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

DE-FE0023330

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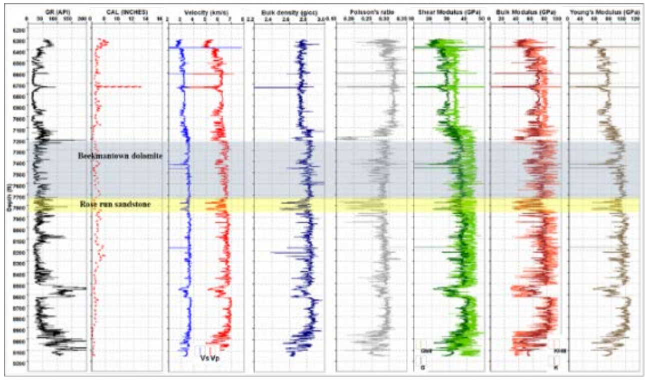
U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

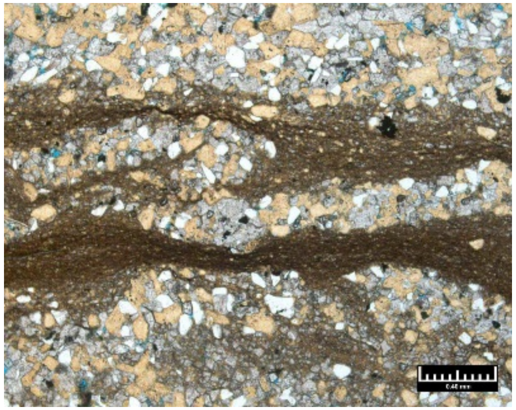
August 1-3, 2017

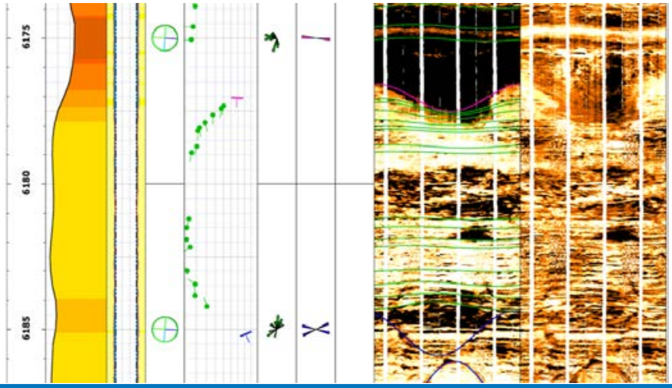
Presentation Outline



1) Technical Status
2) Accomplishments to Date
3) Lessons Learned
4) Synergy Opportunities
5) Project Summary

- Appendix Material





Acknowledgements

- The project was funded by the U.S. DOE / National Energy Technology Laboratory (Contract DE-FE0023330) under their program on technologies to ensure permanent geologic C-storage. Project Coordinator – William O'Dowd.
- Co-funding provided by Ohio Development Services Agency Ohio Coal Dev. Office (Grant CDO-D-14-17).
- Project team includes S. Bhattacharya, Neeraj Gupta, Joel Main, Glenn Larsen, Ashwin Pasumarti, Nat Voorhies, James E. Hicks, Amber Conner, Mark Kelley.

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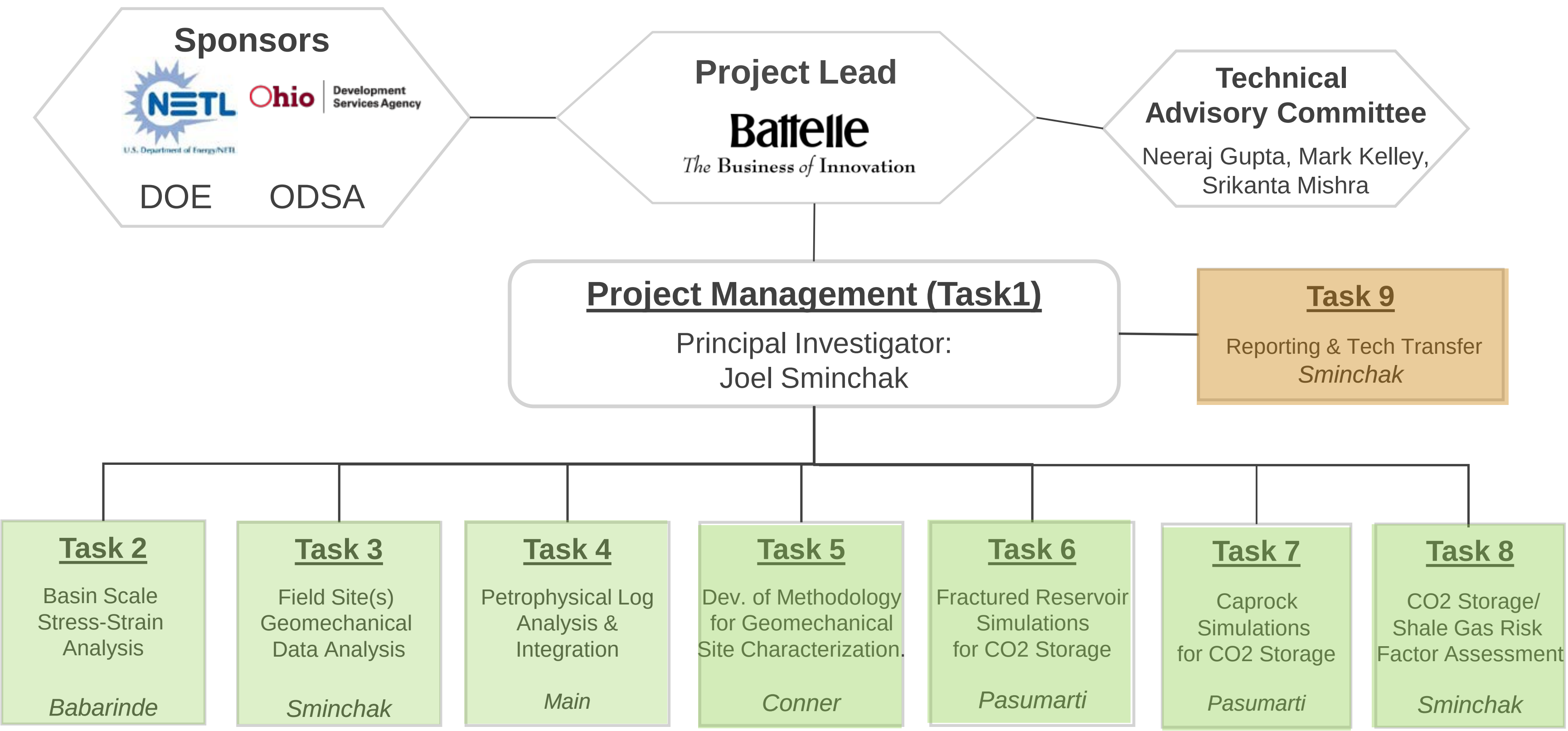
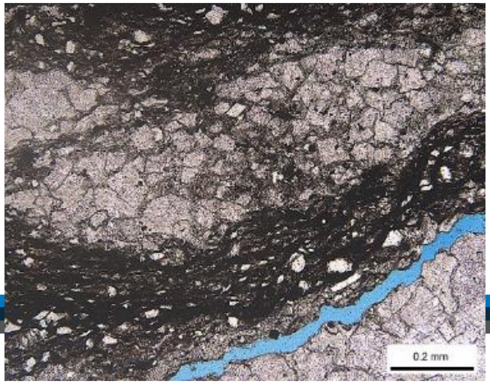
Technical Status

- 3 year project from October 2014-September 2017.
- Project is divided into seven main technical tasks.



Technical Status- Objectives

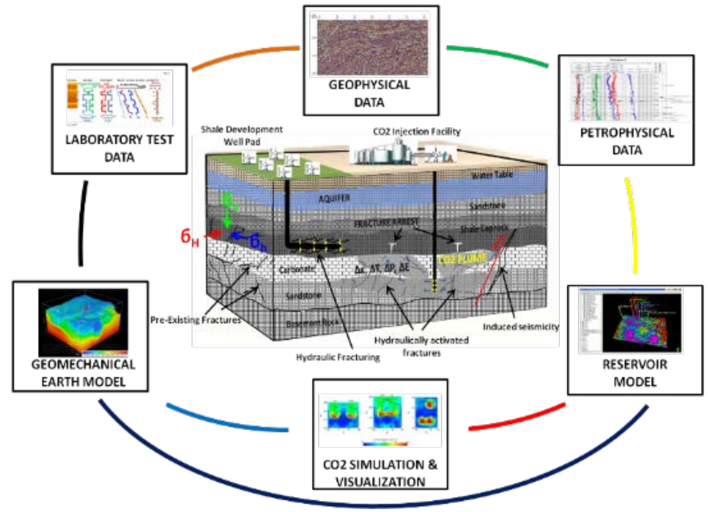
- This work was designed to perform realistic analysis of geomechanical risk factors related to CO_2 storage:
  - Which reservoir rock formations are more fractured in the region?
  - Which rocks have larger risk factors related to subsurface deformation?
  - What are the key methods and tools for evaluating geomechanical effects of CO_2 storage 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?

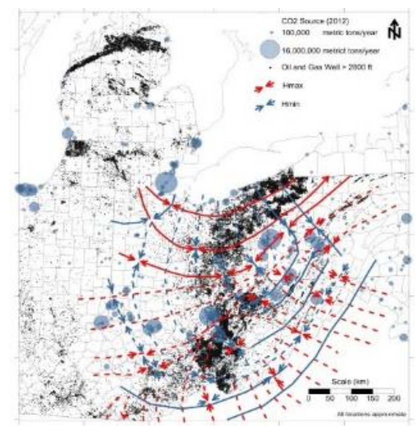


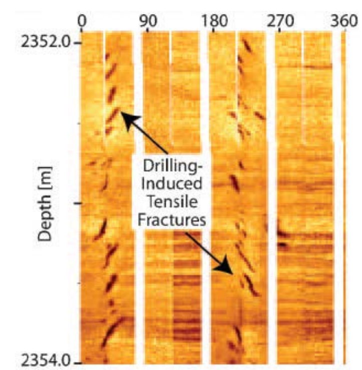
Technical Status- Objectives

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.



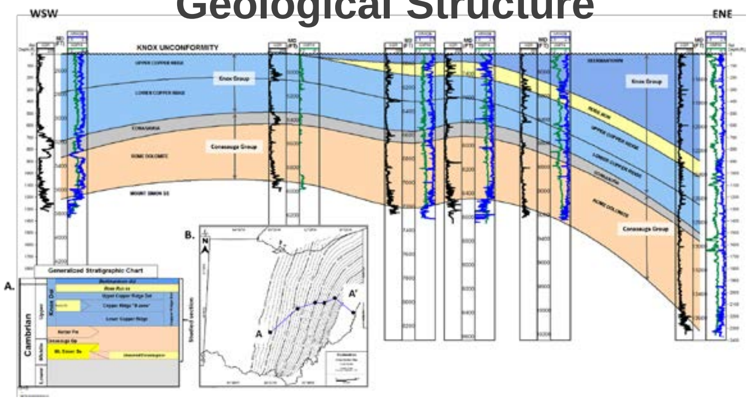




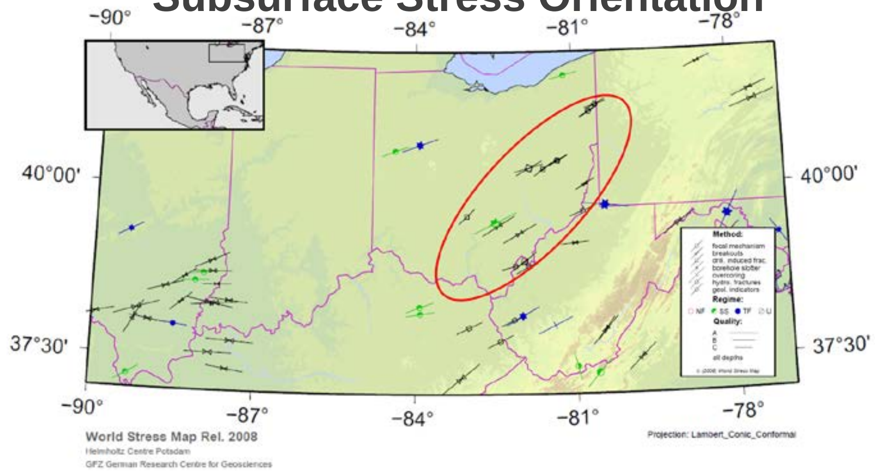
Technical Status-
Basin Scale Stress-Strain Analysis

- Analyze regional geologic stress regime, fracture density, geomechanical parameters.

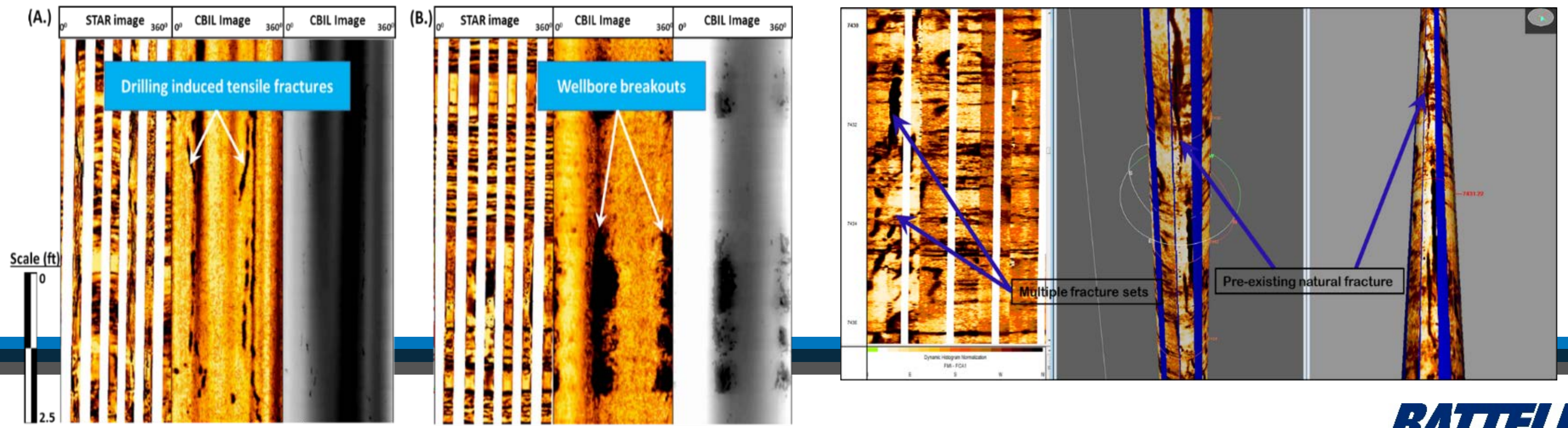
Geological Structure



Subsurface Stress Orientation



Geophysical Image Logs



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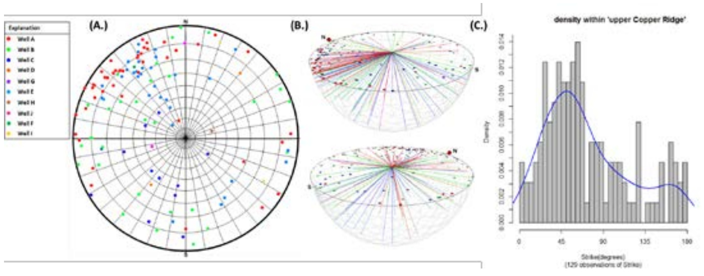
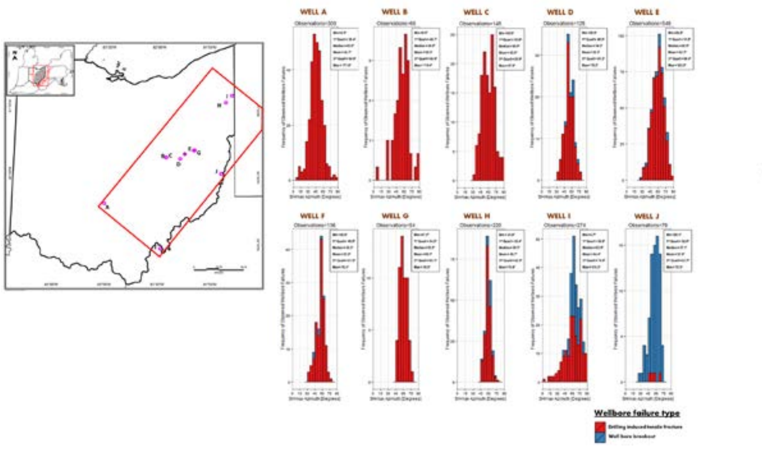
Technical Status-
Basin Scale Stress-Strain Analysis

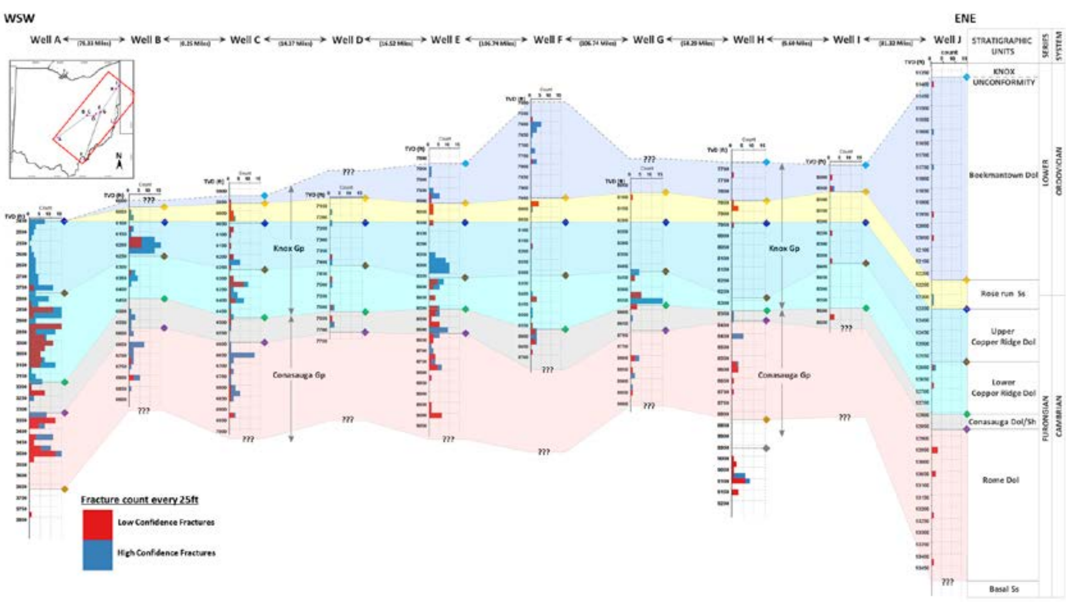
- 1,760 fractures/breakouts analyzed from 10 wells' image logs, fractures interpreted for:
  - Fracture intensity variation spatially
  - Predominant fracture orientation.

