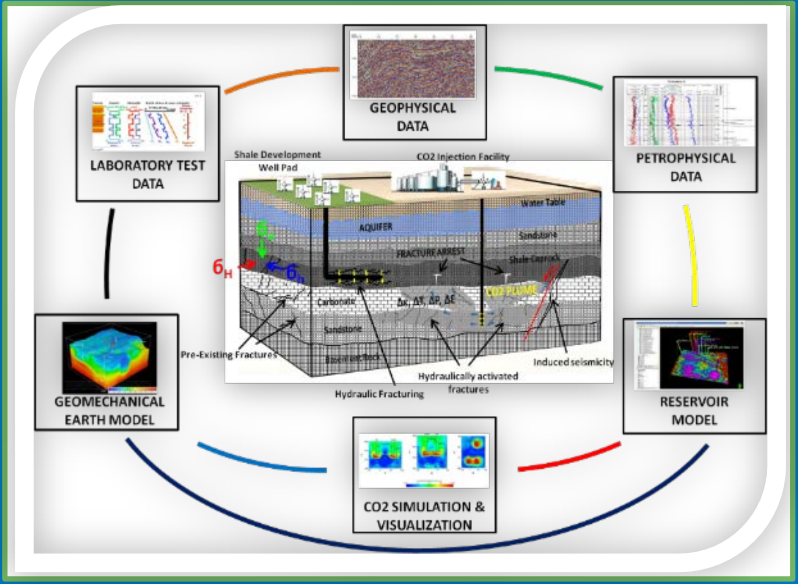
Geomechanical Framework for Secure CO_2 Storage in Fractured Reservoirs and Caprocks for Sedimentary Basins in the Midwest U.S.

DE-FE0023330



J.R. Sminchak and Neeraj Gupta
Battelle, 505 King Ave, Columbus, Ohio

U.S. Department of Energy
National Energy Technology Laboratory
DE-FOA0001037 Kickoff Meeting
November 12-13, 2014

Ohio Development Services Agency

U.S. DOE/NETL

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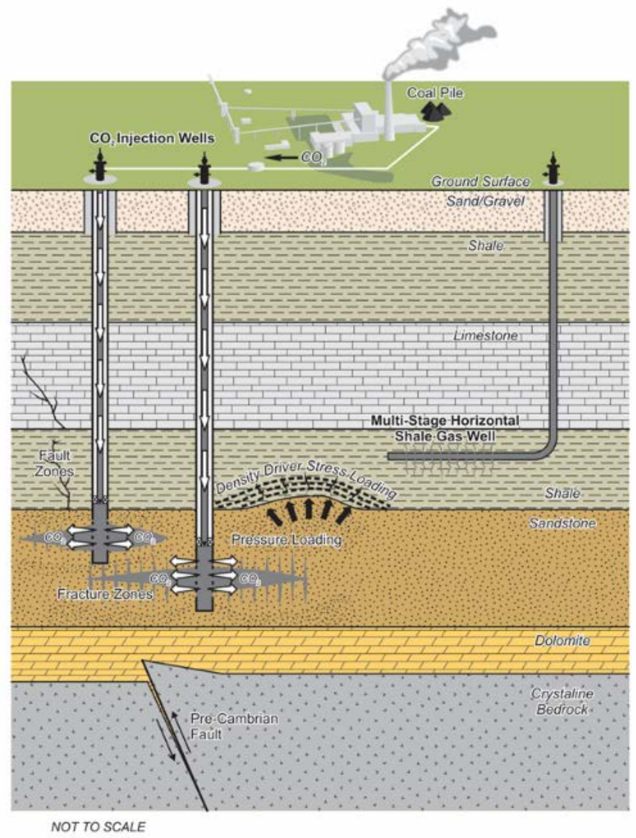
Outline

1. Benefit to Program
2. Project Overview
3. Methodology
4. Expected Outcomes
5. Organization Chart
6. Task/Subtask Breakdown
7. Deliverables/Milestones
8. Risk Matrix
9. Schedule

Lockport Dolomite, National Lime & Stone Company, Lima, Ohio

Project Impact/Benefit

- The project addresses FOA 1037 Area of Interest 1-Geomechanical Research.
- Specifically, research impacts include:
  - characterizing the paleo-stress/strain setting,
  - defining geomechanical parameters,
  - evaluating the potential for (and effects of) subsurface deformation,
  - assessing CO_2 storage processes based on rock core tests and geophysical logging in the regions being considered for large-scale CO_2 storage.



Project Impact/Benefit

Project Impact/Benefit to DOE-NETL C-Storage Program

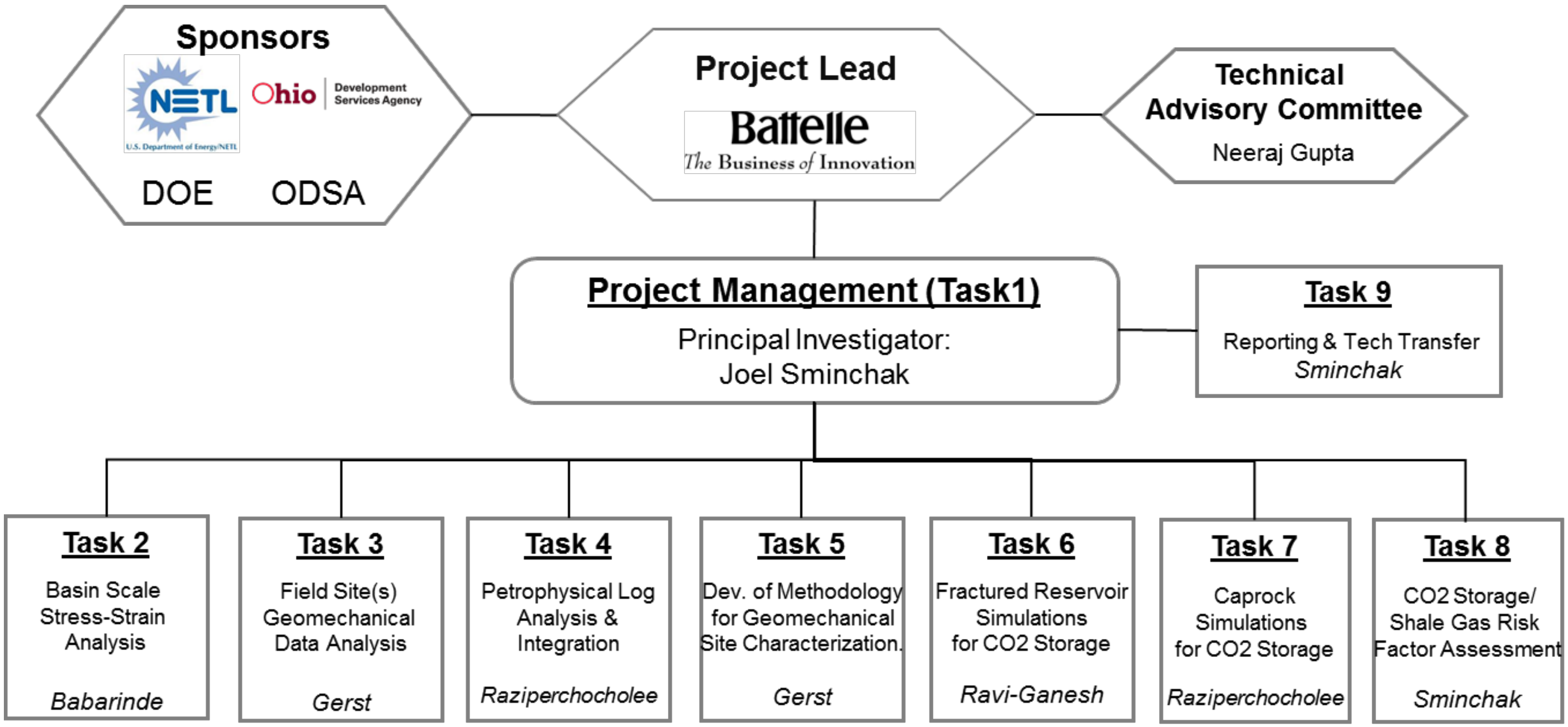
- Project has significant synergies with other ongoing work on carbon storage technologies (carbon capture & storage), shale gas developments, other CO_2 storage research.
- Provides a better understanding of geomechanical stress parameters for Midwest U.S., a key issue for CO_2 storage in the region's deep rock formations.
- Reduces uncertainty related to existing/future power plant locations by mapping key geomechanical items.

Project Overview

- Project selected for award under U.S. DOE NETL FOA 1037 in ***Area of Interest 1-Geomechanical Research for secure CO_2 storage***.
- NETL PM = William O'Dowd.
- Seven major technical tasks….

