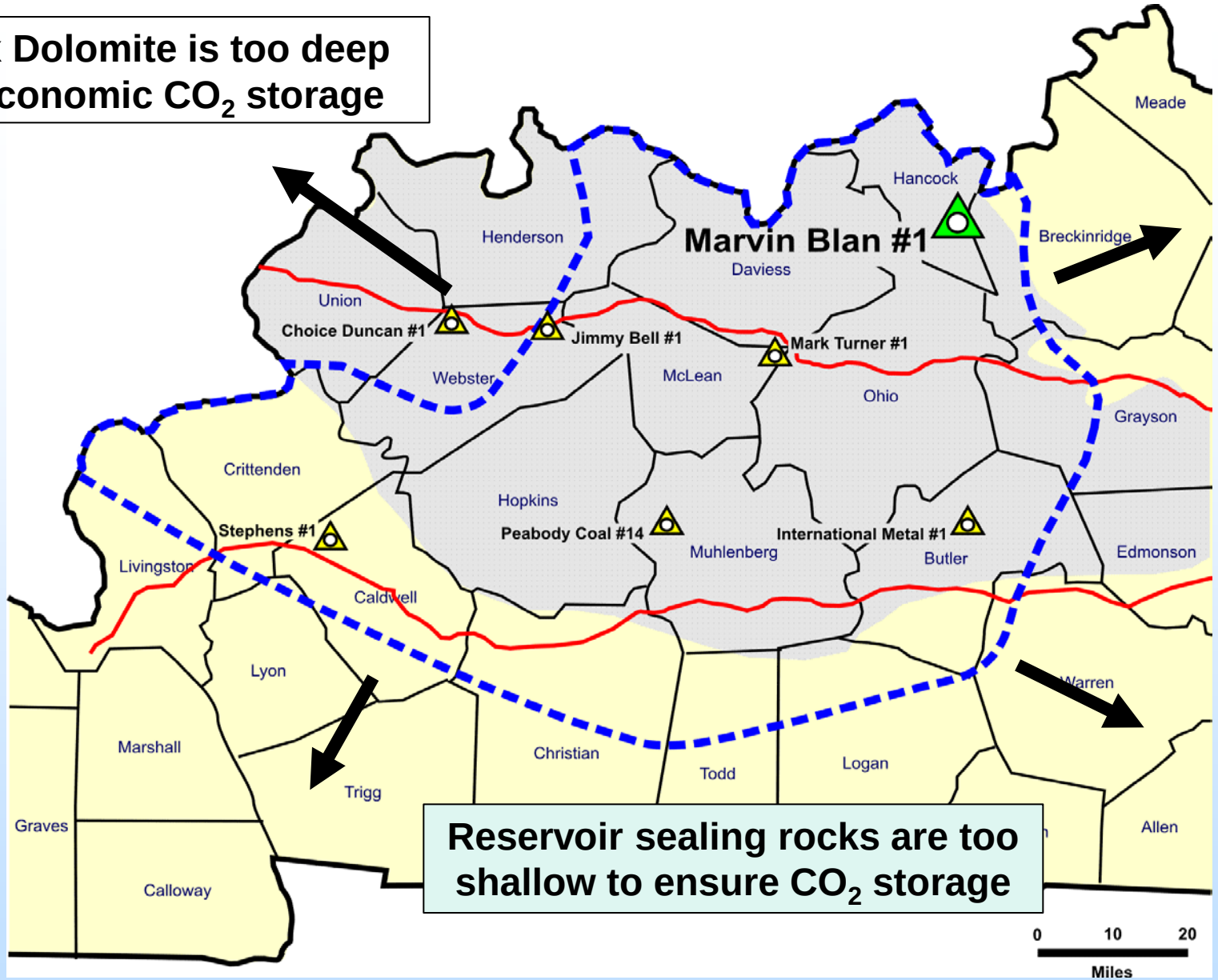
Geomechanical testing of core



Task 4 – Regional Significance

- Regional cross sections completed
- Regional maps completed and submitted to NatCarb
- Regional seismic data acquired, processed, and interpretation complete

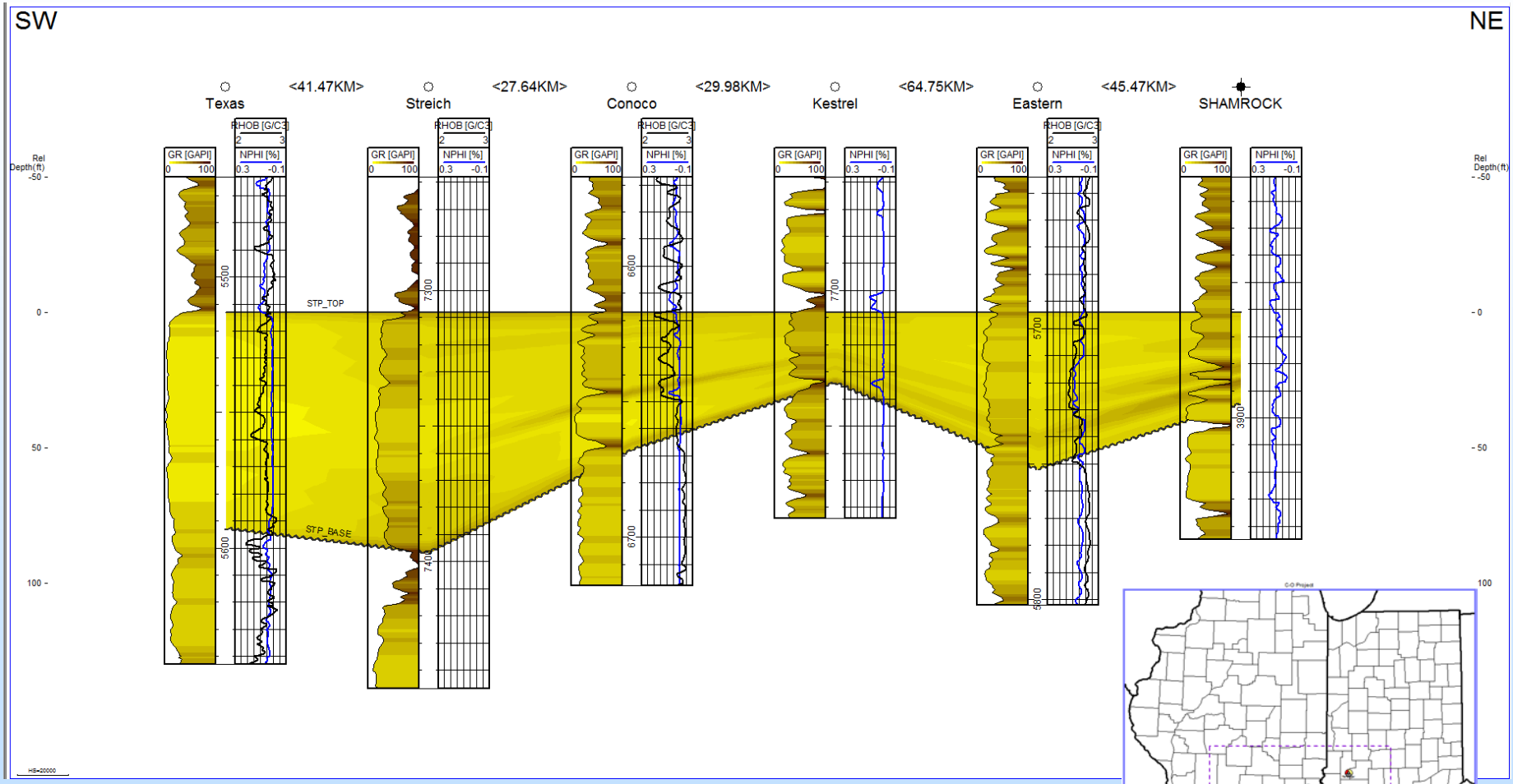
Knox Dolomite is too deep for economic CO_2 storage



Reservoir sealing rocks are too shallow to ensure CO_2 storage

The potential area for CO_2 storage in the Knox Dolomite in western Kentucky is about 6,400 mi^2. More research is needed to determine the actual extent.