Fracture Orientation



Fracture Intensity

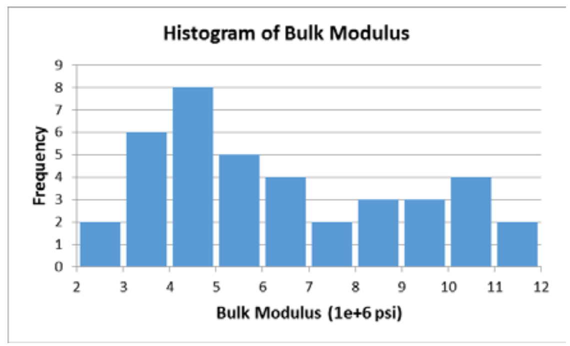


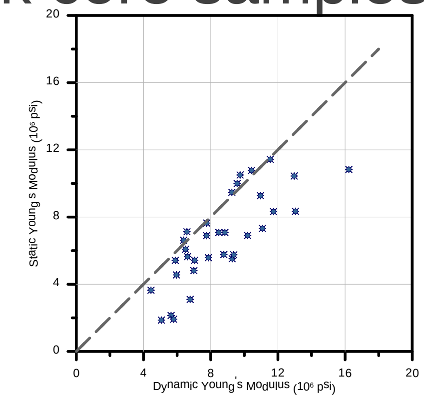


Technical Status-
Geomechanical Parameters in the Region

- Geomechanical test data for region was compiled and analyzed for spatial, population trends.
- Data was supplemented with tests on 8 rock core samples.







Parameter	Confining Pressure (psi)	Bulk Density (g/cc)	Compressional Velocity (ft/s)	Shear Velocity (ft/s)	Dynamic Young's Modulus (1e+6 psi)	Dynamic Poisson's Ratio	Bulk Modulus (1e+6 psi)	Shear Modulus (1e+6 psi)	Compressive Strength (psi)	Static Young's Modulus (1e+6 psi)	Static Poisson's Ratio
Count	50	50	39	39	39	39	39	39	44	44	44
Minimum	460	2.24	12500	7636	4.44	0.085	2.17	1.92	15,161	1.87	0.151
Maximum	3160	2.83	22629	13199	16.22	0.350	11.38	6.53	89,225	11.45	0.417
Range	2700	0.59	10129	5563	11.78	0.27	9.22	4.61	74,064	9.57	0.266
Median	1650	2.60	17094	9568	8.78	0.26	5.74	3.44	30,020	5.77	0.26
Mean	1656.60	2.60	17302.97	9791	8.69	0.25	6.35	3.47	33,136	6.23	0.26
Sample Standard Deviation	615.94	0.15	2592.66	1182.57	2.48	0.07	2.71	0.96	15,529	2.59	0.07

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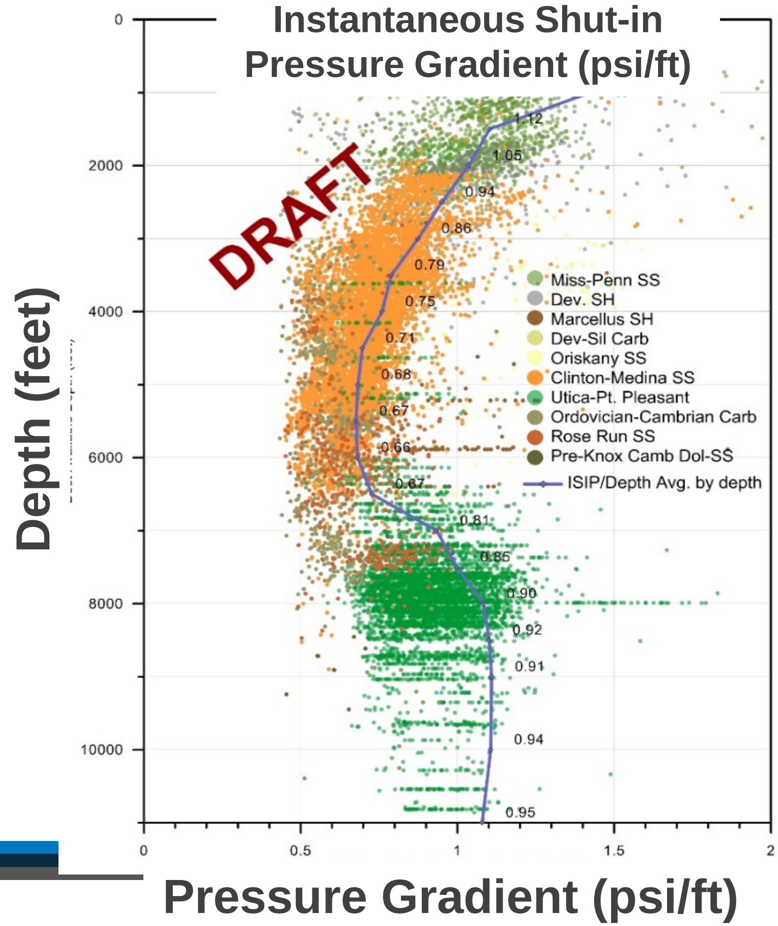
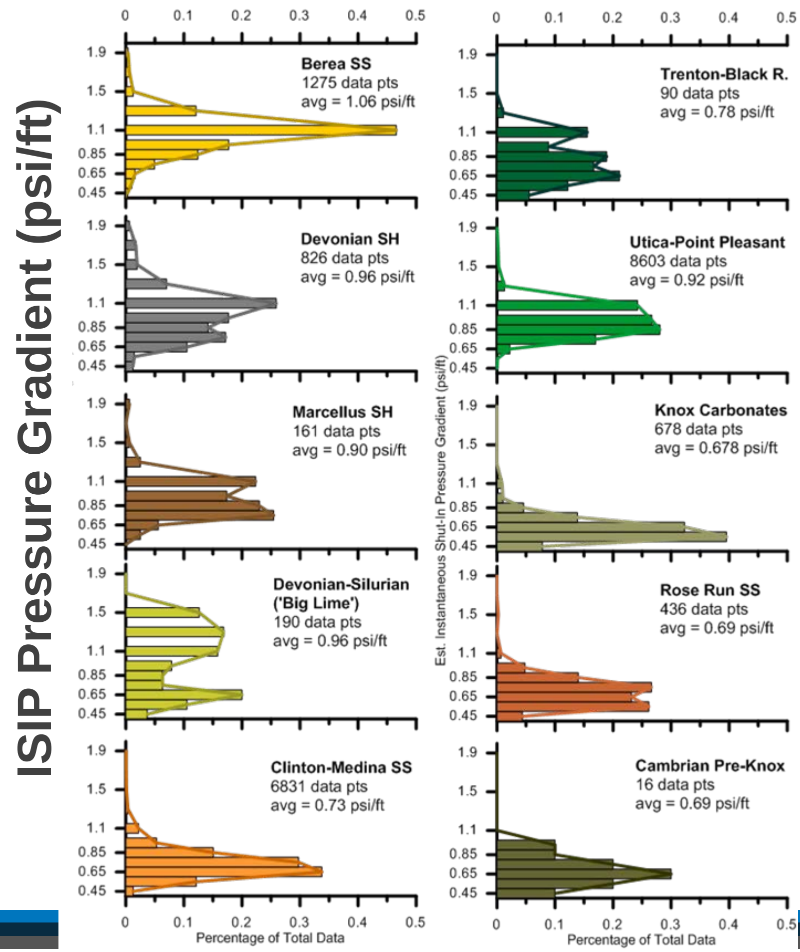
Technical Status- Geomechanical Conditions

- Fracture treatment data used to help constrain in-situ stress magnitudes.
- More than ***20,000 data*** compiled on instantaneous shut-in pressures and breakdown pressures from KY, MI, NY, OH, WV. Data suggest ISIP (~Sh_{min}) gradient of ~0.7-1.0 psi/ft





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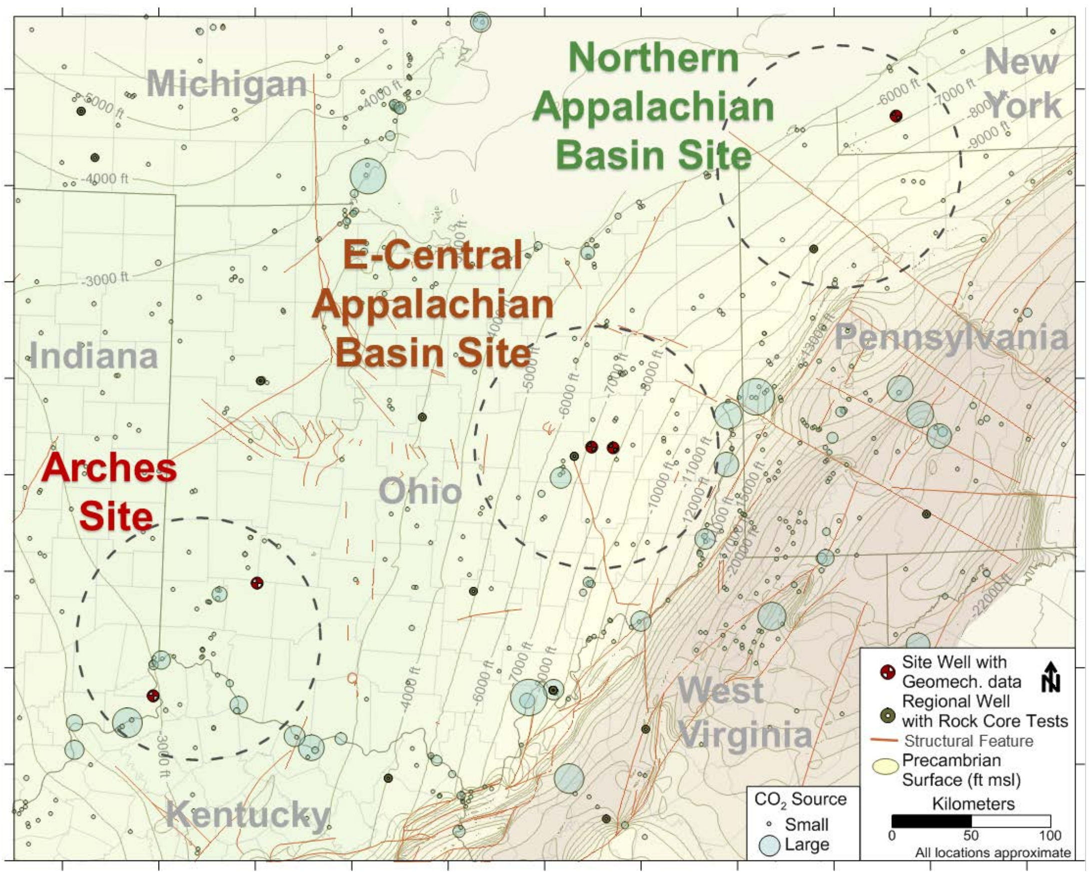
Technical Status- Site Analysis

- 3 Sites identified for more detailed analysis & geomech. simulations.



System	Series	Arches Province	E.Central App. Basin	Northern App. Basin
SILURIAN	Upper		Bass Island Dol	Bass Islands Dol
			Salina Gp	Salina Gp
			Lockport Dol	Lockport Dol
			Clinton Gp: Rochester Sh	Clinton Gp
	Lower		Clinton Gp: "Packer Shell" Dayton Fm	
			"Clinton" ss	Medina Gp
ORDOVICIAN	Upper		Queenston Sh	Queenston Sh
		Kope/ Clays Ferry Fm	Cincinnati Gp	Lorraine Fm
			Point Pleasant Fm	Utica Sh
	Middle	Lexington Ls	Trenton/Lexington Ls	Trenton Ls
		High Bridge Gp	Black River Gp: Black River Ls	Black River Gp
			Black River Gp: "Gull River" Ls	
		Wells Creek Fm	Wells Creek Fm	
		St. Peter Ss		
	Lower	Beekmantown Dol	Beekmantown Dol	Tribes Hill Fm
CAMBRIAN	Upper	Knox Gp: Copper Ridge Dol	Knox Gp: Rose Run ss	Little Falls Fm
				Galway Fm: Rose Run Ss
			Knox Gp: Copper Ridge Dol	Galway Fm: A-Dolomite
				Galway Fm: B-Sand
				Galway Fm: B-Dolomite
		Eau Claire Fm	Conasauga Gp: Undifferentiated	Galway Fm: C-Sand
				Potsdam Fm
	Middle	Mt. Simon Fm	Conasauga Gp: basal ss	
	Lower			
PRECAMBRIAN		Middle Run Fm		
		Granite Rhyolite Complex	Grenville Complex	Grenville Complex

CO2 Storage Interval

Containment Layer

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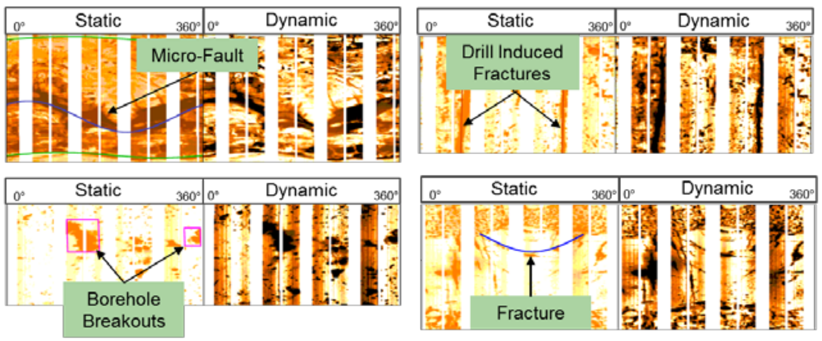
Technical Status- Site Analysis

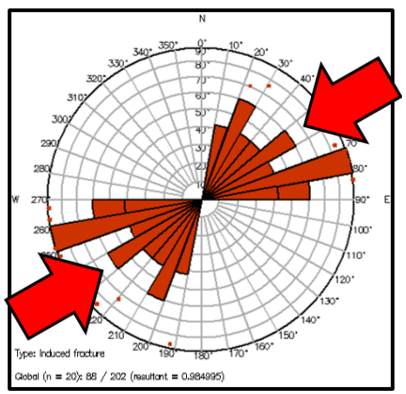
- >9700 ft. of image log data processed from 3 wells to identify natural fractures, breakouts, drilling induced fractures.
  - **Arches site**
    - 2,650 ft. analyzed through the Rose Run, Copper Ridge, Davis Shale, Eau Claire, and Mt. Simon formations
  - **East-Central Appalachian Basin site**
    - 3,600 ft. analyzed through the Queenston, Utica, Point Pleasant, Trenton, Black River, Gull River, Wells Creek, Beekmantown, Rose Run, Copper Ridge, Conasauga, Maryville, and Basal Sand
  - **Northeastern Appalachian Basin site**
    - 3,400 ft. analyzed through the Utica, Trenton-Black River, Little Falls, Rose Run, Galway A Dolomite, Galway B Sand, Galway B Dolomite, and Galway C Sand

Technical Status

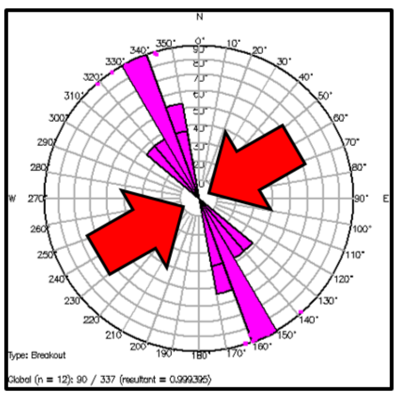
- **Arches site**: 134 fractures, 55 induced fractures, 5 micro-faults, and 586 breakouts were interpreted on image logs.