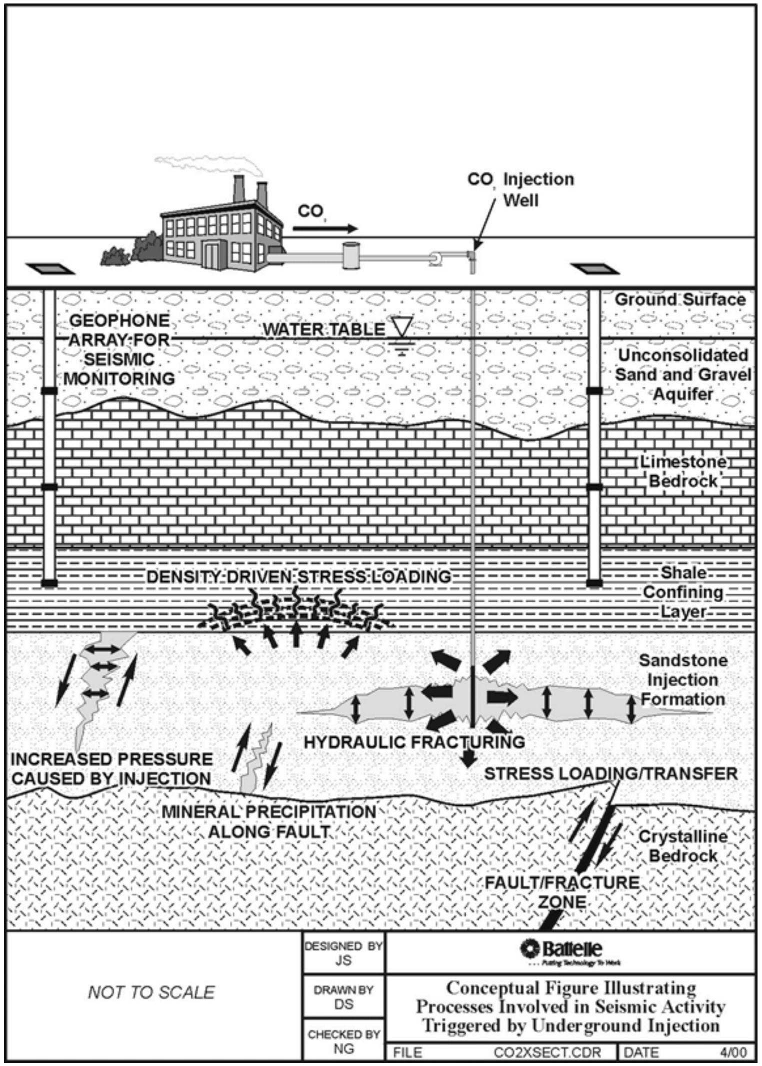
Project Overview

- Project is divided into seven main technical tasks.



Project Overview: Statement of the Problem

- Geomechanical stability of rock formations has been identified as a major challenge to large-scale carbon capture and storage applications.
- Faults, fractures, seismic stability can affect CO_2 injection potential and storage security.

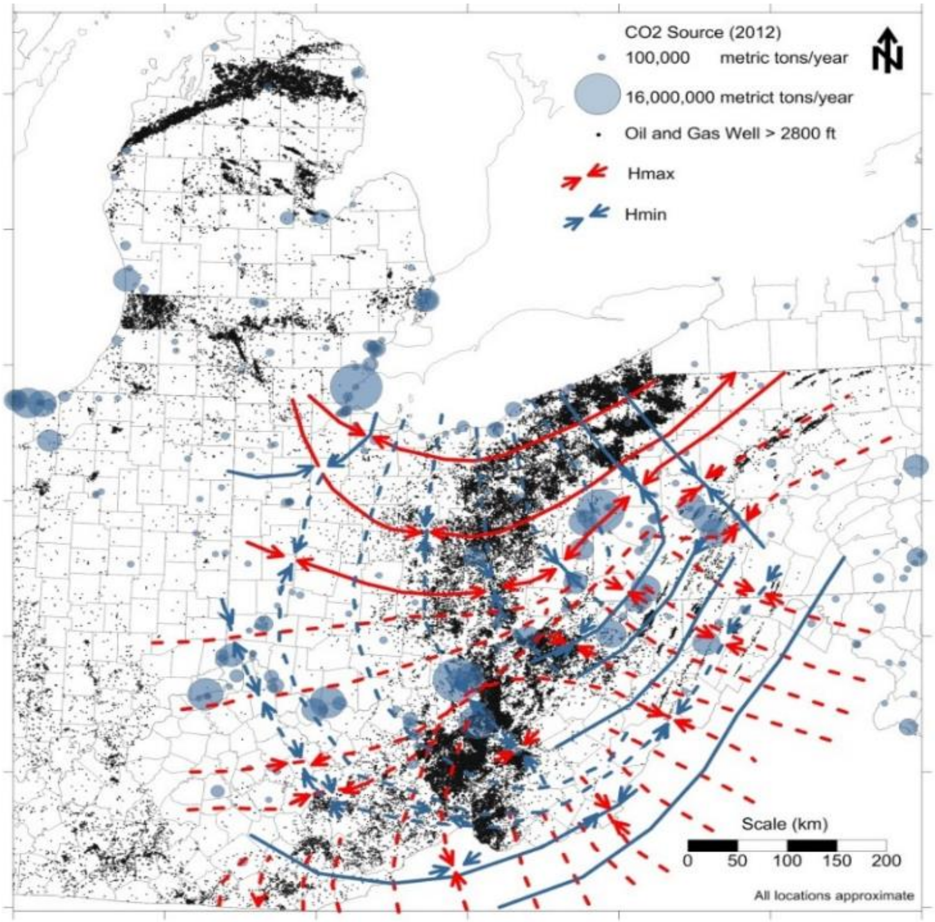


Sminchak, J.R. and N. Gupta. 2001. *Issues Related to Seismic Activity Induced by the Injection of CO2 in Deep Saline Aquifers*. First National Conference on Carbon Sequestration, Wash., DC, May 14-17, 2001.

Project Overview: Statement of the Problem

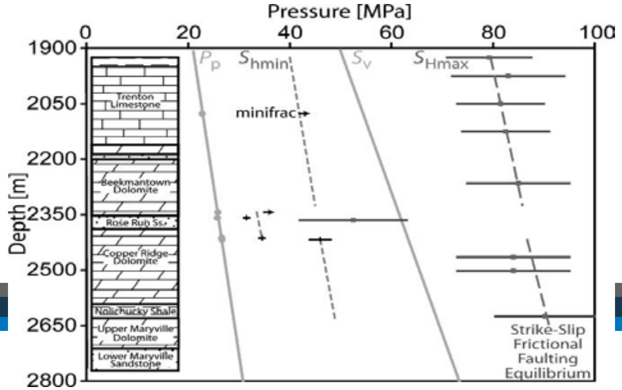
- Geomechanical processes are especially important in Appalachian Basin due to geologic structural setting and nature of deep rock formations.

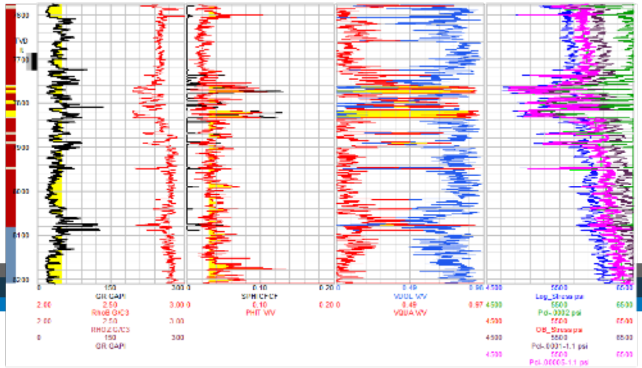
Conceptual Geomechanical Stress-Strain Setting in Appalachian Basin In Relation to Large CO_2 Sources and Oil & Gas Wells



Project Overview: Statement of the Problem

- This work was designed to perform realistic analysis of geomechanical risk factors related to CO_2 storage:
  - Which reservoir rock formations are more fractured in the region?
  - Which caprocks have larger risk factors related to fracturing?
  - What are the key methods and tools for evaluating fractured zones in deep layers?
  - How can these methods be safely and cost effectively employed?
  - How can we better understand basin-scale stress-strain regime to more accurately define stress magnitude at depth?





