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 and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 16-18, 2016

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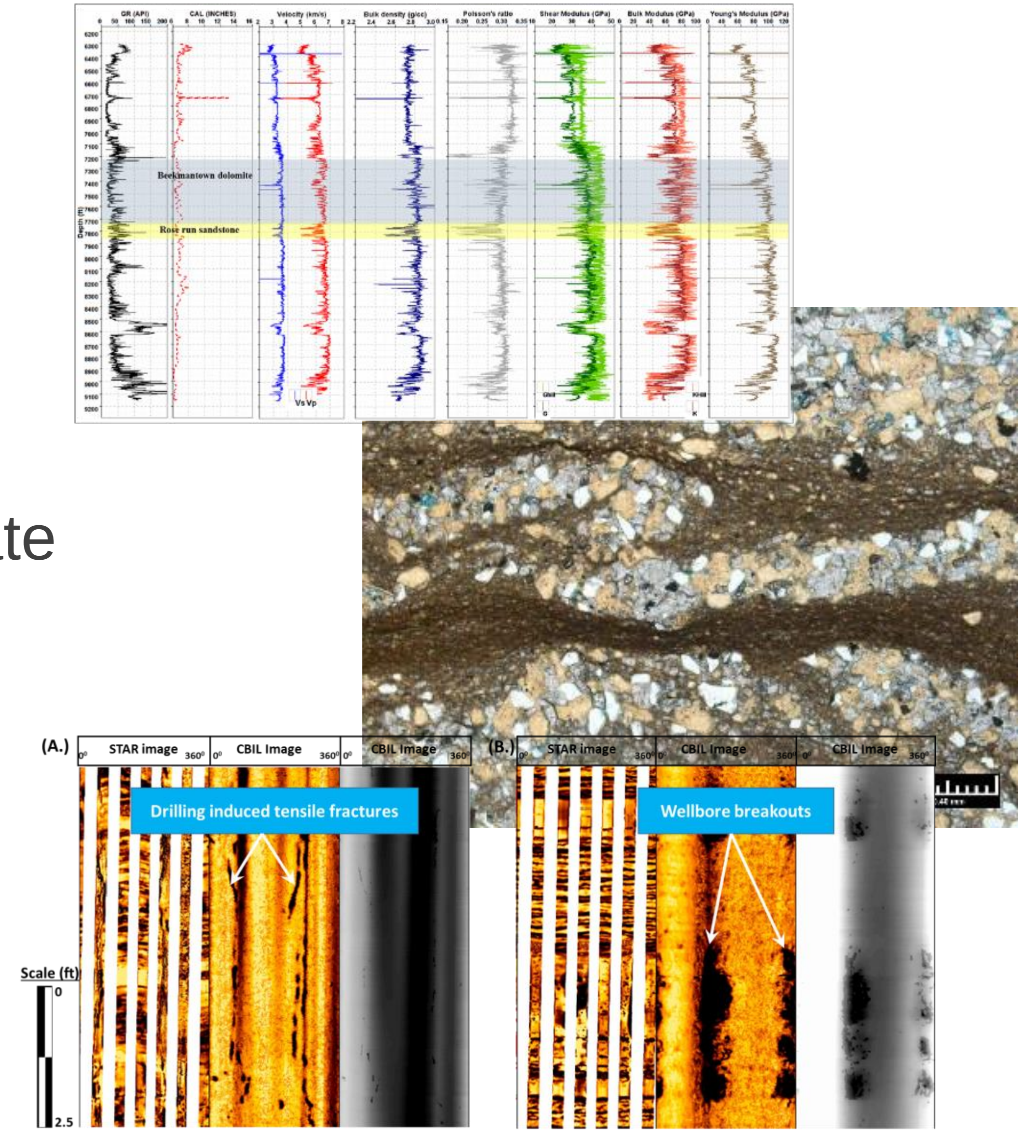

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Acknowledgements

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  Project Manager – William O'Dowd, NETL Sequestration Division.

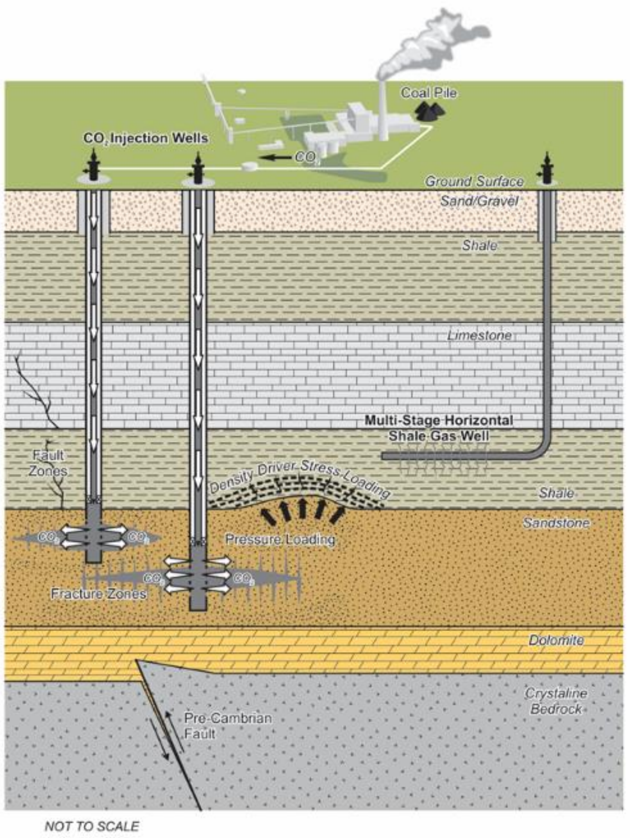
- Co-funding provided by Ohio Development Services Agency Agreement Ohio Coal Development Office (Grant CDO-D-14-17).

- Project team includes Neeraj Gupta, Amber Conner, Joel Main, Andrew Burchwell, Ashwin Pasumarti, Jackie Gerst, Mark Kelley, Glen Larsen, Srikanta Mishra, Nat Voorhies, and many more.

U.S. DOE/NETL

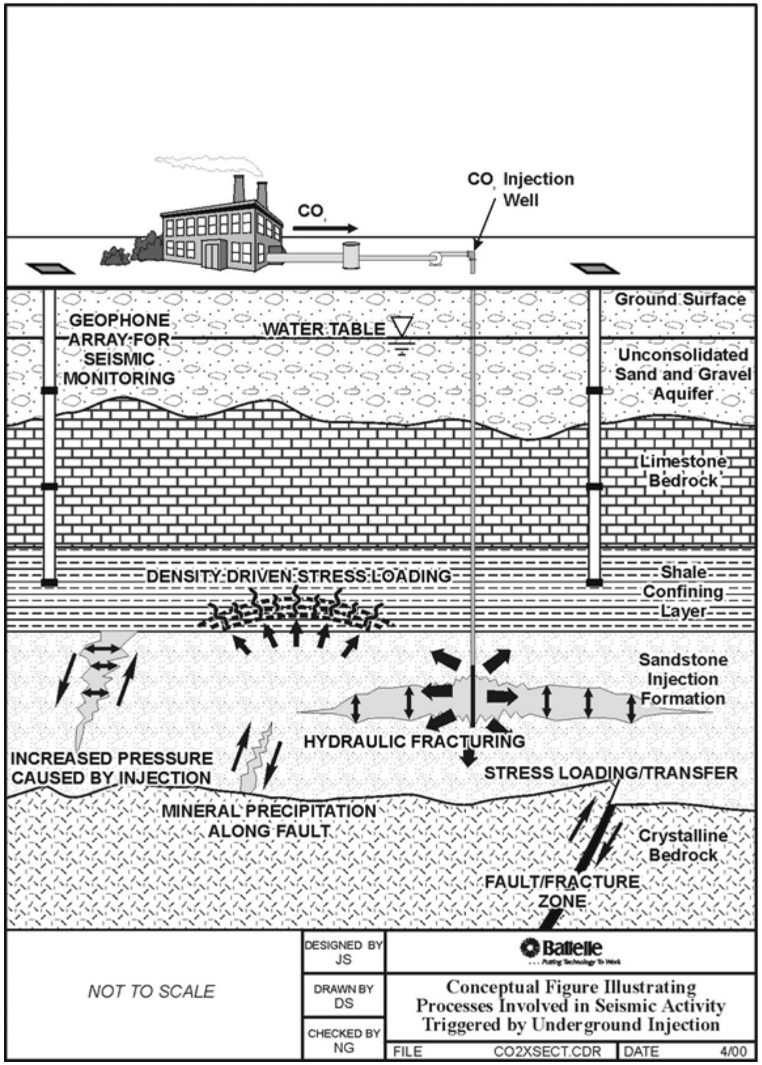
Benefit to Program

- 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.



Benefit to 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.

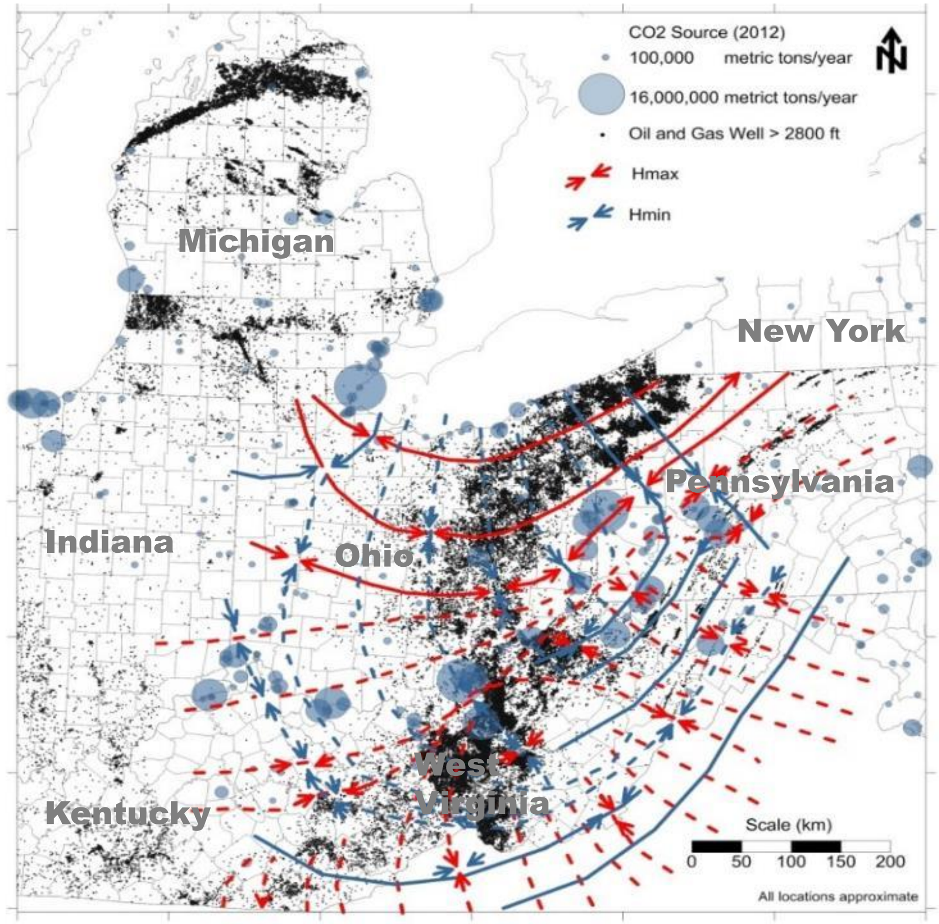


Sminchak, J.R., and Gupta, N. 2003. *Aspects of induced seismic activity and deep-well sequestration of carbon dioxide*. Environmental Geosciences, v. 10, n. 2, pp. 81-89.

Benefit to Program

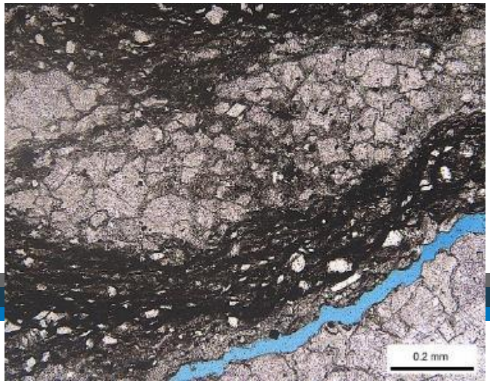
- Geomechanical processes are especially important in Appalachian Basin due to geologic structural setting and nature of deep rock formations.