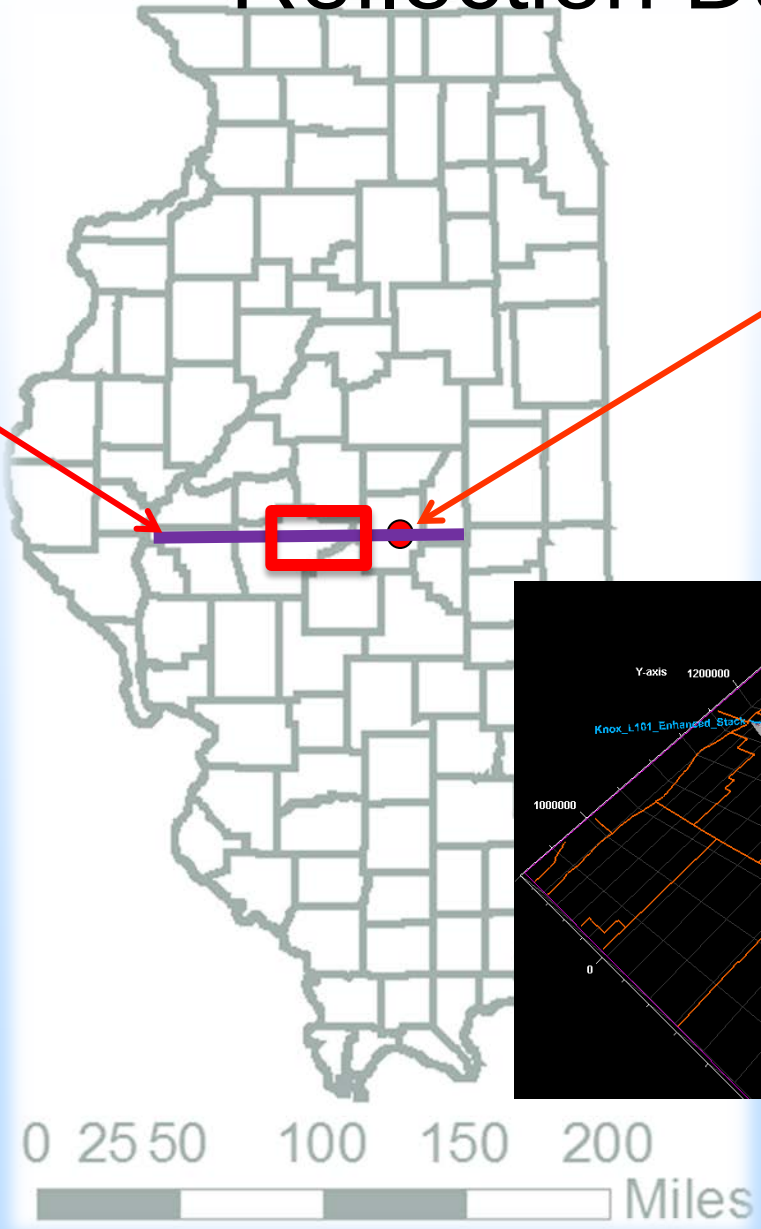
SW-NE cross section of St Peter Ss with interpretive fill from gamma-ray log