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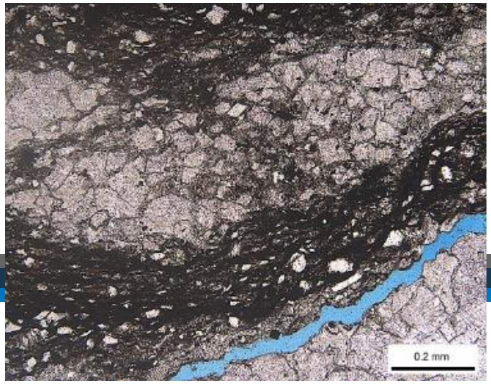
Project Overview: Statement of the Problem

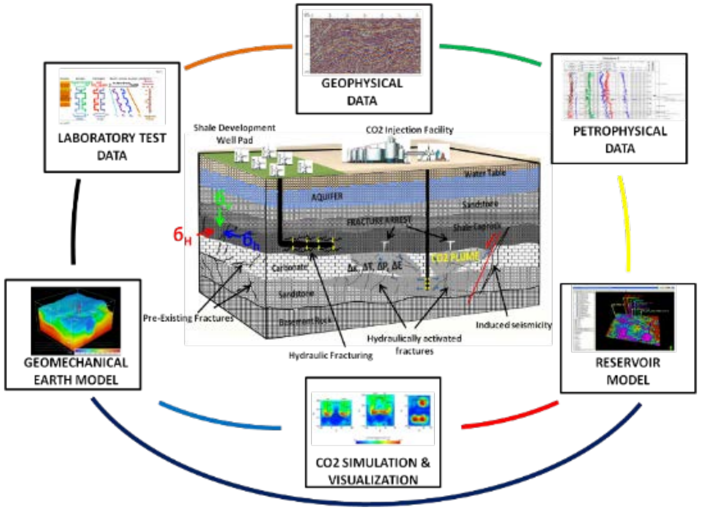
- Project addresses CO_2 storage field application:
  - How does fractured matrix affect CO_2 storage security and its injection capacity in the region's various rock formations?
  - How can test data from real rock samples from the region better define geomechanical issues?
  - What is the collective impact of shale gas hydraulic fracturing on CO_2 storage application?
  - How does integrated CO_2 storage and shale gas development, in combination with the complexity of stimulated fracture network in shale caprock, affect safe storage of CO_2?

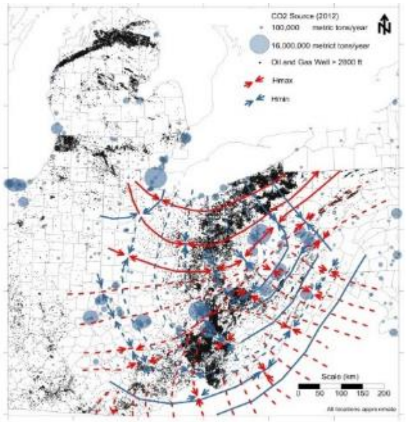


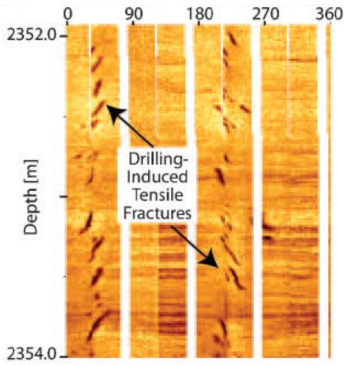
Project Overview: Objectives

Objectives

- Characterize fractured reservoirs stress/strain setting in Appalachian Basin region,
- Assess CO_2 storage processes based on rock core tests and geophysical logging.
- Evaluate the potential and effects of subsurface geomechanical deformation.



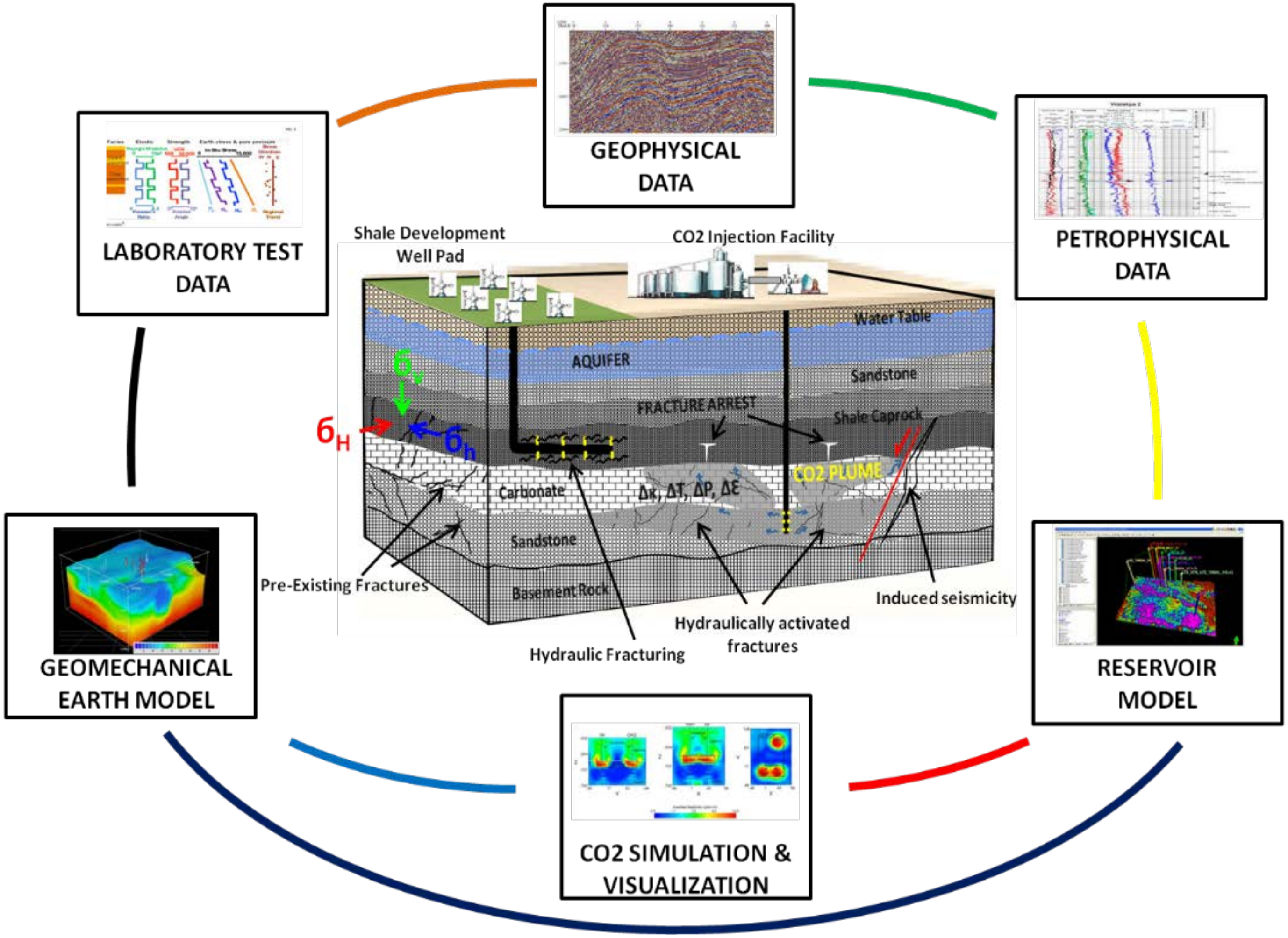




Project Methodology

1. Systematic assessment of the stress-strain setting for geologic formations in the Appalachian Basin region,
2. Methodology for evaluating potential geomechanical stress at CO_2 storage sites,
3. Reservoir simulations to evaluate geomechanical deformation in geologic reservoirs in the region,
4. Evaluation of activated natural fractures on injectivity enhancement and CO_2 storage security, and
5. Assessment of CO_2 storage in areas with hydraulic fracturing for shale gas development.

Project Methodology



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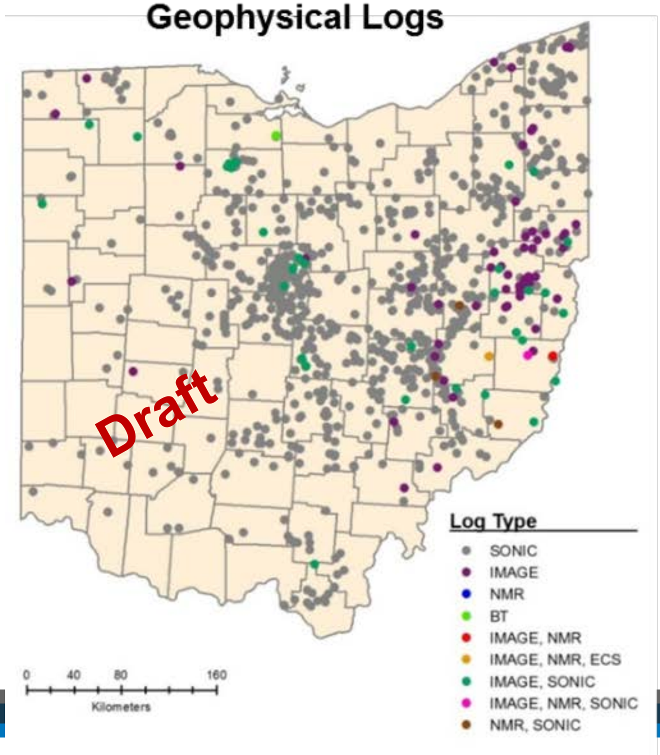
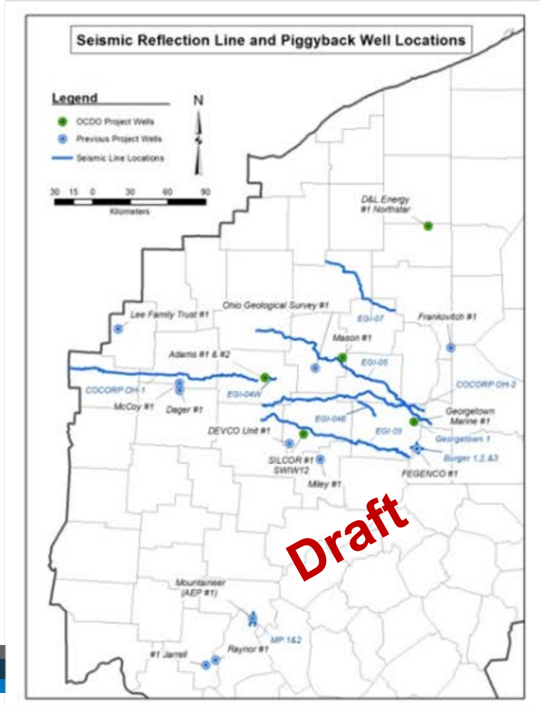
Task 2: Basin Scale Stress-Strain Analysis