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



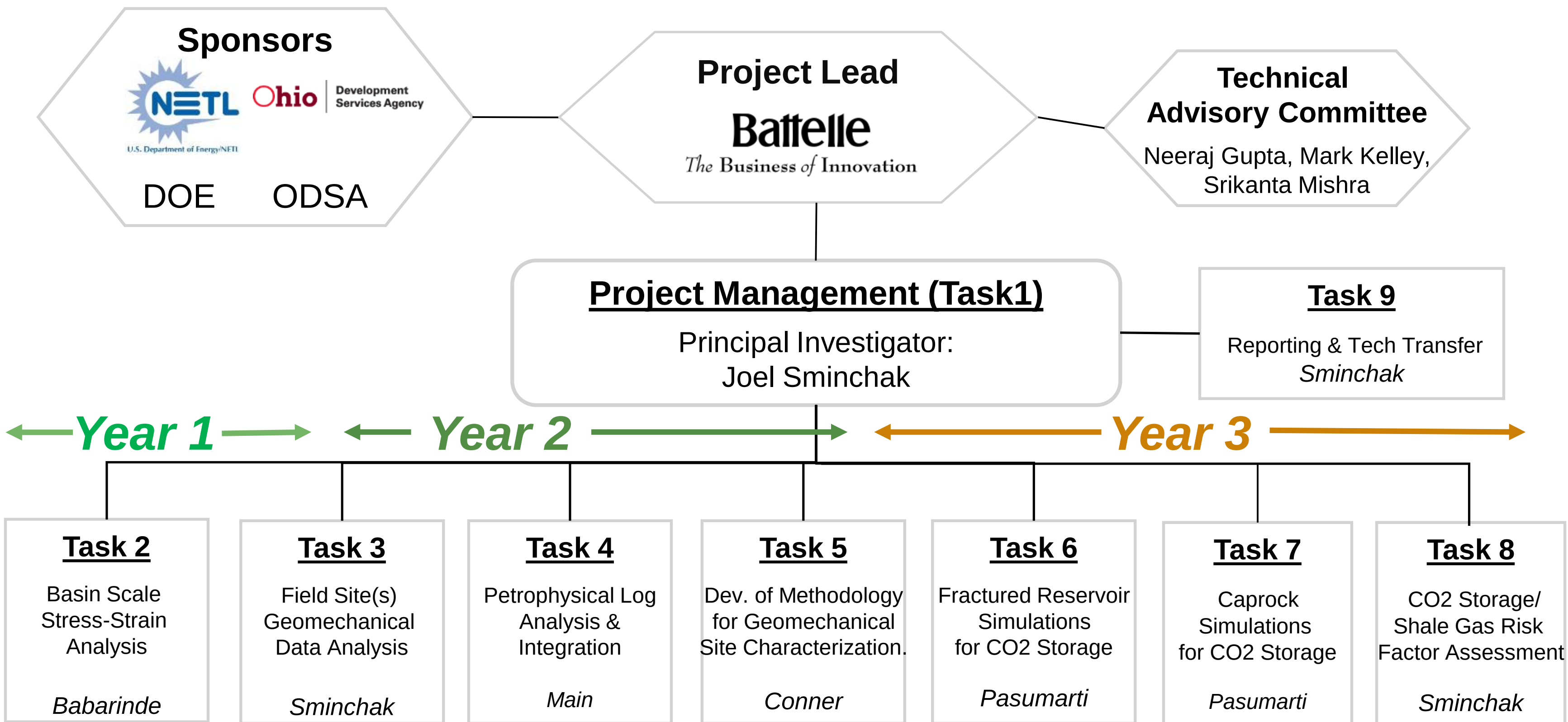
Benefit to Program

- 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

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



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Technical Status

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

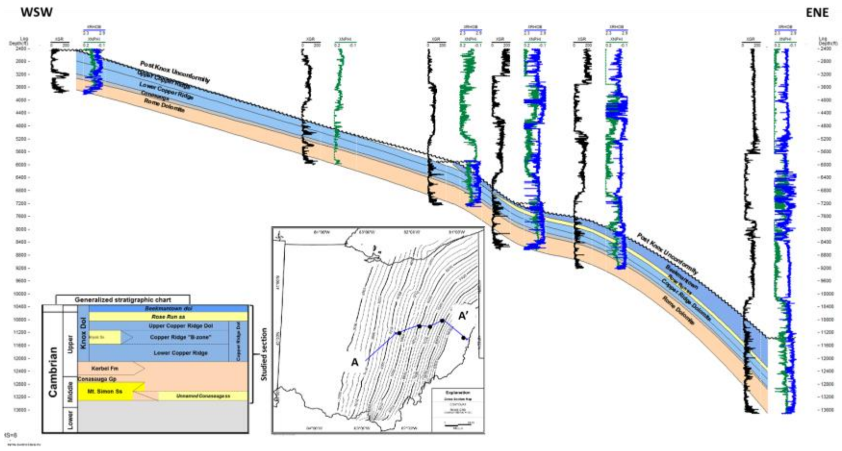
Year 2

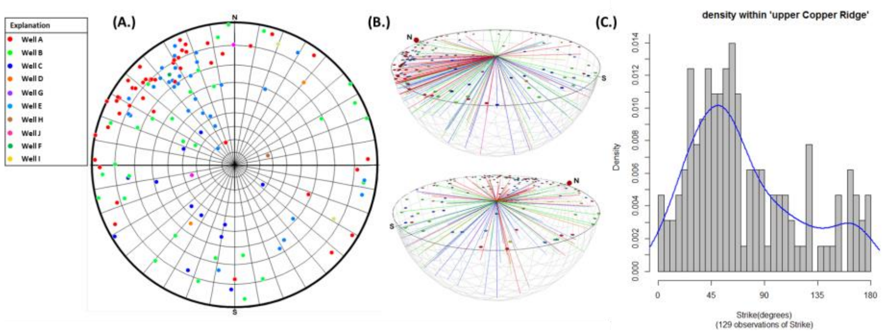
Year 3

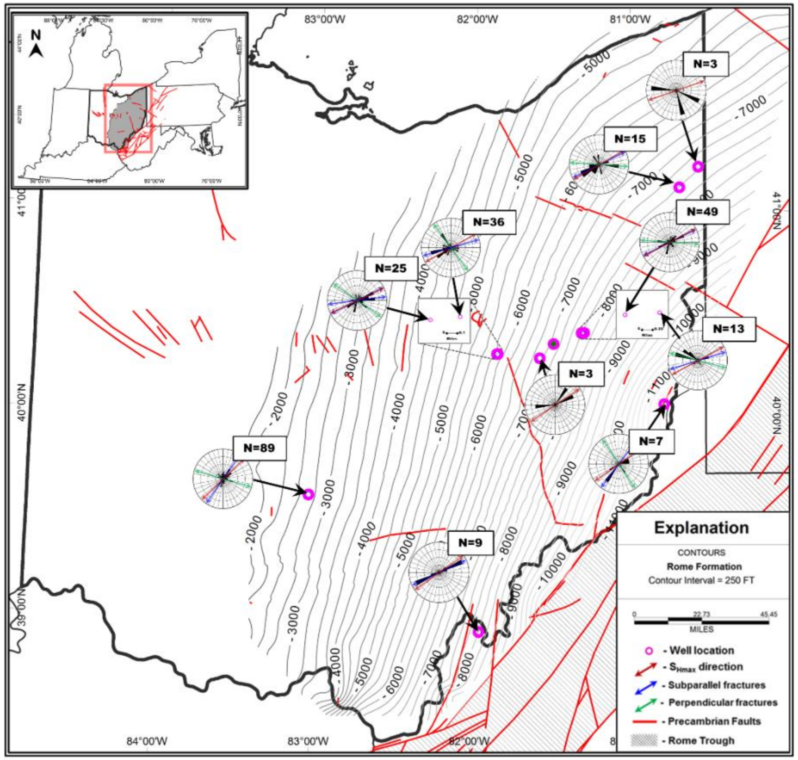
Year 2

Accomplishments to Date
Task 2: Basin Scale Stress-Strain Analysis

- Basin Scale Stress Strain Analysis completed to describe basin evolutions, stress state, fracture density.







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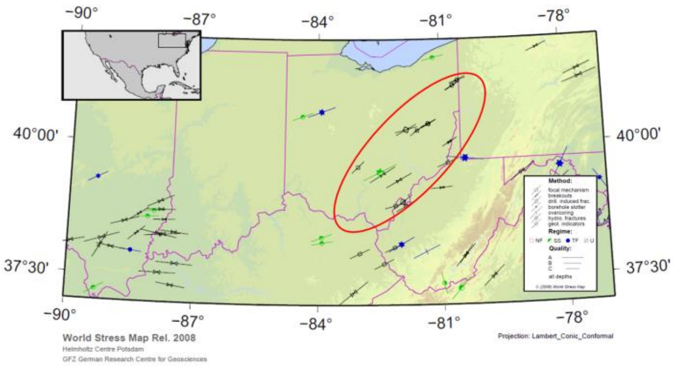
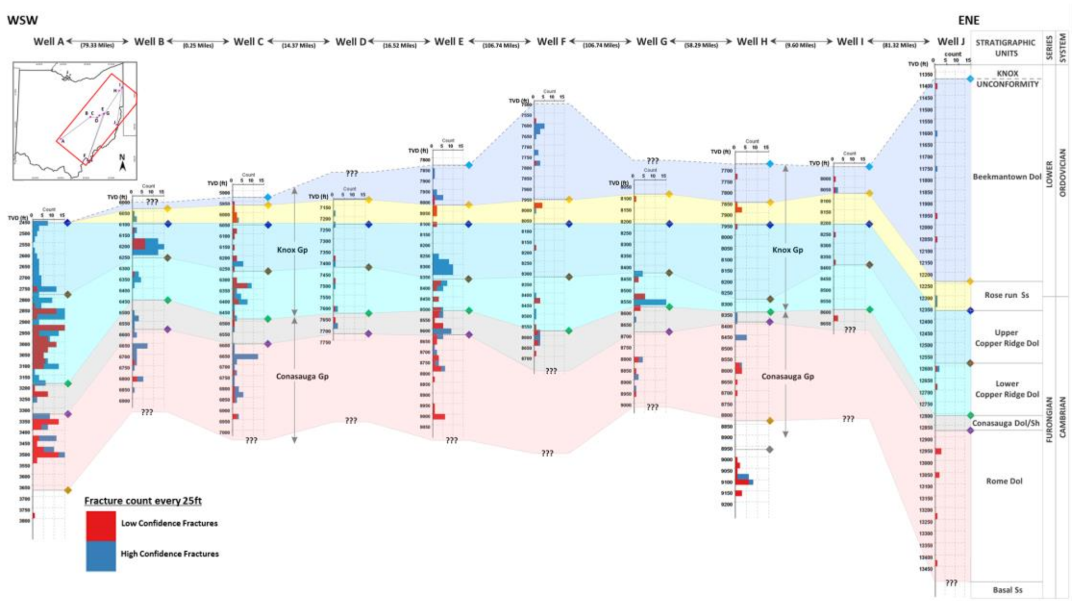
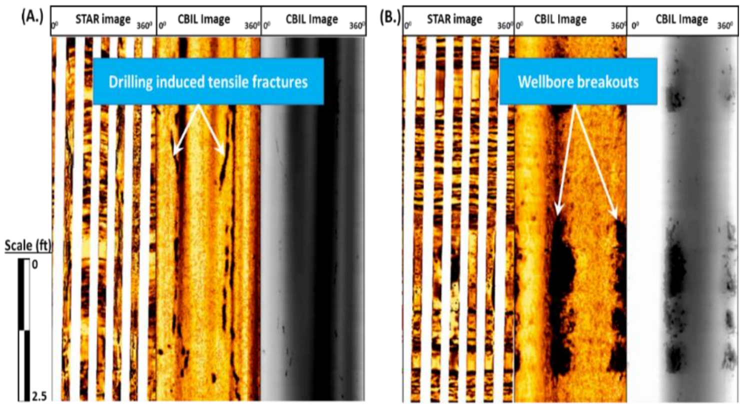
Task 2: Basin Scale Stress-Strain Analysis

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







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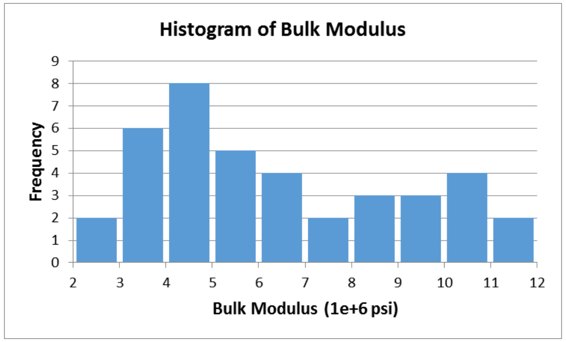
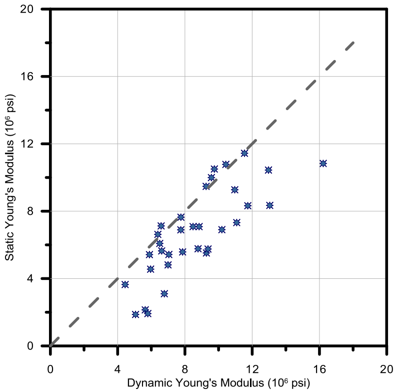
Task 2: Basin Scale Stress-Strain Analysis