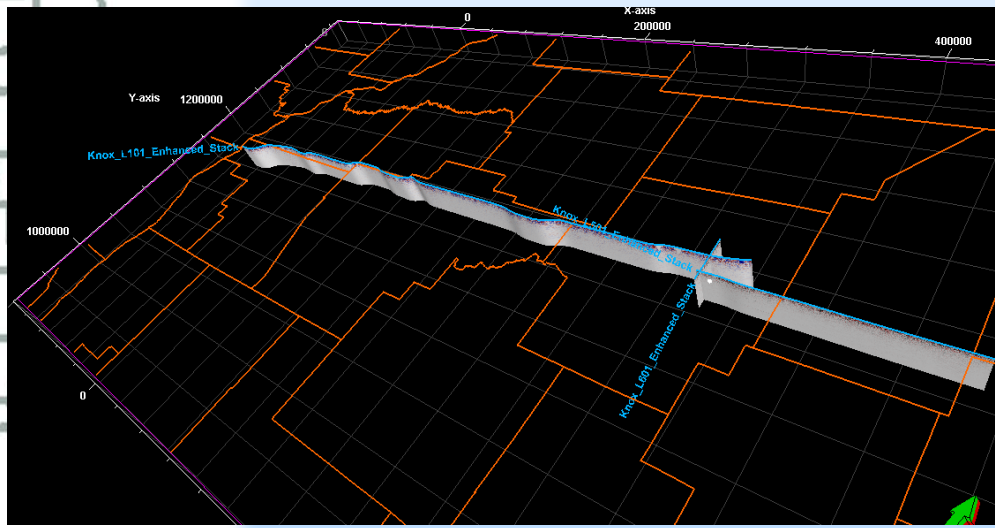


Acquisition of 120 miles of 2D Seismic Reflection Data

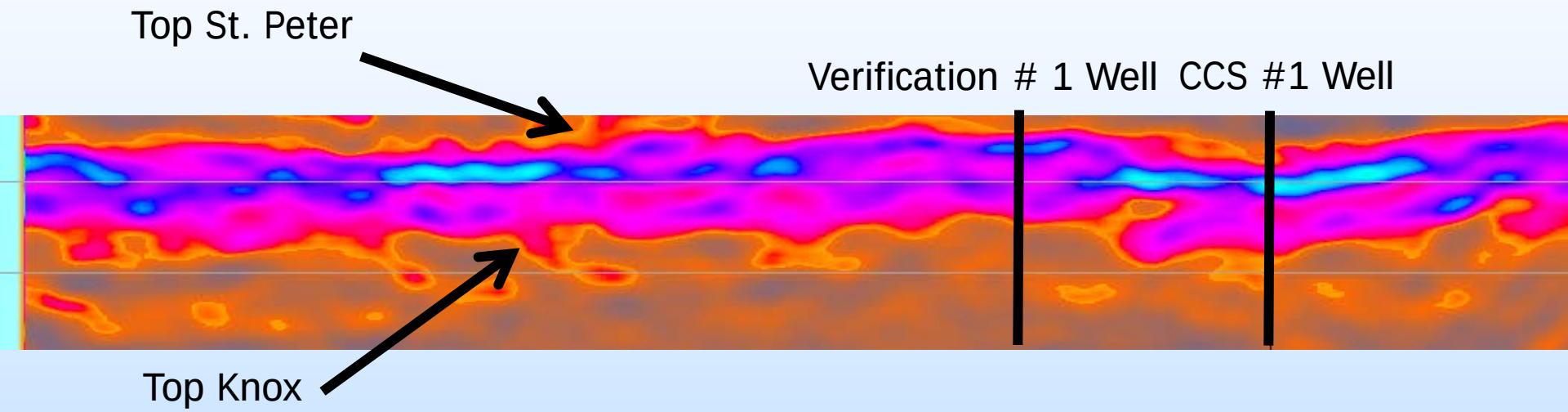
Seismic line

Decatur Project

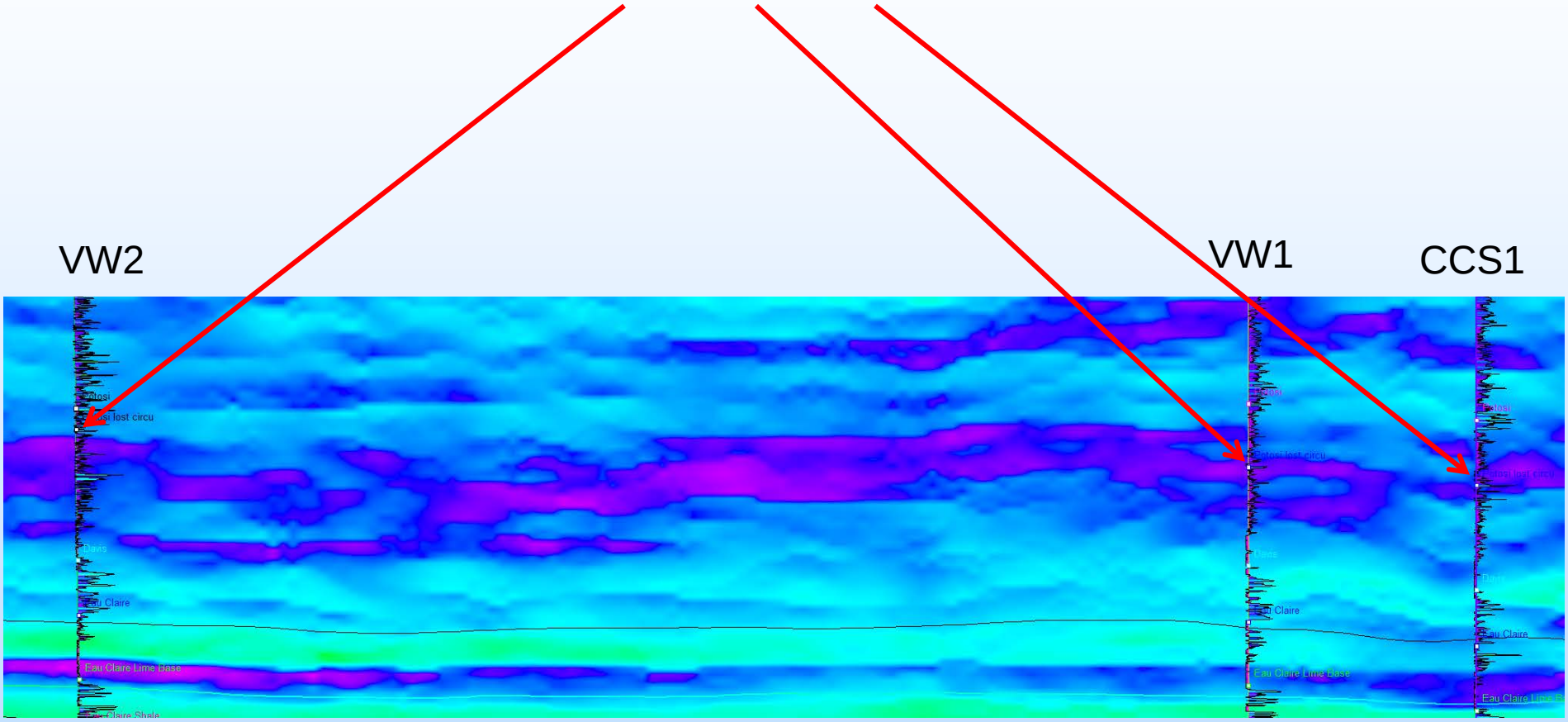




Seismic Inversion: Density
St. Peter Sandstone



Potosi Lost Circulation Zone

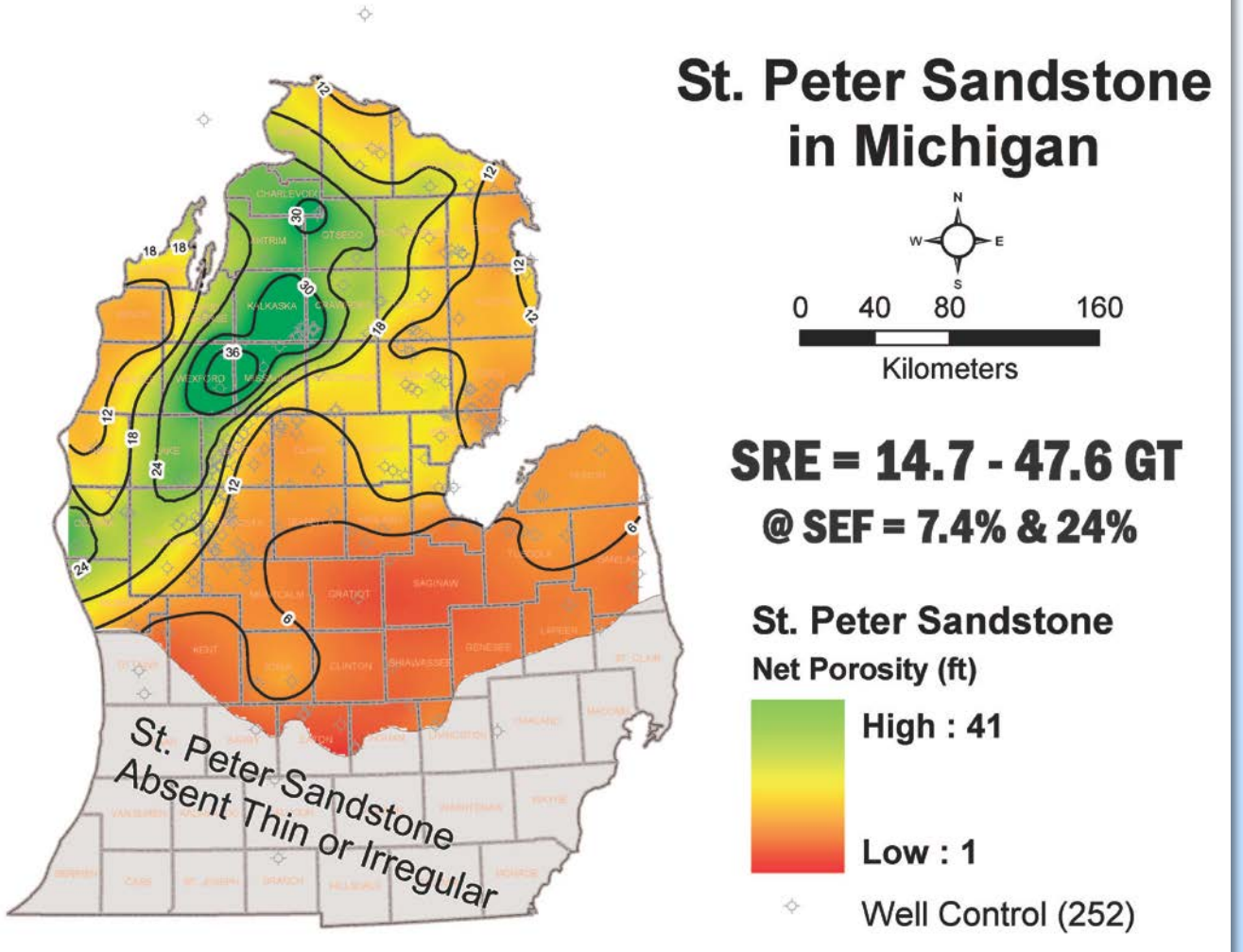


Cambro-Ordovician transition and occurrence of thin clay beds near the top of the Eminence Formation, Colosseum Trail, Ha Ha Tonka State Park, Missouri

Task 5 – Resource Estimates

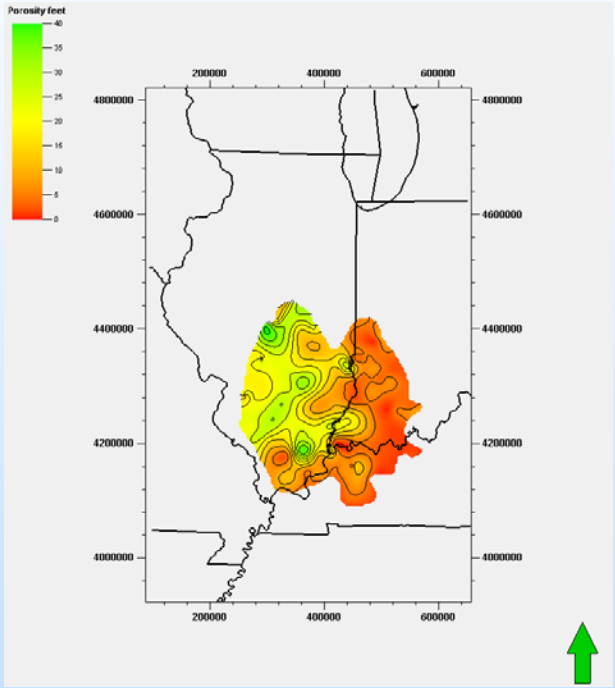
- Resource estimate of the St. Peter Sandstone is a complete
- Poster on methodology presented at NETL meeting in August, 2012
- Resource estimates of the Knox is complete

St. Peter Sandstone
Geological Carbon Storage Resource Estimate
14.7 – 47.6 Gt (@ p_{10} and p_{90})

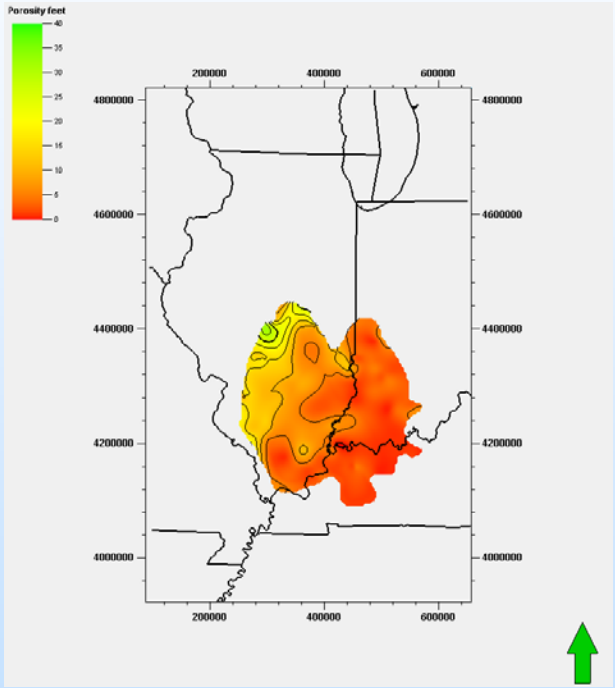


Illinois Basin St. Peter Sandstone CO_2 Storage Resource

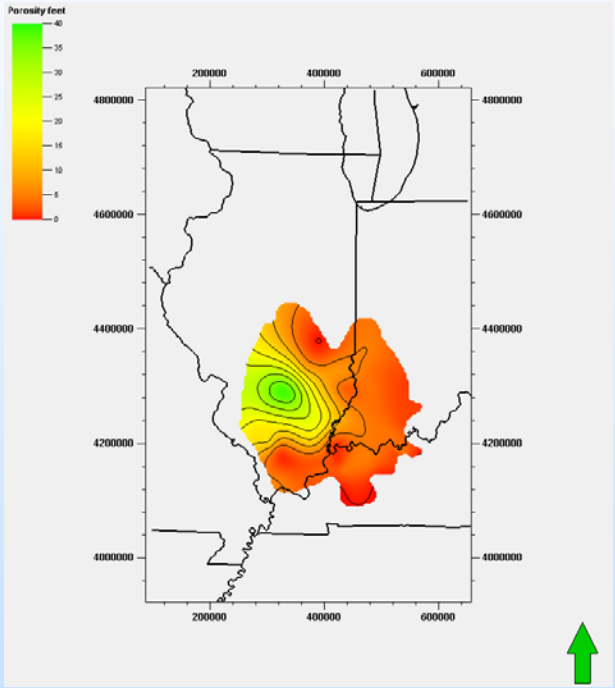
Improving resource estimation through enhanced characterization