- Tectonic setting definition
- Regional analysis of paleo stress-strain orientation and magnitude
- Systematic survey of geomechanical and petrophysical parameters for CO_2 storage zones in Midwest.

Geophysical Logs

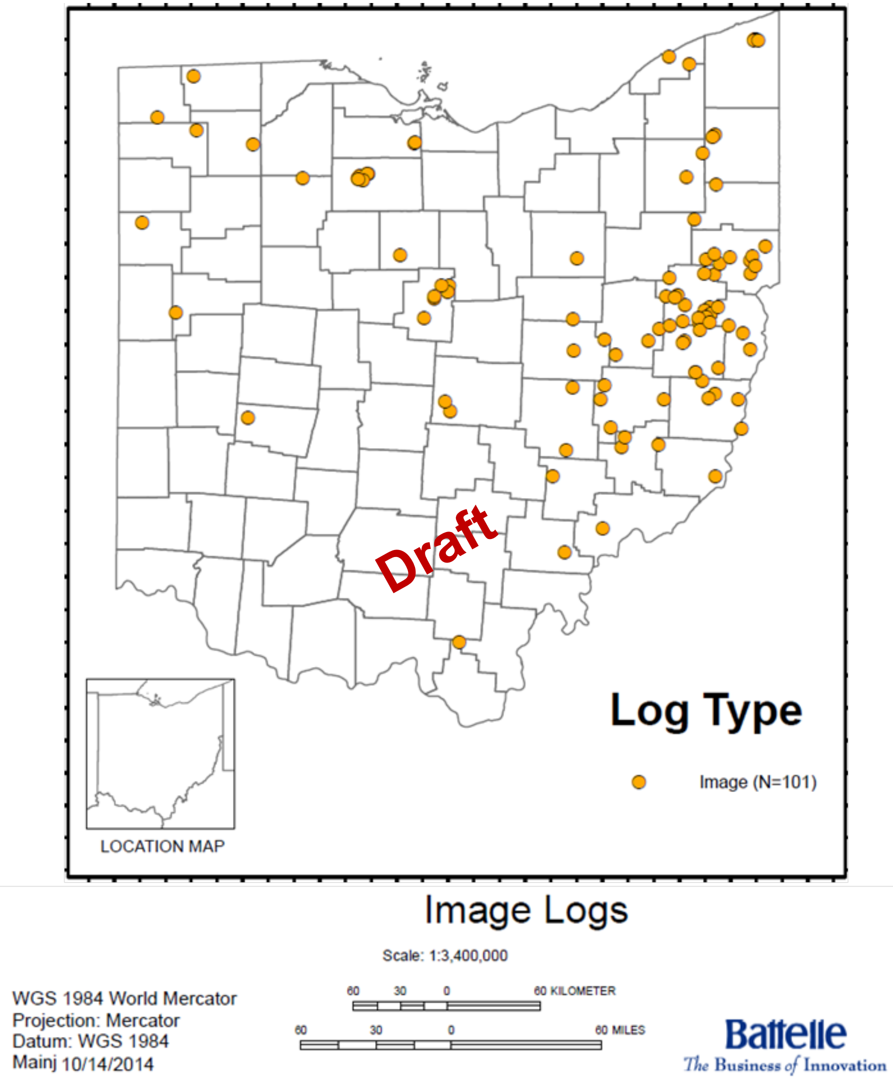


Seismic Survey Data



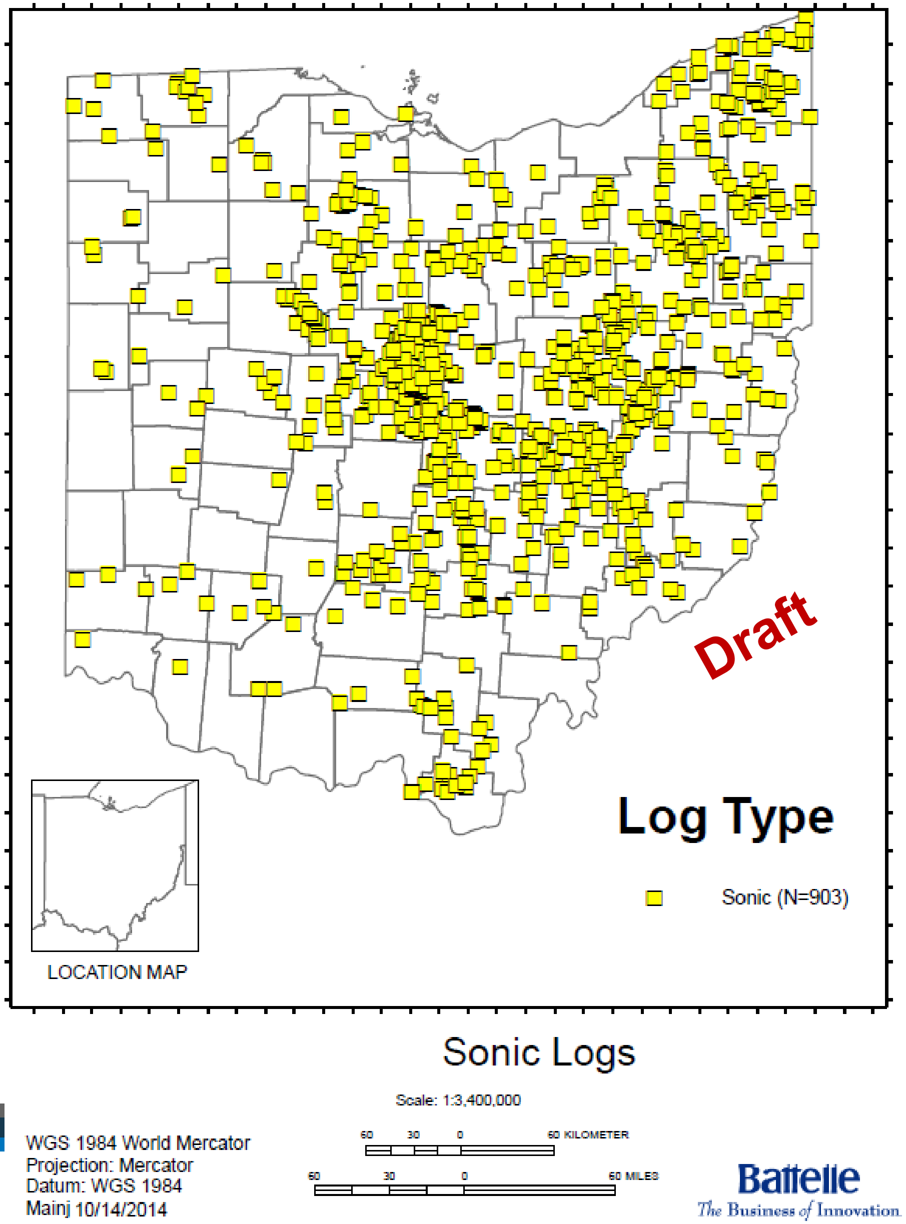
Task 2: Basin Scale Stress-Strain Analysis

- **Image Log Evaluation**
- Determination of orientation maximum (S_{Hmax}) and minimum (S_{hmin}) horizontal stresses around the region.
- Characterization and evaluation of fractured reservoirs.
- Delineation of pre-existing natural fractures from drilling induced tensile fractures (DITFs).