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

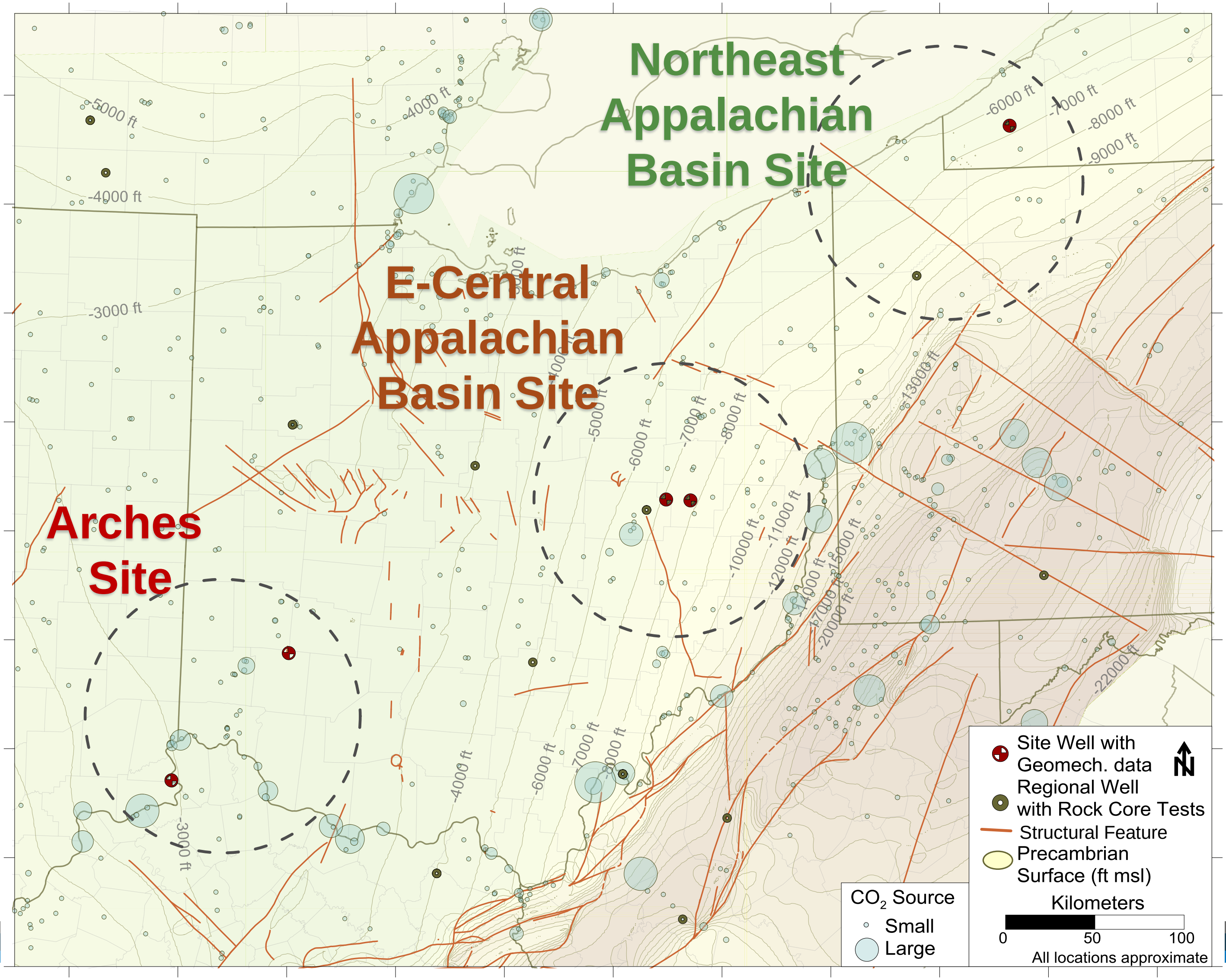




Parameter	Confining Pressure (psi)	Bulk Density (g/cc)	Compressional Velocity (ft/s)	Shear Velocity (ft/s)	Dynamic Young's Modulus (1e+6 psi)	Dynamic Poisson's Ratio	Bulk Modulus (1e+6 psi)	Shear Modulus (1e+6 psi)	Compressive Strength (psi)	Static Young's Modulus (1e+6 psi)	Static Poisson's Ratio
Count	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

Task 3: Site Geomechanical Analysis

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



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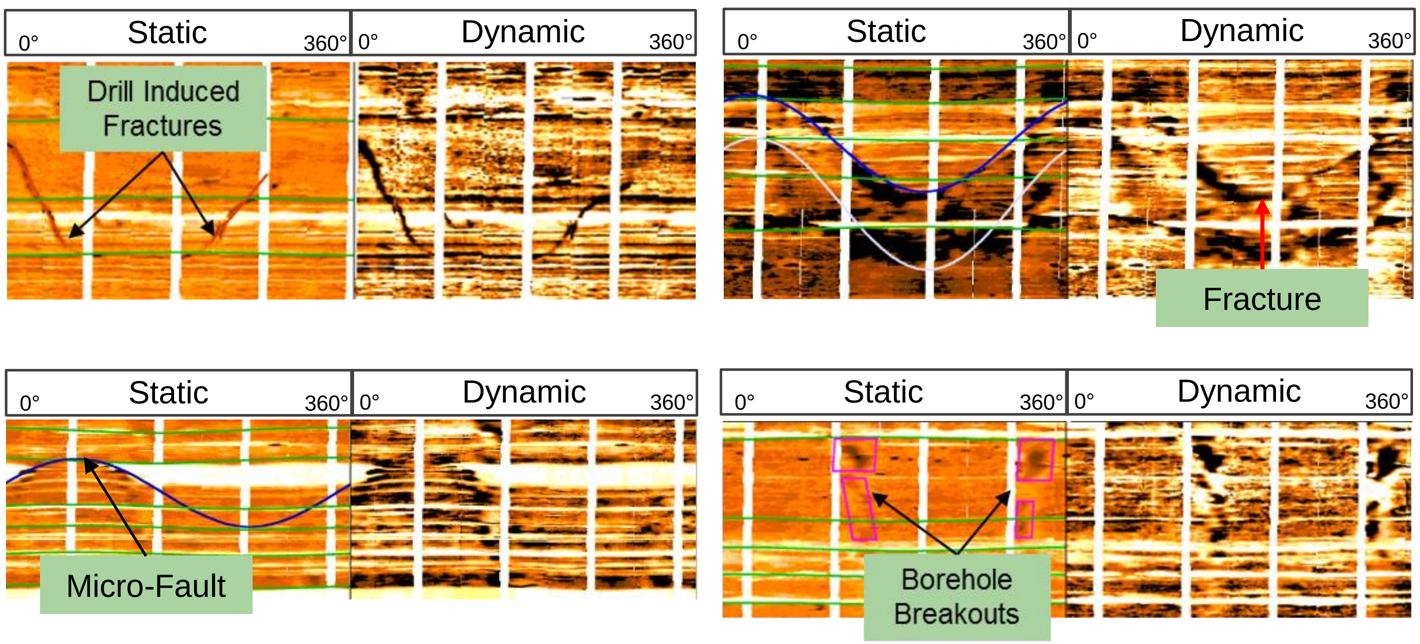
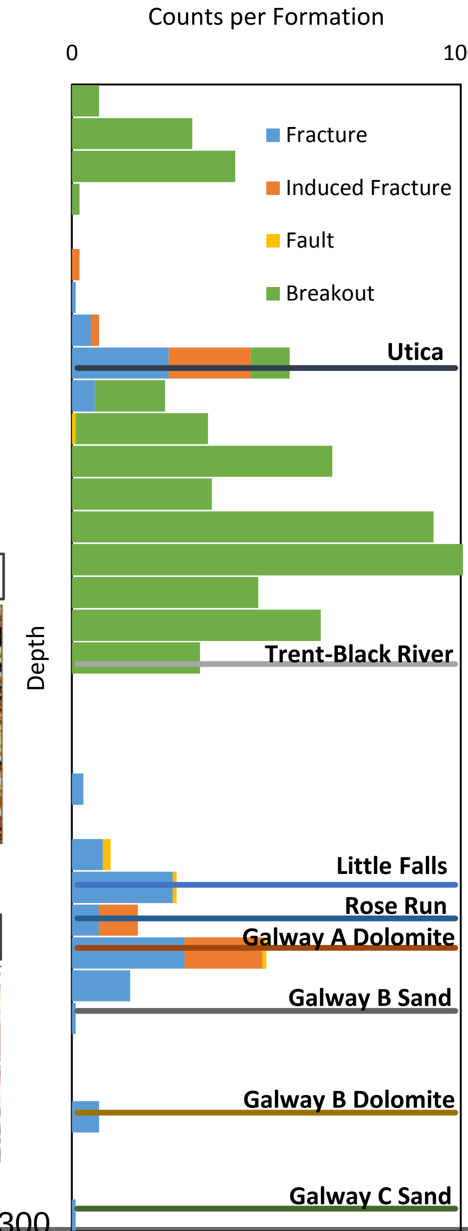
Task 3: Site Geomechanical Analysis

- >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, Rome, and Basal Sand
  - Northeast 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

Task 3: Site Geomechanical Analysis

- Northeastern Appalachian Basin Site: 134 fractures, 55 induced fractures, 5 micro-faults, and 586 breakouts were interpreted on image logs.





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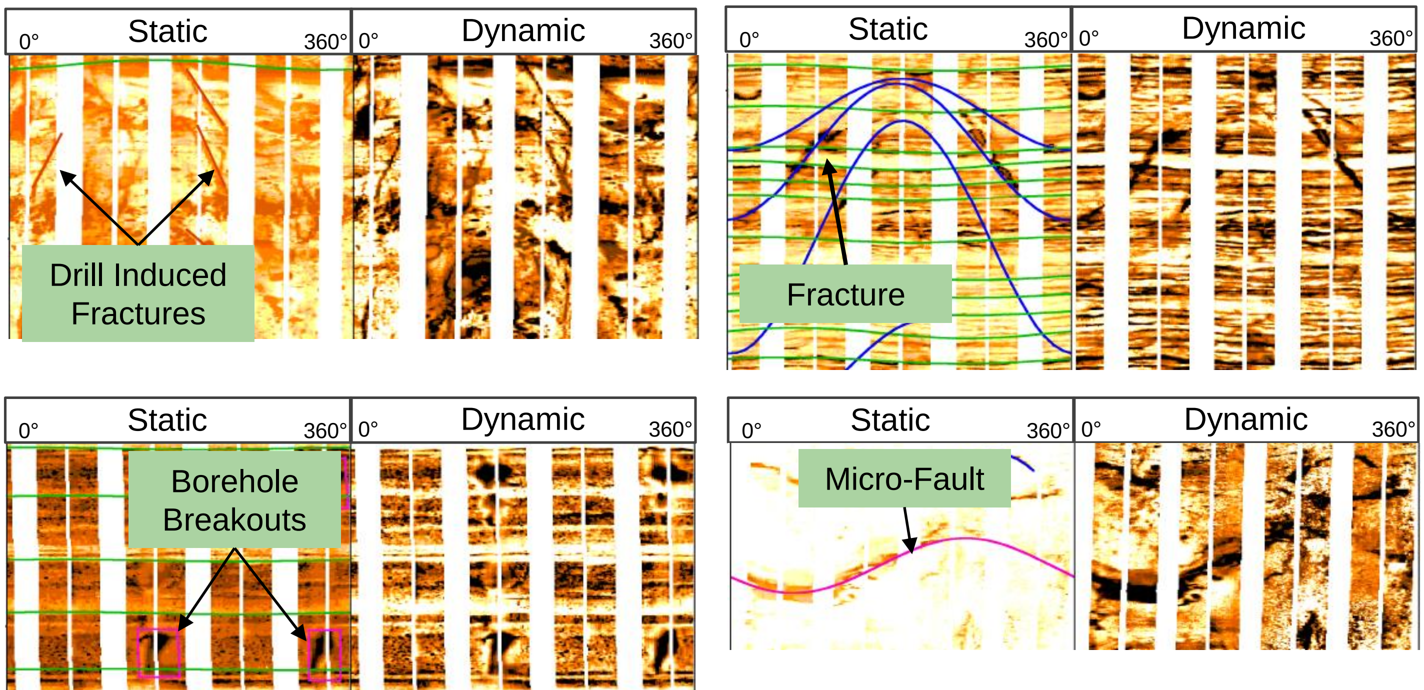
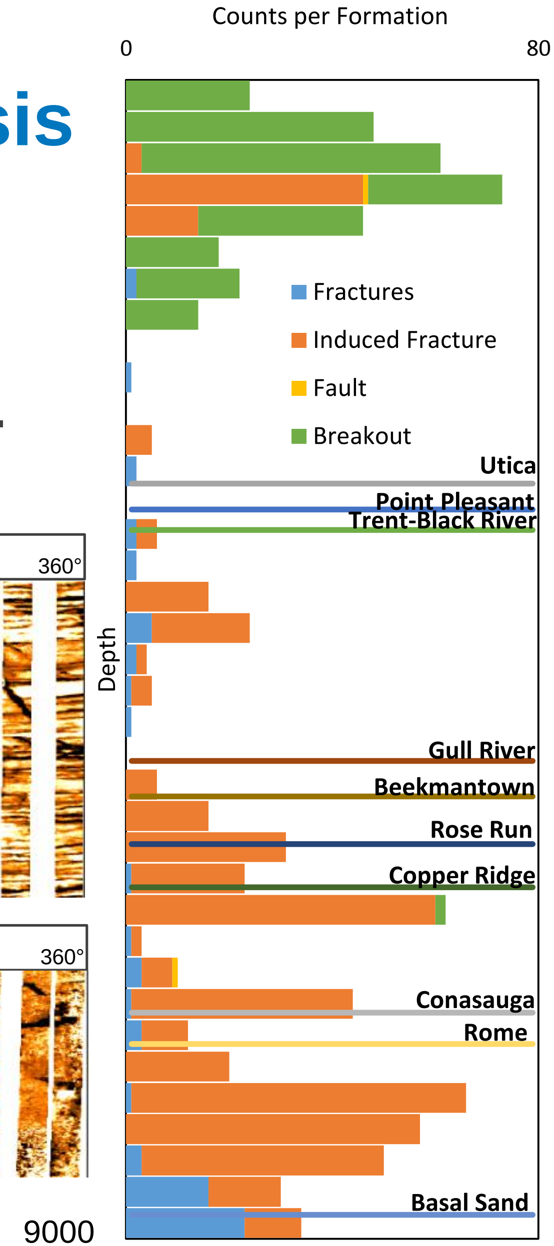
Task 3: Site Geomechanical Analysis

- East-Central Basin site: 70 fractures, 522 induced fractures, 2 micro-faults, and 242 breakouts were interpreted on image logs.





