Integrated characterization of CO_2 storage reservoirs on the Rock Springs Uplift combining geomechanics, geochemistry, and flow modeling

DE-FE0023328

John Kaszuba
University of Wyoming

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National Energy Technology Laboratory
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Presentation Outline

- Benefits and overview
- Technical status
- Accomplishments to date
- Synergy opportunities
- Summary

Benefit to the Program

- **Program goals addressed**
  - Develop and validate technologies to ensure 99% storage permanence
  - Develop Best Practice Manuals (BPMs) for monitoring, verification, accounting (MVA), and assessment; site screening, selection, and initial characterization; public outreach; well management activities; and risk analysis and simulation.

Project Benefits Statement

The project will conduct research under **Area of Interest 1, Geomechanical Research**, by **developing a new protocol and workflow to predict the post-injection evolution** of porosity, permeability and rock mechanics, relevant to estimate rock failure events, uplift and subsidence, and saturation distributions, and how these changes might affect geomechanical parameters, and consequently reservoir responses. **The ability to predict geomechanical behavior in response to CO_2 injection, if successful, could increase the accuracy of subsurface models that predict the integrity of the storage reservoir**.

Project Overview:
Goals and Objectives

Overall Objective

Improve understanding of the effects of CO_2 injection and storage on geomechanical, petrophysical, and other reservoir properties.

- Combines integrated, interdisciplinary methodology using existing data sets (Rock Springs Uplift in Wyoming)
- Culminates in integrated workflow for potential CO_2 storage operations

Project Overview: Goals and Objectives

Specific Objectives

1) Test new facies and mechanical stratigraphy classification techniques on the existing RSU dataset

2) Determine lithologic and geochemical changes resulting from interaction among CO_2, formation waters, and reservoir rocks in laboratory experiments

3) Determine the effect(s) of CO_2-water-reservoir rock interaction on rock strength properties; this will be accomplished by performing triaxial strength tests on reservoir rock reacted in Objective #2 and comparing the results to preexisting triaxial data available for reservoir rocks

Project Overview: Goals and Objectives

Specific Objectives (continued)

4) Identify changes in rock properties pre- and post-CO_2 injection
5) Identify the parameters with the greatest variation that would have the most effect on a reservoir model
6) Make connections between elastic, petro-elastic, and geomechanical properties
7) Develop ways to build a reservoir model based on post-CO_2-injection rock properties
8) Build a workflow that can be applied to other sequestration characterization sites, to allow for faster, less expensive, and more accurate site characterization and plume modeling.

Project Overview:
Goals and Objectives

Relationship to DOE program goals

Our approach can be adapted to other sites to guide site characterization and design of surveillance and monitoring techniques to meet the goal of 99% safe storage, reach ±30% model accuracy, contribute to the BPM, and reduce time and cost of site characterization.

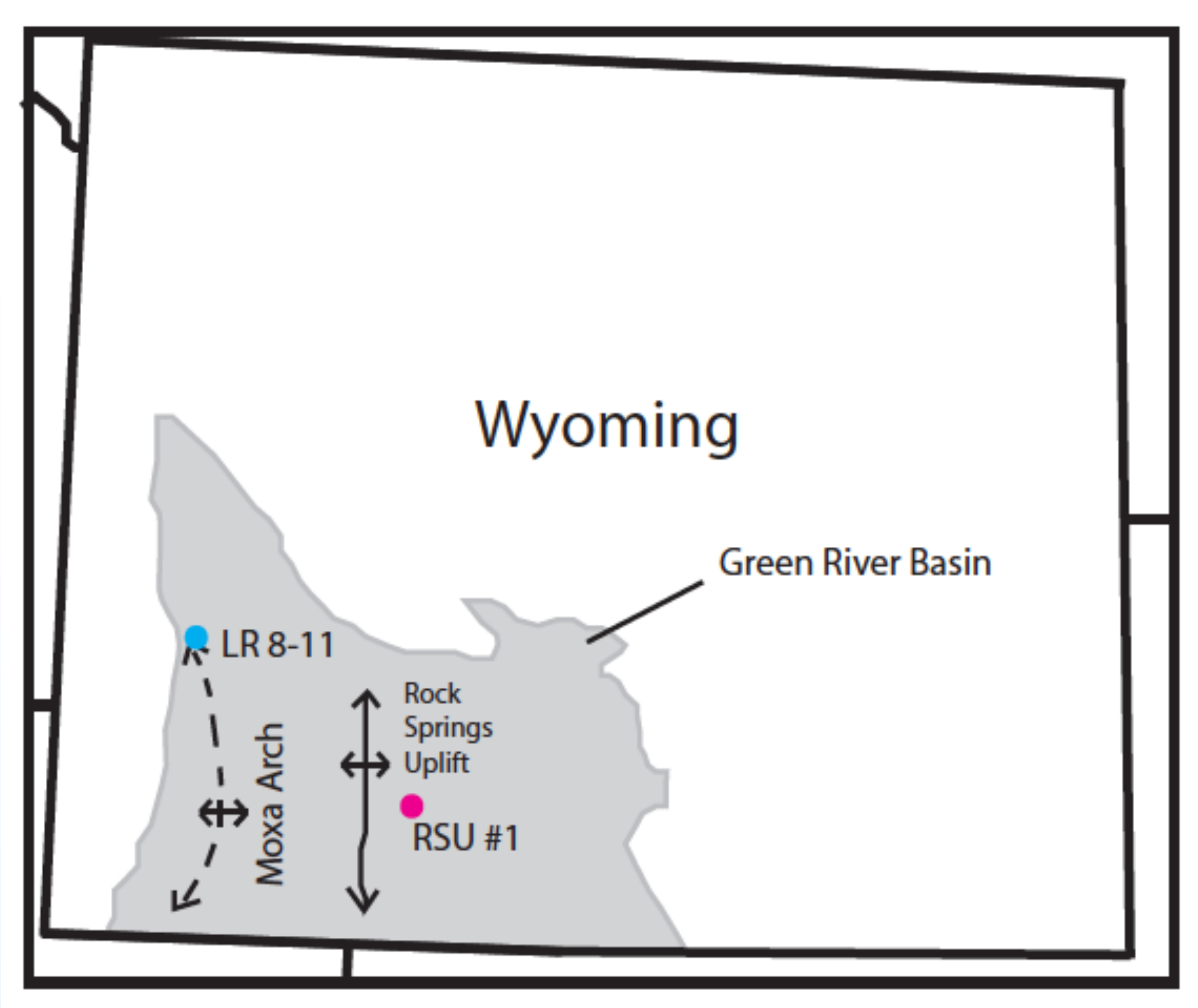
Technical status

Interdisciplinary Team

- Vladimir Alvarado: Reservoir Engineer
- Erin Campbell-Stone: Structural Geology, Geomechanics, Wyoming Geology
- Dario Grana: Rock Physics
- Kam Ng: Geomechanics
- John Kaszuba: PI, Geochemistry