Task 2: Basin Scale Stress-Strain Analysis

- **Sonic Log Evaluation**
- Determination of geomechanical parameters for reservoirs of interest.
- Characterization of fractured reservoir and in some occasions identifying multiple fractures with different orientation pattern at depth



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Task 3: Site Geomechanical Analysis

- Project will test rock cores from injection formations and caprocks for geomechanical properties. Work will supplement geomechanical test data from other projects.
  - Triaxial compressive test for acoustical velocities,
  - Acoustic velocities,
  - Static and dynamic Young's modulus,
  - Poisson's ratio,
  - Fracture toughness,
  - Bulk modulus, and
  - Shear modulus.

'Newburg'-Lockport

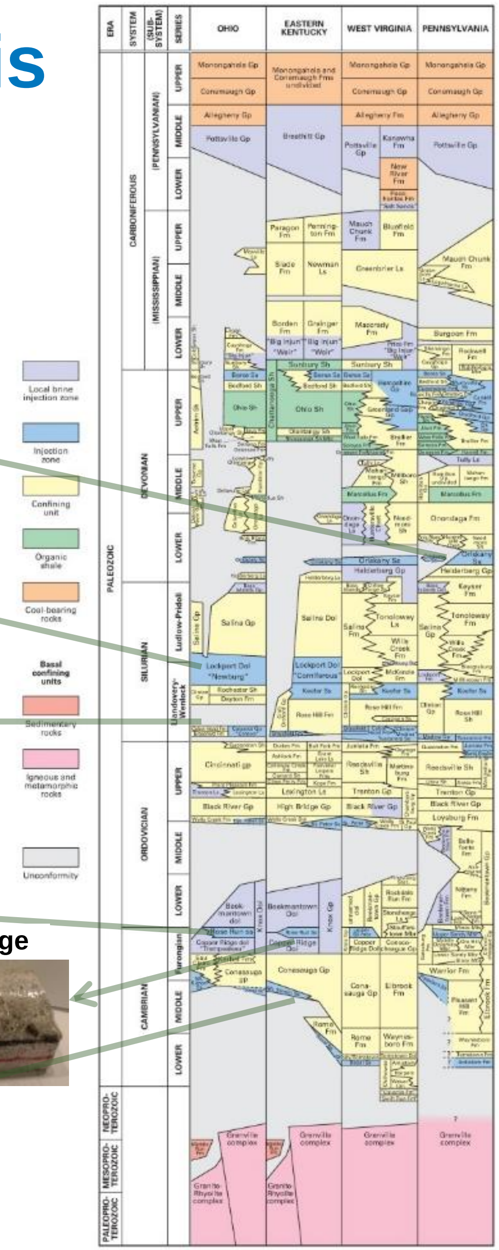
Oriskany

'Clinton'-Medina

Rose Run

Mt. Simon

Trempealeau-Copper Ridge



Source: Sminchak, J.R., Gupta, N., Moody, M., and Miller, J. 2014. Geologic and Reservoir Assessment for Brine Disposal in the Northern Appalachian Basin. SPE Unconventional Resources Technology Conference, August 25-27, Denver, CO.

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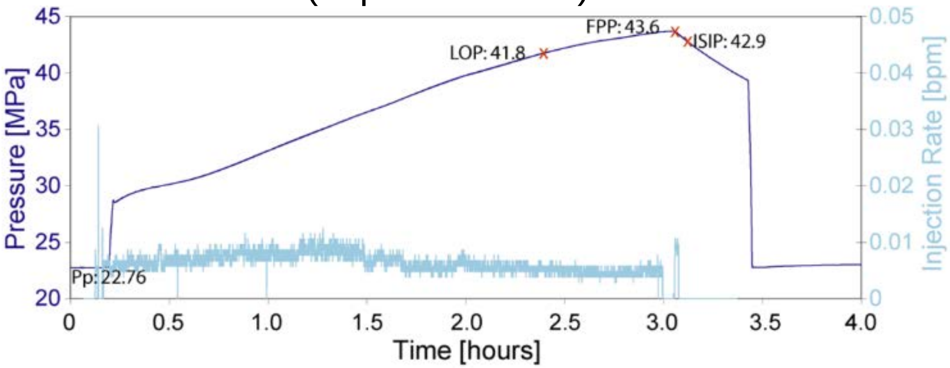
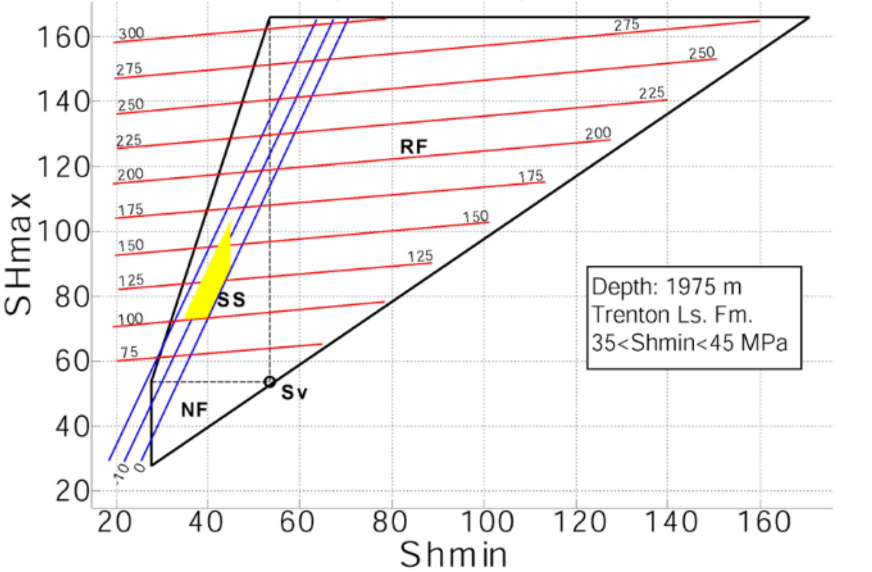
Task 3: Site Geomechanical Data Analysis

- With limited available data (such as minifrac tests);
- Stress magnitudes at depth would be constrained utilizing bulk volume of conventional logs in our log library across different states

Example- Trenton LS Caprock Minifrac Test*
(depth = 2077 m)





Source: Lucier, Zoback, Gupta, and Ramakrishnan. 2006. *Geomechanical aspects of CO2 sequestration in a deep saline reservoir in the Ohio River Valley Region*. Environmental Geosciences, v 13 no 2, p. 85-103.

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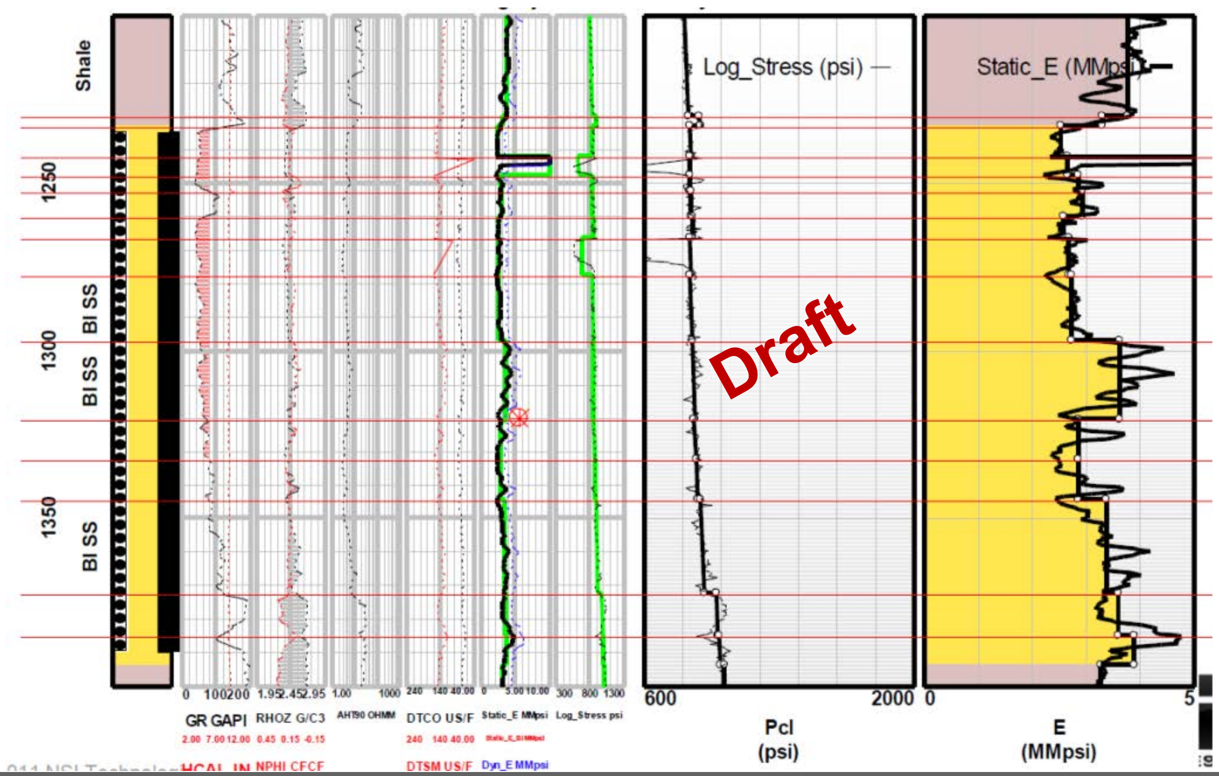
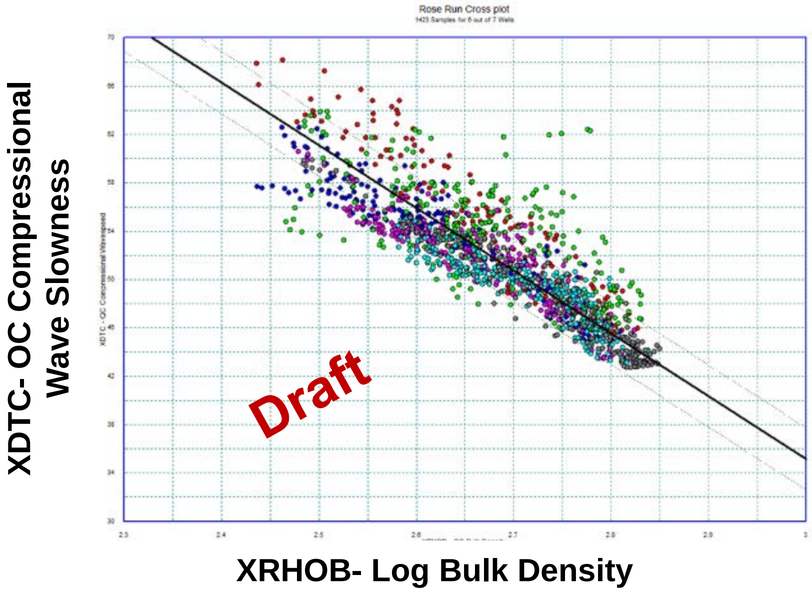
Task 4: Petrophysical Log Analysis & Integration