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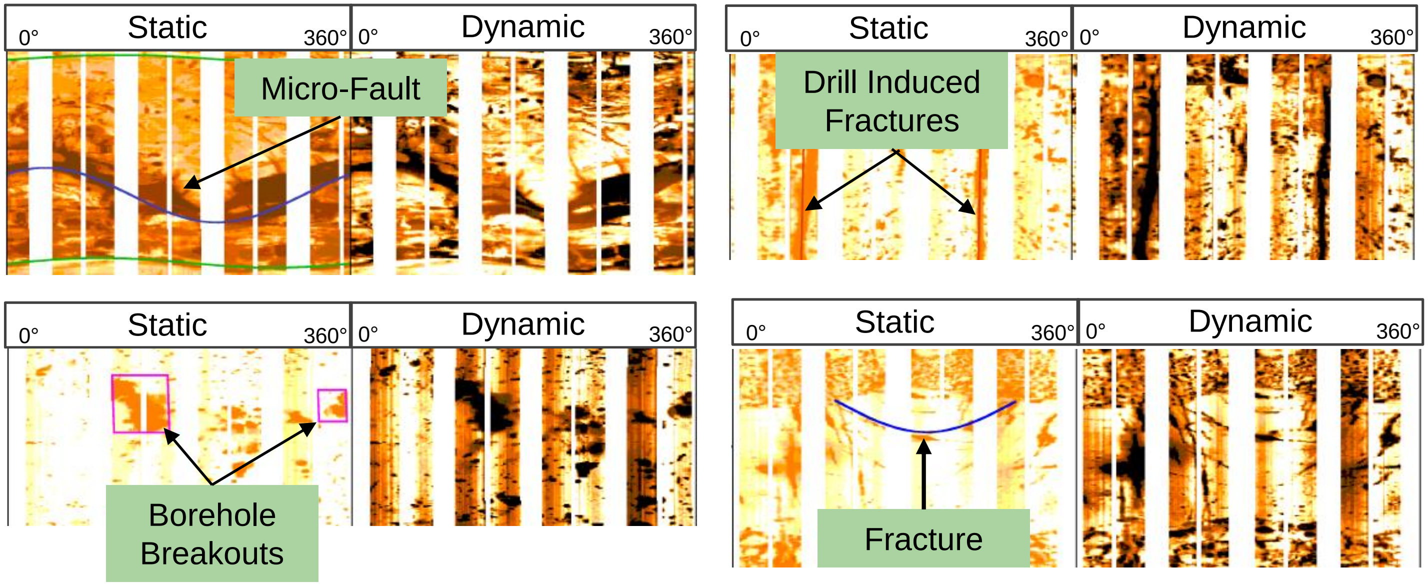
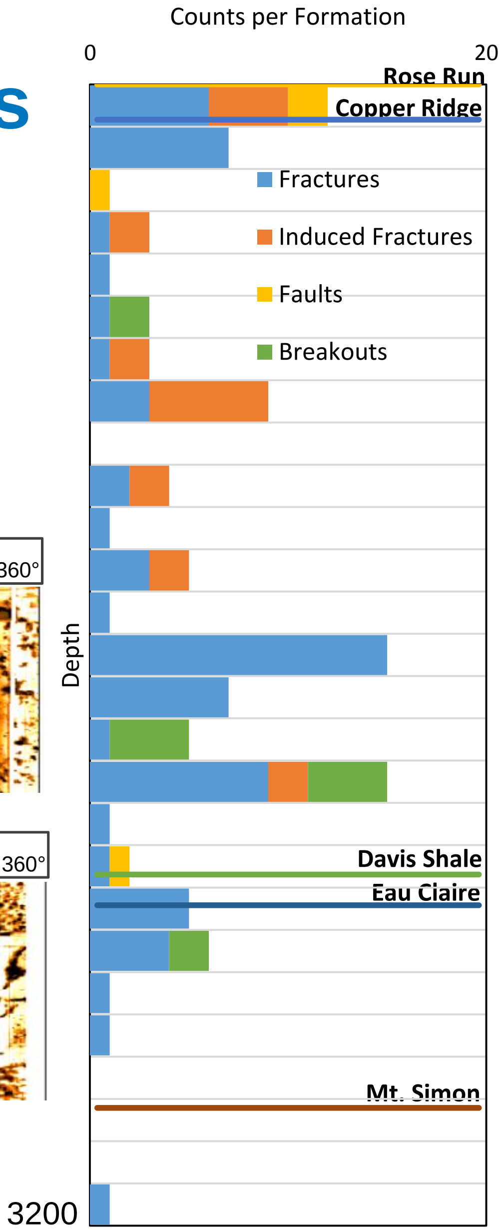
Task 3: Site Geomechanical Analysis

- Arches site: 73 fractures, 20 induced fractures, 4 micro-faults, and 12 breakouts were interpreted on image logs





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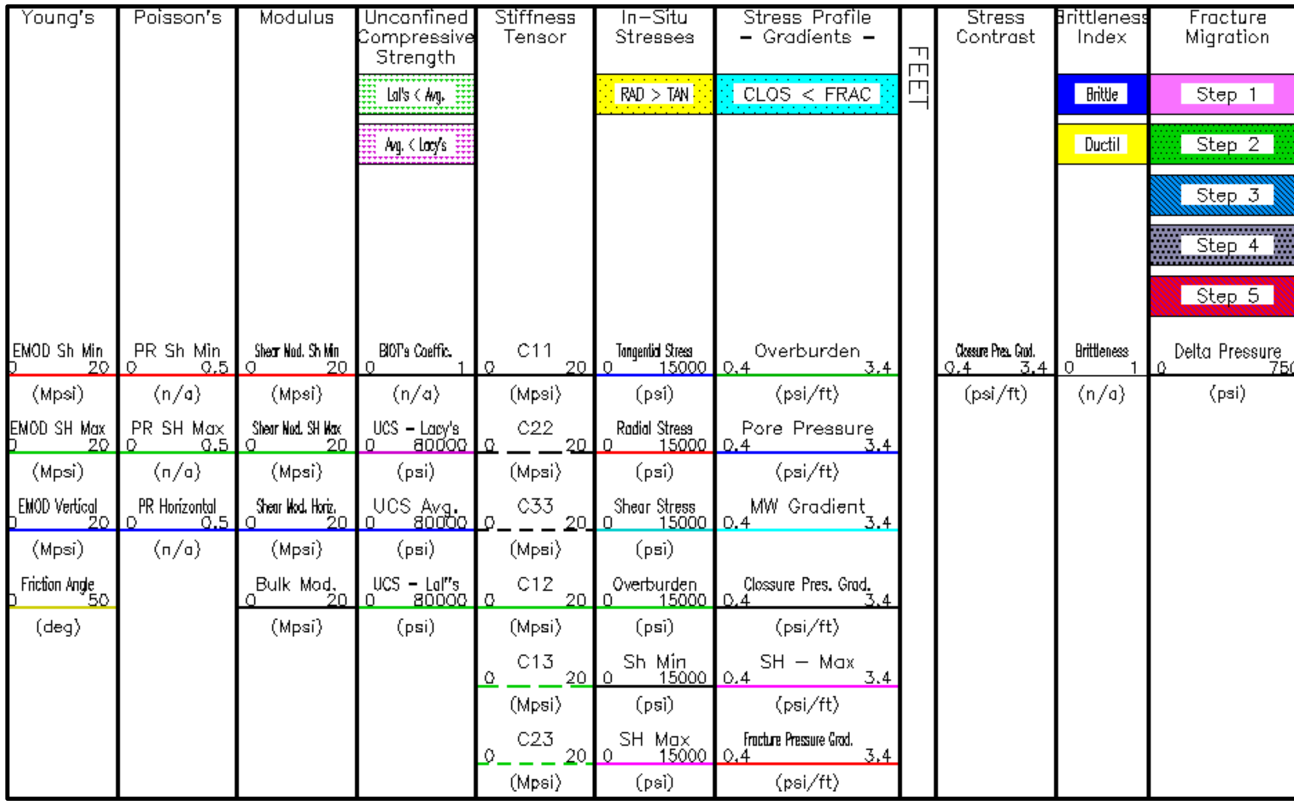
Task 4: Petrophysical Log Analysis & Integration

- Additional log processing was completed to derive continuous geomechanical parameters for each well using the acoustic and image logging data.

Derived Parameters

1. Young's Modulus
2. Poison's Ratio
3. Shear Modulus
4. Bulk Modulus
5. BOIT's Coefficient
6. Stress Magnitudes
7. Fracture Migration



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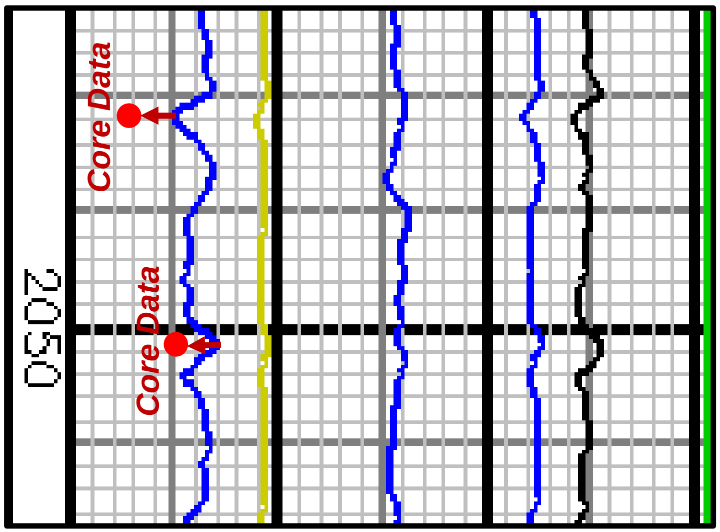
Task 4: Petrophysical Log Analysis & Integration

- Approximately 12,000 feet of geophysical log analysis of the Cambro-Ordovician rock will fill gaps on rock properties.
- Calibration to rock tests will ensure accuracy of geomechanical logs.

Curve Calibration



	Arches	E. Central App. Basin	NE App. Basin
Log Top (feet)	170	3,090	3,860
Log Bottom (feet)	3,704	8,710	7,305
Total Footage (feet)	3,543	5,620	3,445
Formations	Utica – Mount Simon	Utica- Basal Sand	Utica - Galway C Sand

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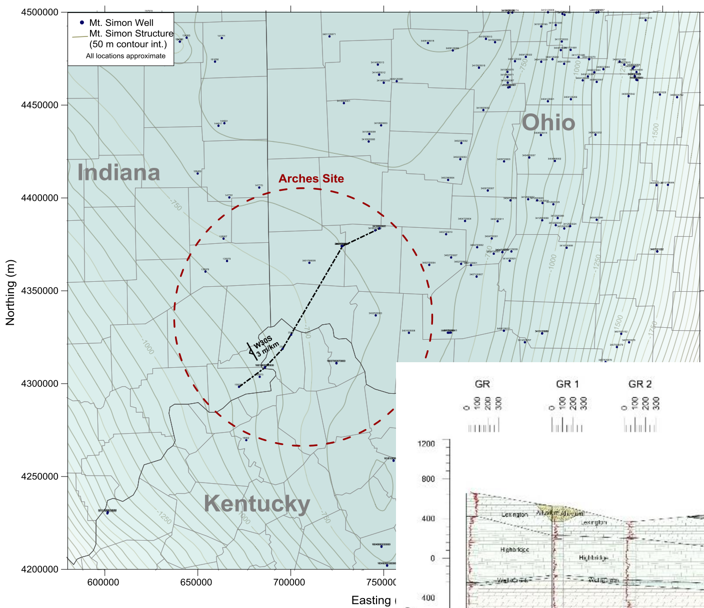
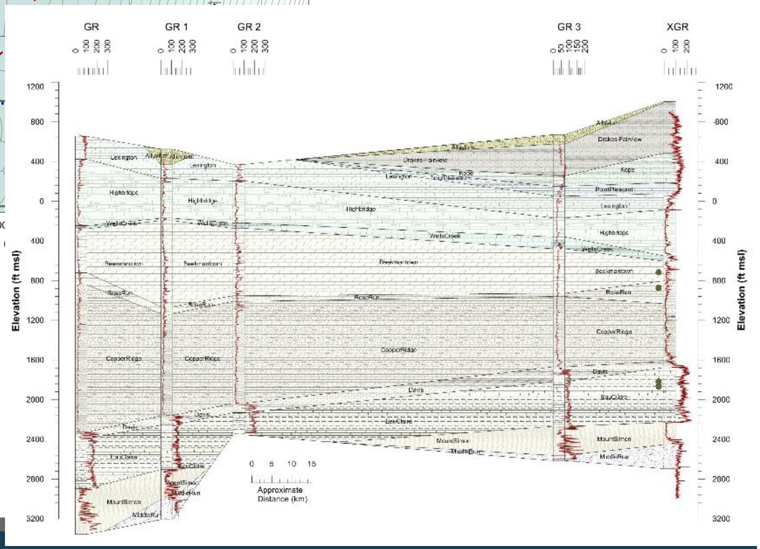
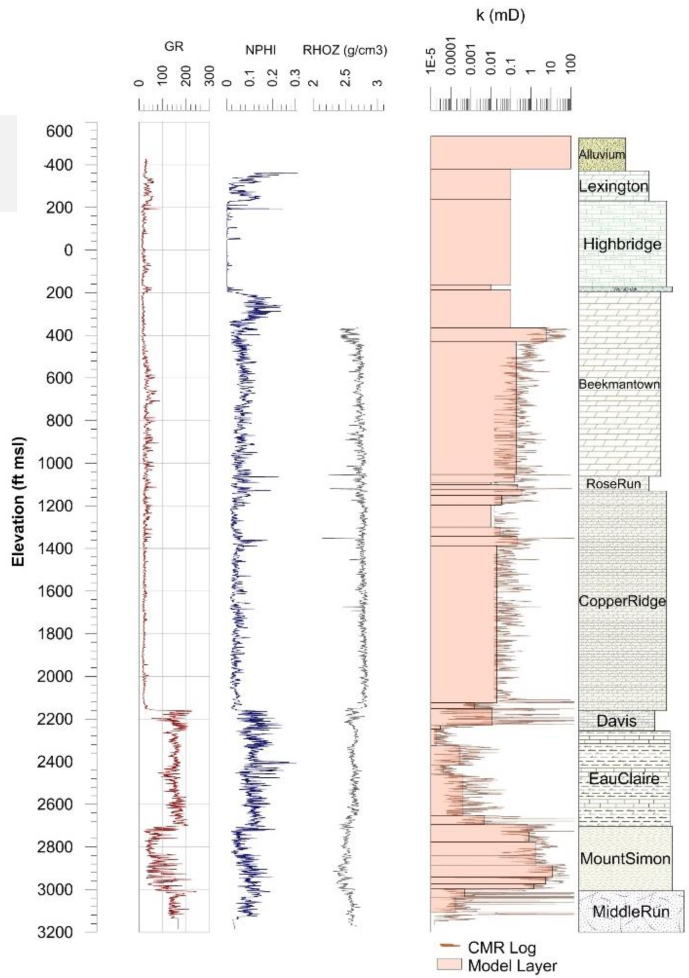
Task 4: Petrophysical Log Analysis & Integration