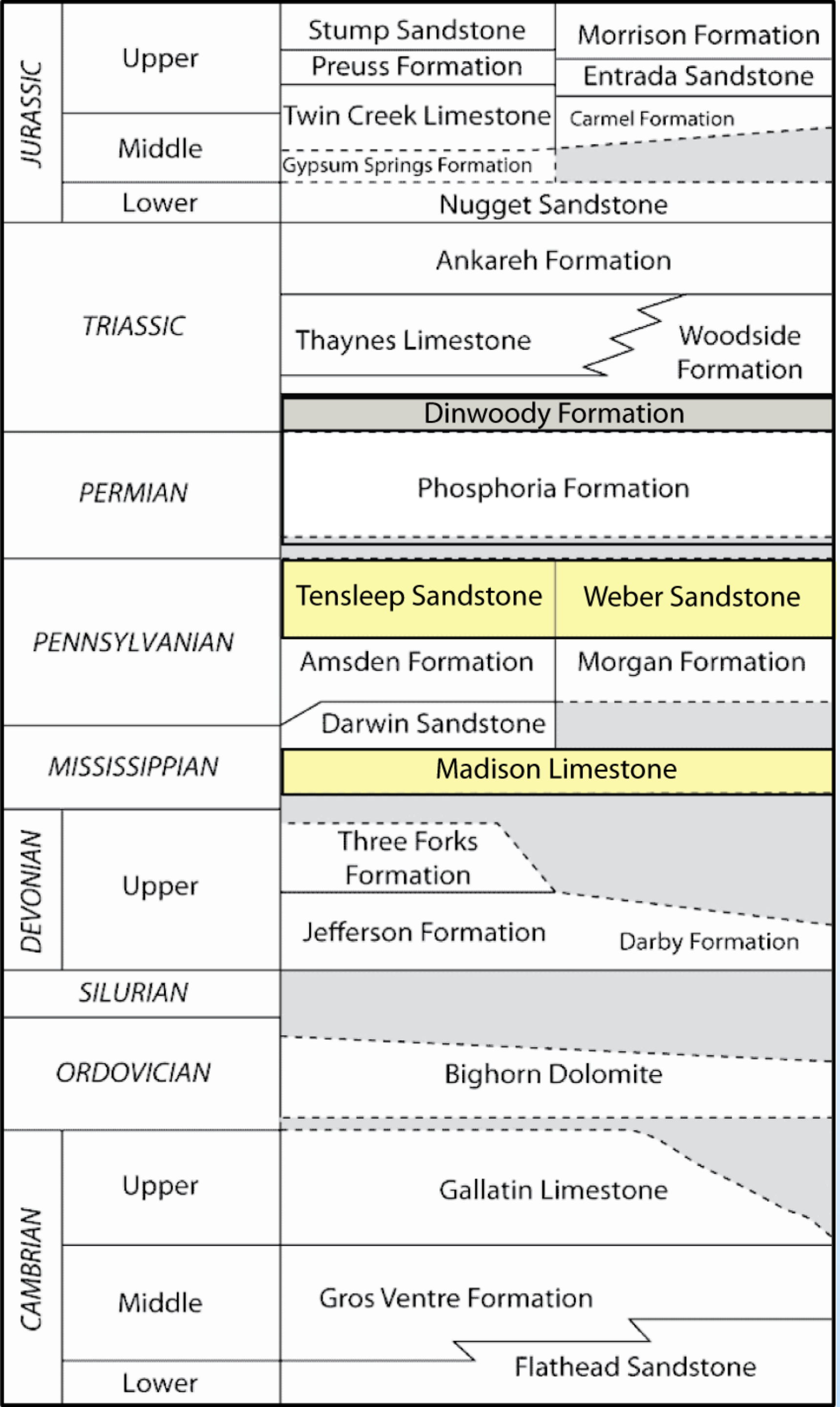
Today’s results predominantly work of D. Grana.

Rocks Spring Uplift, WY



Spaeth 2015

Stratigraphy

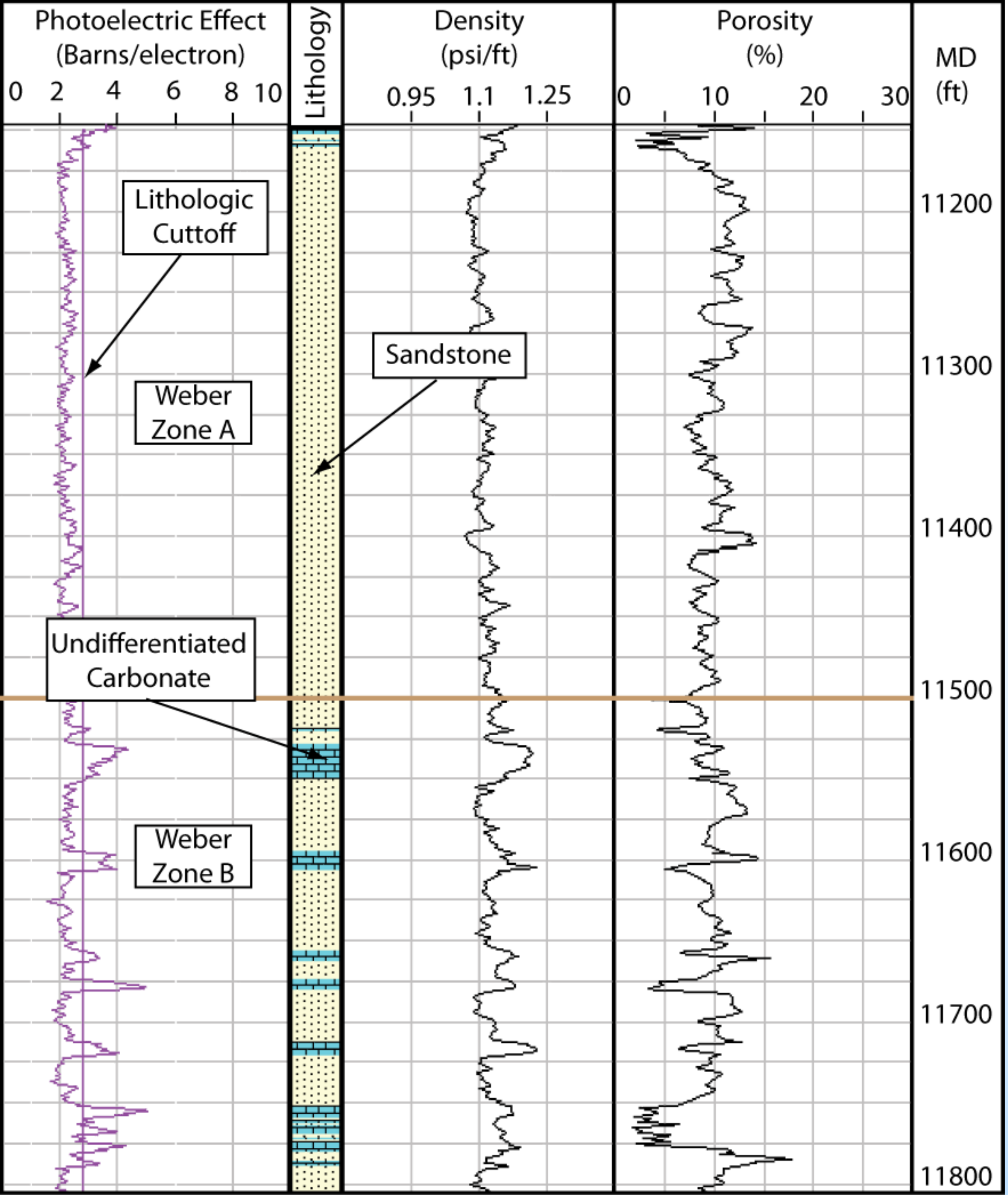


3400 – 3600 m (11150 – 11800 ft)

3725 – 3855 m (12225 – 12650 ft)