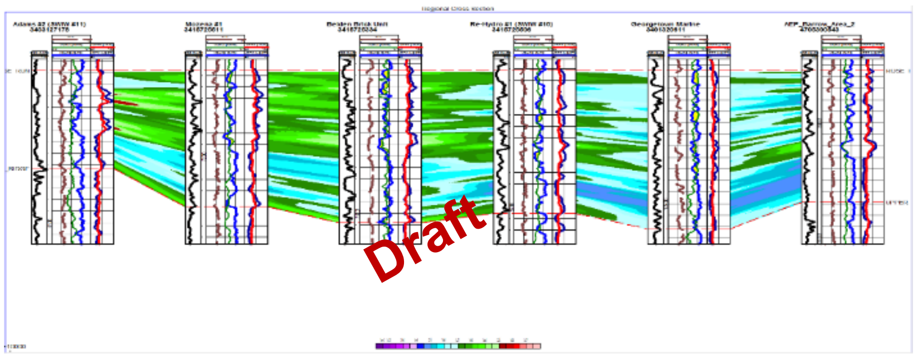
- Translation of petrophysical log data to geomechanical parameters
- Calibration of logs with static geomechanical test data.



Task 4: Petrophysical Log Analysis & Integration

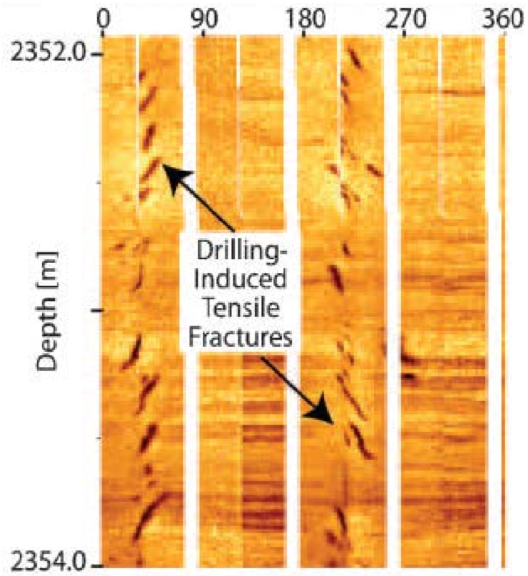
- Example: Correlation of log bulk density to compressional wave velocity to estimate geomechanical parameters based on common geophysical logs (density, gamma).





Task 4: Petrophysical Log Analysis & Integration

- Project is focused on major storage zones & caprocks in the Midwest U.S.
- Scope for processing and analysis of advanced image logs from operators in the region to better define stress setting in the region.



Candidate Storage Reservoir (Age, Group, or Formation)	Corresponding Caprock Formations (Age, Group, or Formation Name)
Cambrian-Ordovician Knox Group (Rose Run Sandstone, Beekmantown Dolomite, and Lower Copper Ridge Dolomite "B" Zone, Krysik sandstone	Non-vuggy sections of Knox Group, Wells Creek Dolomite/Limestone, Black River Group (Limestone), Trenton Limestone, Utica/Point Pleasant Shale, Cincinnati Group, Queenston Shale
Cambrian Rome Formation and underlying Basal Sandstone	Cambrian Conasauga Group (Maynardville Limestone, Nolichucky Shale, etc.)

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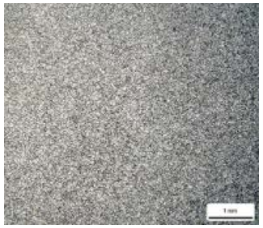
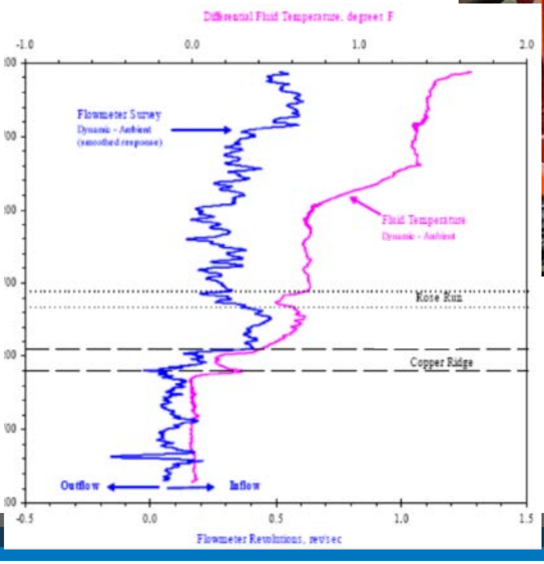
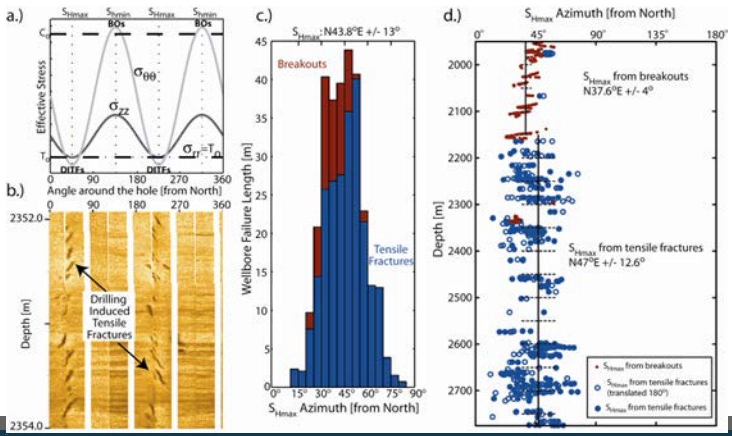
Task 5: Development of Methodology for Geomechanical Site Characterization

- The objective of this task is to describe options and steps for operators drilling CO_2 injection wells, preparing Class 6 UIC permits, and monitoring CO_2 storage sites.
  - Geophysical logging options
  - Rock core tests
  - Injection tests
  - Geomechanical monitoring