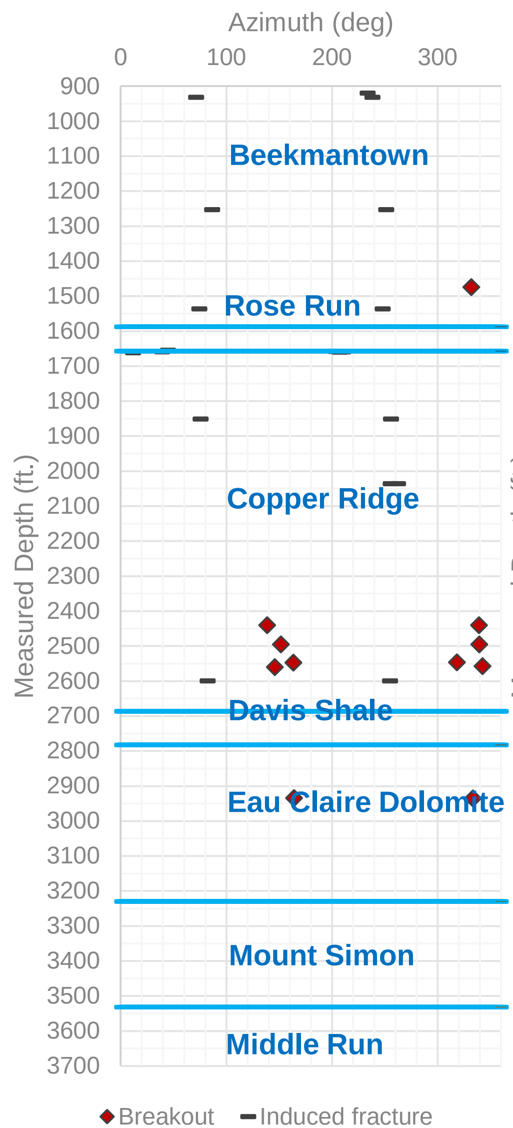
Induced Fractures



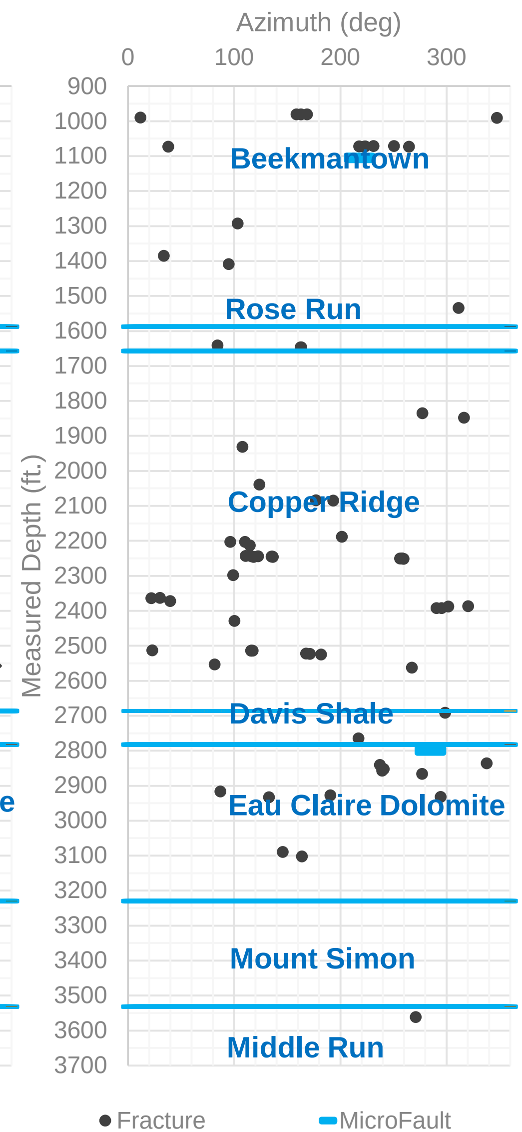
Borehole Breakouts



Arches Site
Drilling Induced Features



Arches Site
Natural Features



Maximum Horizontal Stress Direction

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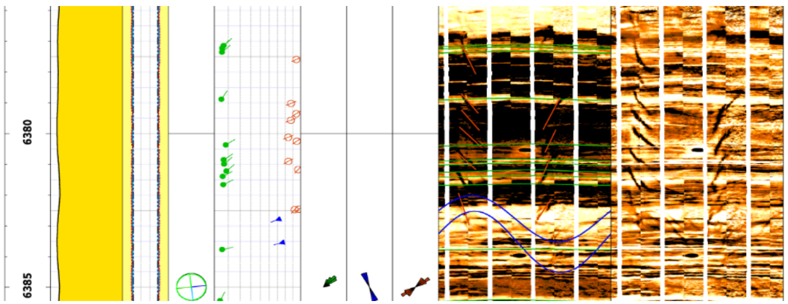
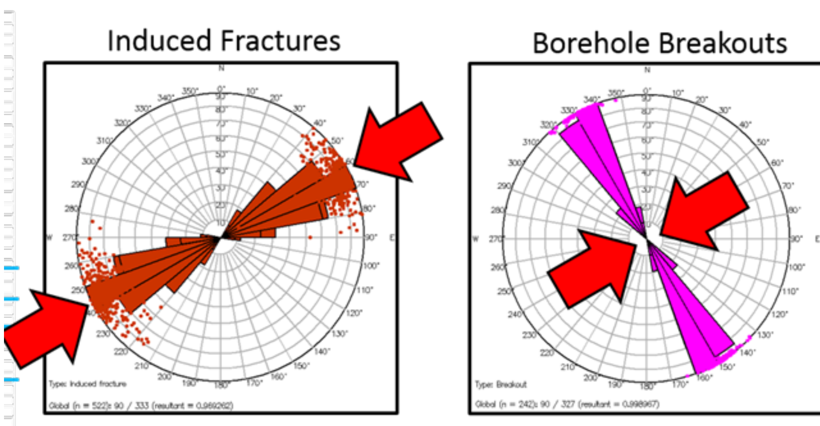
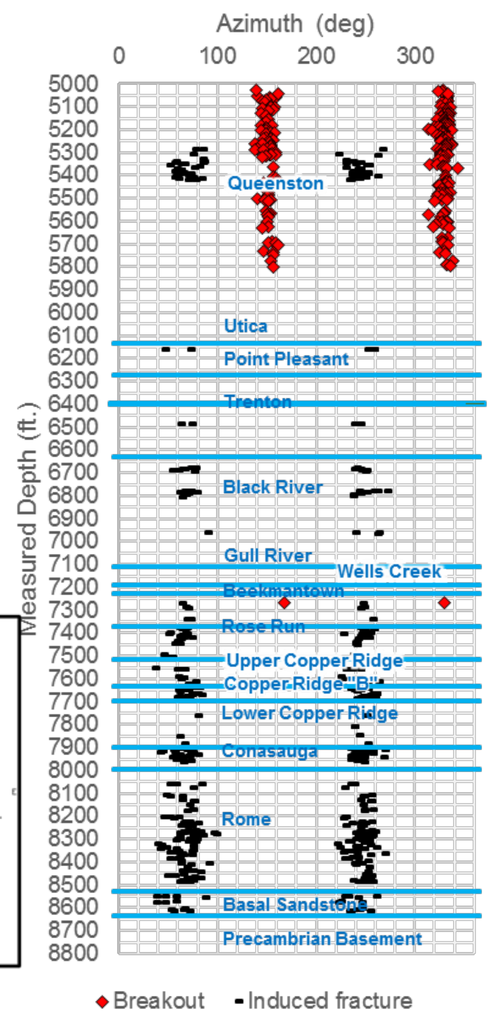
Technical Status

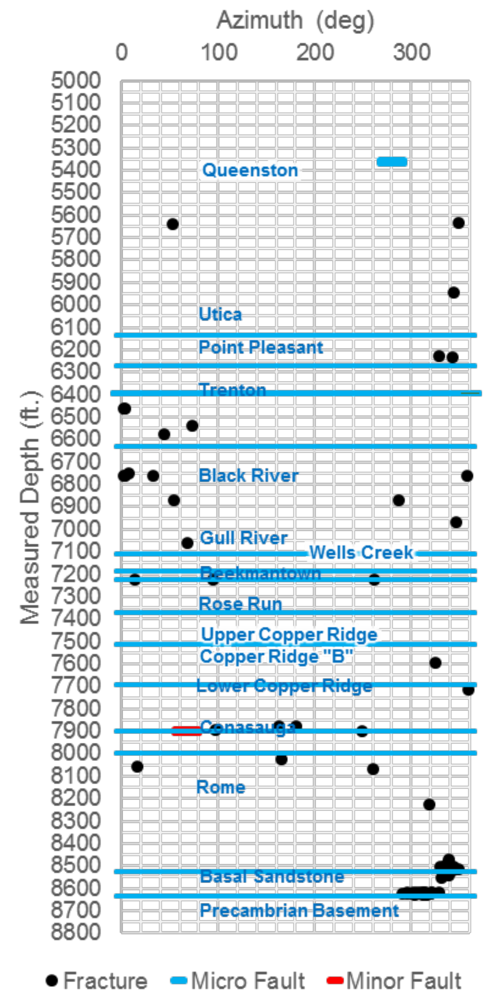
- **East-Central Appalachian Basin site:** 70 fractures, 2 micro-faults, 242 breakouts, 522 induced fractures.





Maximum Horizontal Stress Direction





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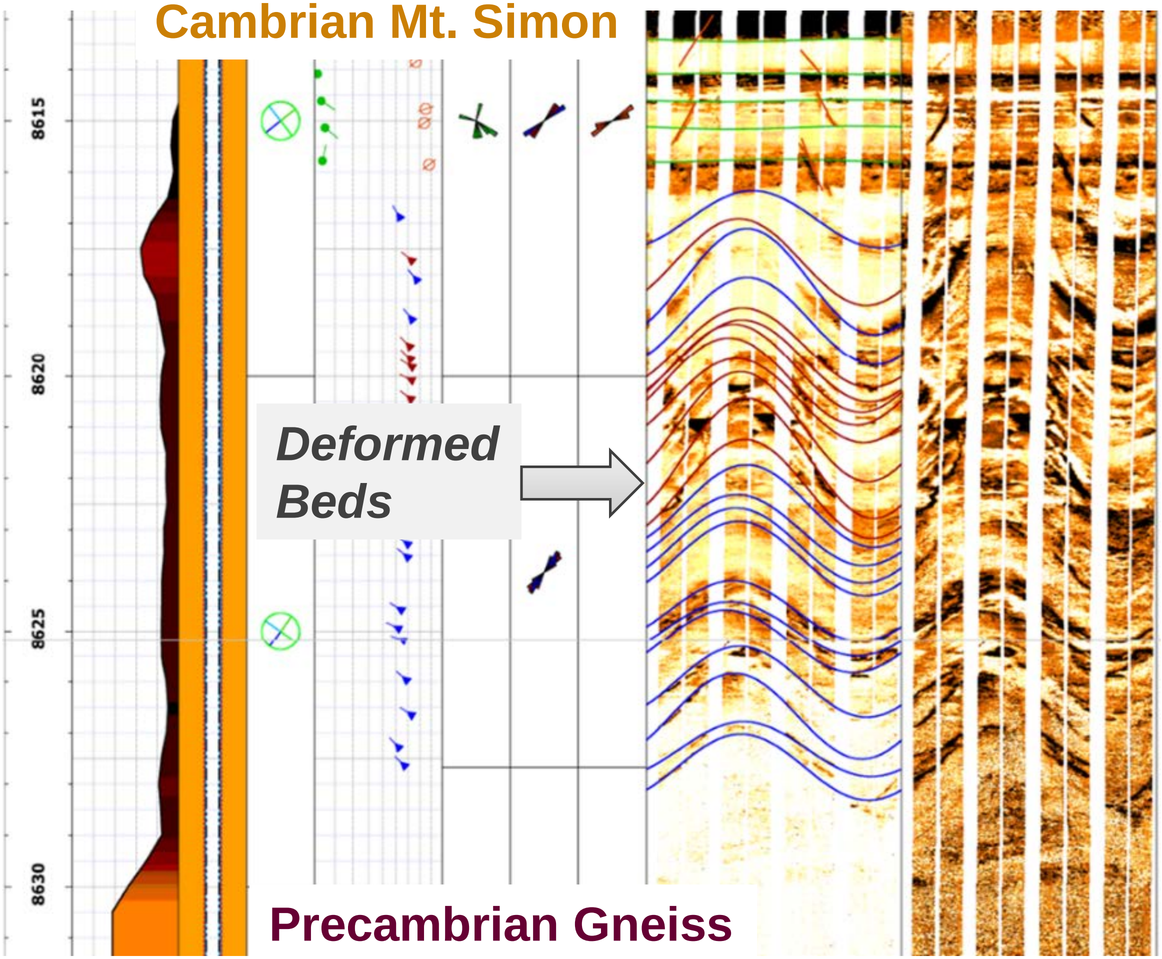
Technical Status

- **East-Central Appalachian Basin** site: Several Deformed beds at the Basal Sand-Precambrian contact.



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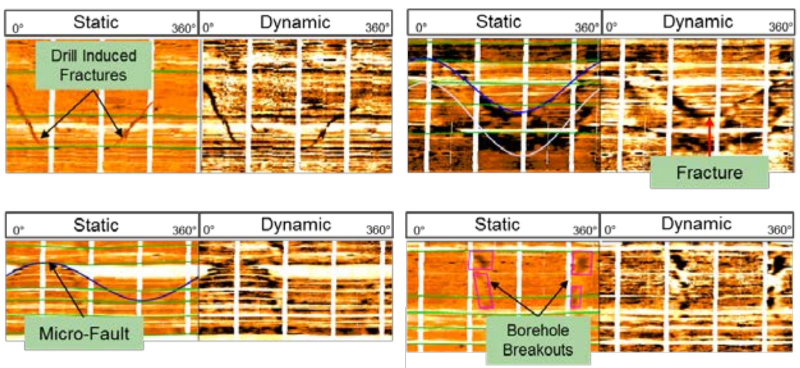
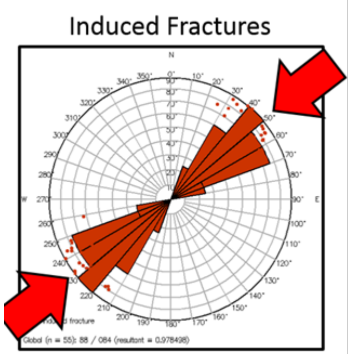
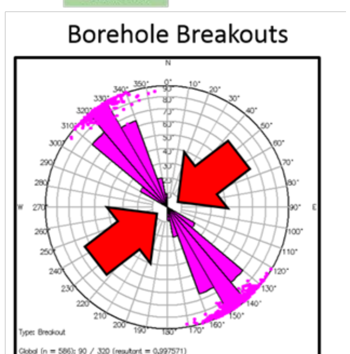
Technical Status

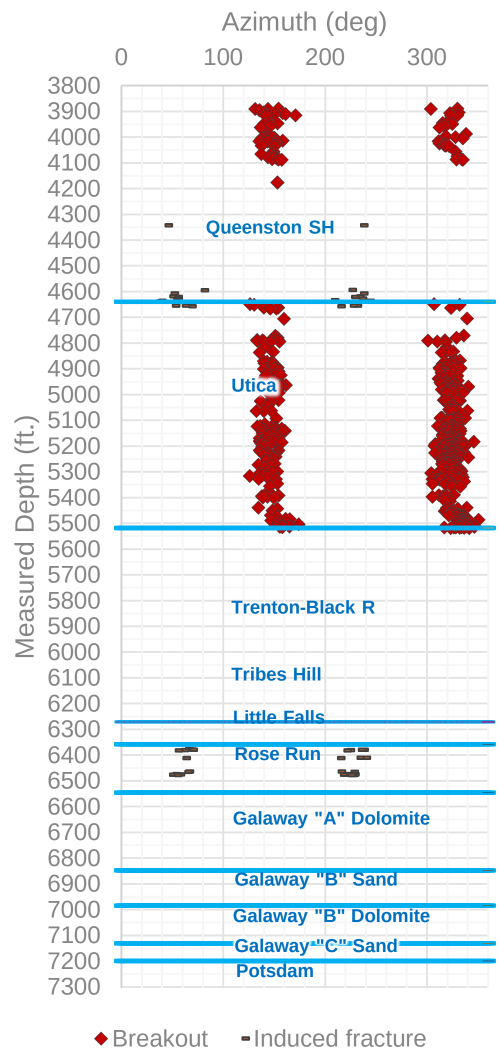
- **Northern Appalachian Basin Site**: 73 fractures, 20 induced fractures, 4 micro-faults, and 12 breakouts were interpreted on image logs.



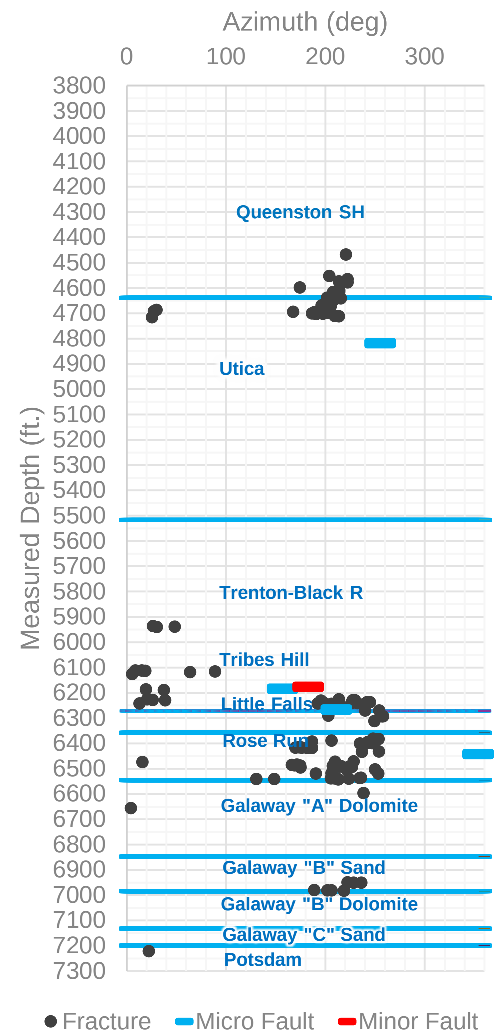




Northern Appalachian Basin Site
Drilling Induced Features



Northern Appalachian Basin Site
Natural features



Maximum Horizontal Stress Direction

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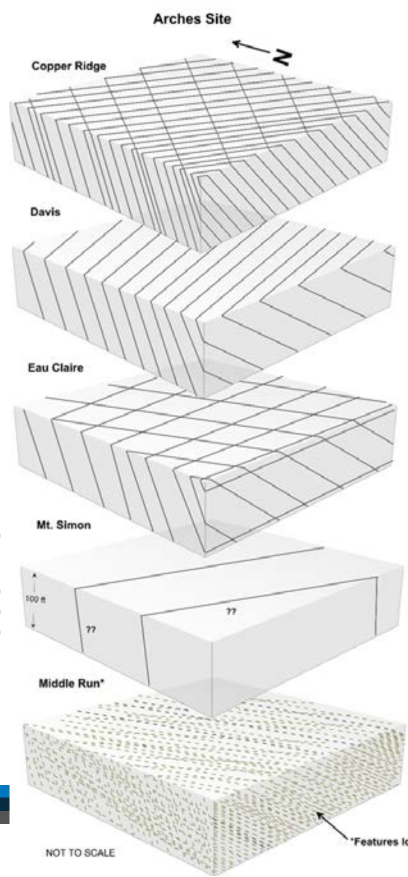
Technical Status- Site Analysis

- Image log analysis, examination of rock core, and thin sections suggest sparse fractures in deeper Ordovician-Cambrian age CO_2 storage zones.