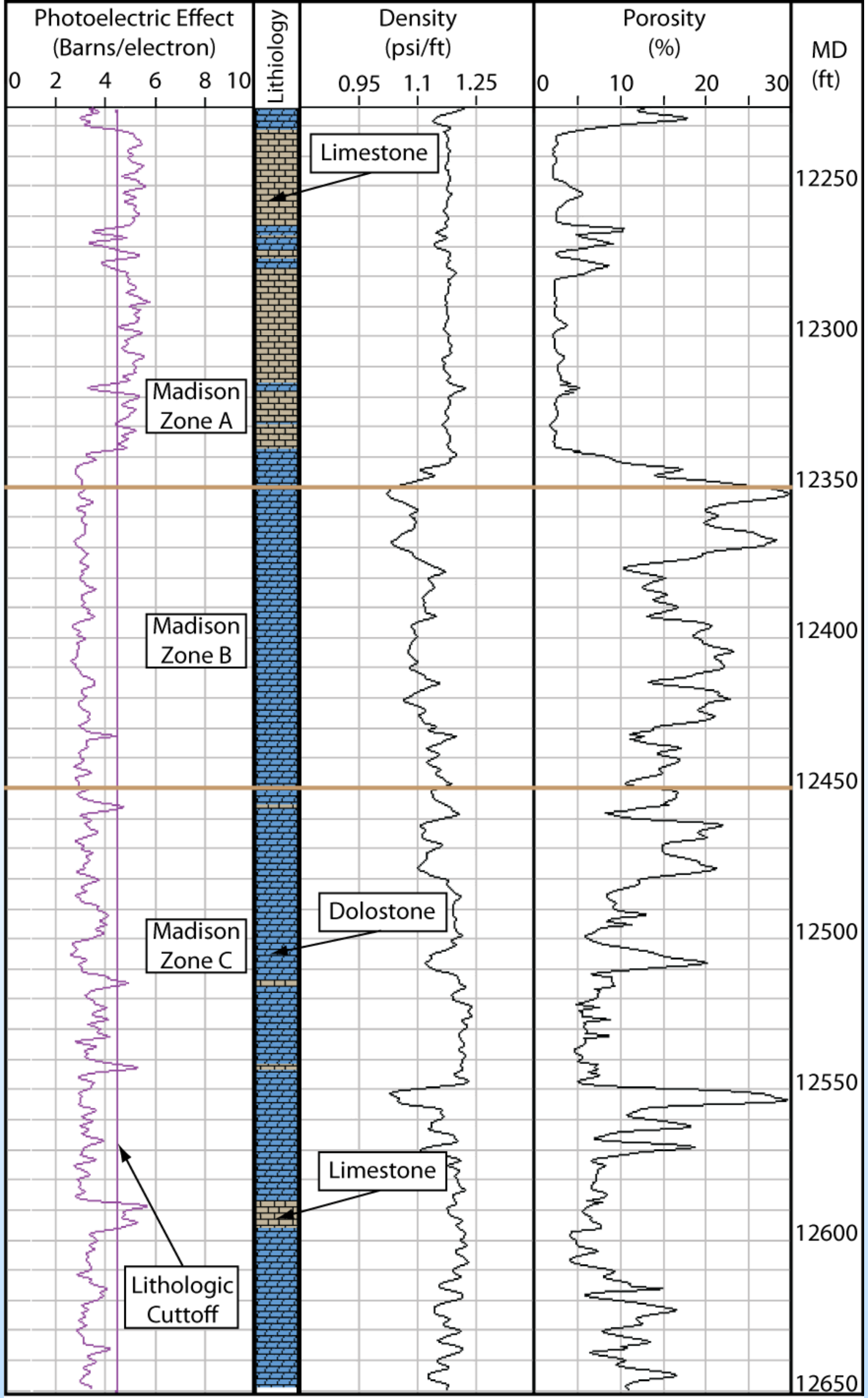
Shafer 2013

Weber Ss



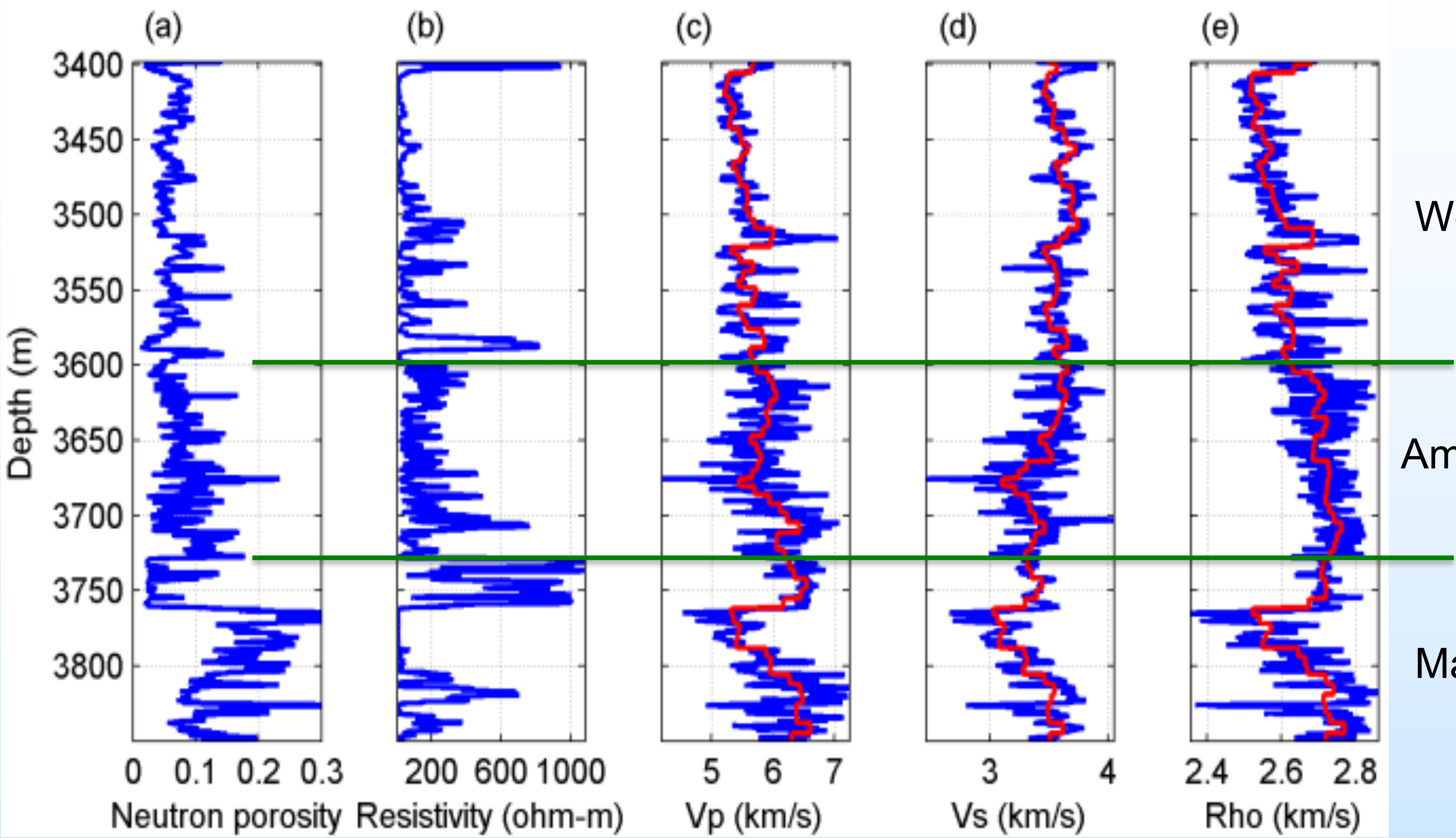
Shafer 2013

Madison Ls



Shafer 2013

Existing Well Logs



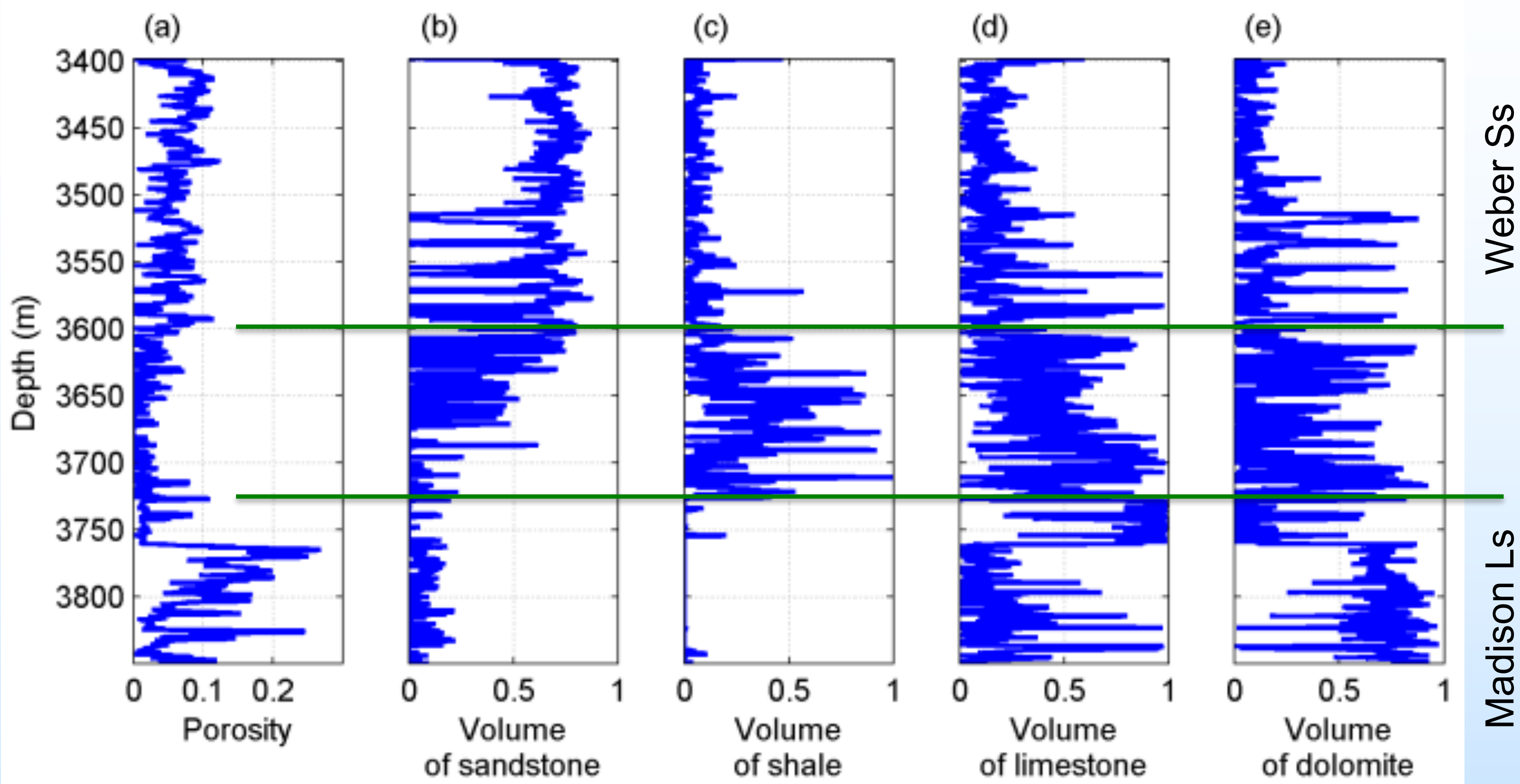
Weber Ss