Method 1: mean porosity



Method 2: variable porosity model



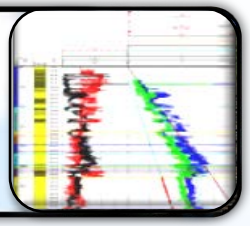
Method 3: net porosity analysis

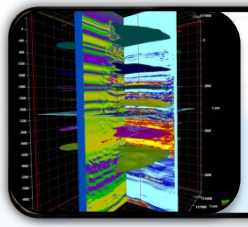
storage resource estimate range of 12.2 to 39.7 Gt.

Task 6 – Injectivity

- Reservoir simulation of CO_2 injection in the Knox and St. Peter has been completed
  - Topical report submitted to USDOE

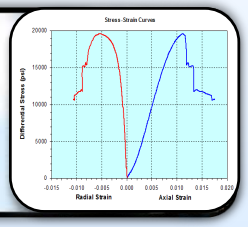
1D Mechanical Earth Model



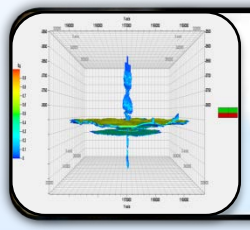


3D Geological Model

Rock Properties from Core

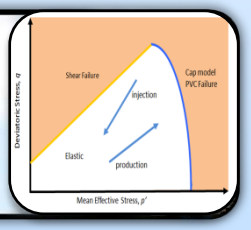


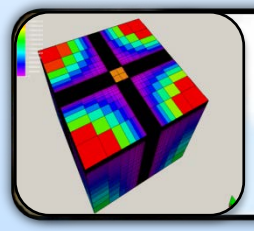
Knox Workflow



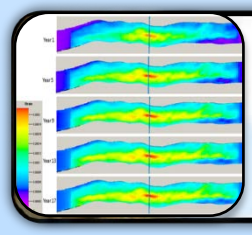
Eclipse Simulations

Formation Stress and Cap Rock Analysis





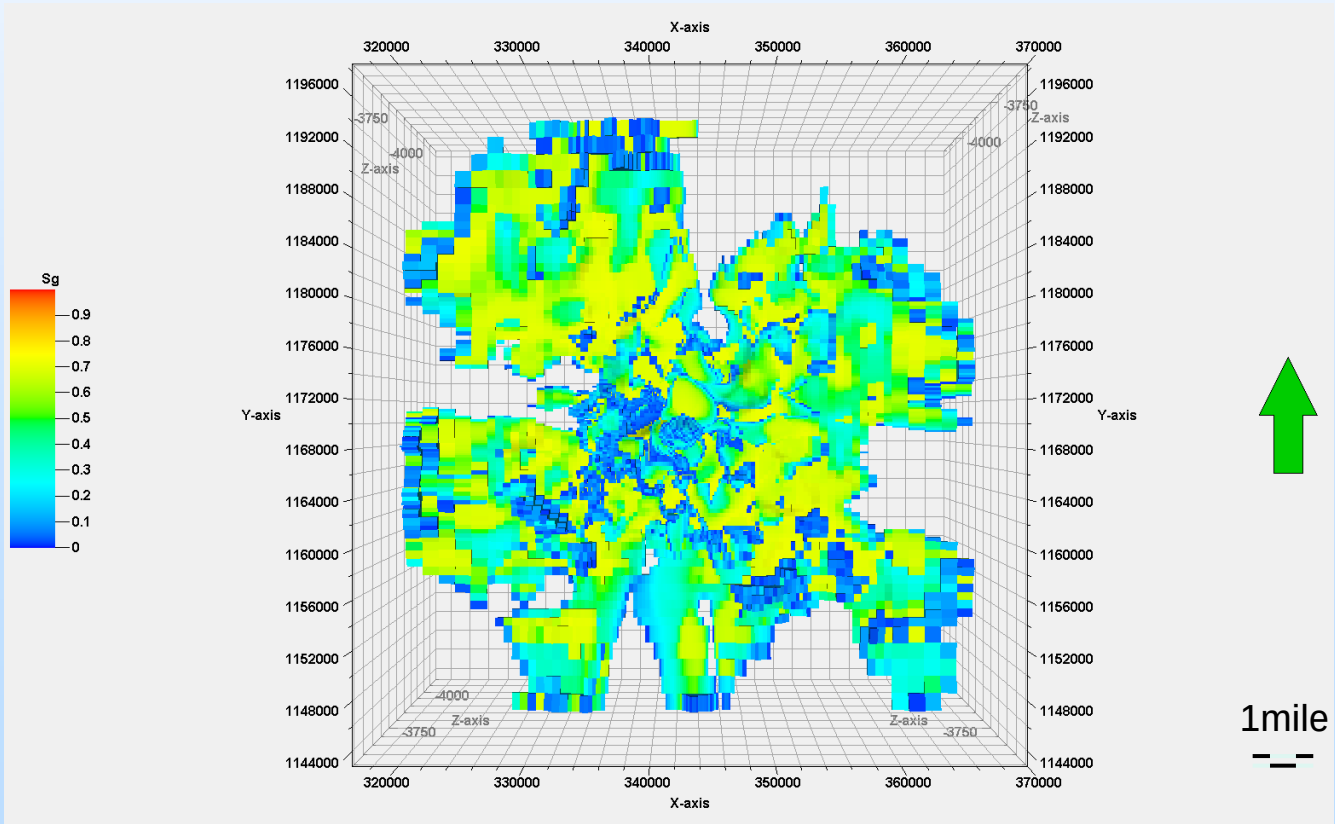
3D Mechanical Earth Model



VISAGE Stress Model

CO_2 injection into Potosi.

CO_2 plume plan view at the end of 20 years (injection rate of 2 million tonnes per year) has an approximate radius of 5 miles based on seismic and well data from Decatur Illinois