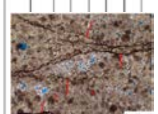
Arches Site

Caprock

Storage Reservoir



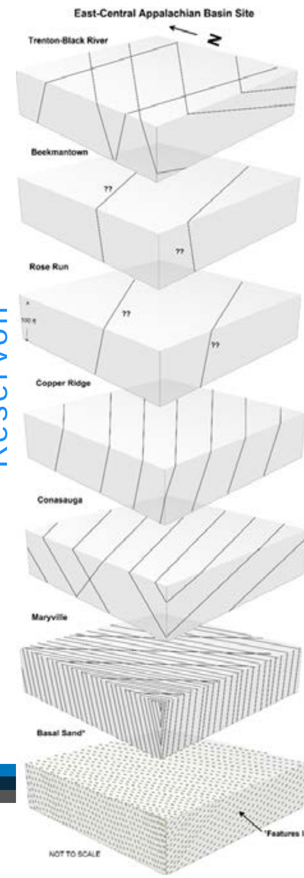
Depth Interval (ft)	Thickness (ft)	Density (fractures/100 ft)	Primary Dip Azimuth	Primary Dip Inclination	Secondary Dip Azimuth	Secondary Dip Inclination	Primary:Secondary
1657-2686	1029	4	120	58	240	58	2:1
2686-2782	96	2	258	32	NA	NA	NA
2782-3230	448	3	273	40	144	40	1:1
3230-3532	302	0	NA	NA	NA	NA	NA
3532-3712	150	29	165	60	300	20	1:1



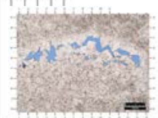
East-Central Appalachian Basin site

Caprock

Storage Reservoir



Depth Interval (ft)	Thickness (ft)	Density (fractures/100 ft)	Primary Dip Azimuth	Primary Dip Inclination	Secondary Dip Azimuth	Secondary Dip Inclination	Primary:Secondary
6352-7230	878	1	28	63	270	80	2:1
7230-7376	146	0	NA	NA	NA	NA	NA
7376-7509	133	0	NA	NA	NA	NA	NA
7509-7896	387	1	225	70	NA	NA	NA
7896-7995	99	2	66	40	250	62	1:1
7995-8524	529	4	337	73	147	73	5:1
8524-8630	106	13	319	65	NA	NA	NA

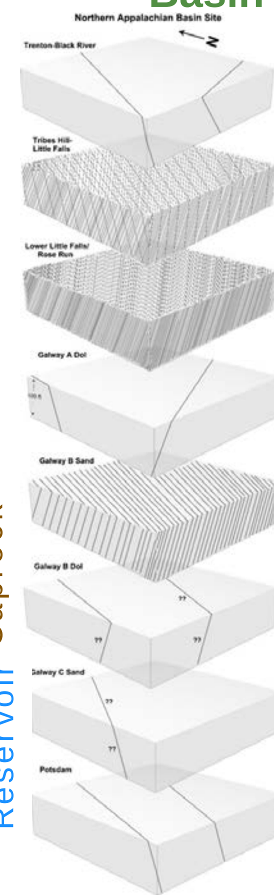


Northern Appalachian Basin site

Storage Reservoir?

Caprock

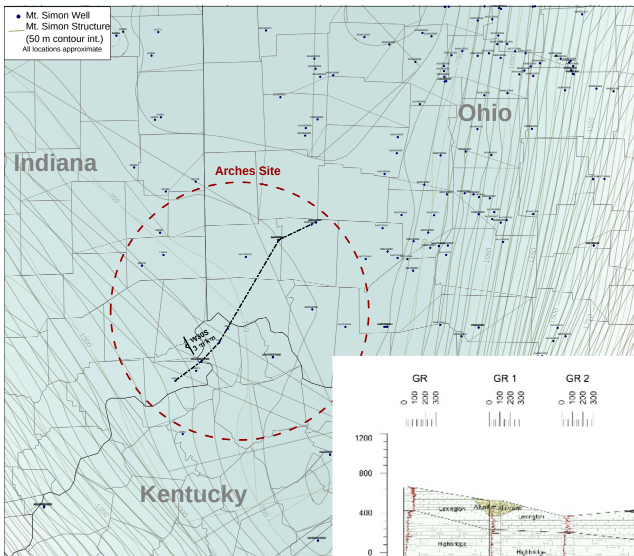
Storage Reservoir



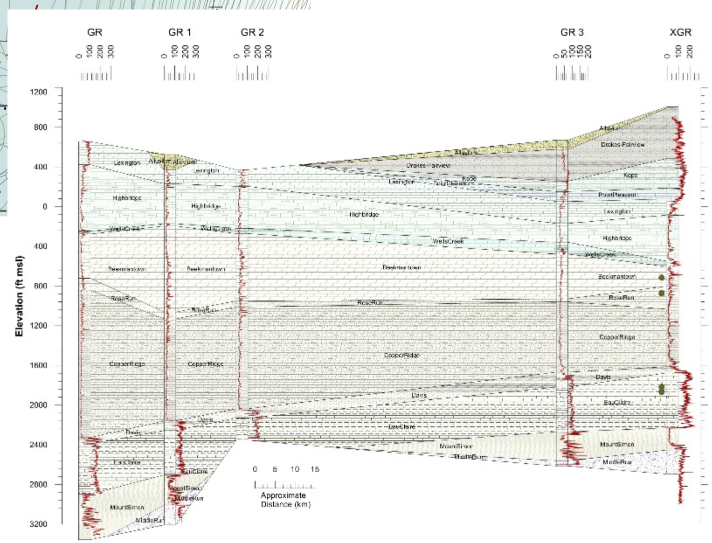
Depth Interval (ft)	Thickness (ft)	Density (fractures/100 ft)	Primary Dip Azimuth	Primary Dip Inclination	Secondary Dip Azimuth	Secondary Dip Inclination	Primary:Secondary
5518-6172	654	1	18	71	67	81	2:1
6172-6359	187	17	225	66	26	63	5:1
6359-6546	187	26	207	74			NA
6546-6848	302	1	239	70	4	65	1:1
6848-6985	137	5	215	72			NA
6985-7075	90	0	0	0			NA
7075-7132	57	0	0	0			NA
7132-7322	190	1	23	69			NA

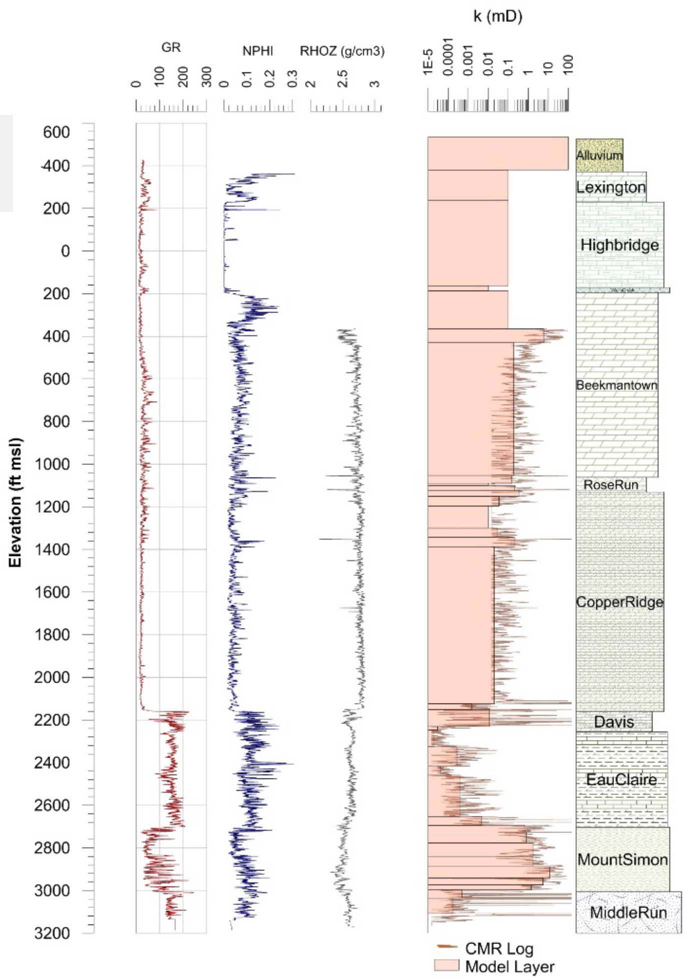
Technical Status- Site Analysis

- Geologic models were built for the 3 sites based on regional well logs, structural geology, and hydraulic parameters.



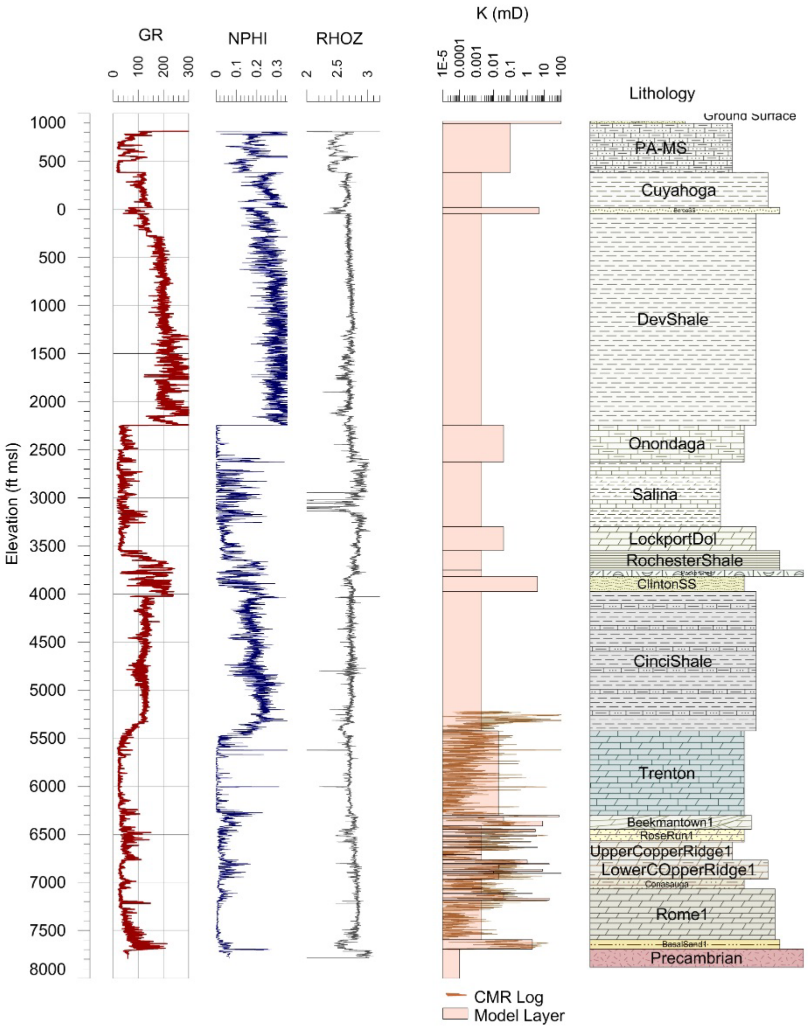
Arches Site



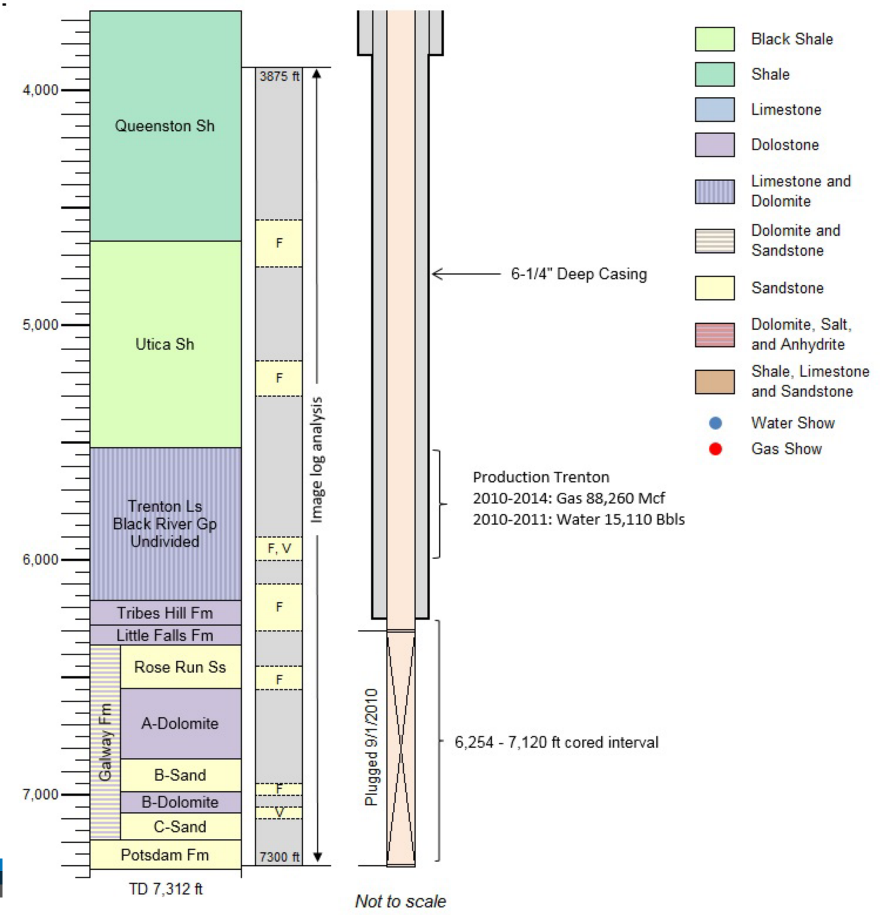


Technical Status- Site Analysis

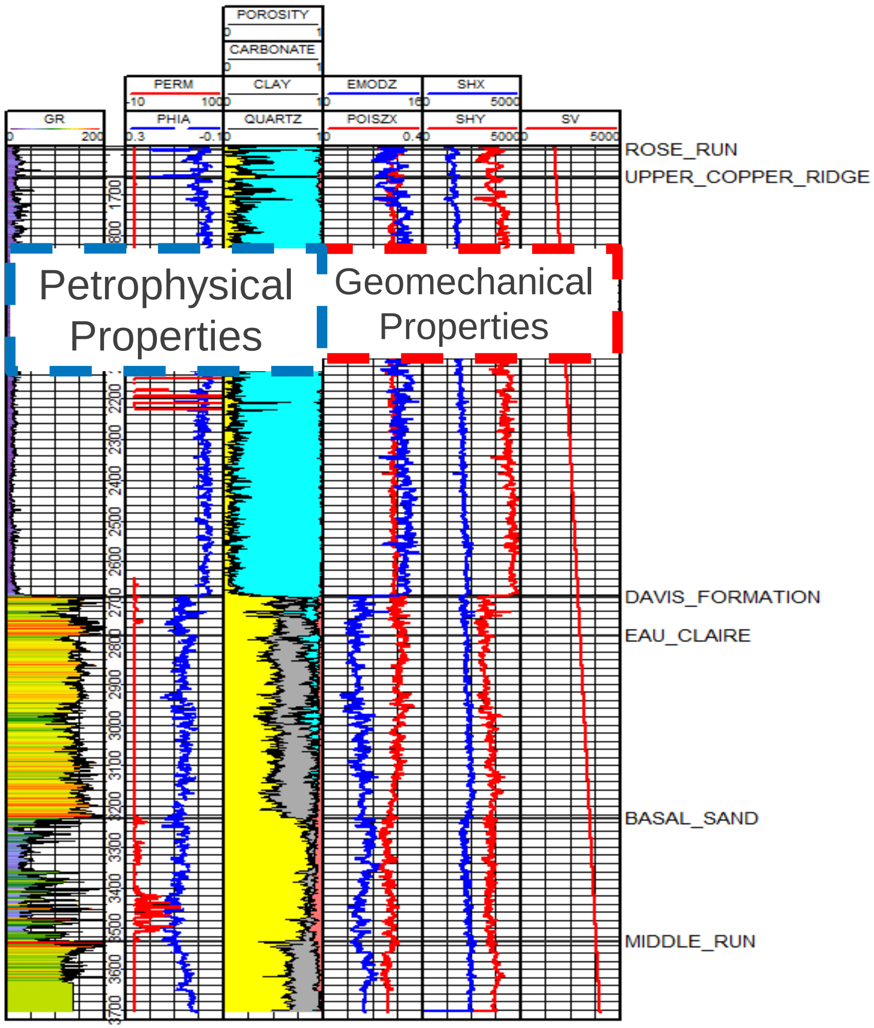
E-Central Appalachian Basin Site



Northern Appalachian Basin Site



Technical Status- Site Analysis



- Geomechanical and petrophysical properties not well-defined in deep saline formations
- Basic and advanced well logs were analyzed to derive geomechanical and petrophysical parameters to define CO_2 injection and cap rock units
  - mineralogy, porosity, permeability, density, Young's modulus, Poisson's ratio, vertical stress, and horizontal stresses