Amsden Fm

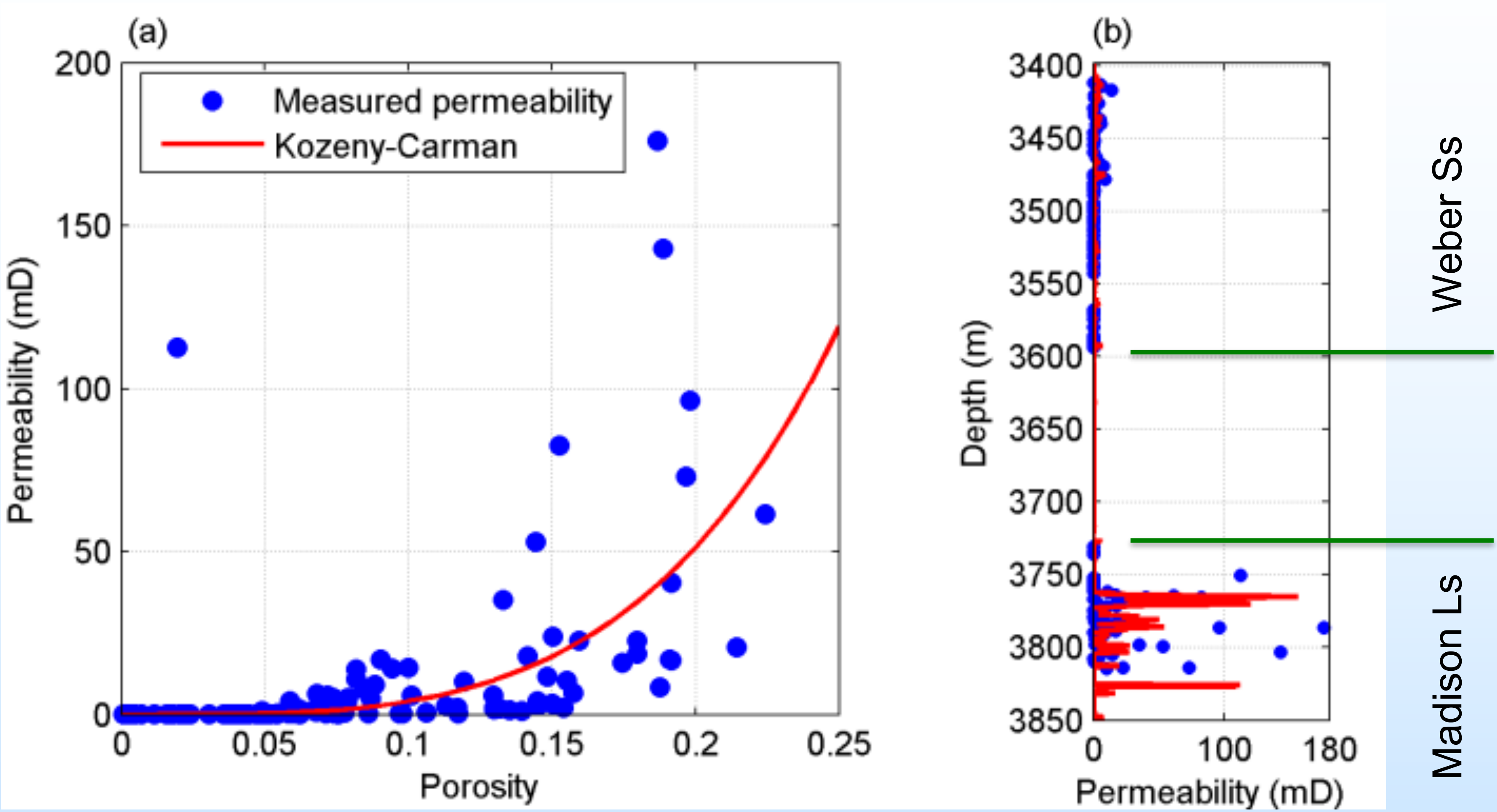
Madison Ls

After Surdam et al., 2013

Petrophysical Data



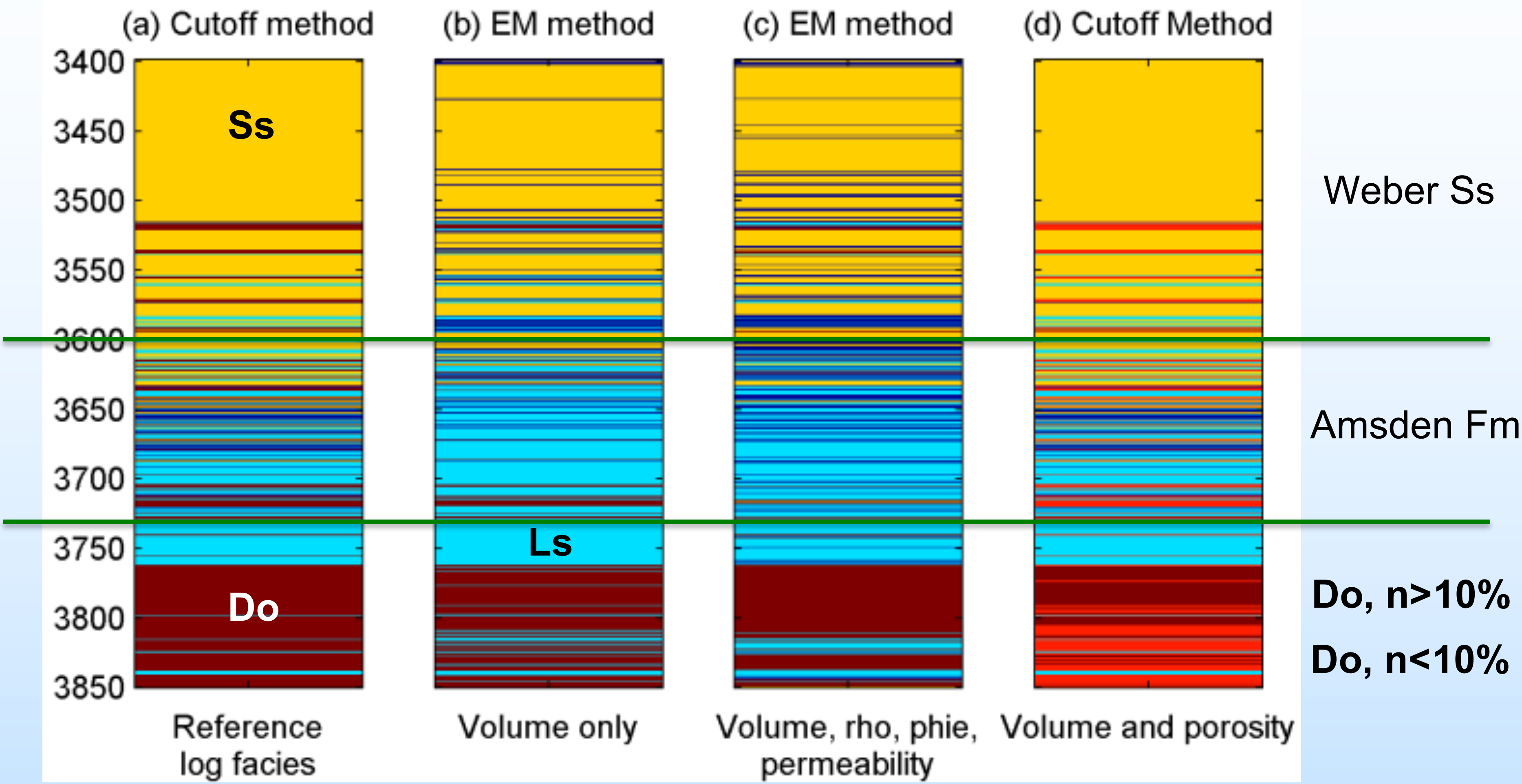
Permeability



Measured permeability from Surdam et al., 2013