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



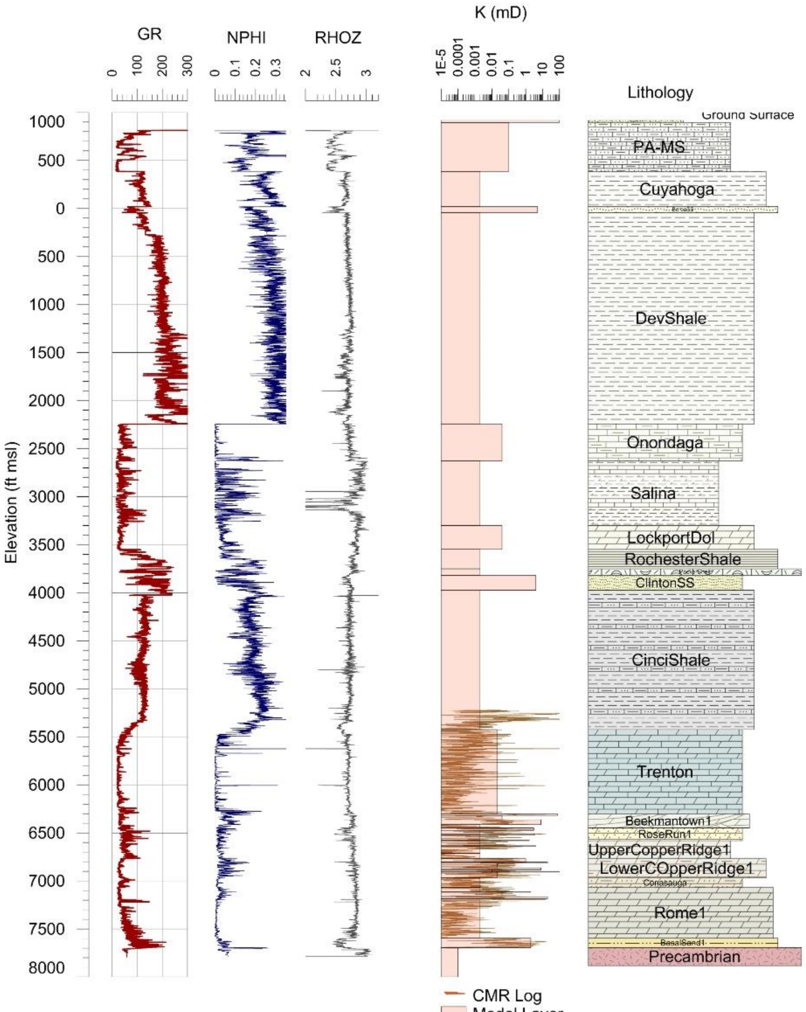
Arches Site



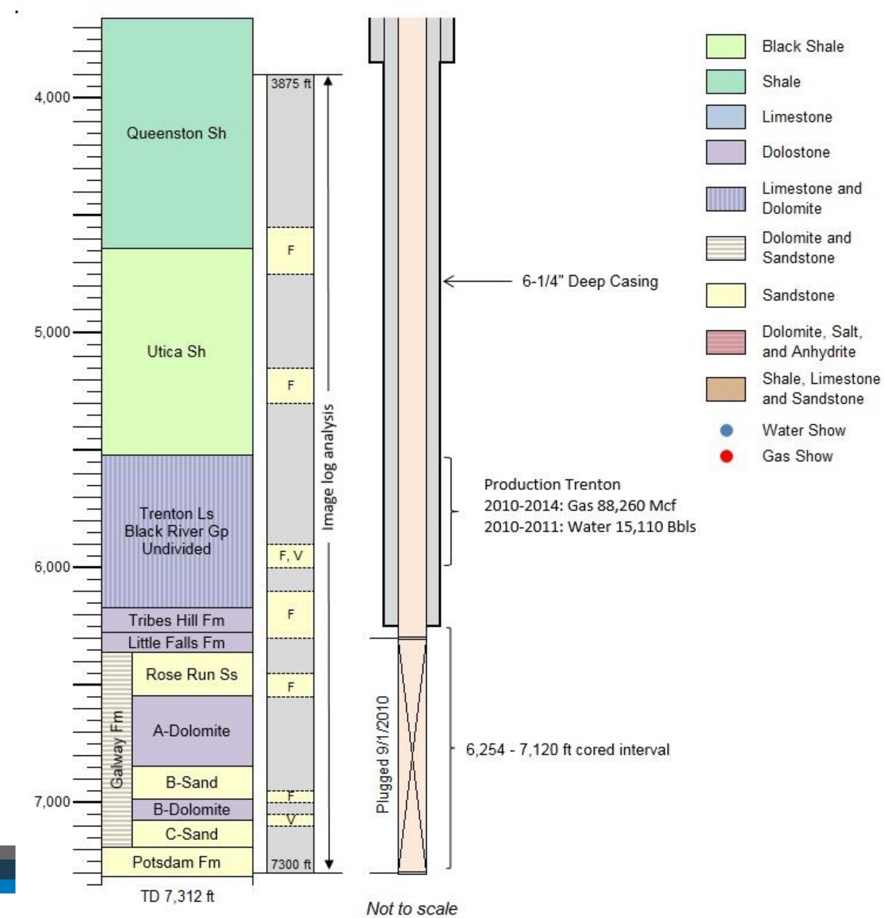


Task 4: Petrophysical Log Analysis & Integration

E-Central Appalachian Basin Site



Northeast Appalachian Basin Site



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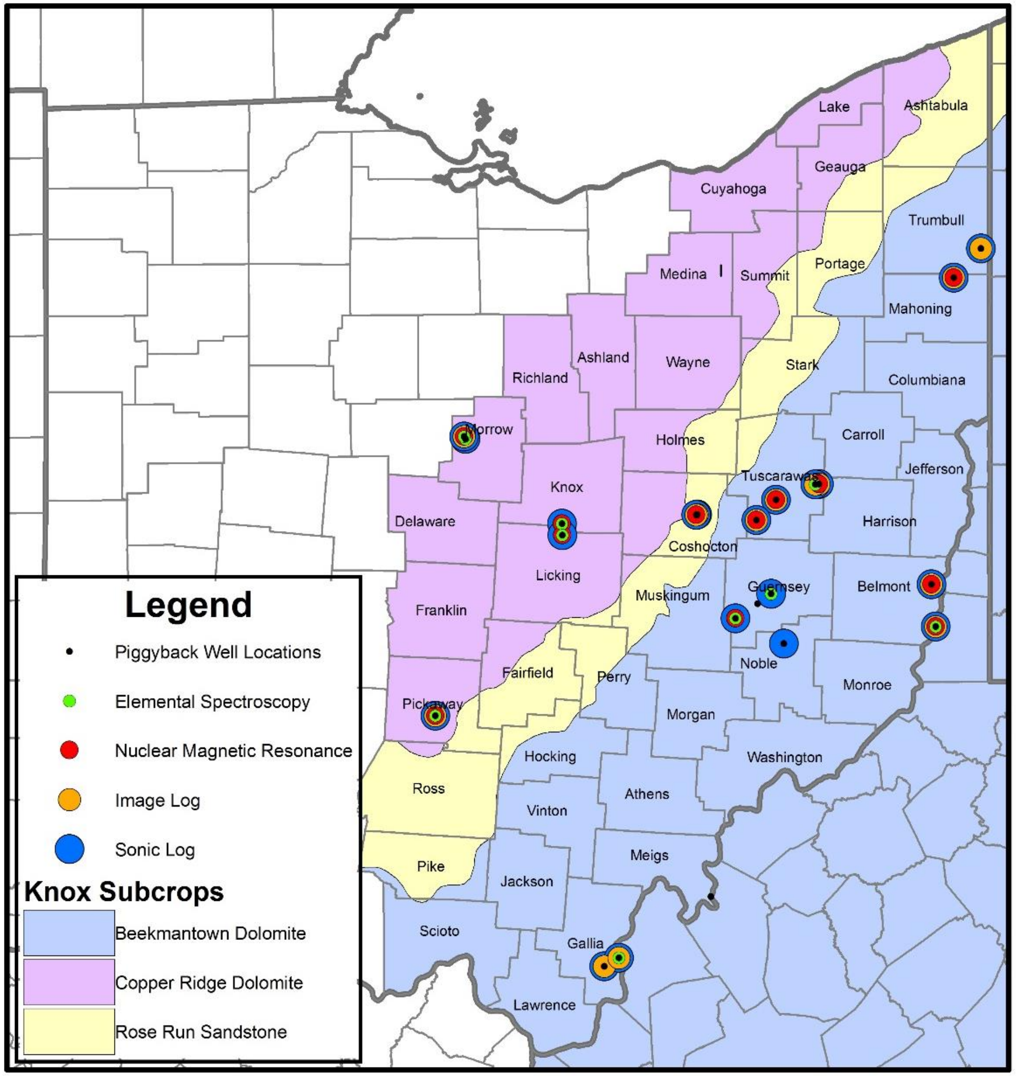
Task 4: Petrophysical Log Analysis & Integration

- Wells analyzed for elastic geomechanical properties based on geophysical logs.
- Elemental Spectroscopy logs provide a continuous estimate of mineralogy breakdown in the deep rock formations.