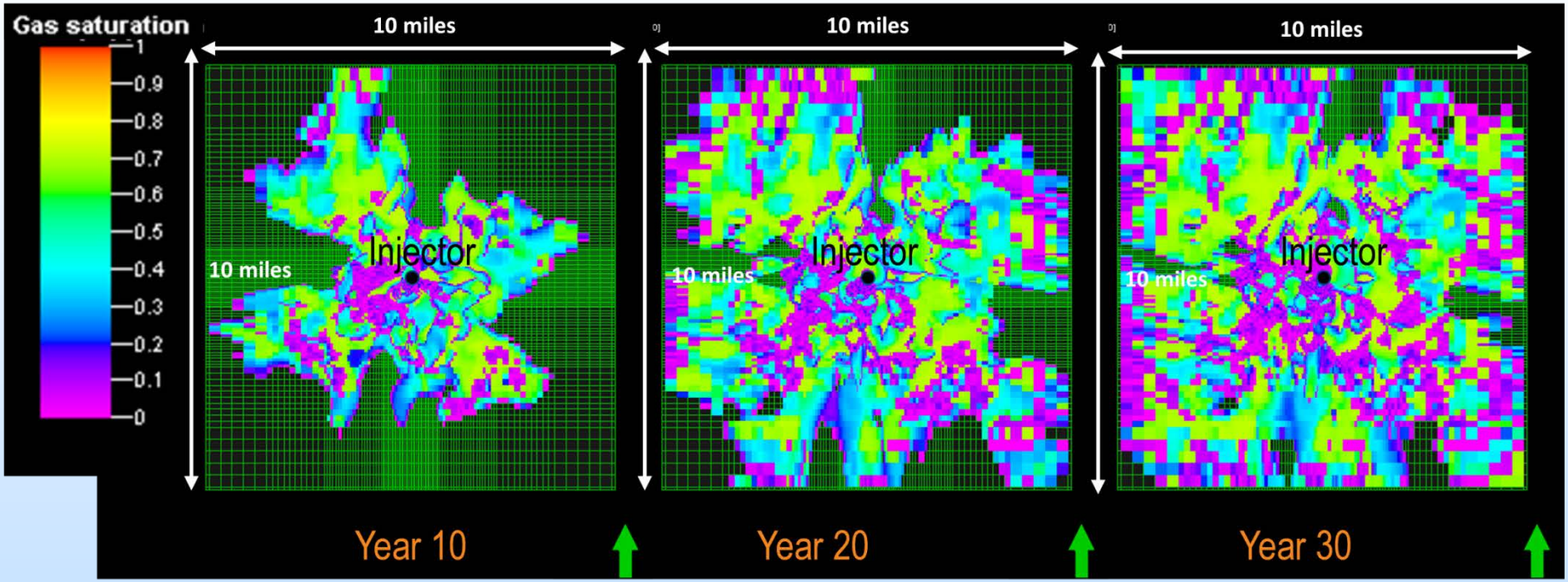
One well will work

1mile

ASME Review Panel Recommendation

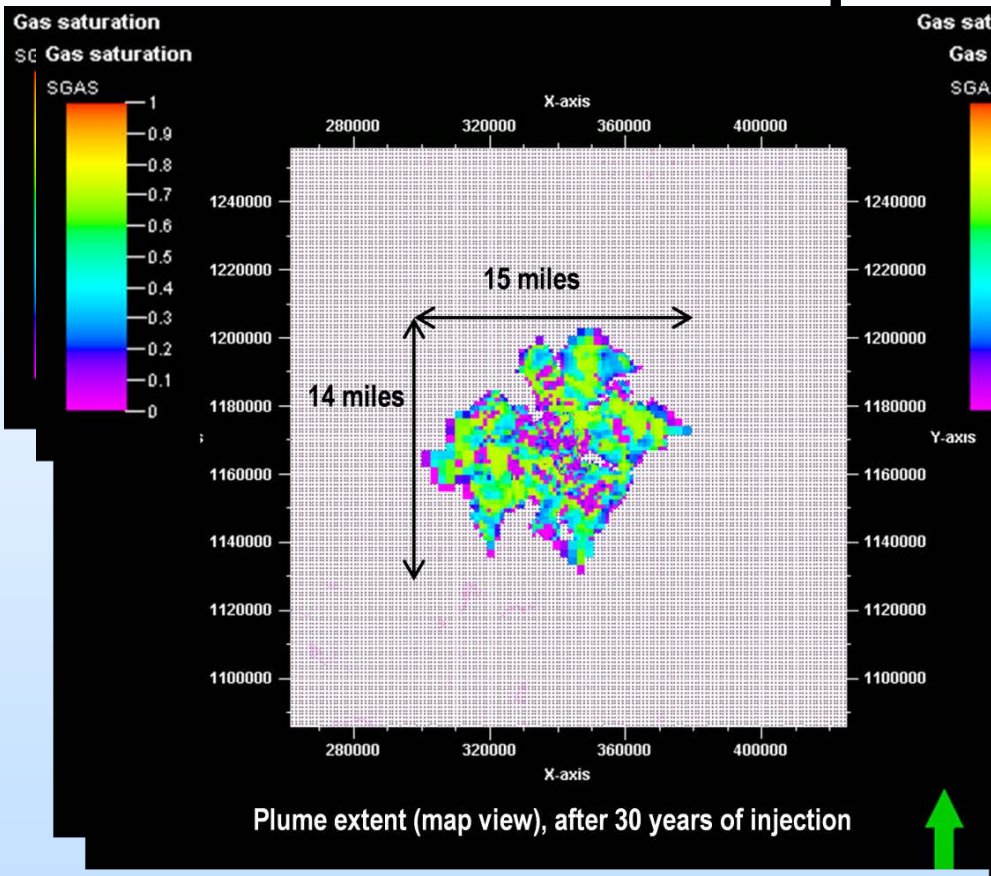
- NETL recommended that we increase the injection rate to 3.2 million tonnes per year for 30 years of injection and 100 years of simulation after injection ceases.
- The new simulations suggest that more realistic models with additional information do give significantly different results.

Potosi plume extent during injection

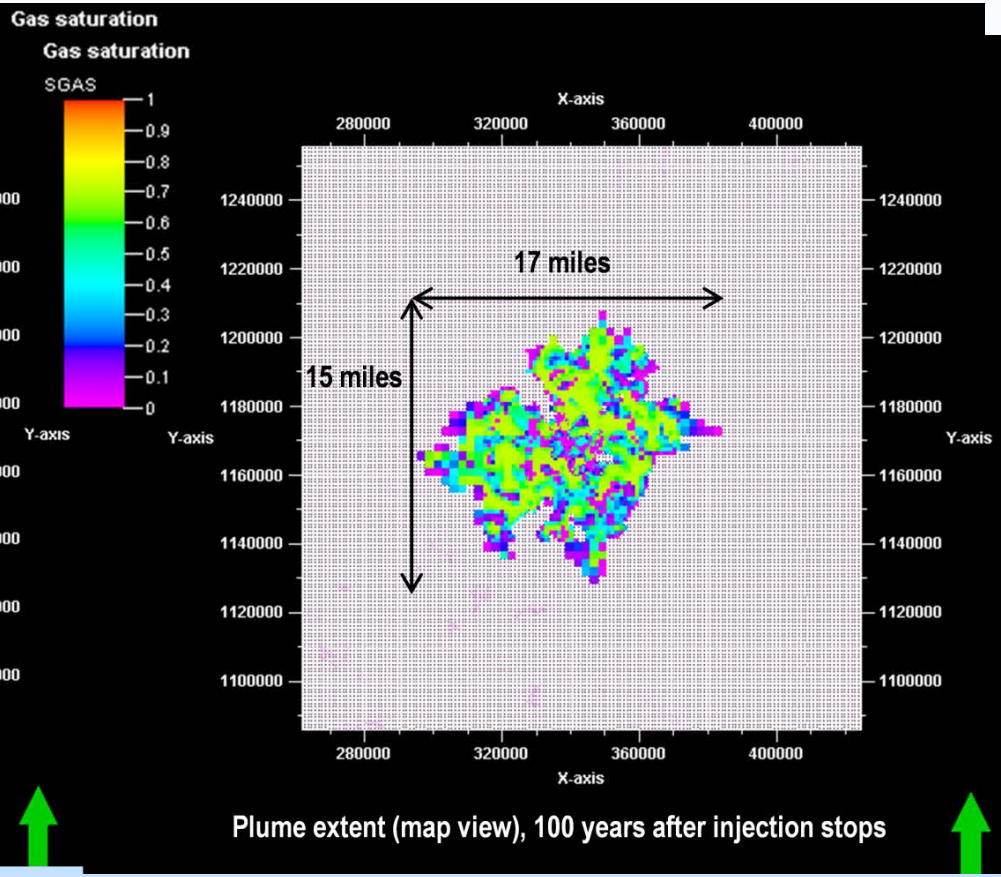


injection rate (3.2 MTPA) could not be achieved before the end of the injection period. Estimated cumulative injection after 30 years from single well