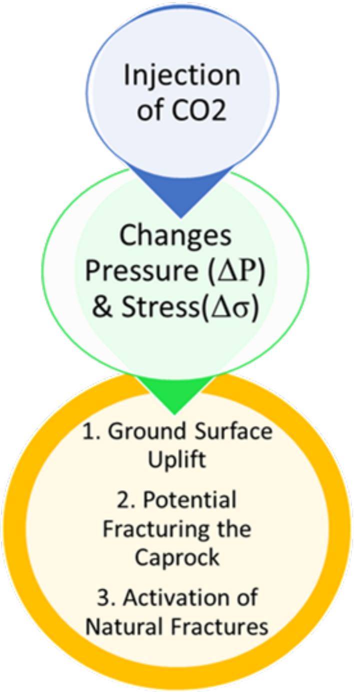


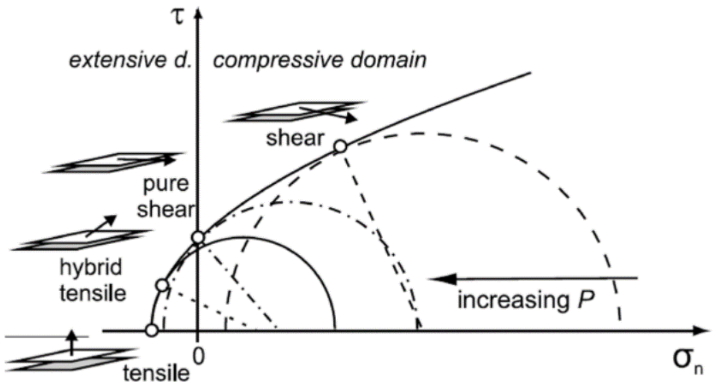




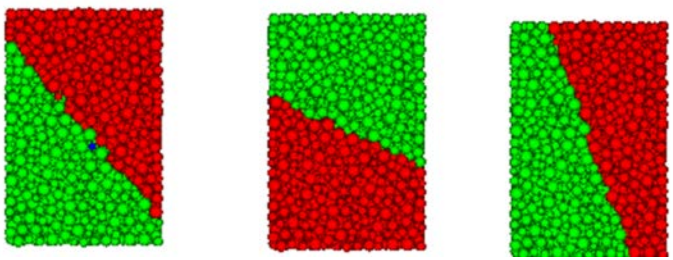
Task 6: Fractured Reservoir Simulations
Task 7: Caprock Simulations for CO_2 Storage

Reservoir simulations to evaluate geomechanical deformation in geologic reservoirs in the region,

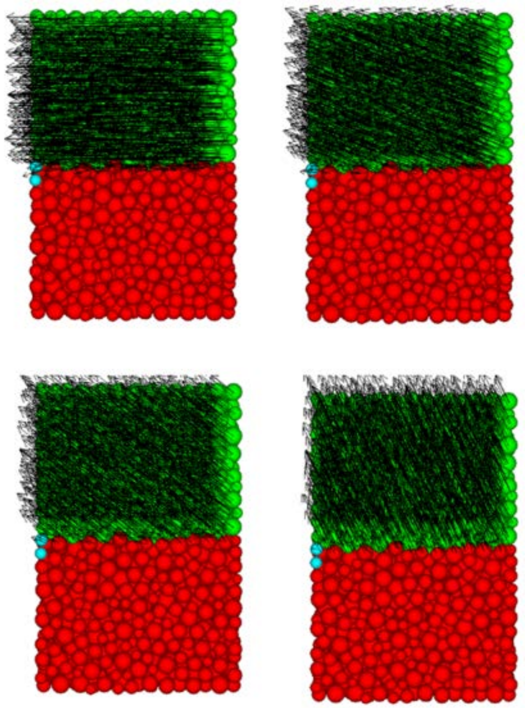




Fracture Dip Angle Activation



Effect of Fracture Dip Angle on its Activation



Raziperchikolaee et al, Transport in Porous Media, 2014
Raziperchikolaee et al, JGR: Solid Earth, 2014

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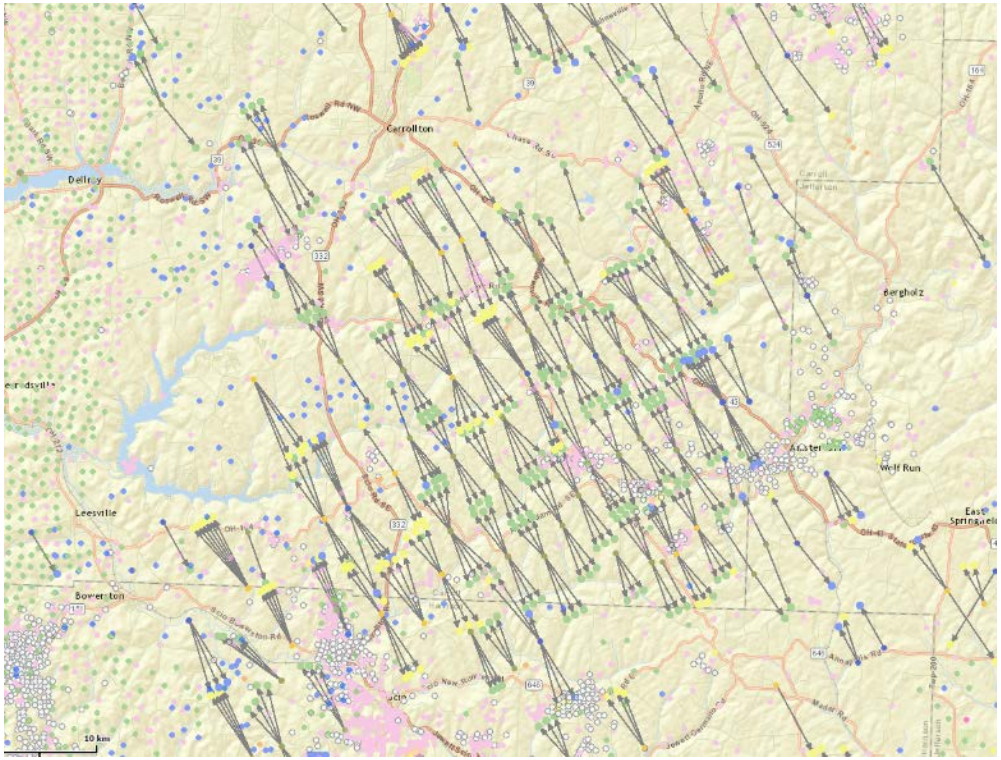
Task 8: CO_2 Storage Site/Shale Gas Risk Factor Assessment

- Mapping CO_2 storage zones and shale gas plays
- Classification of risk factors related to CO_2 storage and shale gas development.

Example- Figure illustrating County scale shale gas development



Source: Ohio Dept. of Natural Resources Oil and Gas Well Information.

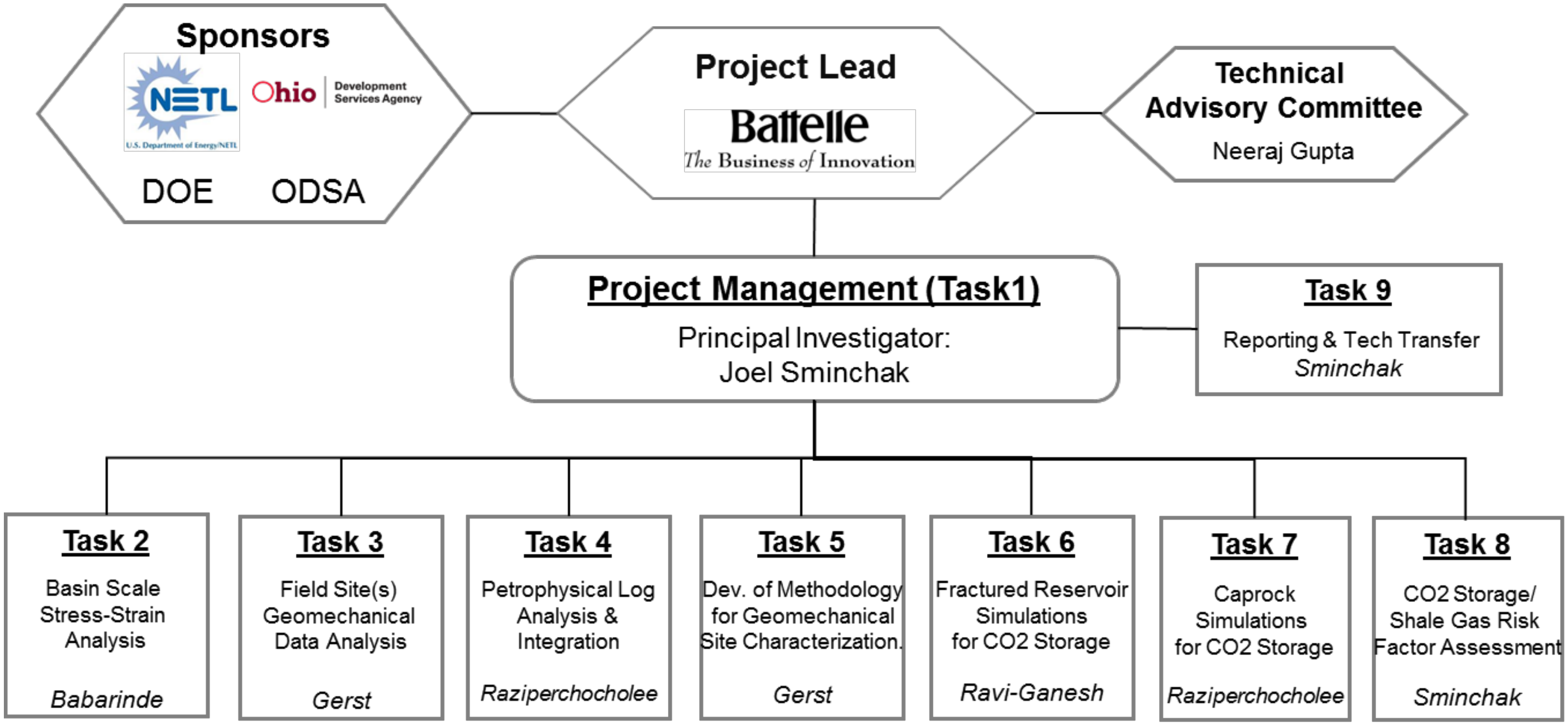
Expected Outcomes

Products

- Systematic inventory of site-specific geomechanical parameters for potential CO_2 storage reservoirs.
- Methodology for characterizing deep rock formations in terms of geophysical logging, rock core testing, geomechanical analysis, and CO_2 storage potential.
- Evaluation of the effects of natural fracture systems on CO_2 injectivity and seismicity near fractured reservoirs.
- Comprehensive geomechanical evaluation of different potential reservoirs.