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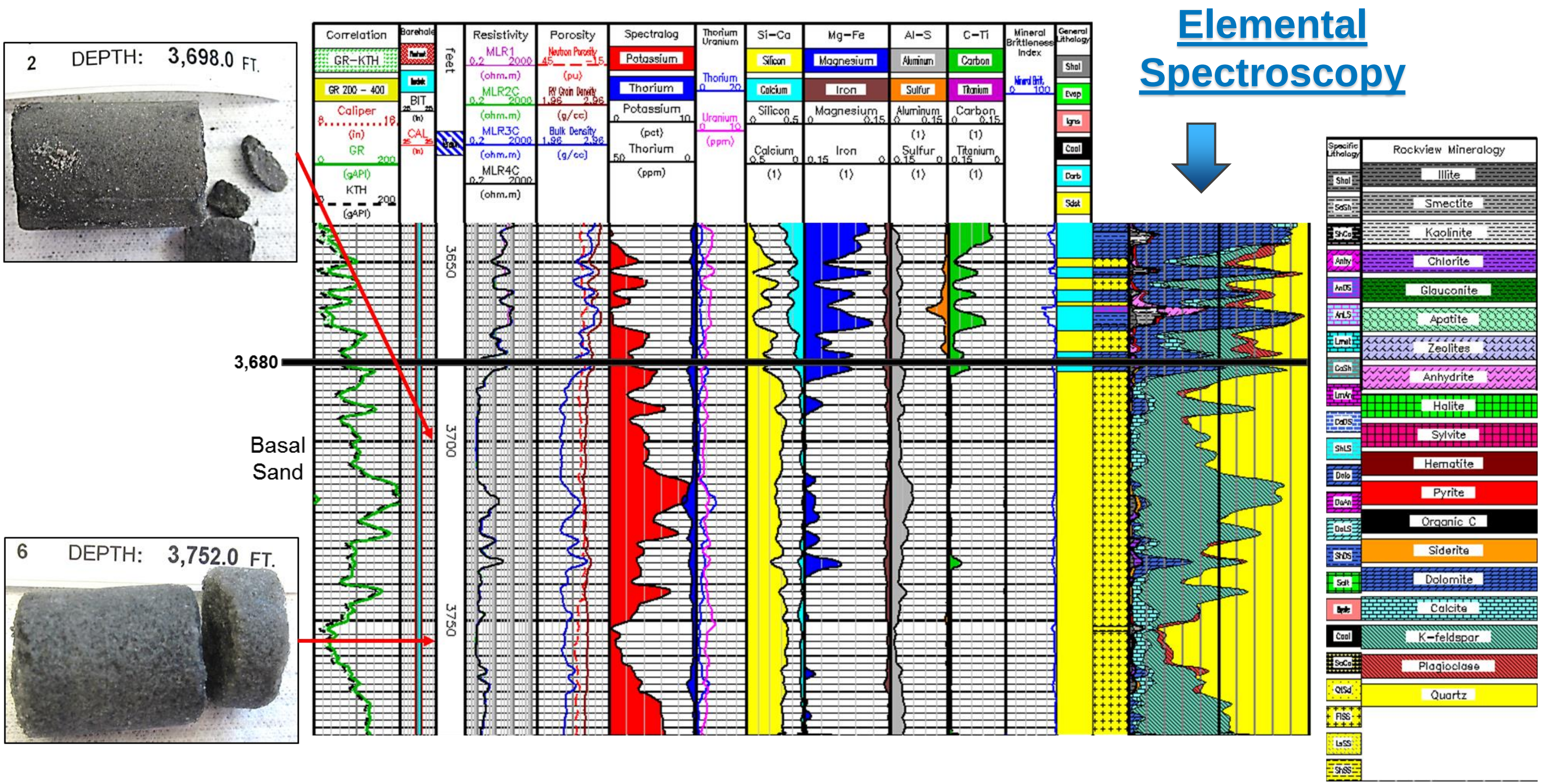
Petrophysical Log Analysis & Integration

- Elemental Spec.- Cambrian Basal Sandstone



Task 4: Petrophysical Log Analysis & Integration

- Voigt-Reuss-Hill (VRH) method was used with the fraction of minerals provided by rock view interpretation to calculate the elastic moduli at every quarter feet in the logged well.

$$M_{voigt} = \sum_{i=1}^{n} m_i M_i$$

$$M_{Reuss} = \sum_{i=1}^{n} \frac{m_i}{M_i}$$

$$M_{Hill} = \frac{M_{voigt} + M_{Reuss}}{2}$$

Fraction of minerals generated as output from the rock view interpretation includes mineral fraction for illite, smectite, kaolinite, chlorite, glauconite, apatite, zeolites, anhydrite, halite sylvite, hematite, pyrite, siderite, dolomite, calcite, k-feldspar, plagioclase and quartz.

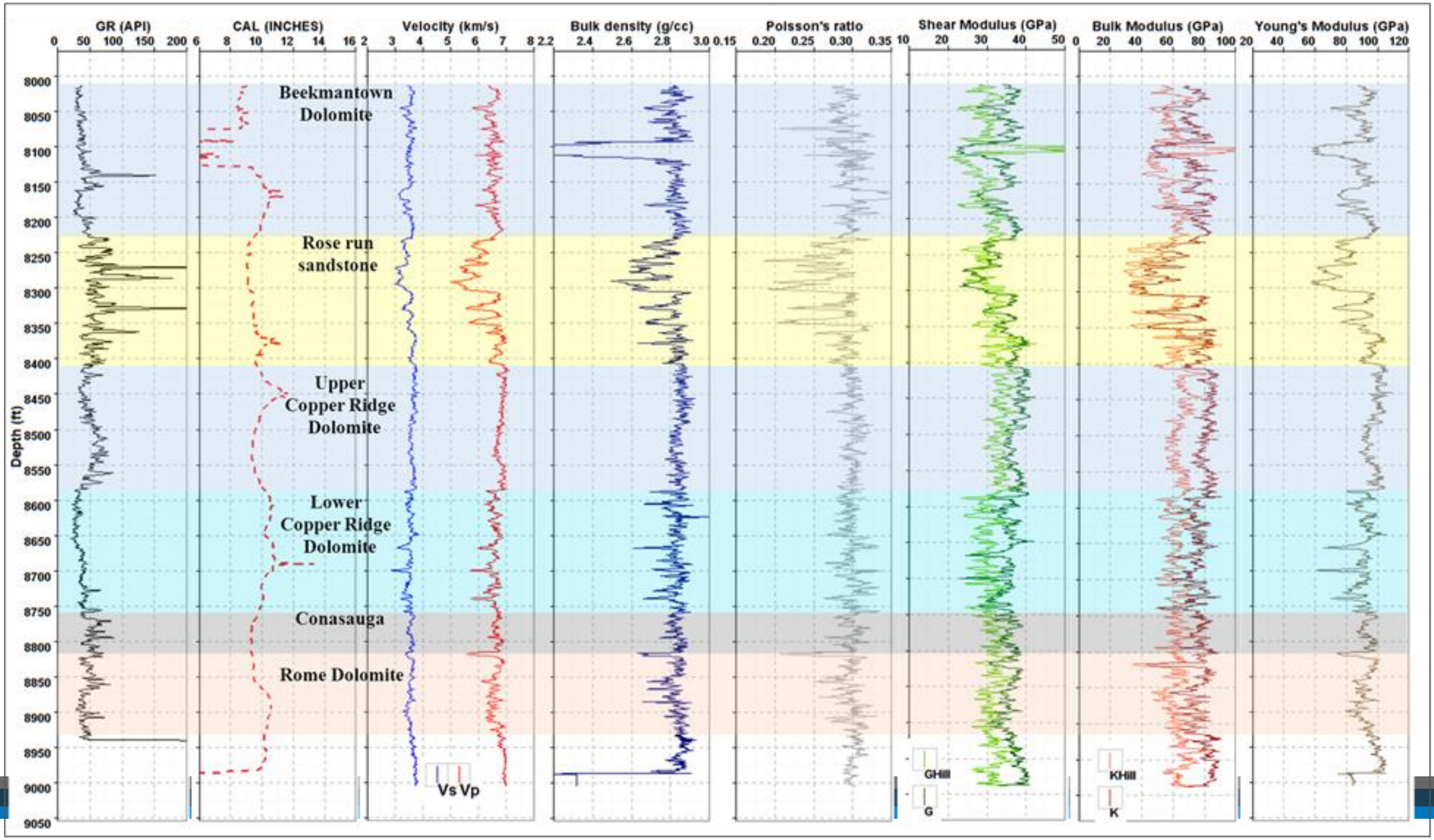
Rock minerals	~K (GPa)	~G (GPa)	Vp (km/s)	Vs (km/s)	Poisson's ratio
Anhydrite	66.5	34	6.15	3.4	0.285
Apatite	83.9	60.7	-	-	-
Calcite	76.8	32	6.63	3.43	0.317
Dolomite	94.9	45	7.38	3.95	0.295
Aragonite	47	39	5.8	3.6	0.187
Halite	25.2	15.3	4.6	2.65	0.252
Hematite	100.2	95.2	-	-	-
Clay minerals	41	17	4.9	2.5	0.324
Clay	12	6	-	-	-
Na-Feldspar	55	28	5.9	3.3	0.272
K- Feldspar	48	24	5.6	3.05	0.289
Plagioclase	75.6	25.6	-	-	-
Pyrite	158	149	8.4	5.45	0.137
Quartz	36.6	45	6.03	4.12	0.064
Siderite	123.7	51	-	-	-

***Variable, K-Bulk modulus, G-Shear modulus, Gigapascals (GPa).
Compiled from Carmichael, 1989 and Simmons and Wang, 1971.

Task 4: Petrophysical Log Analysis & Integration

- Calculated geomechanical parameters compared with sonic derived parameters.

Ghill Khill
Gsonic Ksonic



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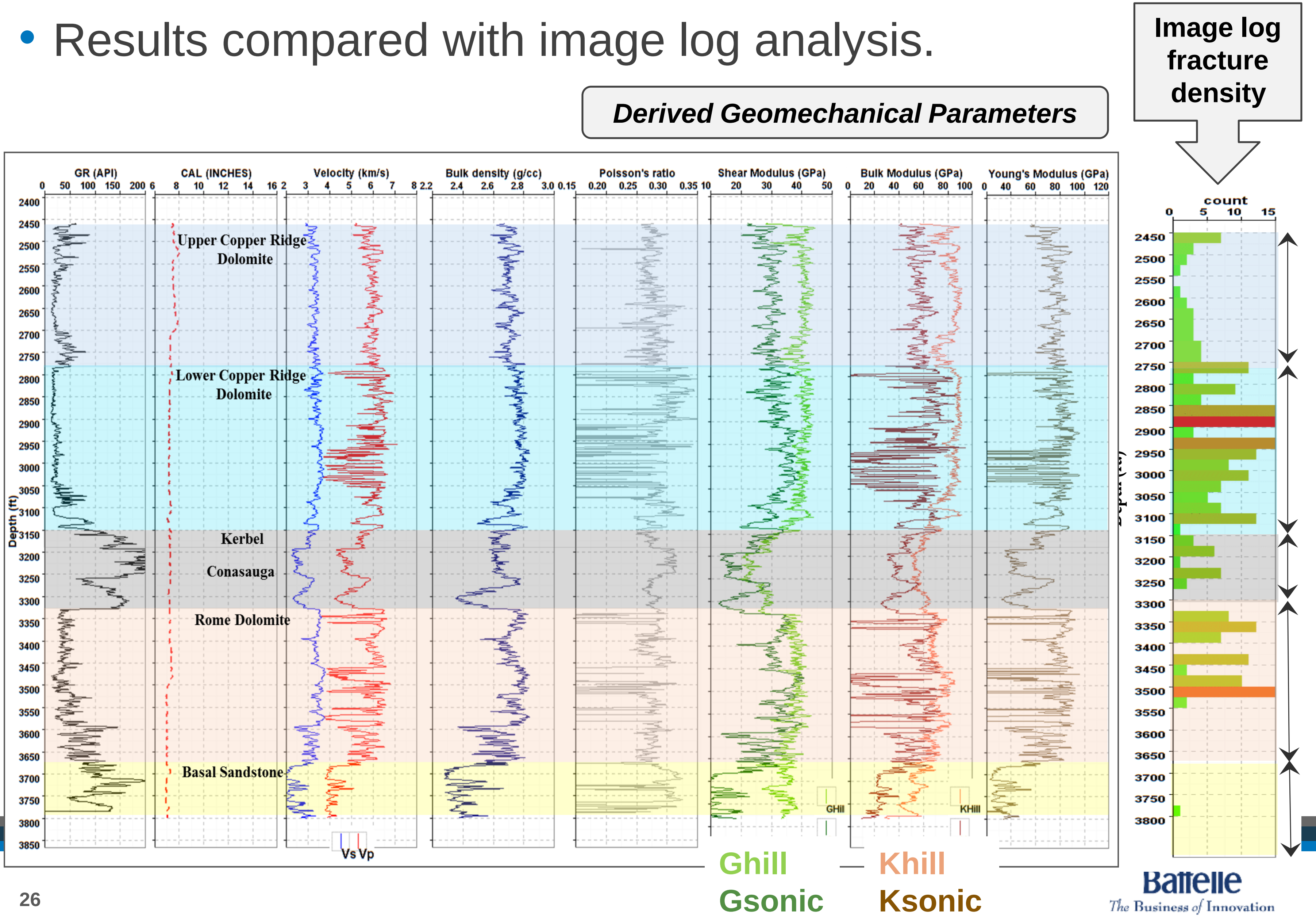
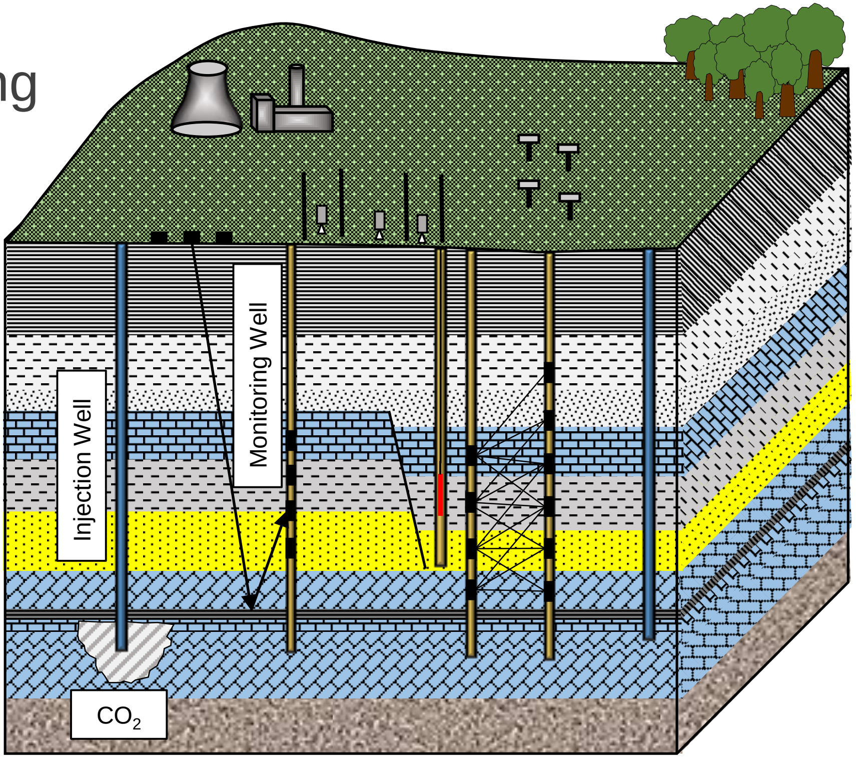
Task 4: Petrophysical Log Analysis & Integration

- Results compared with image log analysis.