Potosi plume extent during injection



Plume extent (map view), after 30 years of injection

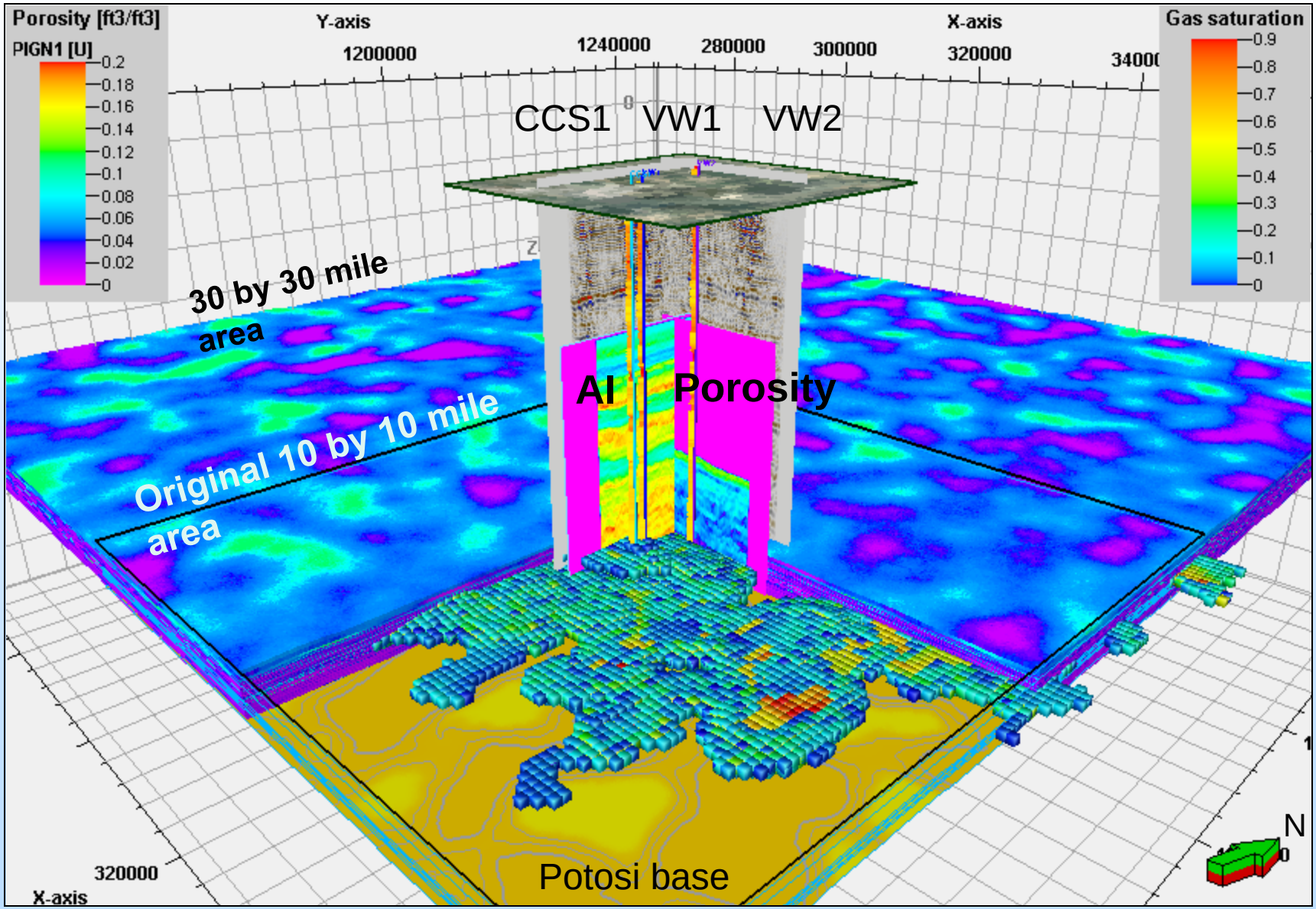


Plume extent (map view), 100 years after injection stops

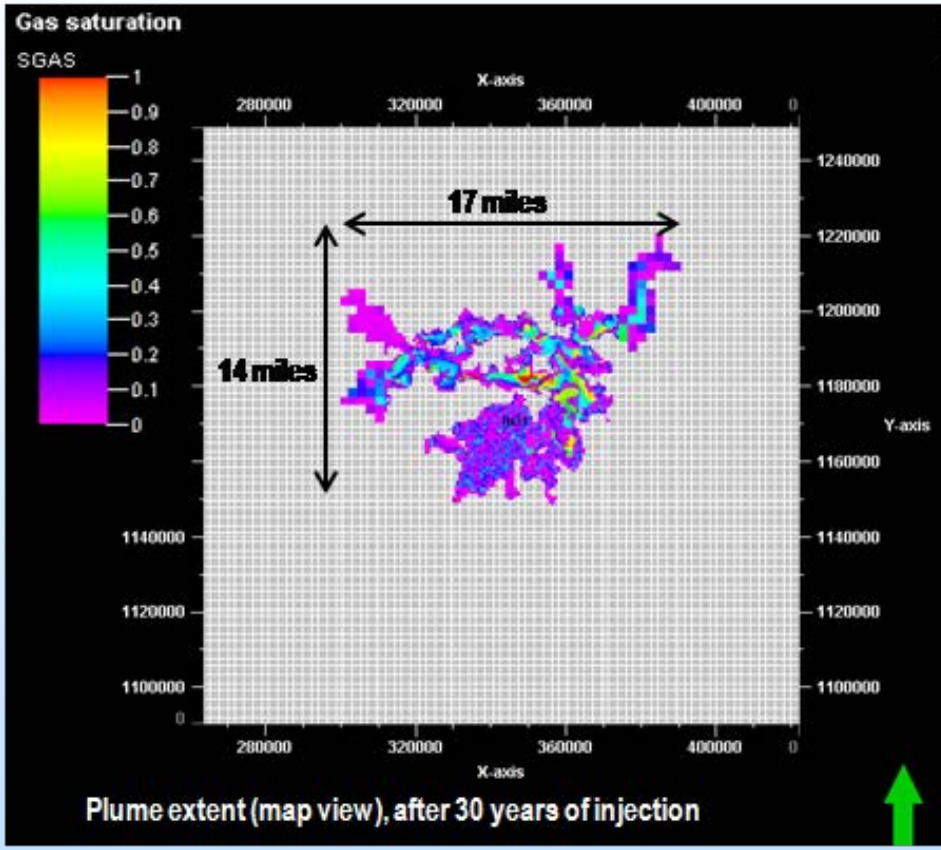
With one well it would 45% of the target volume

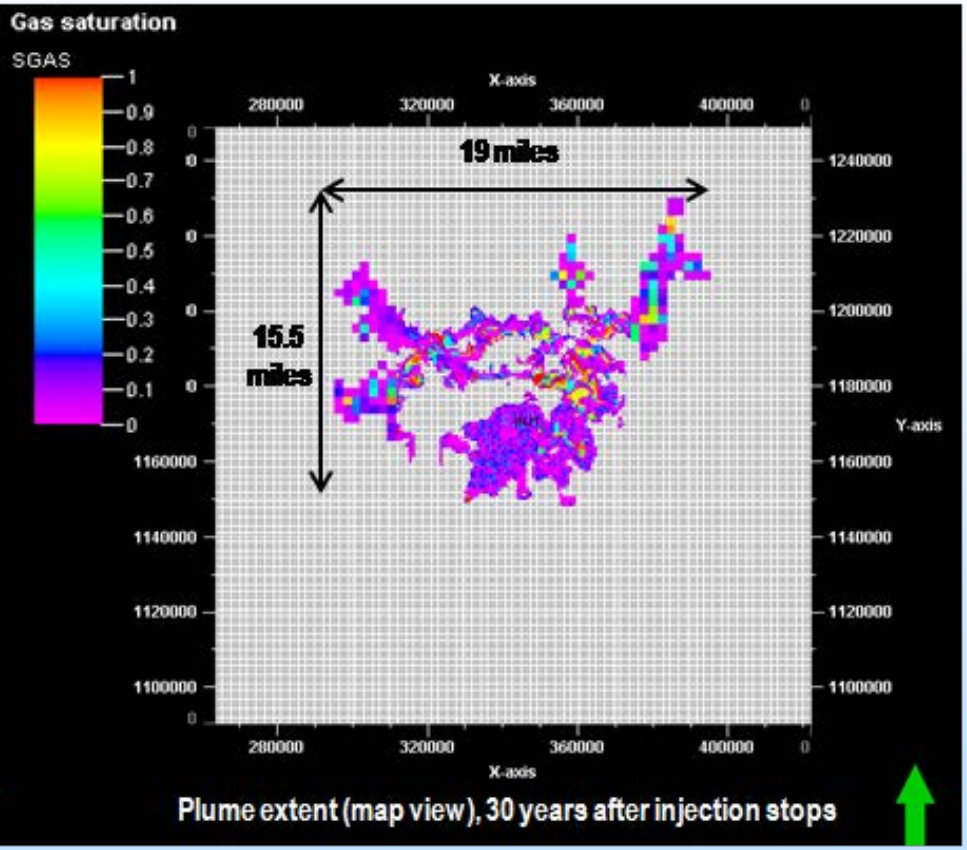
Will take two wells

CO_2 Plume at 30 Years, Potosi Formation, high permeability reservoir realization. Target Injection Rate: 3.2 MTPA for 30 Years. Actual volume 26 MT (27% of target) Acoustic Impedance and Porosity volumes obtained through seismic inversion.