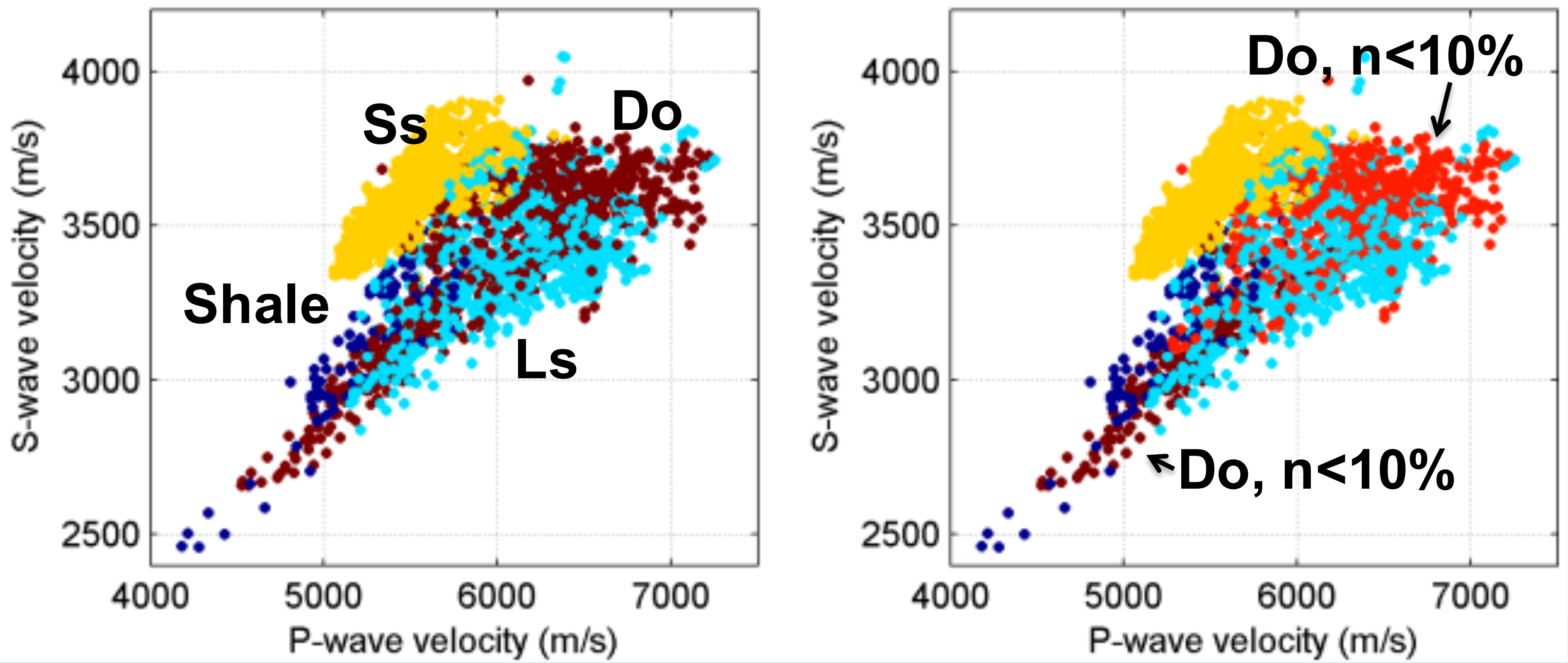
Calculated permeability (Kozeny-Carman): $K = \frac{\rho g}{\mu} C_k f_k(n) d_{10}^2$

Facies Classification

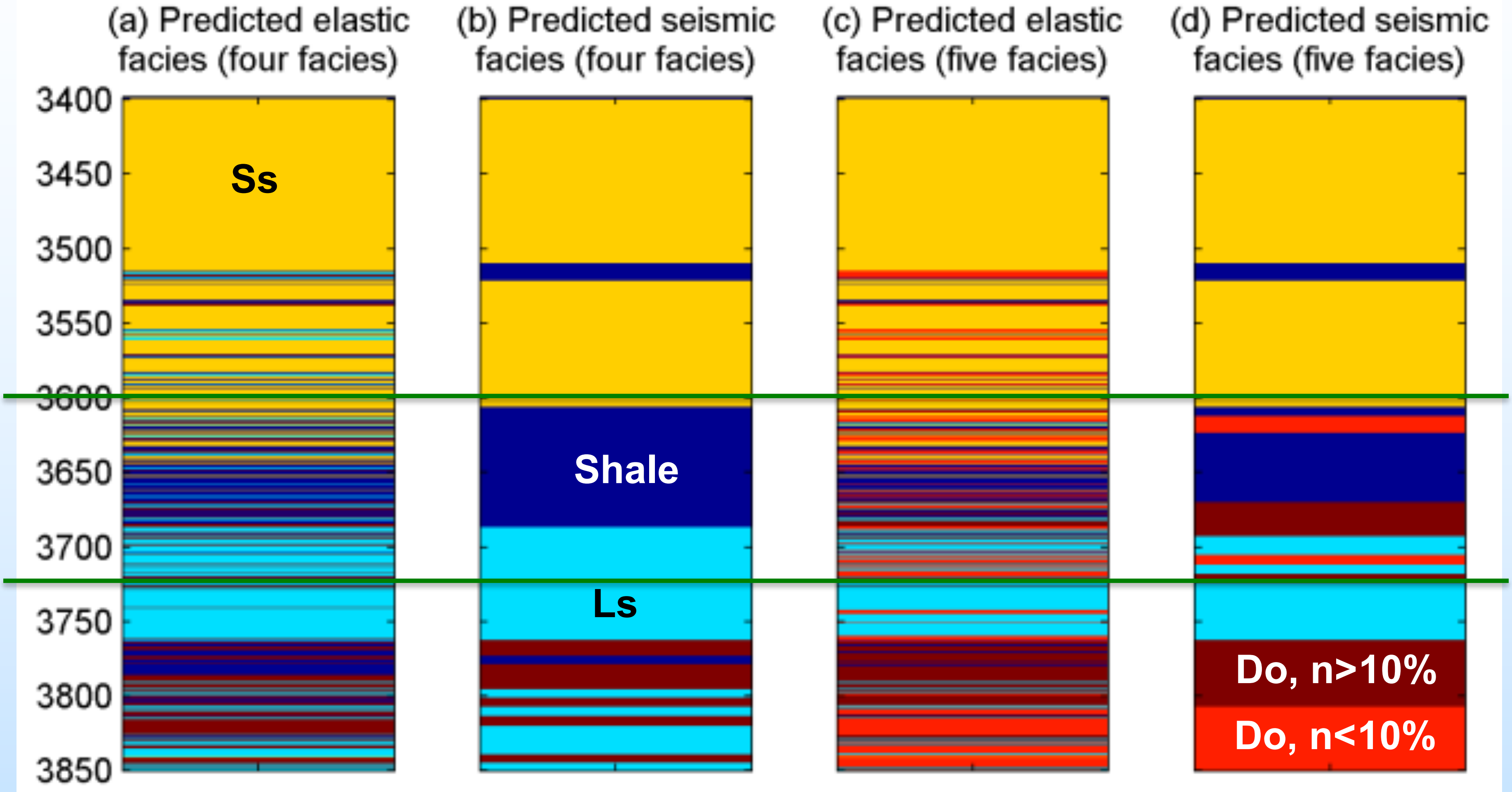


+Shale (dark blue)