Project Organization Chart

- Project organized into 7 main technical tasks.



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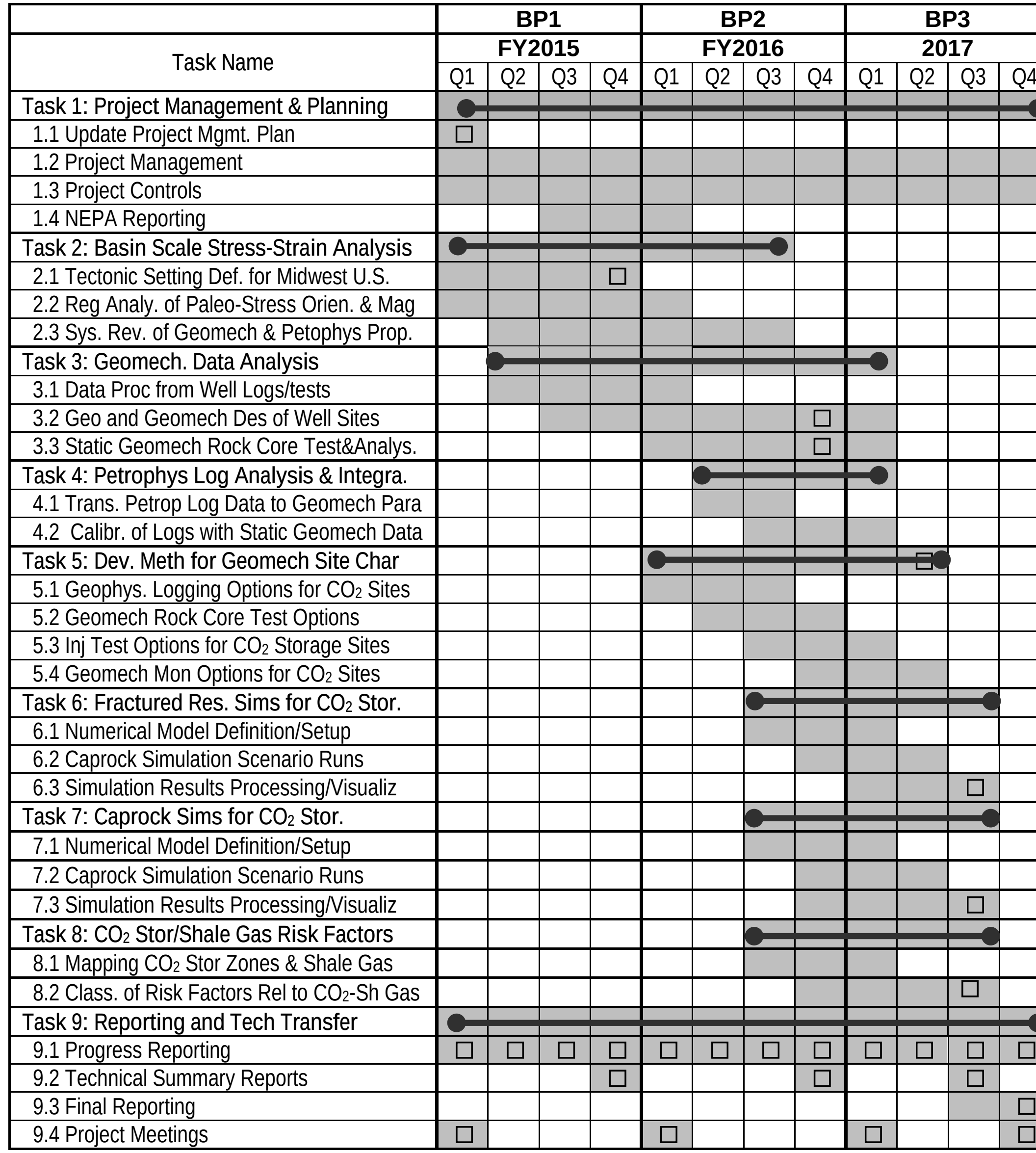
Task/Subtask Breakdown

- Project is designed with a sequential series of tasks over 3 years.



Deliverables/Milestones

Milestones

Budget Period	Milestone Description	Planned Due Date	Verification Method
1	Submit Updated Project Management Plan to DOE	30 days after initial award	Project Management Plan
1	Collect and Analyze Geotechncial Data for Basin Scale Paleo-Stress/Strain Analysis	September 2015	Topical Report
2	Acquire and Process 3-4 Advanced Geophysical Logs from Key Wells in the Region	September 2016	Annual Report, Upload data to EDX
2	Complete Testing of 10 Rock Cores for Geomechanical Parameters	September 2016	Annual Report, Upload data to EDX
3	Complete Development of a Methodology for Geomechanical Site Characterization for CO_2 Storage Sites	March 2017	Summary Technical report
3	Complete Reservoir Simulations for fractured reservoirs and caprocks	June 2017	Topical Report with Simulation Results
3	Develop maps and identify risk factors for CO_2 Storage/Shale Gas Zones in the Region	June 2017	Summary Technical Report
3	Preparation of final technical report detailing all test data, analysis, and project results	90 days after end of the project	Final Technical Report

Deliverables/Milestones

Deliverable List

Deliverable	Task	Description	Deliverable Due Date
Project Management Plan	1	Updated Project Management Plan	30 days after initial award
Annual Renewal Application	1	Annual report with technical progress, key findings, and request for continued funding	30 days before end of Budget Period 1 and Budget Period 2
Project Fact Sheet	1	Updated fact sheet for project	30 days after initial award
Basin Scale Paleo-Stress/strain Analysis	2	Basin scale paleo-stress strain setting analysis (Topical report)	September 2015
EDX Upload of Data	3-4	Submit relevant geophysical and core test geomechanical data (upload to EDX, summarize in annual report)	June 2017
Methodology for Geomechanical Site Characterization	5	Summary Methodology for Geomechanical Site Characterization (summary technical report)	March 2017
Reservoir Simulations	6-7	Analysis of Simulation Results (Topical report)	June 2017
CO_2 Storage/Shale Gas Risk Factor Analysis	8	Summary of CO_2 Storage/Shale gas risk factors (summary technical report)	June 2017
Final Technical Report	9+	Technical report detailing all methods, simulations, analyses, and findings	90 days after end of the project

Risk Matrix

Risk Factors	Goal	Suggested Approach
Obtaining log and testing data from regional oil and gas wells	Obtain geophysical logs, rock core samples from operators in the region to cover study area	Maintain and expand relationship with industry Monitor and retrieve log/data submitted to state agencies Budget to support some log processing and testing Share findings with industry to encourage collaboration
Small sample size for geotechnical test parameters	Expand pool of geomechanical data	Supplement planned testing with existing geophysical logs, geomechanical test data from other projects, including data already collected by Battelle
Quantifying stress magnitude at depth	Better define magnitude of stress in deep rock formations	Utilize combination of paleo-stress/strain analysis and field logs from region to assess geomechanical regime for the region and calibrate with available field tests
Simulation of coupled flow-geomechanics	Simulate fractured reservoir and caprock flow-geomechanical deformation	Use models such as GEM with track record of application in the oil and gas industry. Flexibility to use national laboratory models (e.g. Tough-Flac) for cross validation
Resource availability	Ensure optimum staff to meet project goals	A geomechanics expert already hired to add to Battelle team; Routine labor planning and project reviews to ensure staff availability and milestone tracking
Environmental, Health, and Safety	Ensure safe workplace	No fieldwork planned, but where applicable team will follow Battelle's framework for HSE management in office, laboratory, and field settings
Site access	No site access needed	Data access issues addressed in technical risks
Management risks	Complete work on time and within budget and achieve all milestones	Monthly labor planning and management project review meetings; clear communication plan; budget and milestone tracking; independent procurement; ISO 9001 certification

*waiting on FN clearance