Potosi plume extent during injection

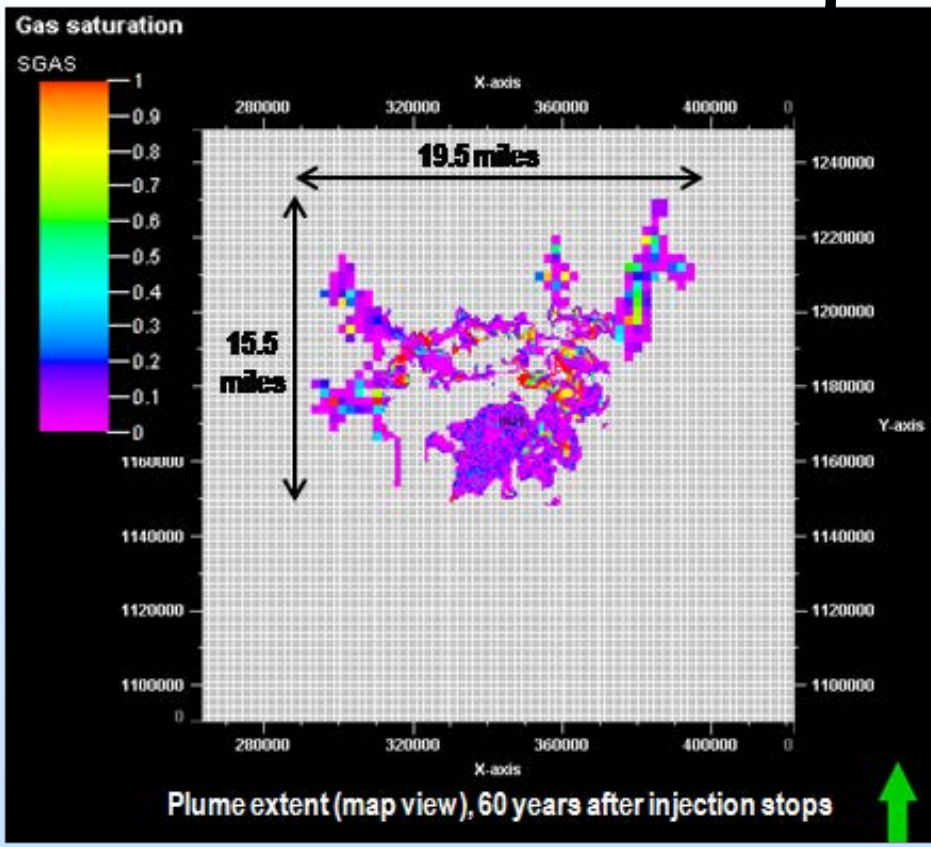


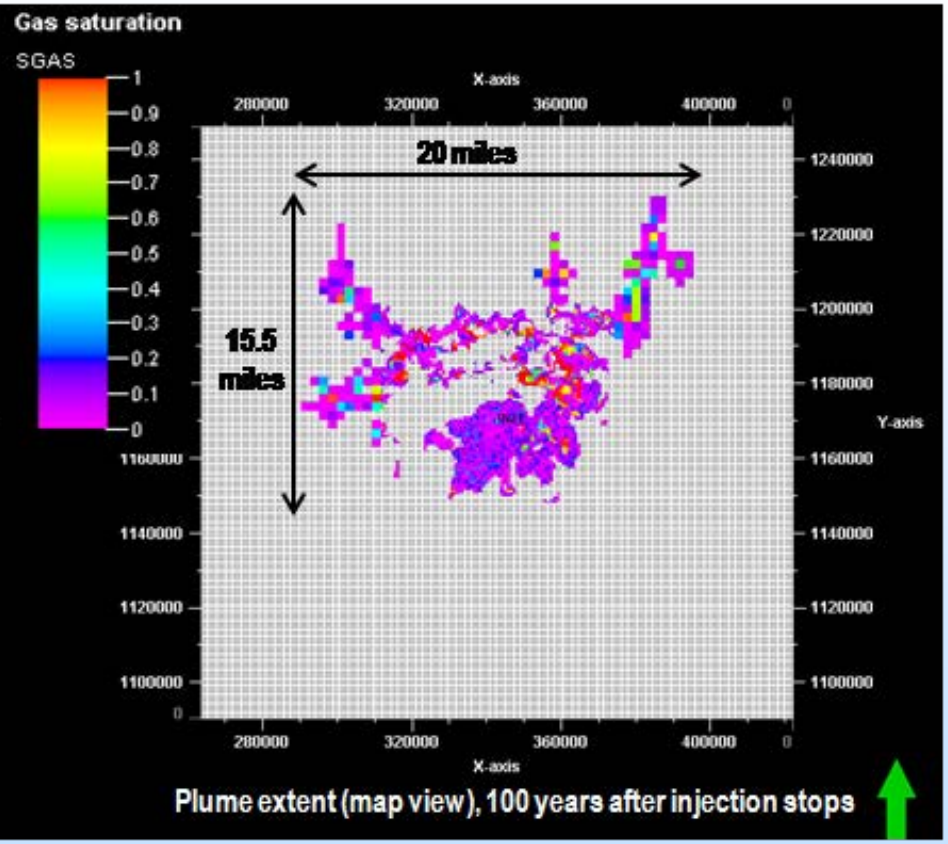


27% of the 96 Mt injection target

Will take 4 wells

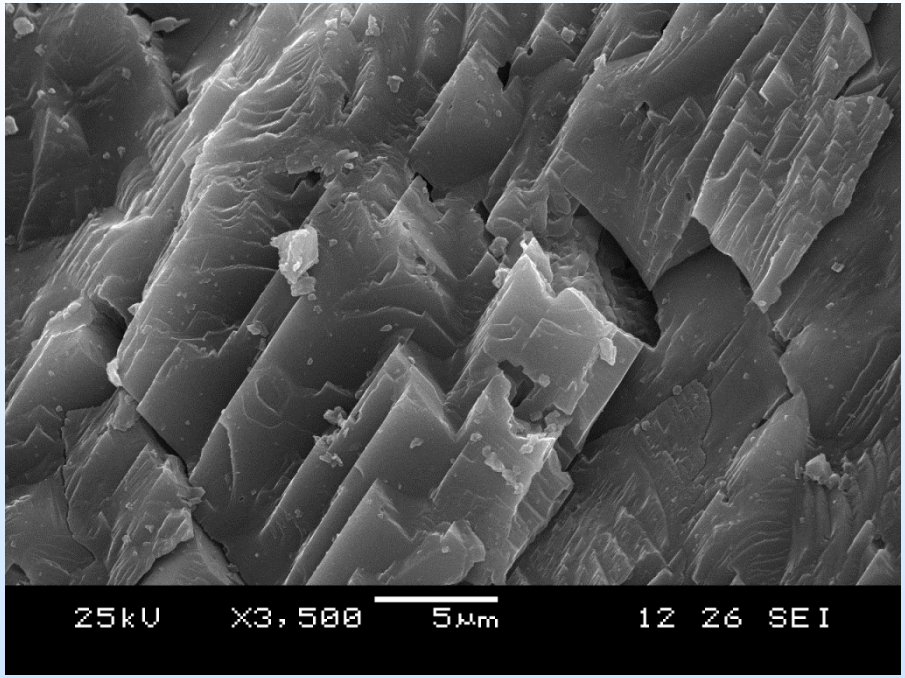
Potosi plume extent during injection

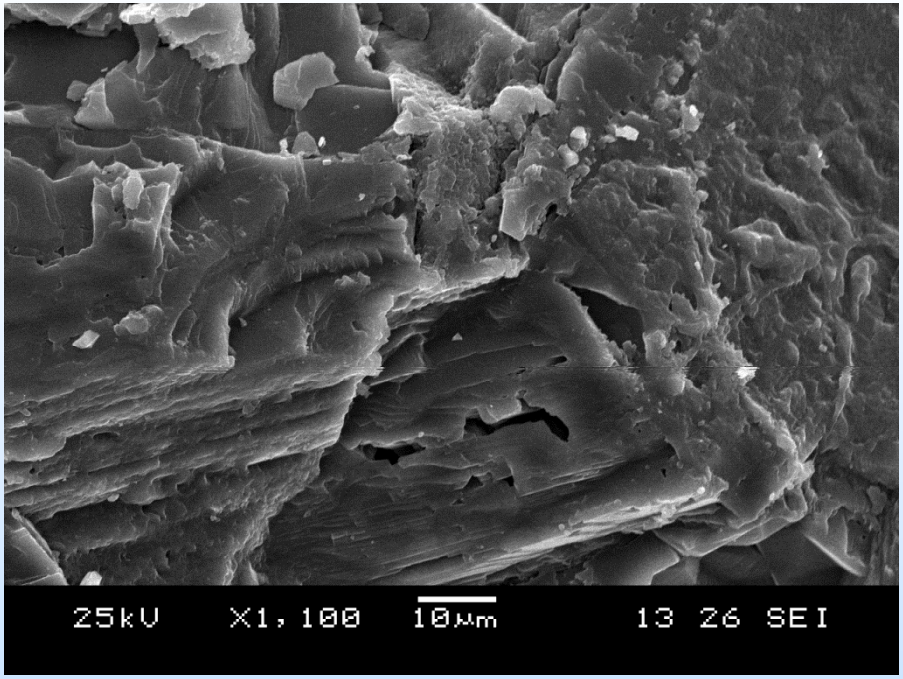




Task 7, 8, 9, 10
Containment

- Laboratory analysis of mineral and CO_2 interactions
- Numerical analysis of brine-CO_2 interactions using data from Kentucky
  - Publication in review





SEM photomicrographs of Potosi Dolomite (sample MO-1-9) before (left) and after (right) exposure to carbon dioxide and brine at 311 K and 9.86 MPa pressure. After three months of exposure, highly etched dolomite crystals and dissolution features were observed.