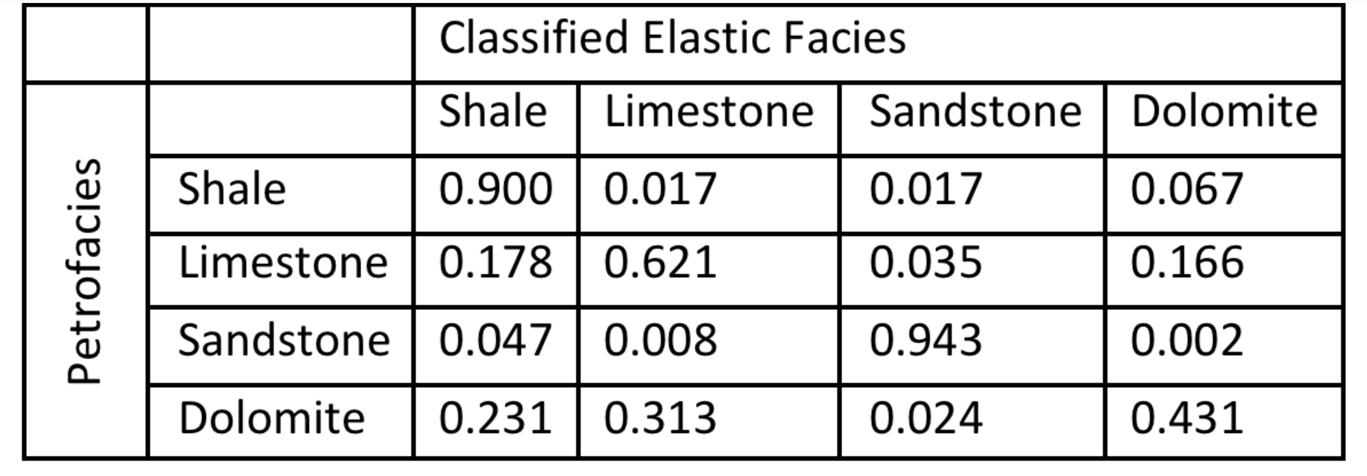
Rock Physics Analysis



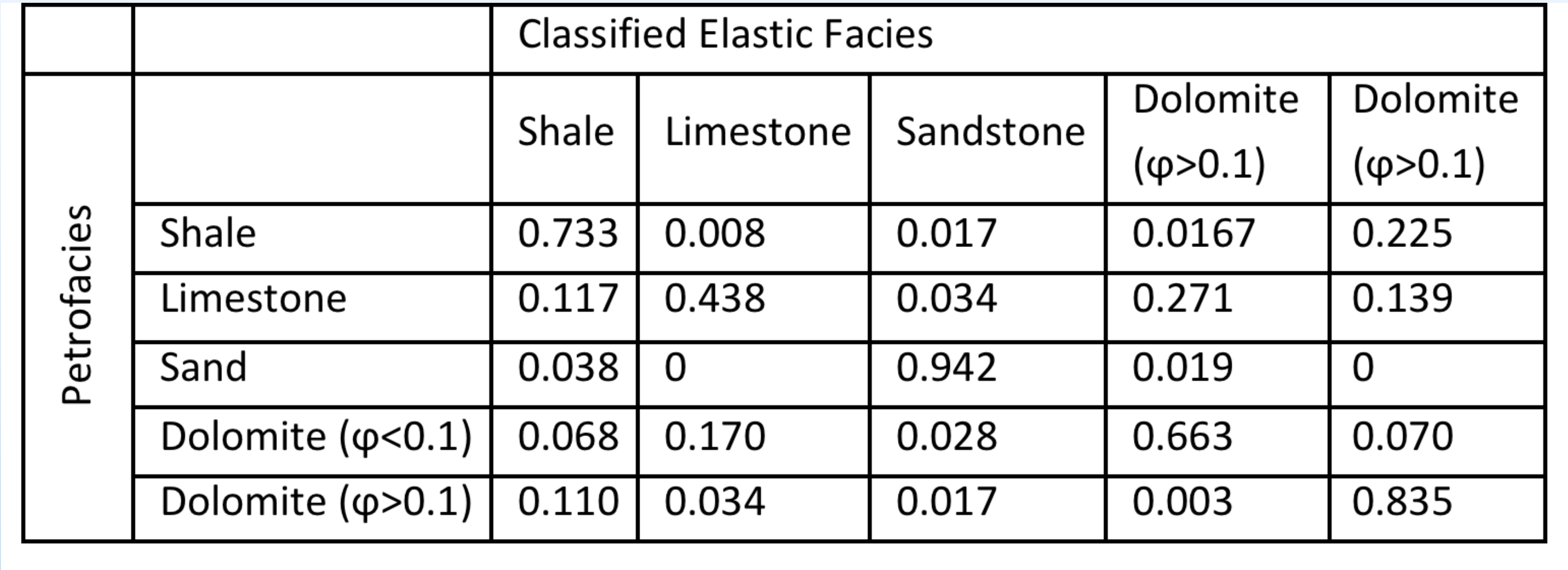
Bayesian Facies Classification



Frequency Table

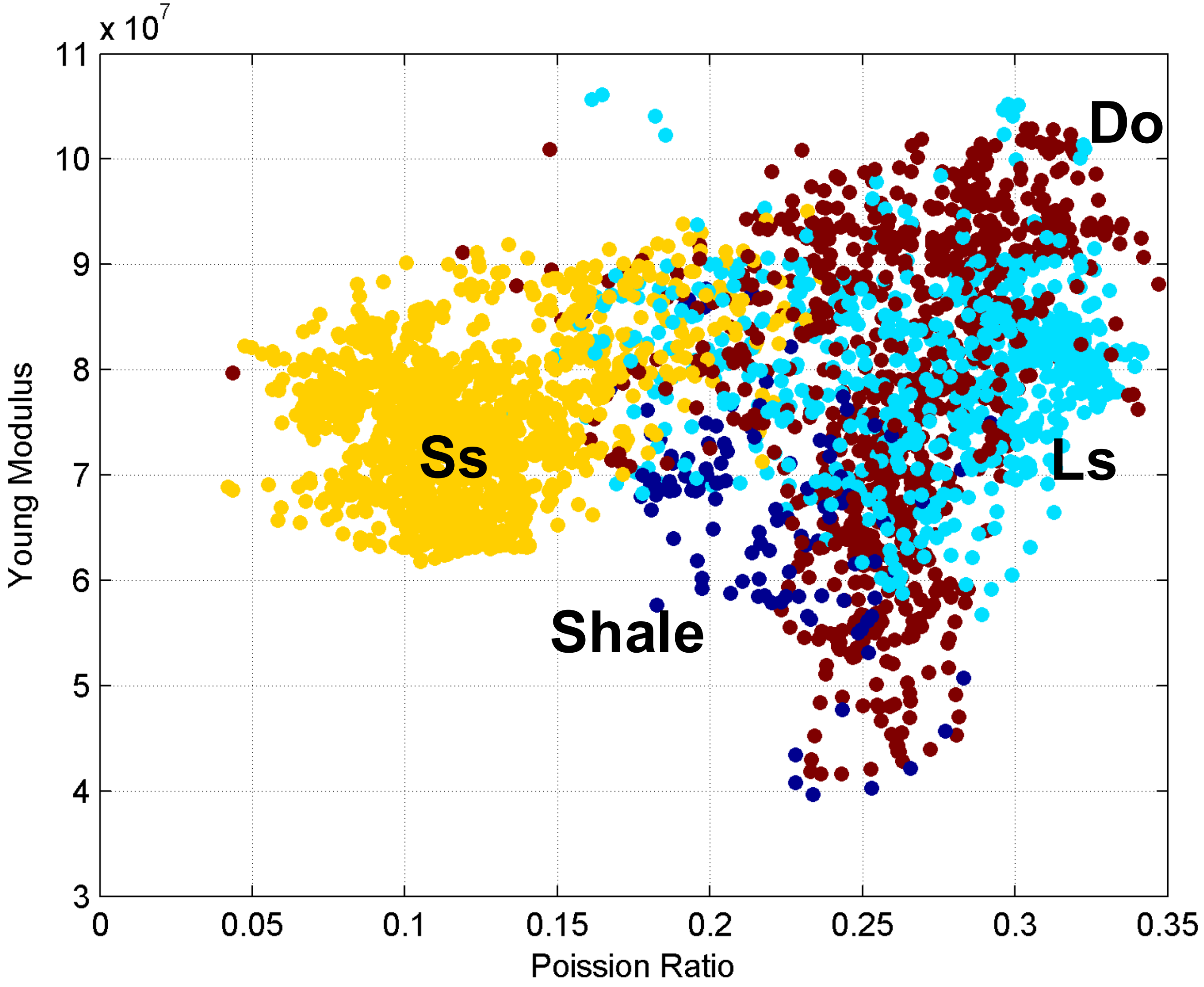


		Classified Elastic Facies			
Petrofacies		Shale	Limestone	Sandstone	Dolomite
	Shale	0.900	0.017	0.017	0.067
	Limestone	0.178	0.621	0.035	0.166
	Sandstone	0.047	0.008	0.943	0.002
	Dolomite	0.231	0.313	0.024	0.431