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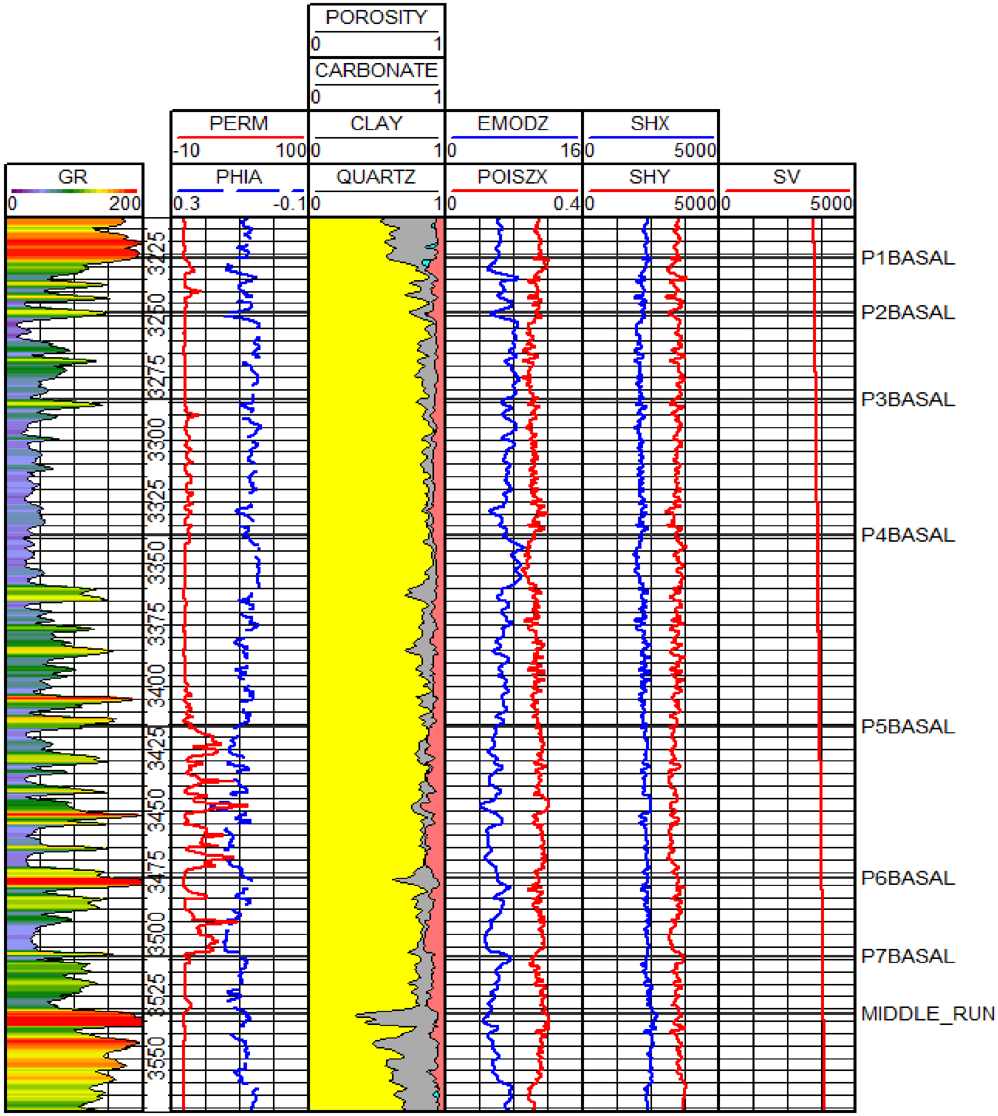
Technical Status



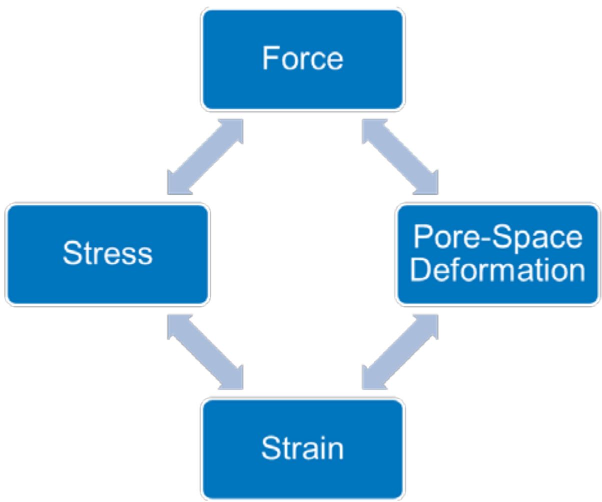
- Geomechanical layers were defined for key storage and caprock formations

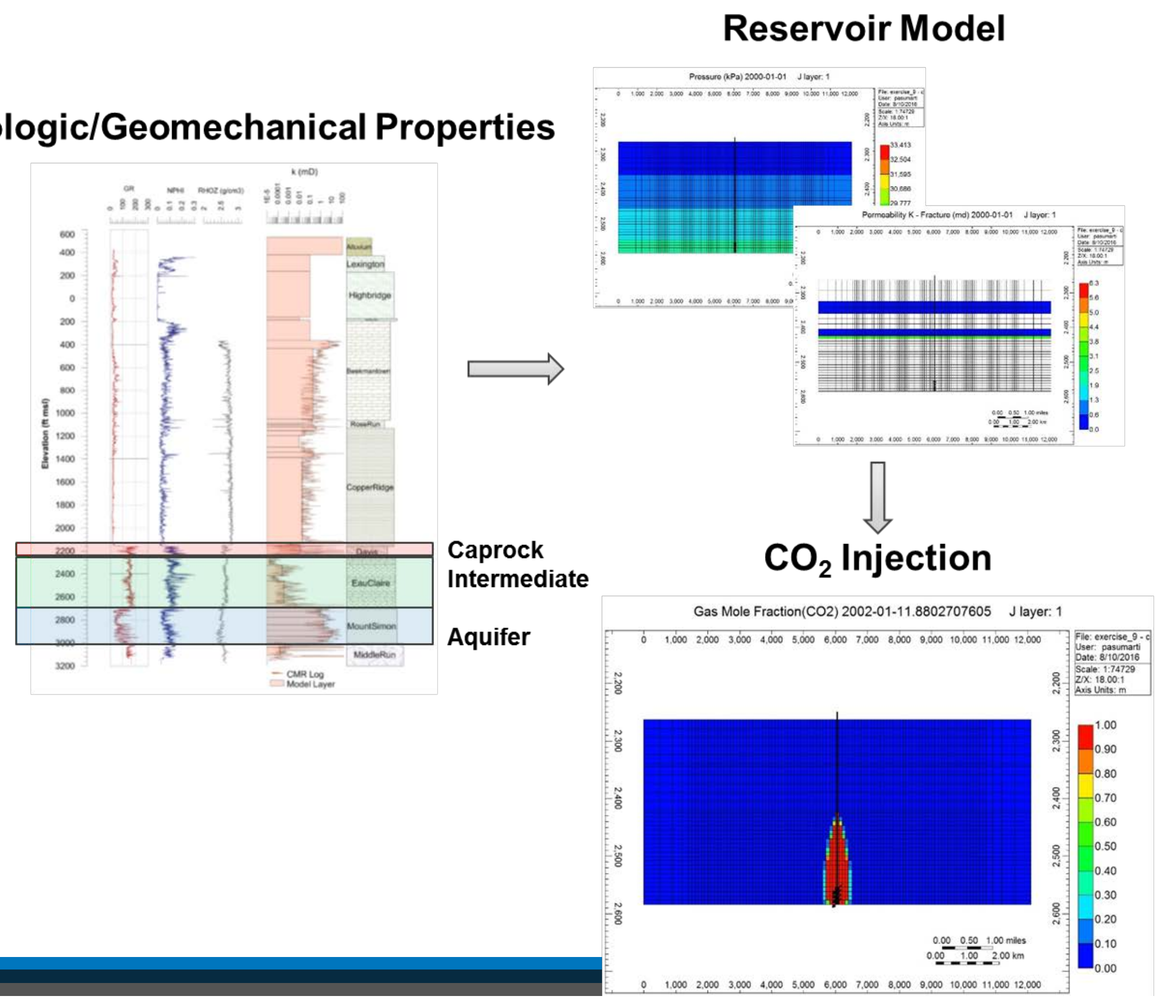
  Ex. Arches Mount Simon Sandstone: Divided Basal Sand reservoir into 7 units that are distinct, in terms of poro-elastic properties for coupled flow-geomechanical simulation

	Poro-elastic Units	Bottom Depth (feet)	Young's Modulus	Poisson's ratio	Sh_{min}/ feet	Sh_{max}/ feet	Porosity	Perm.
Seal	Alluvium-Eau Claire	3,227	8.68	0.29	1.31	3.08	0.02	0.52
Reservoir	P1 Basal Sand	3,249	6.52	0.27	0.68	1.05	0.1	7
	P2 Basal Sand	3,284	7.79	0.25	0.64	1.08	0.06	8
	P3 Basal Sand	3,339	7.08	0.26	0.65	1.03	0.07	17
	P4 Basal Sand	3,416	7.09	0.26	0.64	1.02	0.07	17
	P5 Basal Sand	3,477	5.53	0.28	0.67	0.96	0.12	119
	P6 Basal Sand	3,509	5.85	0.27	0.68	0.98	0.11	55
	P7 Basal Sand	3,643	5.97	0.27	0.68	0.98	0.11	14

Technical Status- Geomech Simulation

- Coupled fluid-flow reservoir geomechanics simulations were completed for the 3 test study areas.

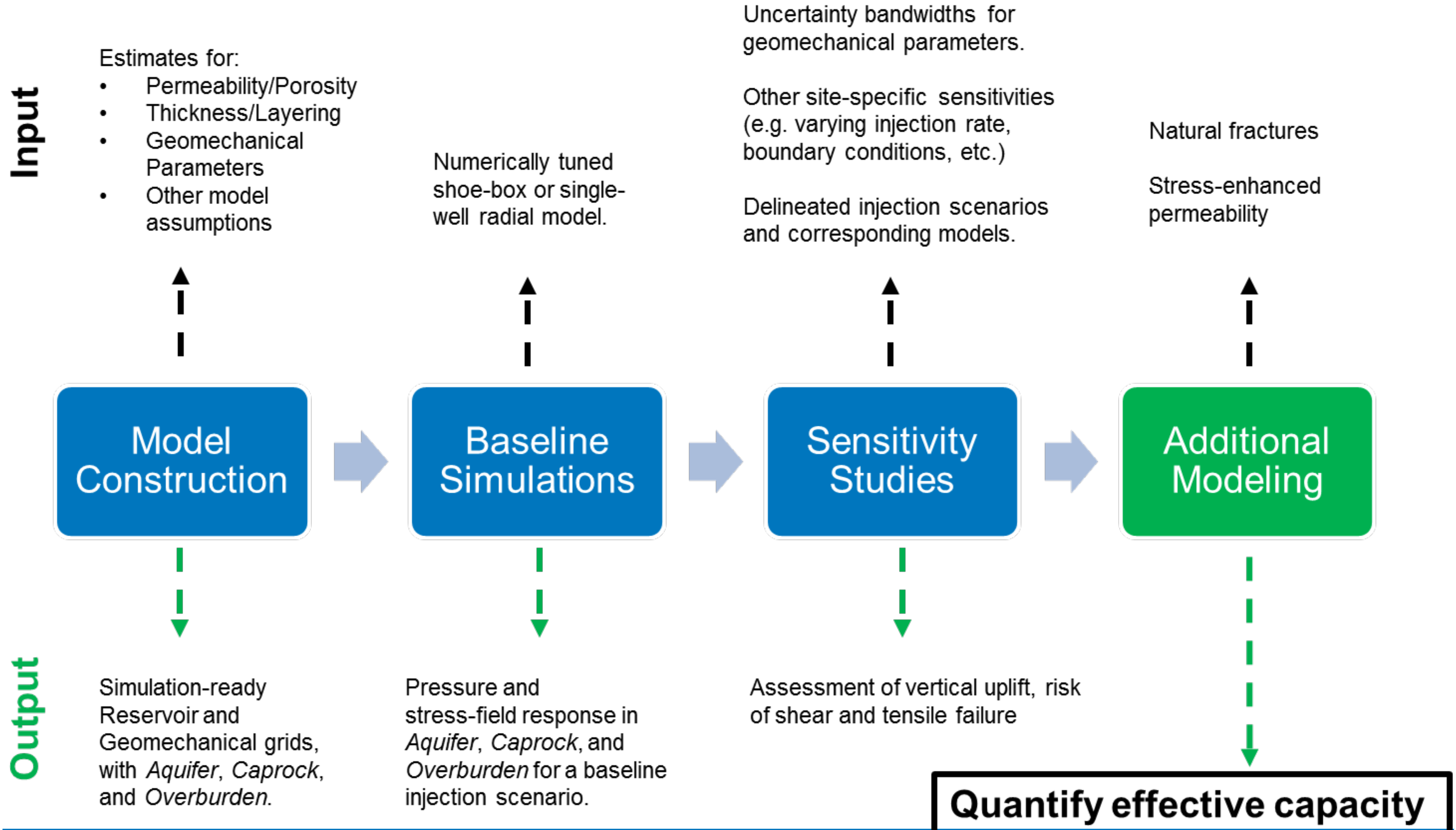




BATTELLE

Technical Status- Geomech Simulation

Analysis Framework for Coupled Fluid-Flow Geomechanics Simulations



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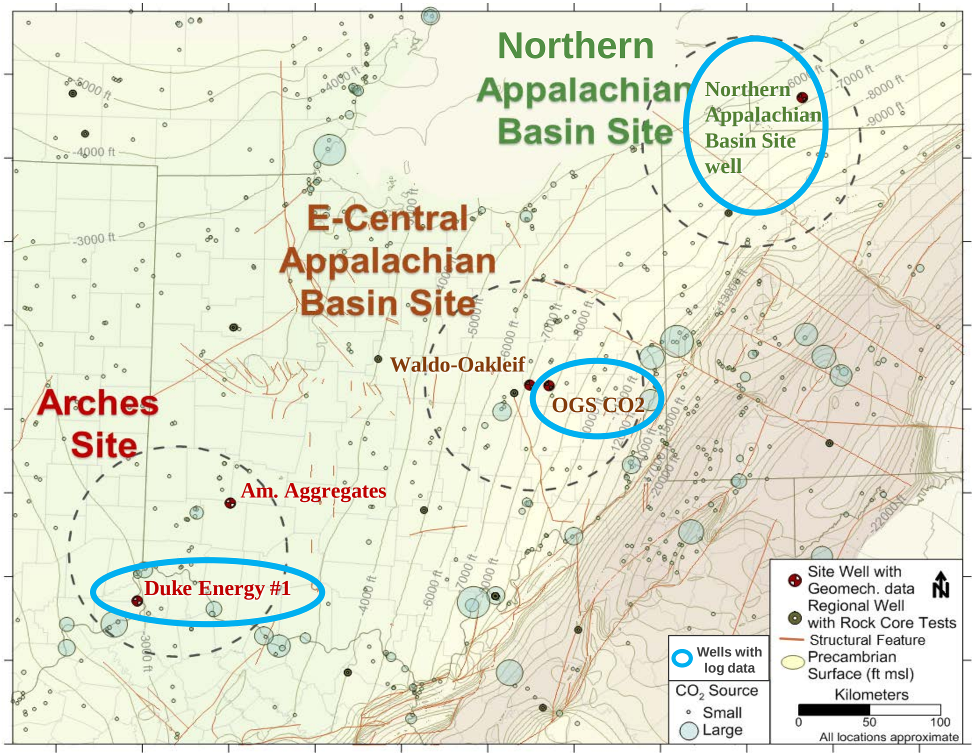
Technical Status- Geomech Simulation

- Coupled flow-geomechanics simulations used to assess:
  - Vertical uplift
  - Fracture activation
  - Induced seismicity
  - Safe operation protocols



WELL Site	Image Log Intervals (ft.)	HSTRESS Log Intervals (ft.)
Northeast Appalachian Basin	3,870-7,305	3,880-7,282
East-Central Appalachian Basin	5,024-8,709	3,090-8,660
Arches	906-3,700	170-3,704
Total Footage Interpreted	**9,914**	**12,506**

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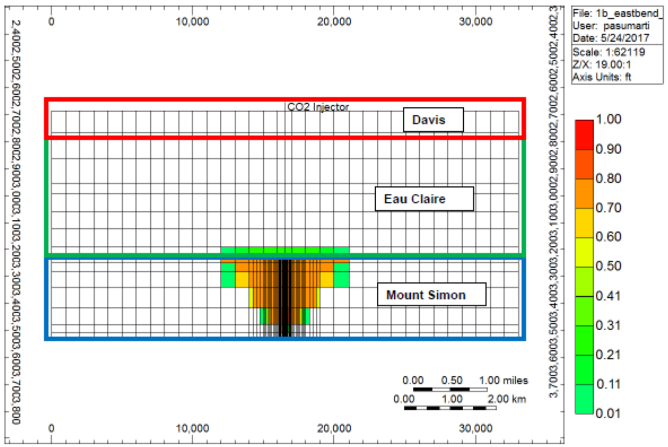
Technical Status- Geomech Simulation