Accomplishments to Date

- Injected CO_2 into Knox in Kentucky
- Acquired Knox and Maquoketa core from Decatur, IL
- Acquired 120 miles of seismic data
- Completed reservoir simulation of CO_2 movement in St. Peter and Knox
- Assessment of St. Peter and Knox to CO_2 using laboratory experiments at reservoir conditions
- Regional cross sections across the Illinois basin and regional maps are being completed
- Resource estimates for St. Peter and Knox are complete

Summary

Key Findings

- St. Peter and Knox are good regional storage targets that have the resources to store industrial levels of CO_2

– Lessons Learned

- Movement of CO_2 within the Knox will be difficult to predict
- Seismic reflection data can be an important tool for evaluating uncertainty

- Remaining Tasks
  - Leakage Pathways
  - Site Selection
  - Risk Assessment
  - Well Bore Management

Acknowledgements

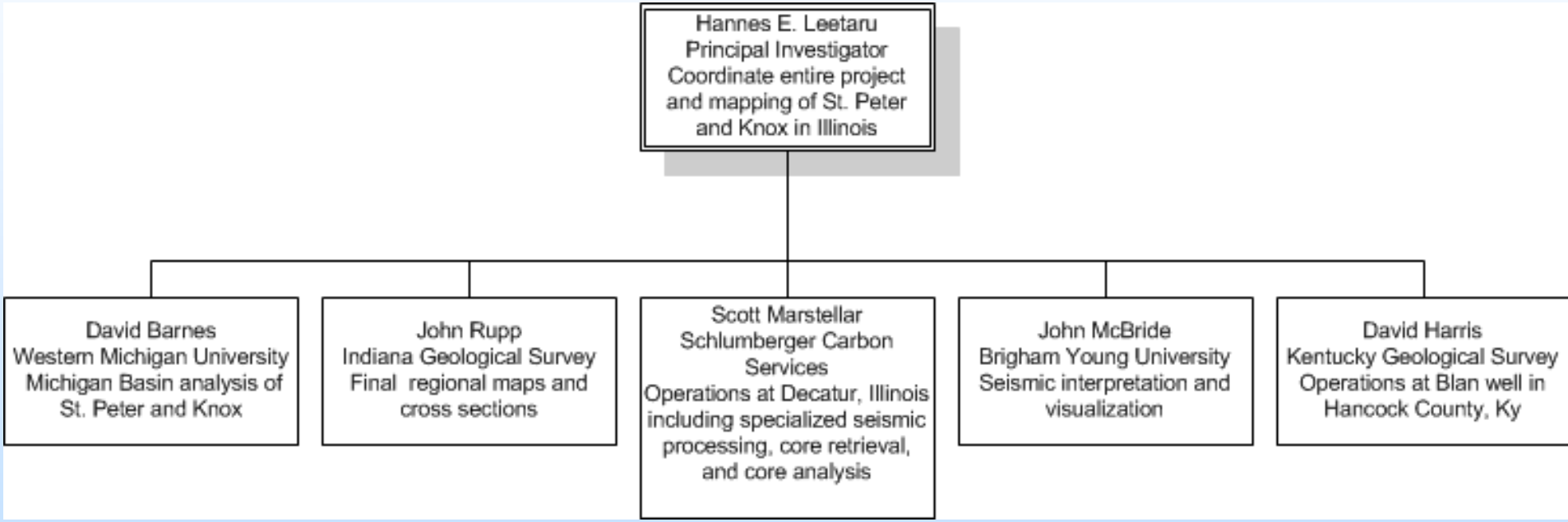
- Project is funded by the U.S. Department of Energy through the National Energy Technology Laboratory (NETL) and by a cost share agreement with the Illinois Department of Commerce and Economic Opportunity, Office of Coal Development through the Illinois Clean Coal Institute
- ConocoPhillips: in-kind match
- Western Kentucky Carbon Storage Foundation: matching funding
- SeisRes 2020, Houston: VSP acquisition and processing
- Sandia Technologies, Houston: engineering and wellsite supervision

DISCLAIMER

Appendix

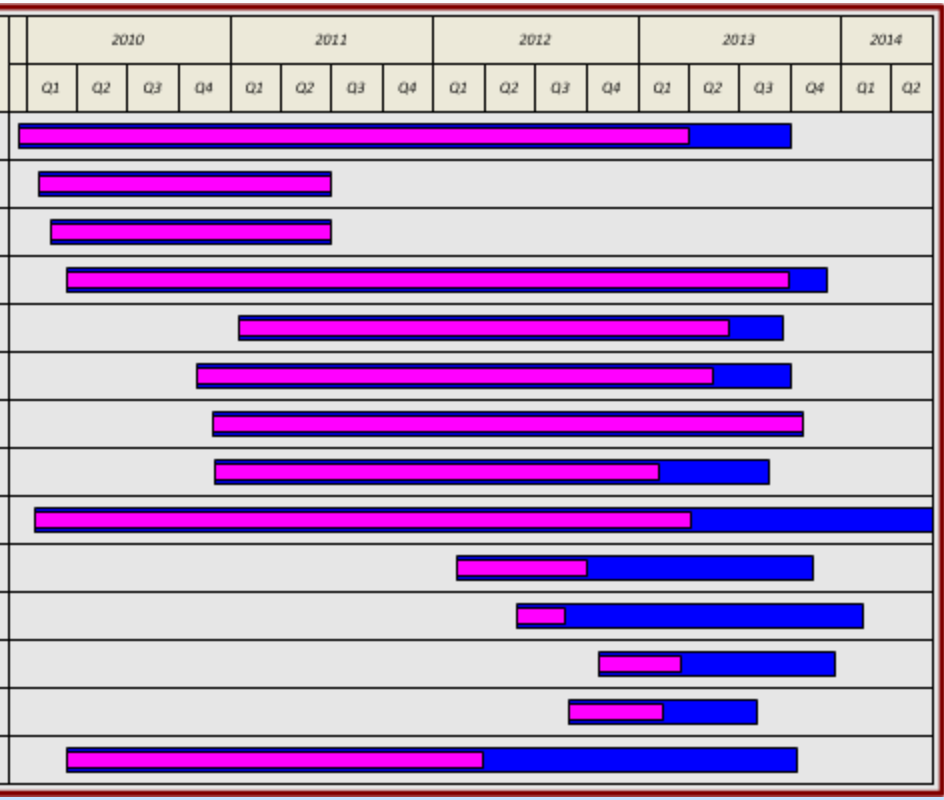
– These slides will not be discussed during the presentation, but are mandatory

Organization Chart



Gantt Chart

ID	Task Name	% Complete	Start	Finish
1	Task 1 Management Plan	87%	12/17/2009	9/30/2013
2	Compile Base Data	100%	1/22/2010	6/30/2011
3	Site Work	100%	2/15/2010	6/30/2011
4	Regional Significance	95%	3/15/2010	12/6/2013
5	Capacity Estimates	90%	1/17/2011	9/16/2013
6	Injectivity of the formation	87%	11/1/2010	9/30/2013
7	Containment Stratigraphic	100%	12/1/2010	10/24/2013
8	Containment - Brine	80%	12/6/2010	8/23/2013
9	Containment - Mineralogic	73%	1/15/2010	6/13/2014
10	Leakage Pathways	36%	2/13/2012	11/11/2013
11	Site Selection	14%	5/30/2012	2/6/2014
12	Risk Assessment	35%	10/24/2012	12/18/2013
13	Well Bore management	50%	8/29/2012	8/1/2013
14	Deliverables	57%	3/15/2010	10/11/2013



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  - H.E. Leetaru, A.L. Brown, D.W. Lee, O. Senel, M.L Couëslan,2012, CO_2 Injectivity, Storage Capacity, Plume Size, and Reservoir and Seal Integrity of the Ordovician St. Peter Sandstone and the Cambrian Potosi Formation in the Illinois Basin: DOE/FE0002068-1.
  - D.C. Harris, D.A., Williams, and R.J. Bowersox, 2012, Summary of Carbon Storage Project Public Information Meeting and Open House, Hawesville, Kentucky, October 28, 2010, DOE/FE0002061-2.
  - J. Bowersox and Hickman, J.B., 2012, An Evaluation of the Carbon Sequestration Potential of the Cambro-Ordovician Strata of the Illinois and Michigan Basins Part 1: Evaluation of Phase 2 CO2 Injection Testing in the Deep Saline Gunter Sandstone Reservoir (Cambro-Ordovician Knox Group), Marvin Blan No. 1 Well, Hancock County, Kentucky, Part 2: Time-lapse Three-Dimensional Vertical Seismic Profile (3D-VSP) of Sequestration Target Interval with Injected Fluids: DOE/FE0002061-3.
  - Yoksoulian, L.E., Freiburg, J.T., Butler, S.K, Berger, P.M., Roy, W.R., in press, Mineralogical alterations during laboratory-scale carbon sequestration experiments for the Illinois Basin, 11th International Conference on Greenhouse Gas Technologies, 18th-22nd November 2012, Kyoto International Conference Center, Kyoto, Japan, *Energy Procedia*, *Volume 37*, *2013*, *Pages 5601-5611.*