Task 5: Development of Methodology for Geomechanical Site Characterization

- Guidance developed for sites with geomechanical concerns in the following areas:
  - Geophysical Logging
  - Geomechanical Rock Core Testing
  - Injection Testing
  - Geomechanical Monitoring



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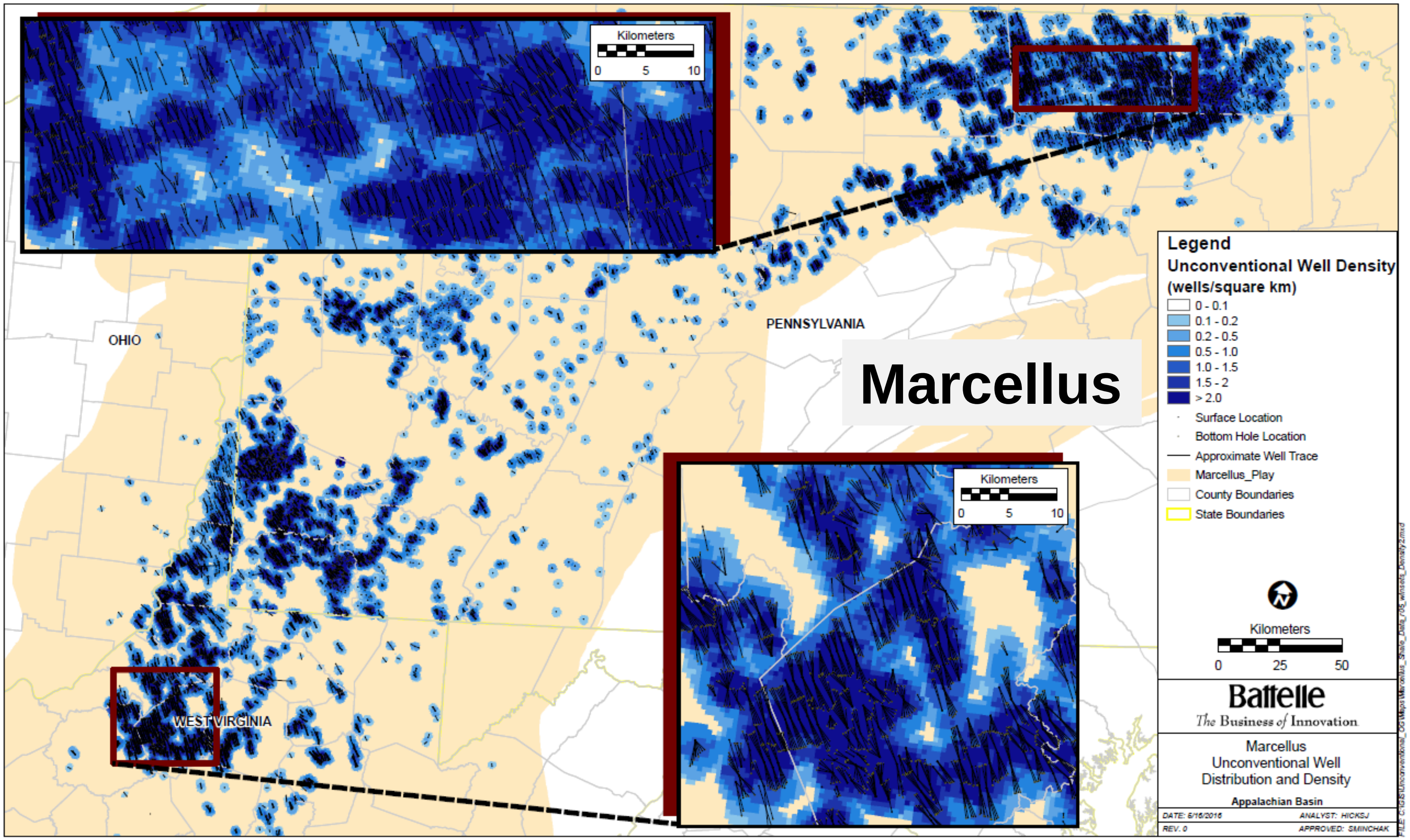
Task 8: CO_2 Storage/Shale Gas Risk Factor Assessment

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



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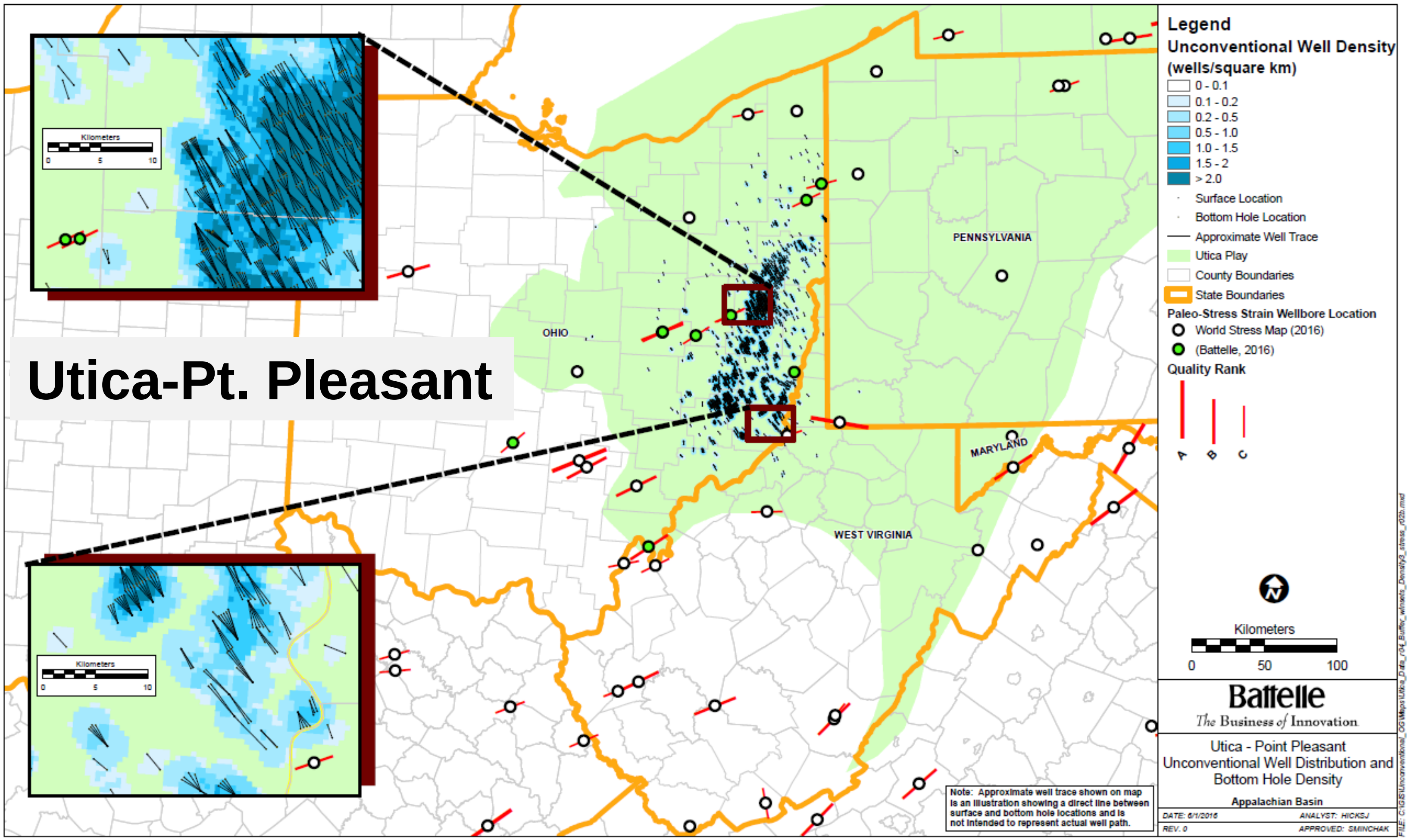
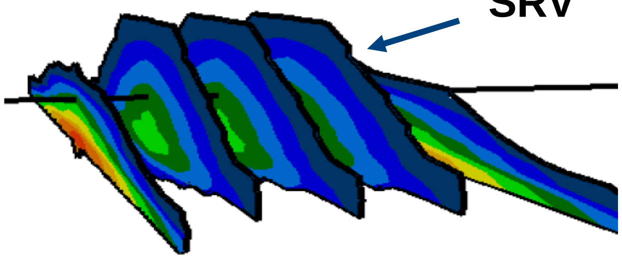
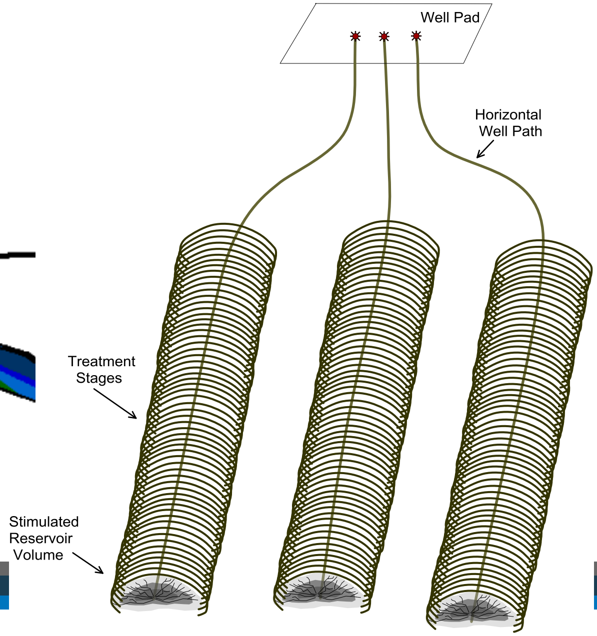


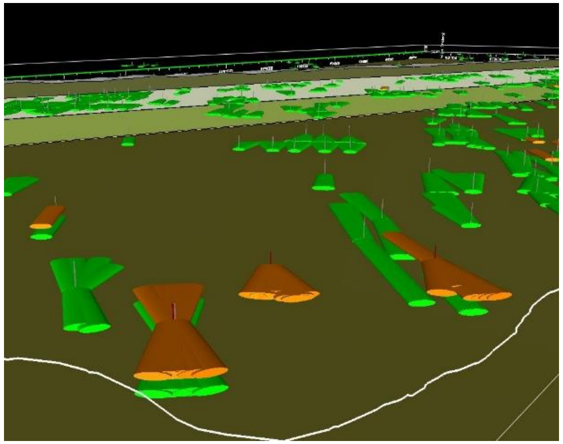
Task 8: CO_2 Storage/Shale Gas Risk Factors

- 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.

Horizontal Well Treatment Stages







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Synergy Opportunities

Synergy 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.

Summary/Results and Conclusions

- First year of the project focused on Paleo Stress-Strain analysis for the Midwest U.S. region.
- Analysis on natural fracture orientation indicates a complex pre-dominant northeast-southwest trend in horizontal stress.
- Analysis on fracture distribution indicates variation in fracture intensity:
  - More fractures were observed on acoustic and resistivity images collected in the western part than eastern part of the study area.
  - Factors controlling fracture orientation include direction of tectonic transport, Basin architecture, Paleo-stress.