- Coupled flow-geomechanics simulations metrics:

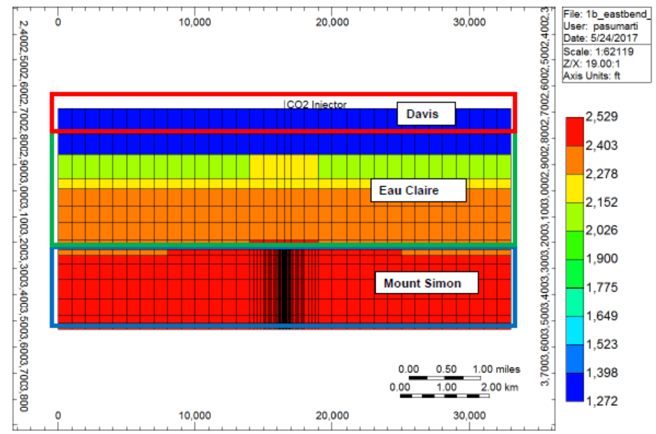
Gas Saturation

Gas Saturation 2030-01-01 J layer: 17



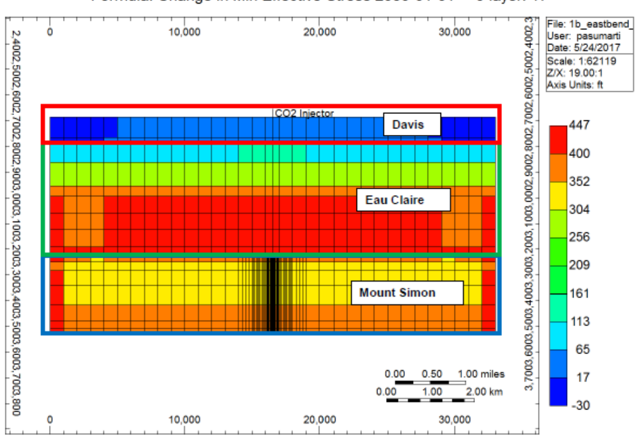
Pressure

Pressure (psi) 2030-01-01 J layer: 17



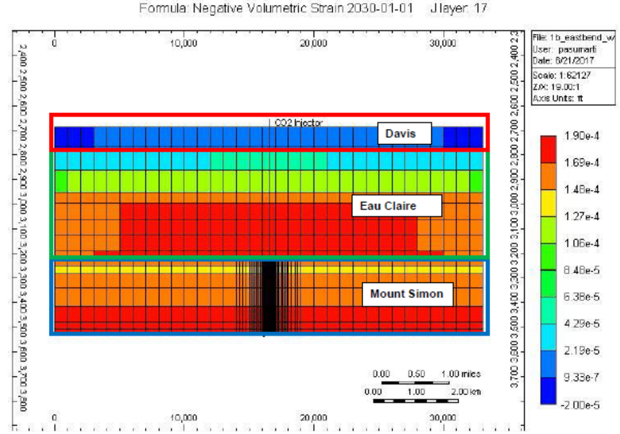
Δ Min. Effective Stress

Formula: Change in Min Effective Stress 2030-01-01 J layer: 17



Volumetric Strain

Formula: Negative Volumetric Strain 2030-01-01 J layer: 17



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Technical Status- Geomech Simulation

- How much CO_2 can we safely inject and store within reasonable geomechanical constraints?
- Coupled flow-geomechanics simulations results were analyzed to examine geomechanical constraints on storage capacity.

Scenario #	Shear Failure?	Tensile Failure?	Surface Uplift (mm)	Storage Capacity (millions of MT)
1 - Base Case (Most Conservative)	No	No	32	11.25
2	No	No	32	11.25
3	No	No	27	11.25
4	No	No	22	12.5
5 (Most Optimistic)	**No**	**No**	**1.2**	**38.25**

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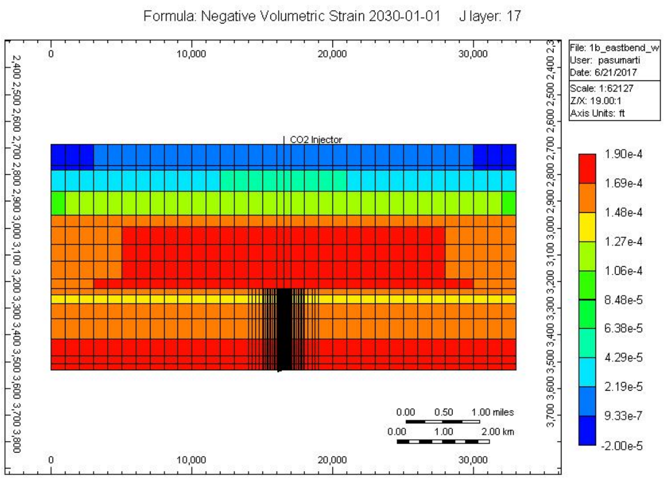
Technical Status- Geomech. Sims

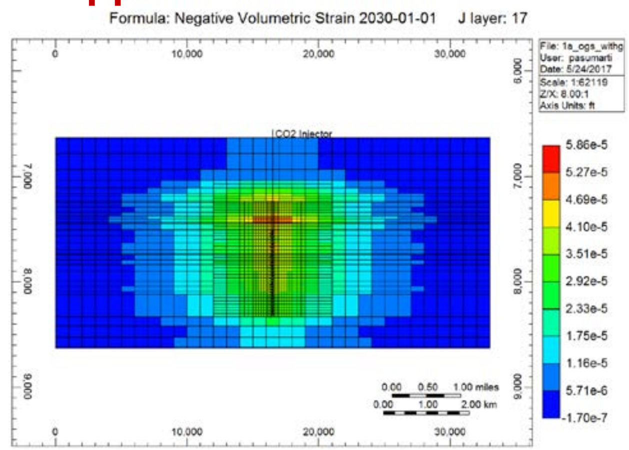
- Together, these three study areas provide a realistic portrayal of the range of geomechanical impacts of CO_2 storage in the Midwest U.S.

Arches Site



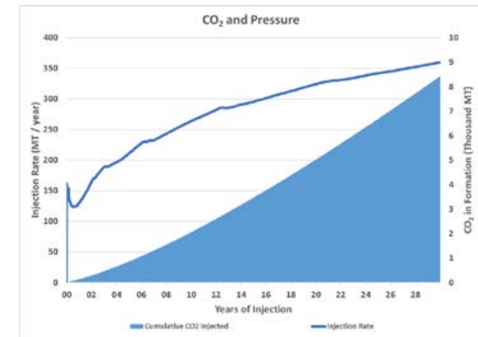
No indication of tensile or shear failure, The stress-strain perturbations are isolated beneath the caprock. Given the shallow depth of the Mount Simon, up to 32 mm of uplift may be expected at the surface >10 million metric ton capacity per well for 30 year injection scenario.

East-Central Appalachian Basin site



No tensile or shear failure, stress-strain perturbations isolated beneath the caprock, up to 4 mm of uplift may be expected at the surface (due to higher Young's modulus values and the deeper injection zone), 30-year effective capacity of ~10 million metric tons CO_2 ,attractive candidate for stacked, multi-reservoir storage of commercial-scale volumes of CO_2.

Northern Appalachian Basin site



Simulation results showed that commercial-scale injection was not feasible due to extremely low injectivity. Geomechancial effects secondary issue. Maybe a fracture reservoir zone.

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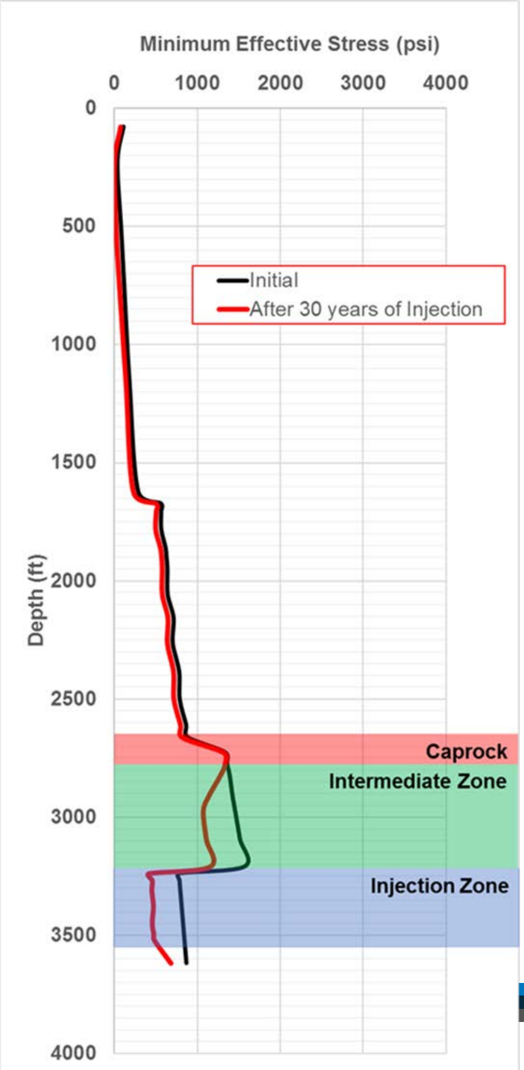
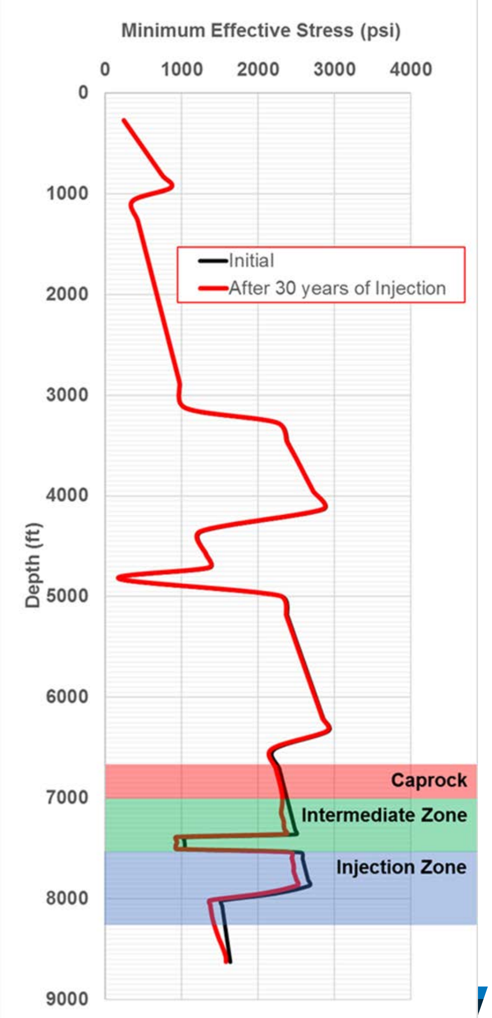
Technical Status- Geomech Sims

- Vertical profile (from the surface to the injection zone) of the minimum horizontal effective stress before and after injection suggests minor effects into caprock and shallow intervals.

Arches Site



East-Central Appalachian Basin site



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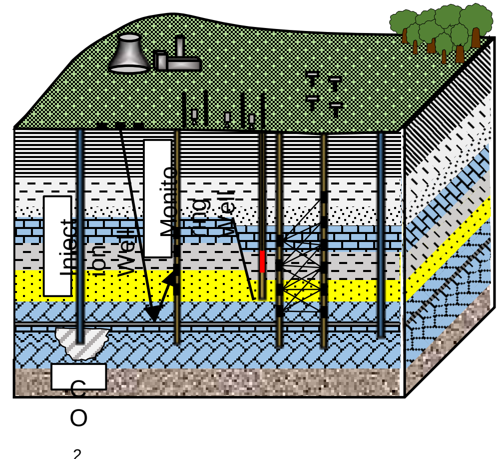
Technical Status- Guidance for Geomechanical Site Characterization

- Guidance document developed for sites with geomechanical concerns in the following areas:
  - Geophysical Logging
  - Geomechanical Rock Core Testing
  - Injection Testing
  - Geomechanical Monitoring
- Conclusion- many geomechanical testing, monitoring, and operating options available to ensure safe, secure CO_2 storage.



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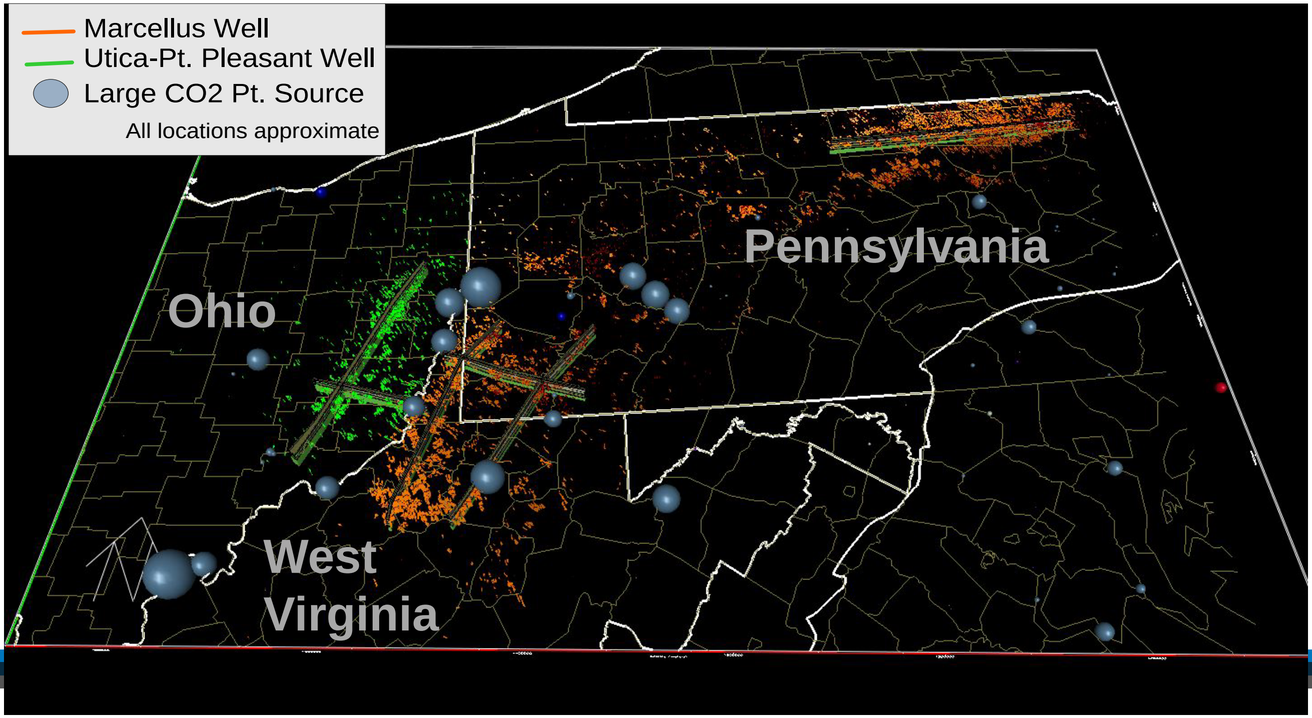
Technical Status- Shale Gas Risk Factors

- There are many deep saline formations and depleted oil & gas fields suitable for CO_2 storage requiring consideration of the potential interaction with unconventional shale gas development.
- Mapping of 10,719 Marcellus and 2,114 Utica-Point Pleasant unconventional well top-hole and bottom-hole locations and true vertical depths portrays the wells' spatial distribution in the subsurface.



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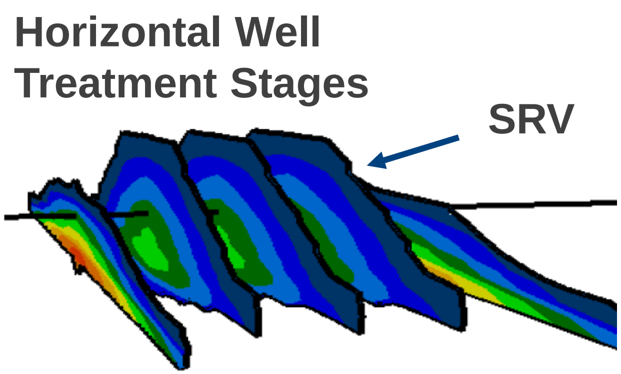
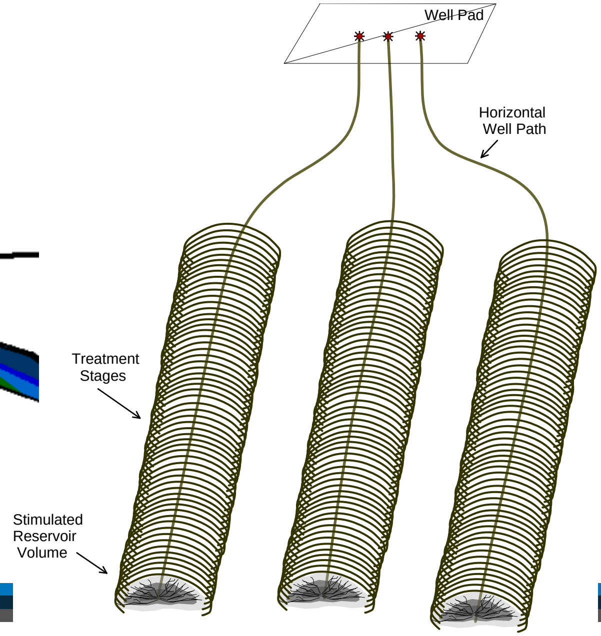
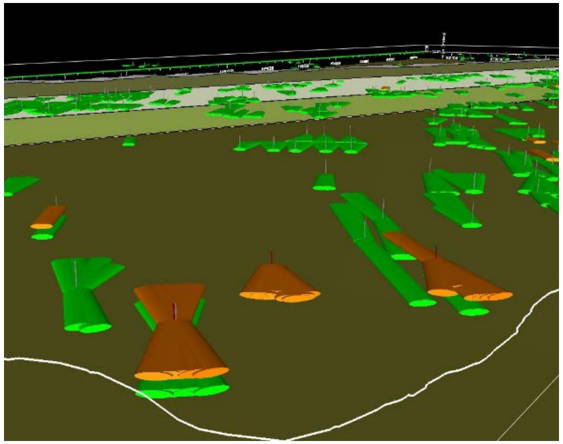
Technical Status- Shale Gas Risk Factors

- Stimulated reservoir volume extends from well along multiple treatment stages. Many (50-75) stages may form a sort of “fracture tunnel” in the subsurface.
- While large areas are covered by horizontal shale gas SRVs, they are mostly limited to discrete, vertical shale intervals, which are not key caprocks for CO_2 storage.