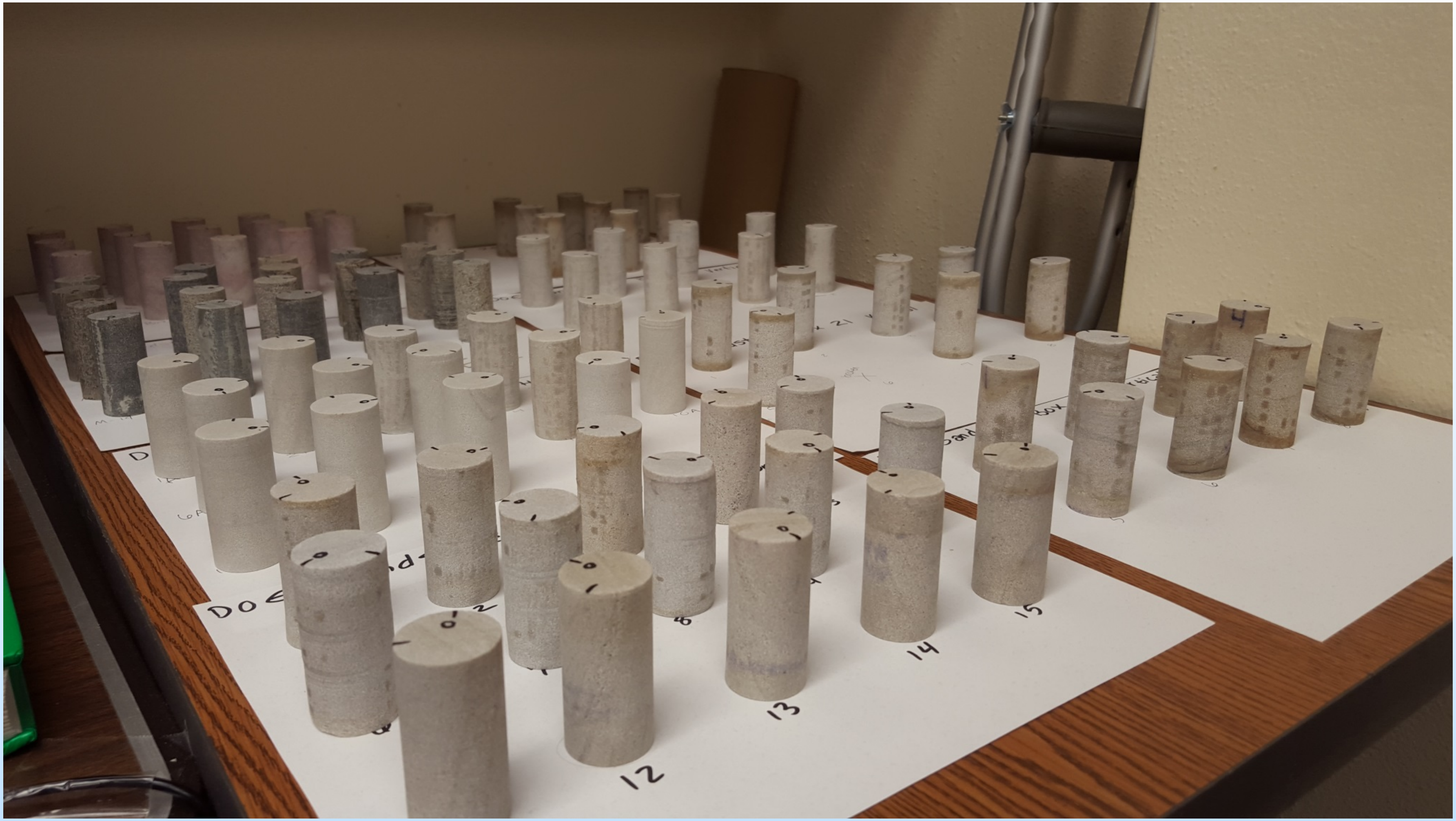


		Classified Elastic Facies				
Petrofacies		Shale	Limestone	Sandstone	Dolomite (φ>0.1)	Dolomite (φ>0.1)
	Shale	0.733	0.008	0.017	0.0167	0.225
	Limestone	0.117	0.438	0.034	0.271	0.139
	Sand	0.038	0	0.942	0.019	0
	Dolomite (φ<0.1)	0.068	0.170	0.028	0.663	0.070
	Dolomite (φ>0.1)	0.110	0.034	0.017	0.003	0.835

Rock Physics & Geomechanics



Experiments - Sample Selection, Preparation, and Workflow



Geomechanics Lab

Interpreted in-situ stress conditions (Shafer 2013)

Geomechanical Parameter	Weber (@11536.5 ft)	Madison (@12,512 ft)
Vertical Stress	12250 psi	13380 psi
Pore Pressure	4914.55 psi	5380.15 psi
S_{hmin} magnitude range	6841 – 7268 psi	8240 – 9895 psi
S_{Hmax} magnitude range	9645 – 12,290 psi	10600 – 19,810 psi

Selected geomechanical test conditions

Geomechanical Parameter	Weber	Madison
Total Confining Pressure	6000 psi, 9000 psi, 13,000 psi	6000 psi, 9000 psi, 13,000 psi
Pore Pressure (brine)	5300 psi	5750 psi
Temperature	200 F	215 F
Ultrasonic Frequency (Vs and Vp)	200 KHz	200 KHz

Accomplishments to date

- Establish infrastructure and culture of communication among disciplines
  - Grounded by knowledge of geologic reservoir conditions
  - 2 PhD students hired, co-advised by coPIs
  - Graduate course in reservoir geomechanics taught Spring 2015 by coPI; PI and grad student participated
- Review results from previous study
- Select/machine samples from core
- Calibrate facies-dependent rock physics models (in sandstone, dolomite and limestone)
- Apply joint rock physics model for the estimation of elastic and electrical properties (velocity and resistivity)
- Implement statistical approach to facies classification and rock physics modeling for uncertainty quantification
- Finalize integrated geochemical-geomechanical test plan/workflow
- Begin initial geochemical tests
- Prepare labs for coreflood and geomechanical tests
  - Update triaxial equipment (ultrasonic, temperature control system, and high temperature load cell)

Synergy opportunities

To be determined

Summary – Key Findings/Lessons Learned

- Four main rock types: sand, shale, limestone and dolomite. For each rock type in each formation, we determined a rock physics model to link rock and fluid properties, such as porosity, lithology and fluid saturations, with elastic and geomechanical properties
- Four probabilistic approaches to quantify uncertainty in facies classification (Expectation Maximization, Bayesian classification, Gaussian mixture classification, and k-means clustering) provided similar results.
- Use Bayesian classification, which is also the most popular in the oil industry.