Summary/Results and Conclusions

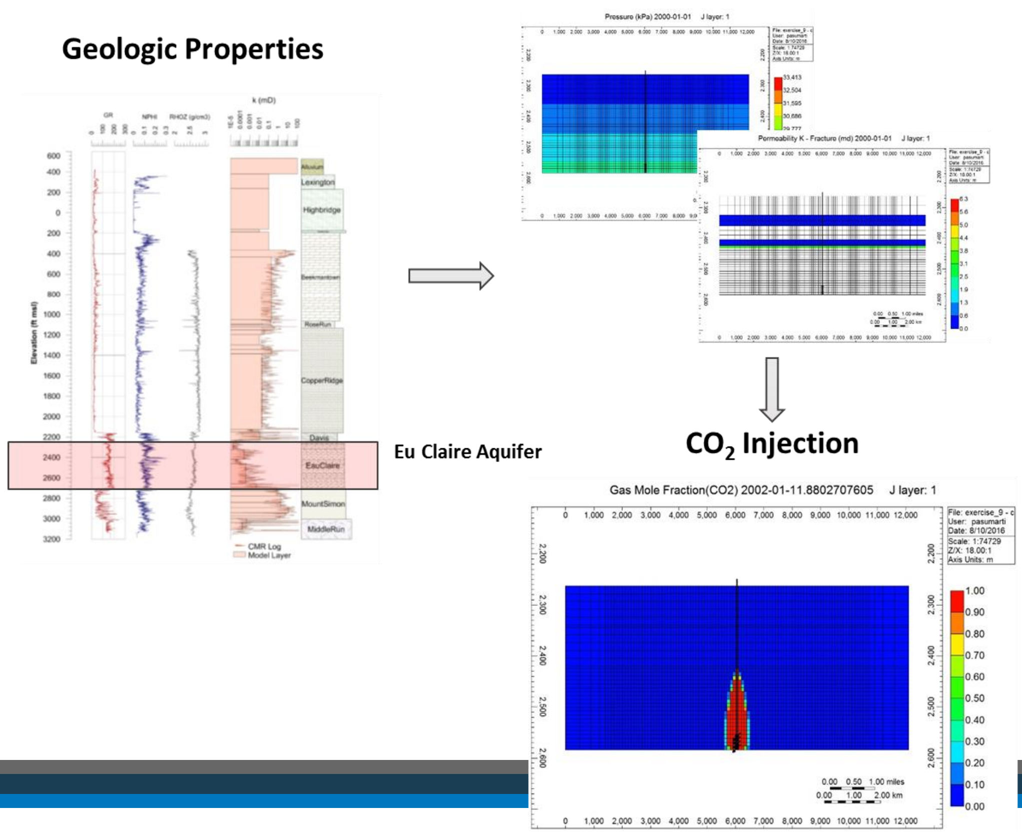
- Processing and analysis of 9,700 ft of geophysical image logs provides a better understanding of geomechanical conditions and features in the Midwest U.S.
- Site geomechanical analysis for 3 sites across the region better defines potential for subsurface deformation due to large scale CO_2 storage applications.
- Guidance developed for sites with geomechanical concerns for geophysical logging, rock core testing, injection testing, and geomechanical monitoring.

Summary- Future Work

Task 6: CO_2 injection simulations for fractured reservoirs

Task 7: CO_2 injection caprock simulations

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



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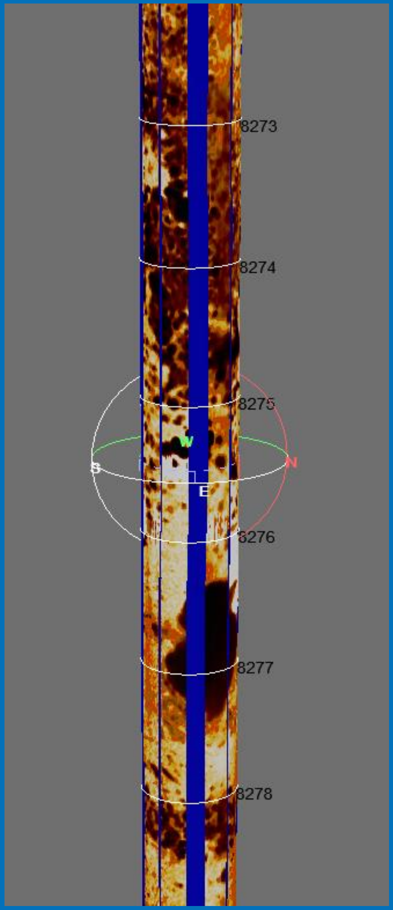
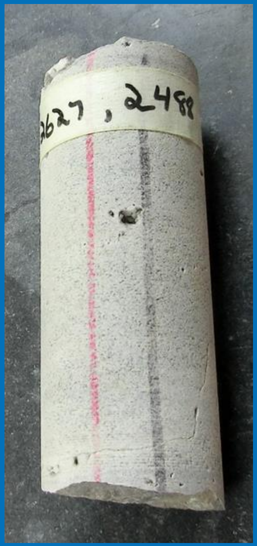
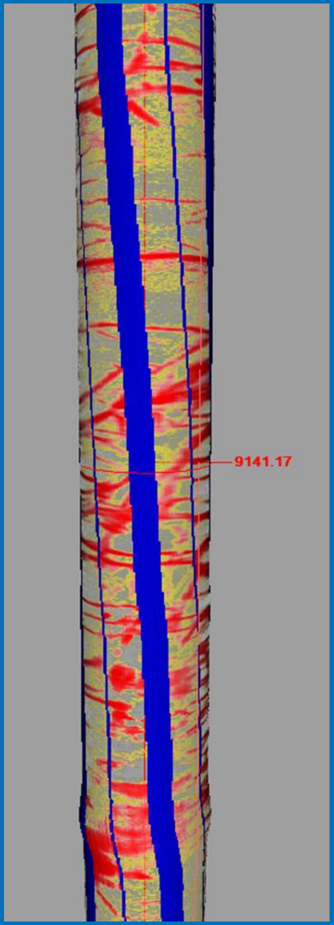


The End. Thank You.





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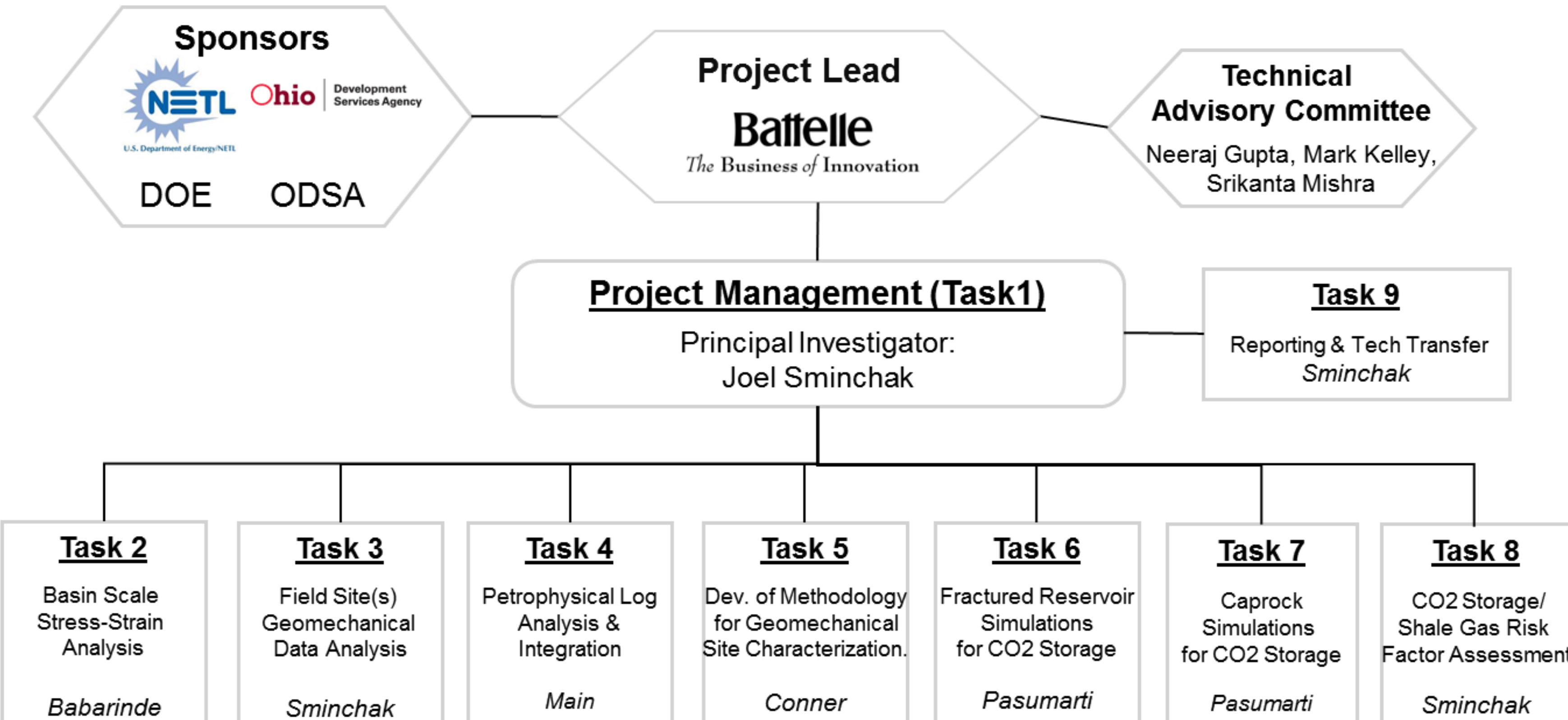
Additional Project Information

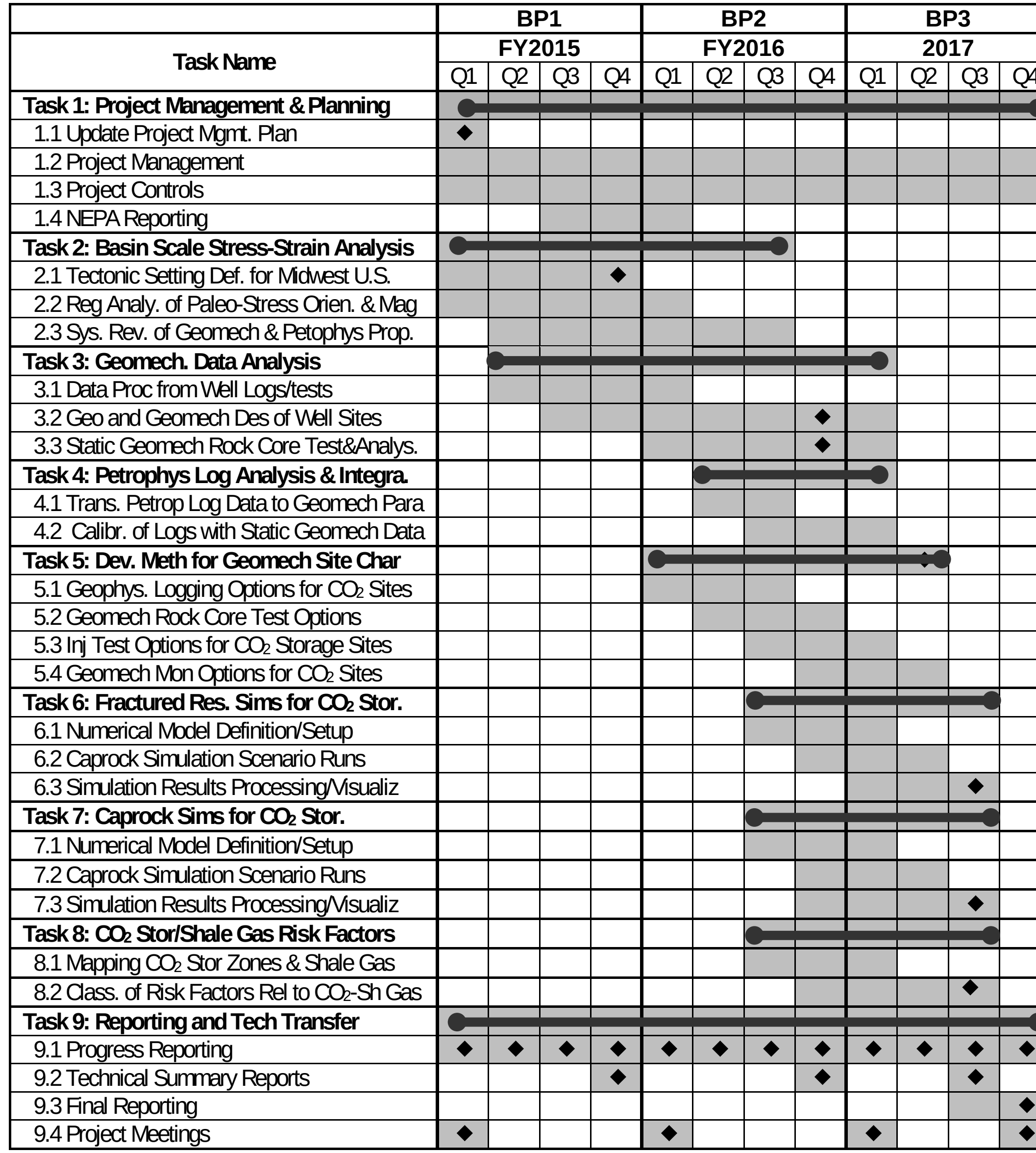
Project Organization Chart

- Project organized into 7 main technical tasks.



Gantt Chart

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



Deliverables/Milestones

Milestones

Budget Period	Milestone Description	Planned Due Date	Completion Date	Verification Method
1	Submit Updated Project Management Plan to DOE	30 days after initial award	**September 10, 2014**	Project Management Plan submitted to DOE PM
1	Collect and Analyze Geotechnical Data for Basin Scale Paleo-Stress/Strain Analysis	September 2015	**September 30, 2015**	Task Report Submitted
2	Acquire and Process 3-4 Advanced Geophysical Logs from Key Wells in the Region	September 2016	**On track for September 2016**	Summary Report, Upload data to EDX
2	Complete Testing of 10 Rock Cores for Geomechanical Parameters	September 2016	**January 2016**	Task 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

Bibliography

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- *Evaluating the influence of Mineralogical Components of CO2 Storage Zones on Mechanical Characterization in northern Appalachian Basin,* Joel Sminchak, Ola Babarinde, Neeraj Gupta, Samin Raziperchikolaee and Mark Kelley, Carbon Capture, Utilization, and Storage Conference, Tysons, Virginia, June 14-16, 2016.

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- *Geomechanical Assessment of Fractured Cambrian-Ordovician Reservoirs for Carbon Storage (Poster Abstract)*, Ola Babarinde, U.S. DOE Carbon Storage R&D Project Review Meeting, Pittsburgh, Pennsylvania, August 18-20, 2015.

- *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.