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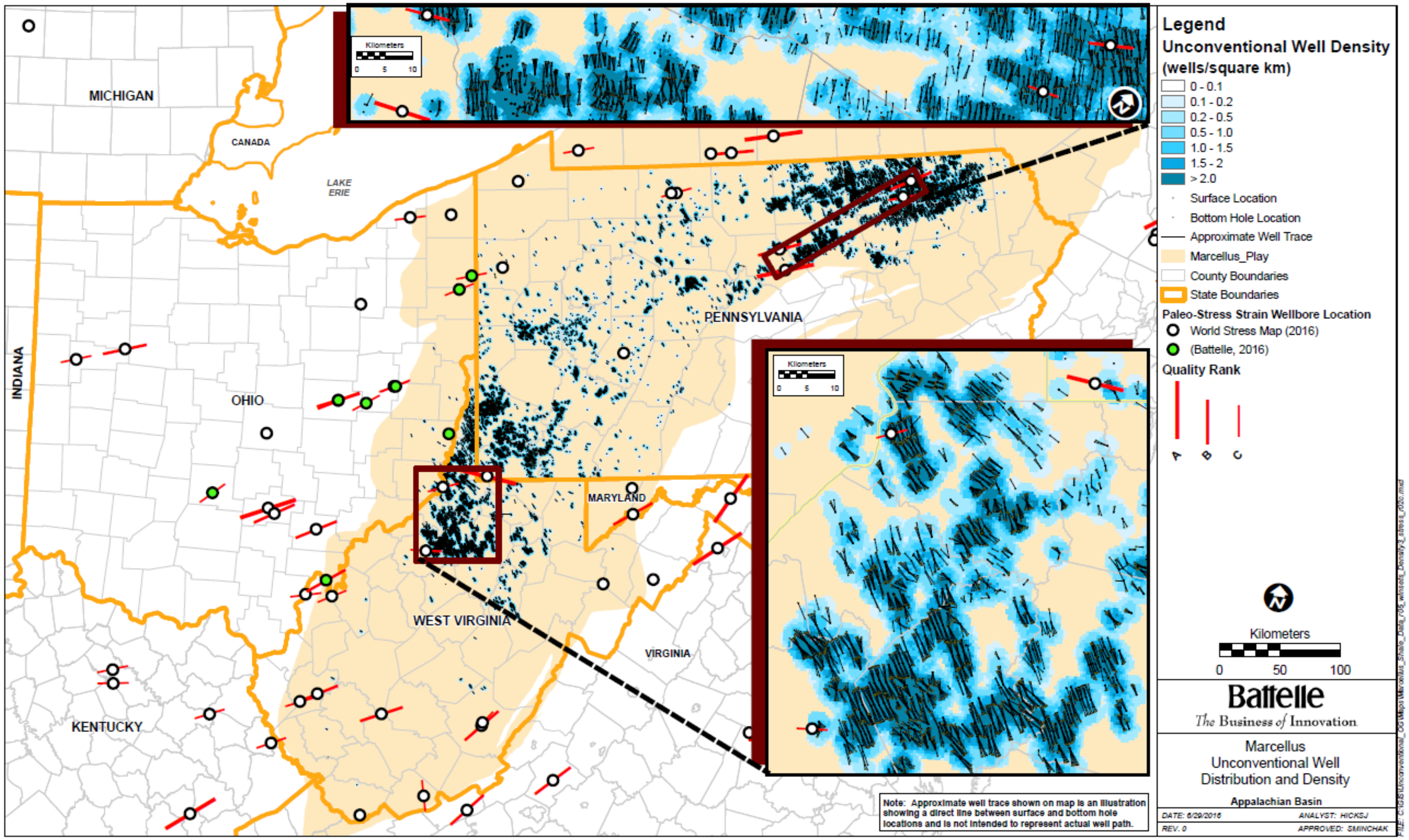
Technical Status- Shale Gas Risk Factors

- More than 13,000 horizontal shale gas wells were mapped to determine their impact on CO_2 storage zones.

Marcellus



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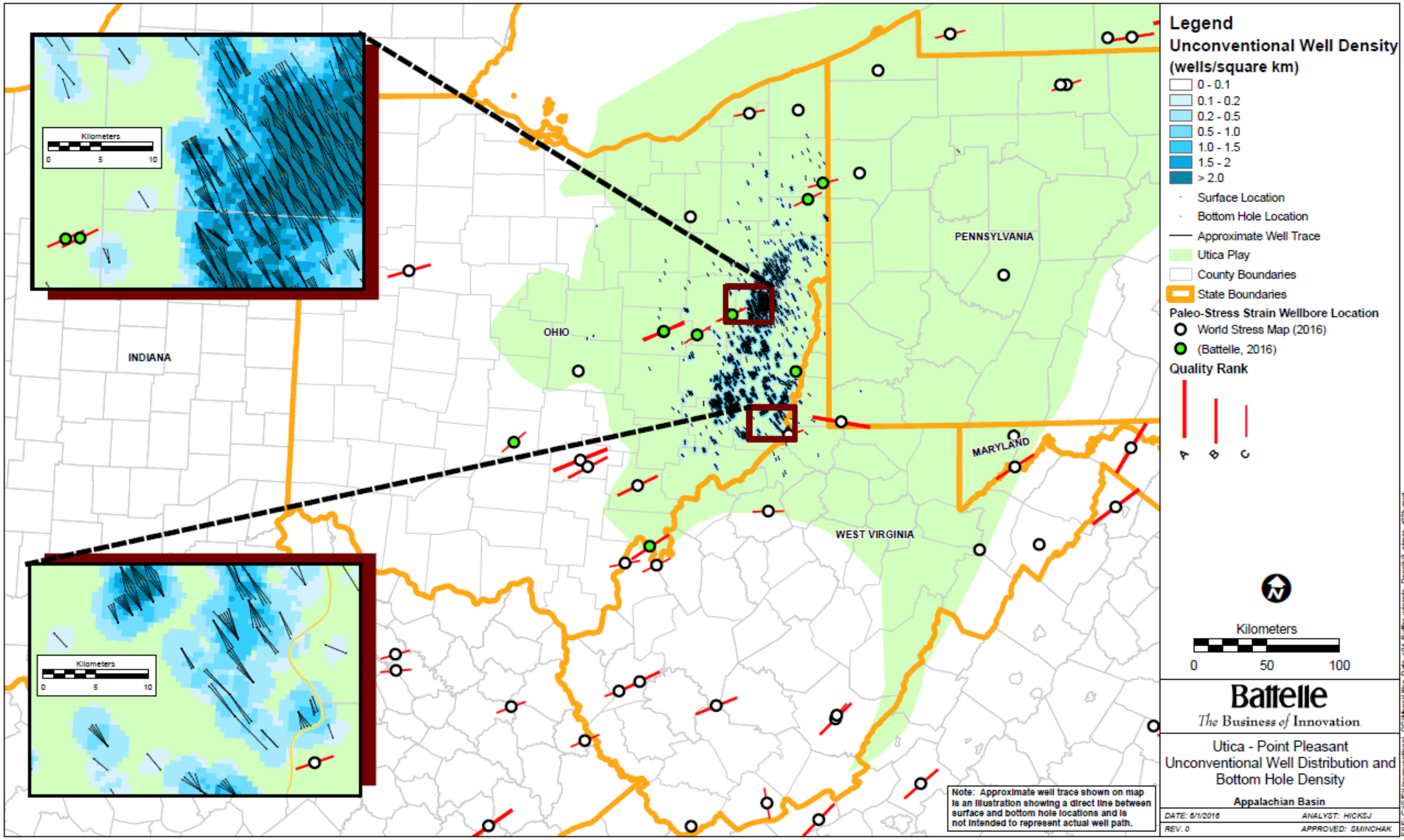
Technical Status- Shale Gas Risk Factors

Utica-Pt. Pleasant



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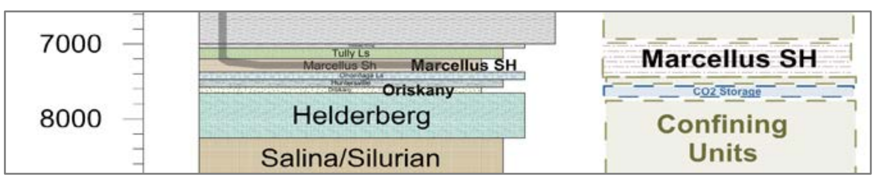
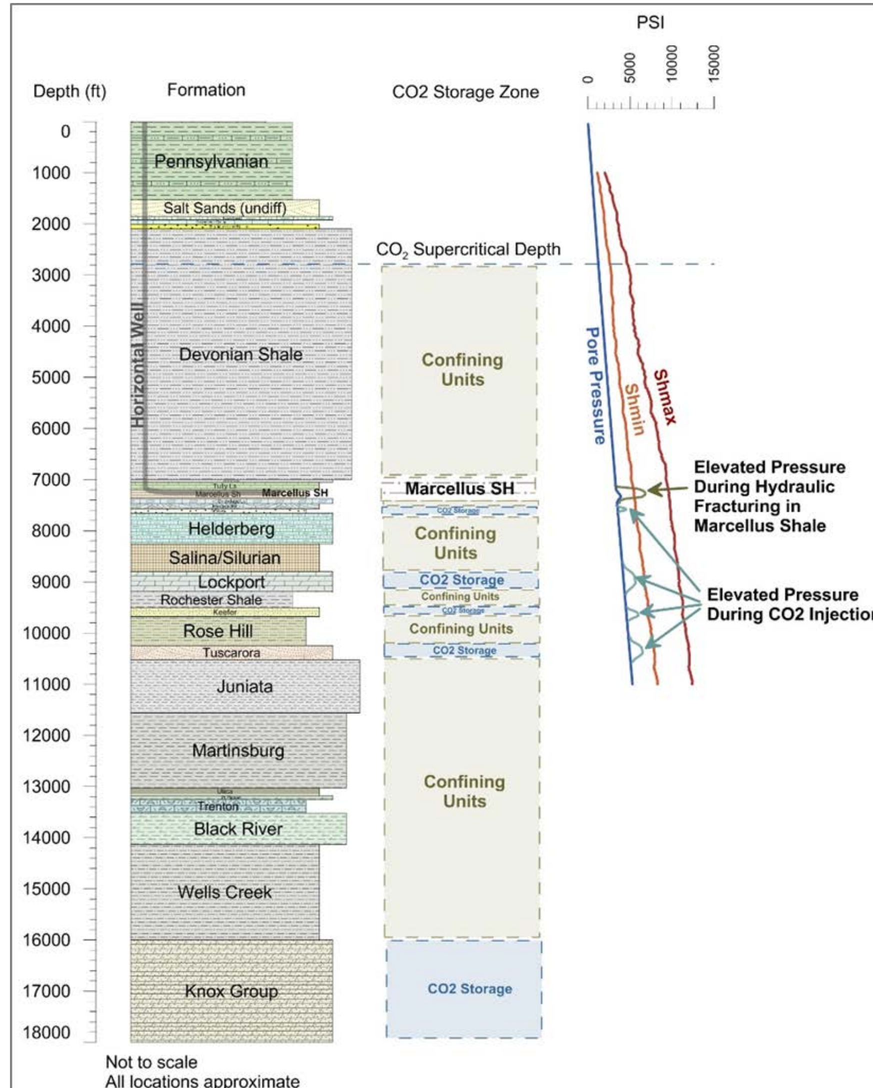
Technical Status- Shale Gas Risk Factors

- Organic shales in the Midwest are not considered primary caprocks for CO_2 storage formations
- Marcellus shale & Utica Point-Pleasant shale are vertically separated from most key CO_2 storage rock formations by several caprock layers and/or intermediate layers with combined thickness >1,000 feet in most areas. Exception = Oriskany Sandstone.





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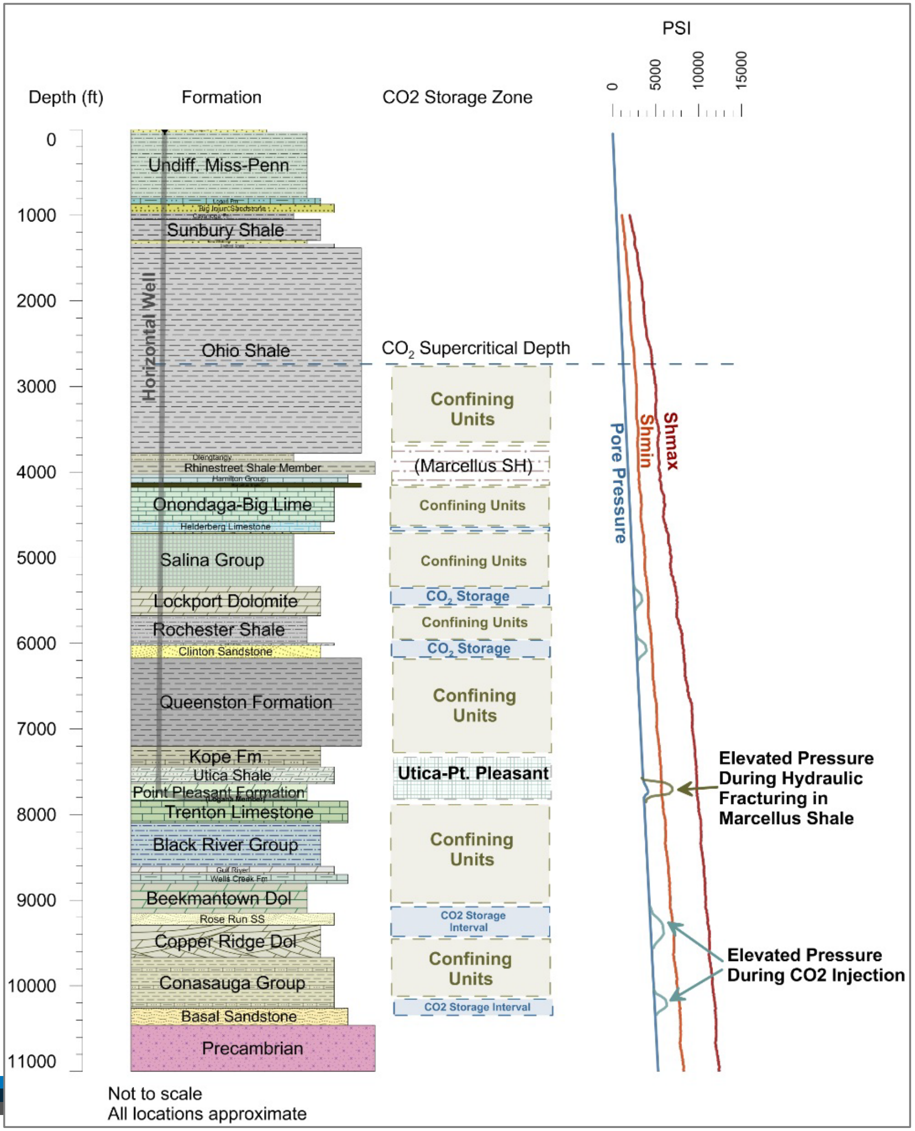
Technical Status- Shale Gas Risk Factors

- Geomechanical simulations suggest that stress changes from CO_2 storage applications are unlikely to affect developed shale gas intervals where they might activate previously hydraulically fractured zones.
- Potential geomechanical effects on legacy oil & gas wells appear to be limited to areas with both CO_2 storage zones and shale gas development, mostly in northern West Virginia and southwestern Pennsylvania, where there is a high concentration of Marcellus wells.



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Accomplishments to Date

- Technical tasks complete. Remaining work = Final Technical Reporting

✓ 2. Systematic assessment of the stress-strain setting for geologic formations in the Appalachian Basin,

✓ 3. Compile geomechanical parameters & data analysis,

✓ 4. Petrophysical log analysis and integration,

✓ 5. Methodology for evaluating potential geomechanical stress at CO_2 storage sites,

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

✓ 7. Caprock simulations, and

✓ 8. Assessment of CO_2 storage in areas with hydraulic fracturing for shale gas development.

Year 1

Year 2

Year 3

Lessons Learned

- Analysis on natural fracture orientation indicates a complex pre-dominant northeast-southwest trend in horizontal stress.
- Processing and analysis of 9,700 ft of geophysical image logs provides a better understanding of geomechanical conditions and features in the Midwest U.S.
- Guidance developed for sites with geomechanical concerns for geophysical logging, rock core testing, injection testing, and geomechanical monitoring.
- Marcellus shale & Utica Point-Pleasant shale are vertically separated from most key CO_2 storage rock formations by several caprock layers and/or intermediate layers.

Lessons Learned

- Description of geomechanical setting for sites in the Arches Provinces, Northeast Appalachian Basin, and Northern Appalachian Basin depict variations in geologic storage across the region.
- Coupled CO_2 injection flow-geomechanics simulations illustrate geomechanical effects and constraints on CO_2 injection rates, storage capacity, and geomech effects.
- Together, research provides a realistic portrayal of the range of geomechanical impacts of CO_2 storage in the Midwest U.S. Acquiring site-specific geomechanical parameters is essential for a wholistic evaluation of CO_2 injection sites. Results generated in this research benefit the establishment of CO_2 storage applications.

Synergy Opportunities

- 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.
- Results may be used for issues like induced seismicity, safe injection protocols, and system design.

Project Summary

- Systematic inventory of site-specific geomechanical parameters for potential CO_2 storage reservoirs in the Midwest U.S.
- Better understanding of stress parameters for the region, which are key input for geomechanical analysis.
- Reduction in uncertainty related to key geomechanical analysis input, such as magnitude of geomechanical stress in the reservoirs.
- Methodology for characterizing deep rock formations with geophysical logs, rock core tests, geomechanical analysis, and CO_2 storage potential.
- Support research on induced seismicity in the reservoirs by developing a regional stress framework and determining safe injection pressures.
- Assessment of the impact of shale gas development on CO_2 storage potential for the region.

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Thanks!

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It can be done

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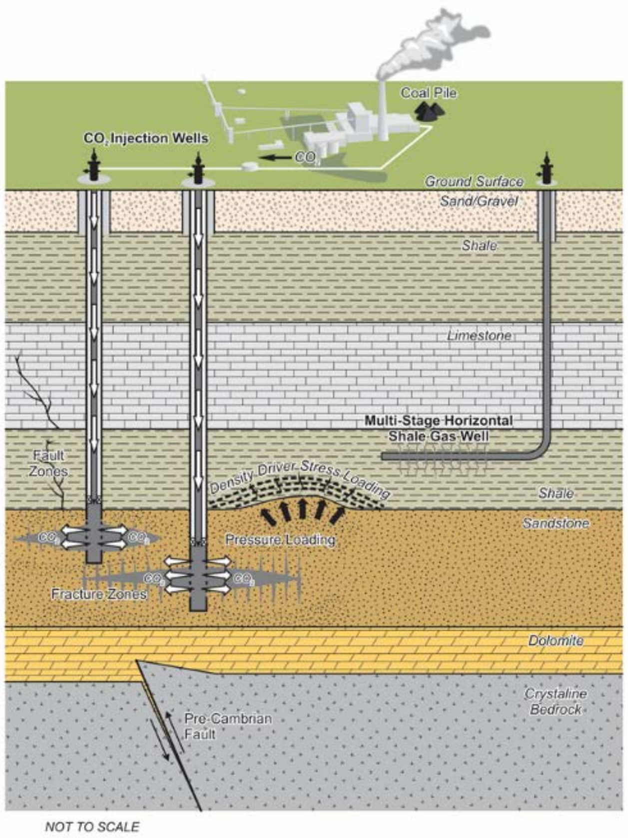
Appendix

Benefit to the Program

- The project addresses FOA 1037 Area of Interest 1-Geomechanical Research.
- Specifically, research impacts include:
  - characterizing the paleo-stress/strain setting in the Midwest U.S.,
  - 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.



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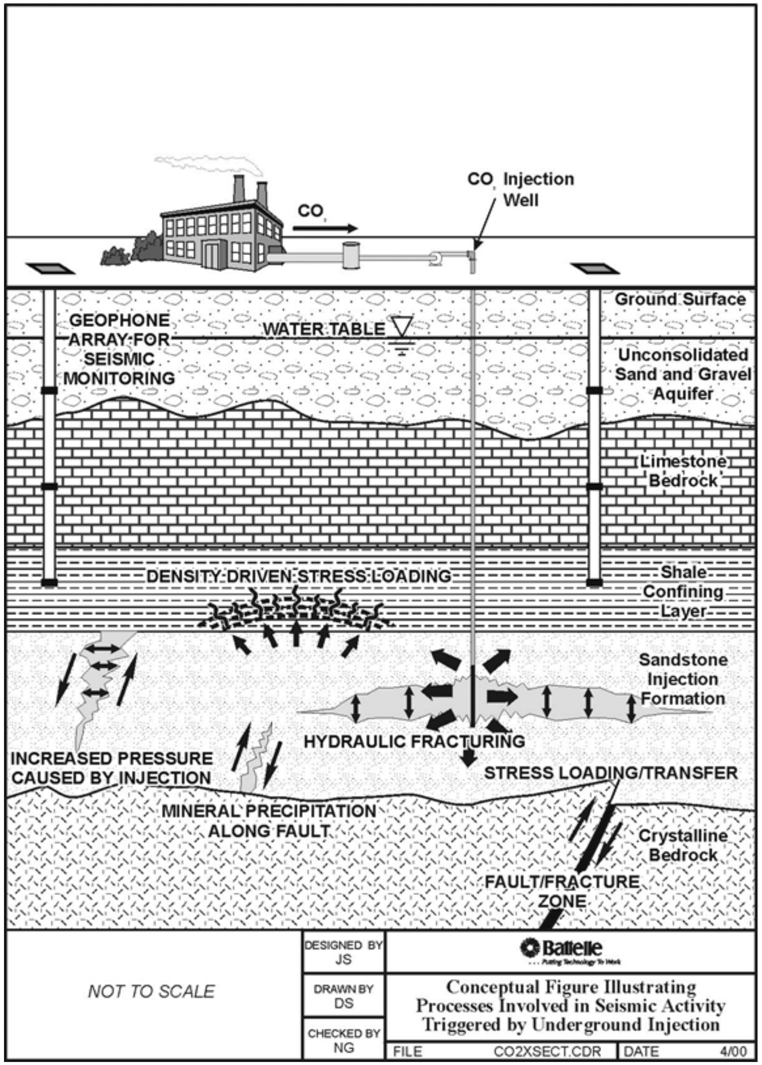
Benefit to the Program

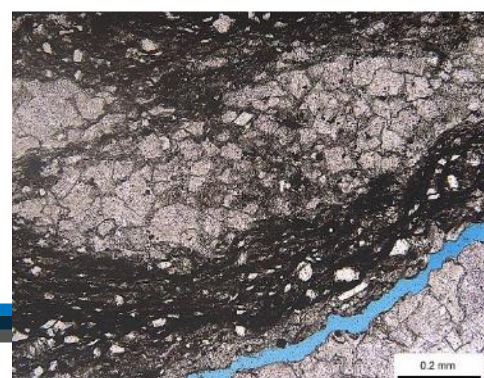
- Geomechanical stability of rock formations has been identified as a major challenge to large-scale carbon capture and storage applications.
- Faults, fractures, seismic stability can affect CO_2 injection potential and storage security.



Sminchak, J.R., and Gupta, N. 2003. *Aspects of induced seismic activity and deep-well sequestration of carbon dioxide*. Environmental Geosciences, v. 10, n. 2, pp. 81-89.

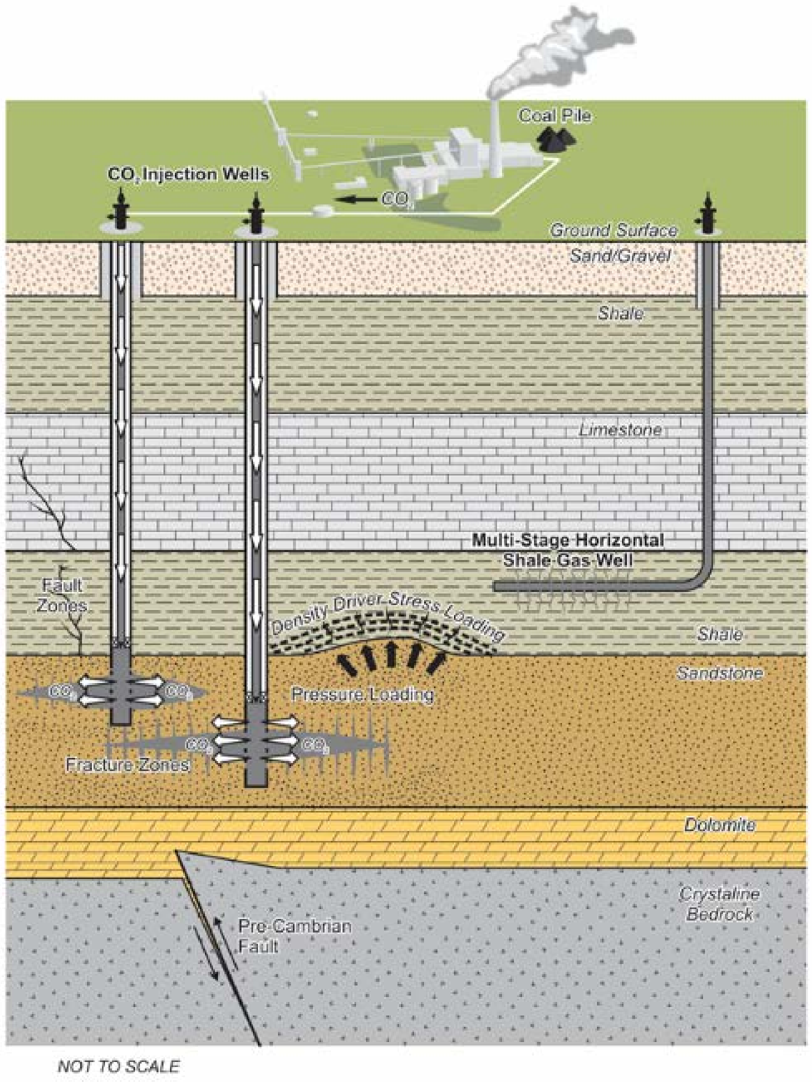
Benefit to the Program

- 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?



Project Overview

- The project addresses geomechanical issues for CO_2 storage applications. Specifically, research impacts include:
  - characterizing the paleo-stress/strain setting in the Midwest U.S.,
  - defining geomechanical parameters,
  - evaluating the potential for (and effects of) subsurface deformation,
  - assessing CO_2 storage processes based on site specific geomechanics.



Project Overview

- Project consists of 7 main technical tasks:

2. Systematic assessment of the stress-strain setting for geologic formations in the Appalachian Basin,
3. Compile geomechanical parameters & data analysis,
4. Petrophysical log analysis and integration,
5. Methodology for evaluating potential geomechanical stress at CO_2 storage sites,
6. Reservoir simulations to evaluate geomechanical deformation in geologic reservoirs in the region,
7. Caprock simulations, and
8. Assessment of CO_2 storage in areas with hydraulic fracturing for shale gas development.

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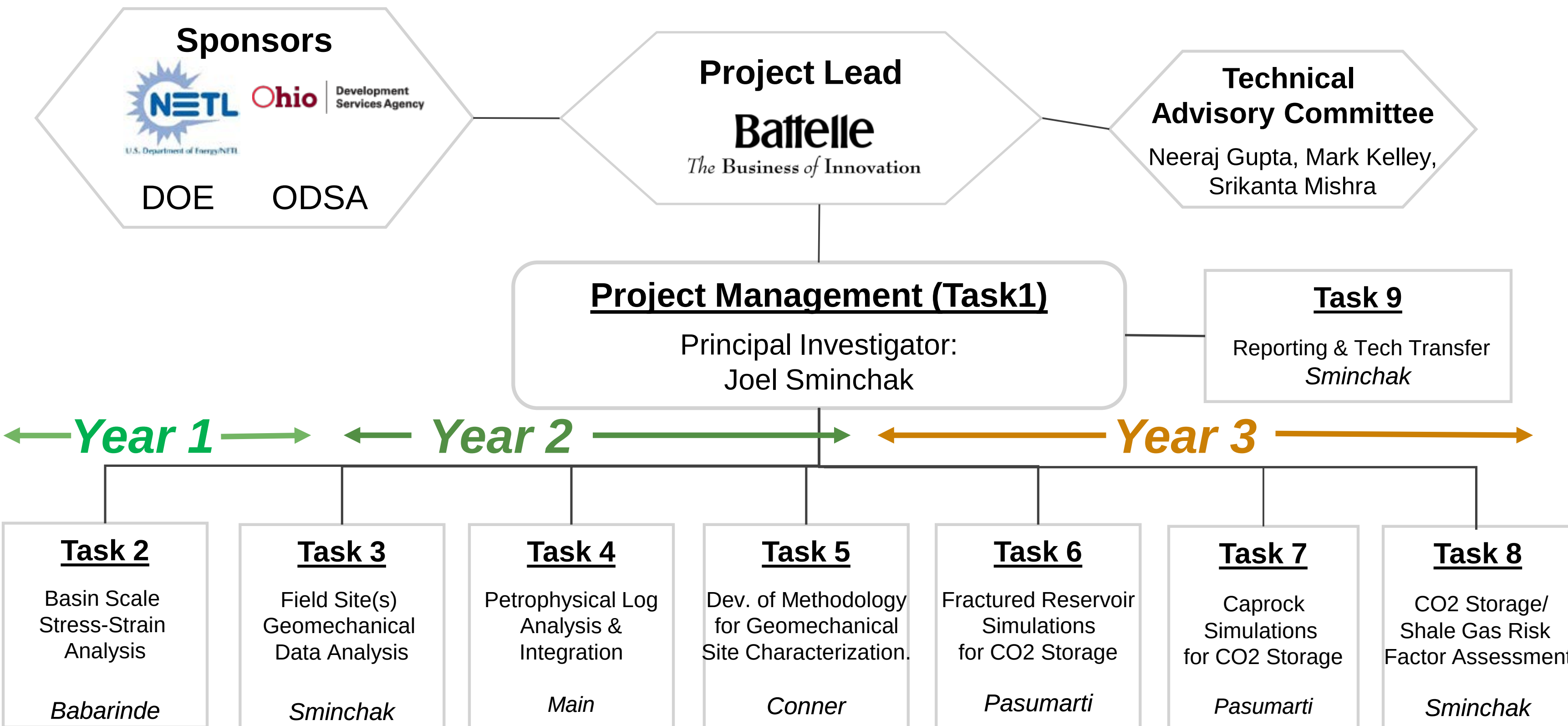
Organization Chart

- 3 year project from October 2014-September 2017.
- Project is divided into seven main technical tasks.



Gantt Chart

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

Task Name	BP1				BP2				BP3			
	FY2015				FY2016				2017			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1: Project Management & Planning												
1.1 Update Project Mgmt. Plan	u											
1.2 Project Management												
1.3 Project Controls												
1.4 NEPA Reporting												
Task 2: Basin Scale Stress-Strain Analysis												
2.1 Tectonic Setting Def. for Midwest U.S.				u								
2.2 Reg Analy. of Paleo-Stress Orien. & Mag												
2.3 Sys. Rev. of Geomech & Petophys Prop.												
Task 3: Geomech. Data Analysis												
3.1 Data Proc from Well Logs/tests												
3.2 Geo and Geomech Des of Well Sites								u				
3.3 Static Geomech Rock Core Test&Analys.								u				
Task 4: Petrophys Log Analysis & Integra.												
4.1 Trans. Petrop Log Data to Geomech Para												
4.2 Calibr. of Logs with Static Geomech Data												
Task 5: Dev. Meth for Geomech Site Char										u		
5.1 Geophys. Logging Options for CO_2 Sites												
5.2 Geomech Rock Core Test Options												
5.3 Inj Test Options for CO_2 Storage Sites												
5.4 Geomech Mon Options for CO_2 Sites												
Task 6: Fractured Res. Sims for CO_2 Stor.												
6.1 Numerical Model Definition/Setup												
6.2 Caprock Simulation Scenario Runs												
6.3 Simulation Results Processing/Visualiz											u	
Task 7: Caprock Sims for CO_2 Stor.												
7.1 Numerical Model Definition/Setup												
7.2 Caprock Simulation Scenario Runs												
7.3 Simulation Results Processing/Visualiz											u	
Task 8: CO_2 Stor/Shale Gas Risk Factors												
8.1 Mapping CO_2 Stor Zones & Shale Gas												
8.2 Class. of Risk Factors Rel to CO_2-Sh Gas											u	
Task 9: Reporting and Tech Transfer												
9.1 Progress Reporting	u	u	u	u	u	u	u	u	u	u	u	u
9.2 Technical Summary Reports				u				u			u	
9.3 Final Reporting												u
9.4 Project Meetings	u				u				u			u

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- *Geomechanical Factors for Assessing the Effects of Subsurface Injection in the Midwestern U.S.*, J.R. Sminchak, Ground Water Protection Council 2017 UIC Conference, February 23, 2017, Austin, Texas.
- *Geomechanical Assessment of Sub-Knox Formations for Safe CO_2 Injection Study in the Midwest U.S,* Shuvajit Bhattacharya, Joint 52nd Northeastern/North-Central Annual 2017 Geological Society of America Meeting, March 19-21, Pittsburgh, Pennsylvania.
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- *Integrated Analysis of Geomechanical Factors for Geologic CO_2 Storage in the Midwestern United States.* J.R. Sminchak, Ola Babarinde, and Neeraj Gupta, 13th International Conference on Greenhouse Gas Control Technologies (GHGT-13), Lausanne, Switzerland, November 14-18, 2016.
- *Structural and Geomechanical Analysis of Fractured Cambrian-Ordovician Reservoirs in the Northern Appalachian Basin*, Ola Babarinde, Eastern Section AAPG Meeting, September 20-22, 2015, Indianapolis, Indiana.
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