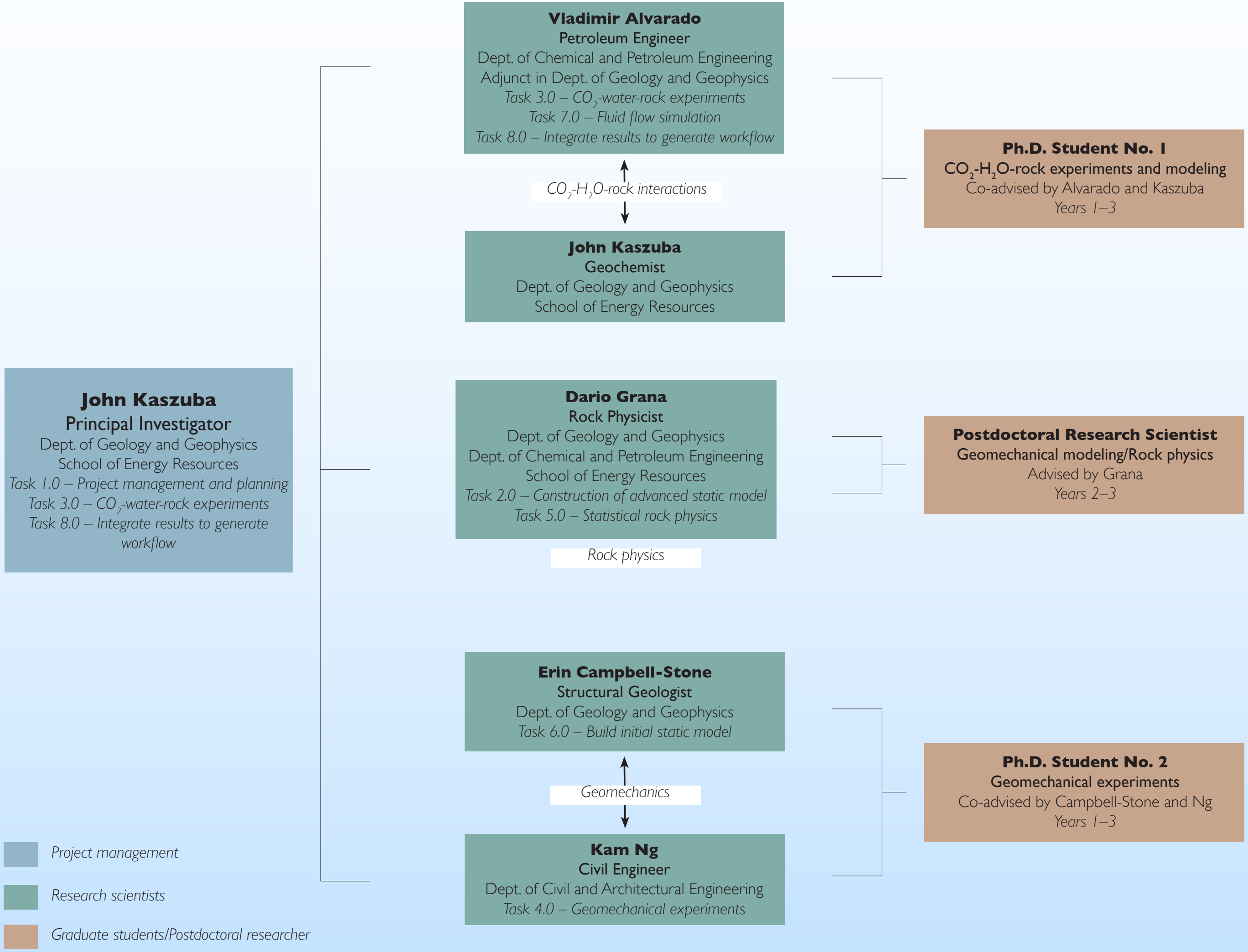
Summary – Key Findings/Lessons Learned

- Distinguish sandstone from other lithologies using elastic properties, but large overlap between limestone and dolomite.
- Uncertainty increases if facies classification is performed at resolution of seismic data rather than the well log scale.
- Geomechanical properties determined for facies

Summary – Future Plans

- Continue geochemical tests
- Begin coreflood tests
- Begin geomechanical tests (unreacted samples)
- Revisit rock physics models
  - Re-evaluate inversion of seismic data to improve resolution
  - Incorporate results of impending geomechanical tests into rock physics model
  - Extend Rock Physics models to 3D static model of the reservoir

Organizational Chart and Communication Plan



John Kaszuba
Principal Investigator
Dept. of Geology and Geophysics
School of Energy Resources
Task 1.0 – Project management and planning
Task 3.0 – CO_2-water-rock experiments
Task 8.0 – Integrate results to generate workflow

Vladimir Alvarado
Petroleum Engineer
Dept. of Chemical and Petroleum Engineering
Adjunct in Dept. of Geology and Geophysics
Task 3.0 – CO_2-water-rock experiments
Task 7.0 – Fluid flow simulation
Task 8.0 – Integrate results to generate workflow

CO_2-H_2O-rock interactions

John Kaszuba
Geochemist
Dept. of Geology and Geophysics
School of Energy Resources

Dario Grana
Rock Physicist
Dept. of Geology and Geophysics
Dept. of Chemical and Petroleum Engineering
School of Energy Resources
Task 2.0 – Construction of advanced static model
Task 5.0 – Statistical rock physics

Rock physics

Erin Campbell-Stone
Structural Geologist
Dept. of Geology and Geophysics
Task 6.0 – Build initial static model

Geomechanics

Kam Ng
Civil Engineer
Dept. of Civil and Architectural Engineering
Task 4.0 – Geomechanical experiments

Ph.D. Student No. 1
CO_2-H_2O-rock experiments and modeling
Co-advised by Alvarado and Kaszuba
Years 1–3

Postdoctoral Research Scientist
Geomechanical modeling/Rock physics
Advised by Grana
Years 2–3

Ph.D. Student No. 2
Geomechanical experiments
Co-advised by Campbell-Stone and Ng
Years 1–3

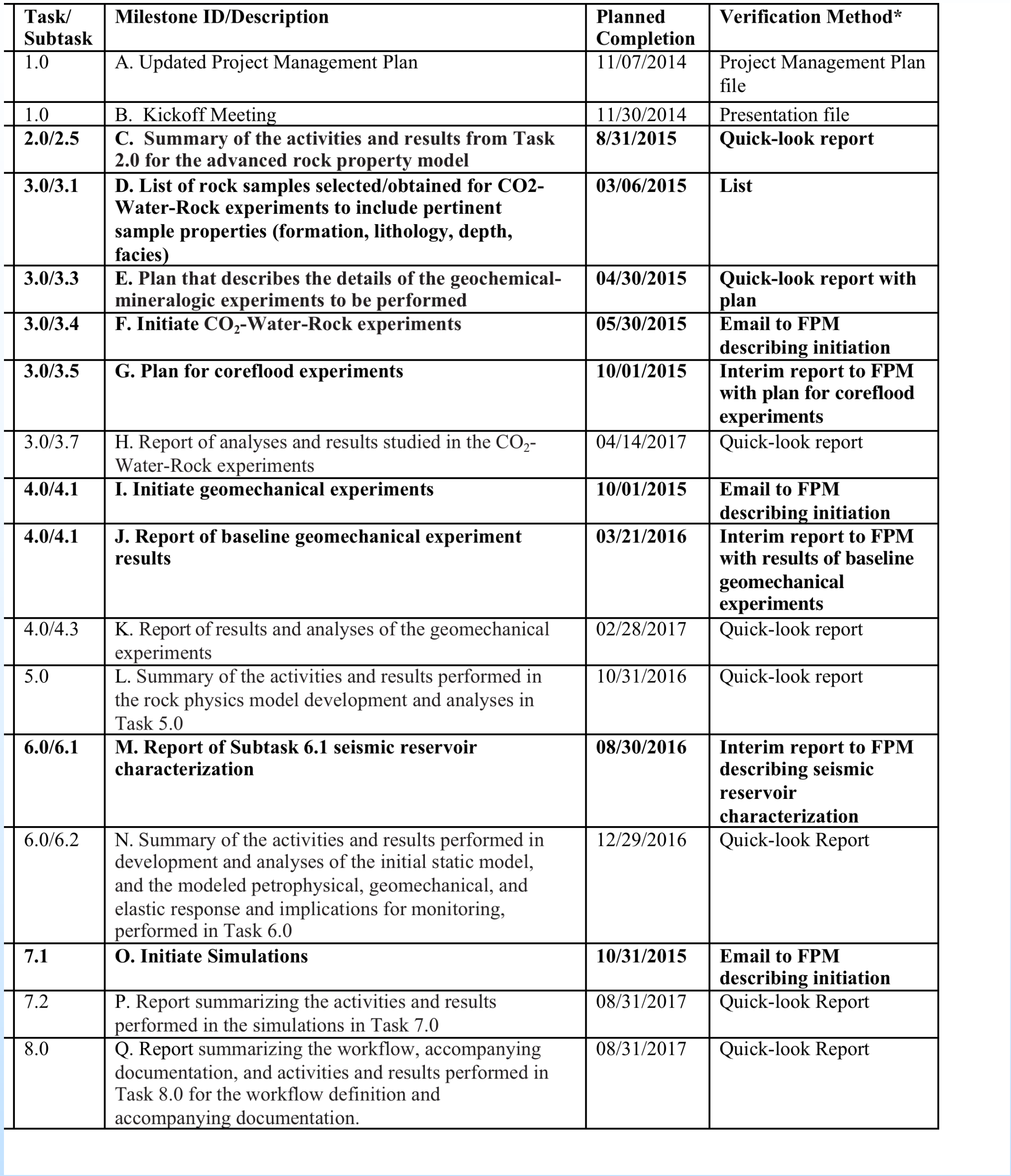
🟦 *Project management*

🟩 *Research scientists*

🟫 *Graduate students/Postdoctoral researcher*

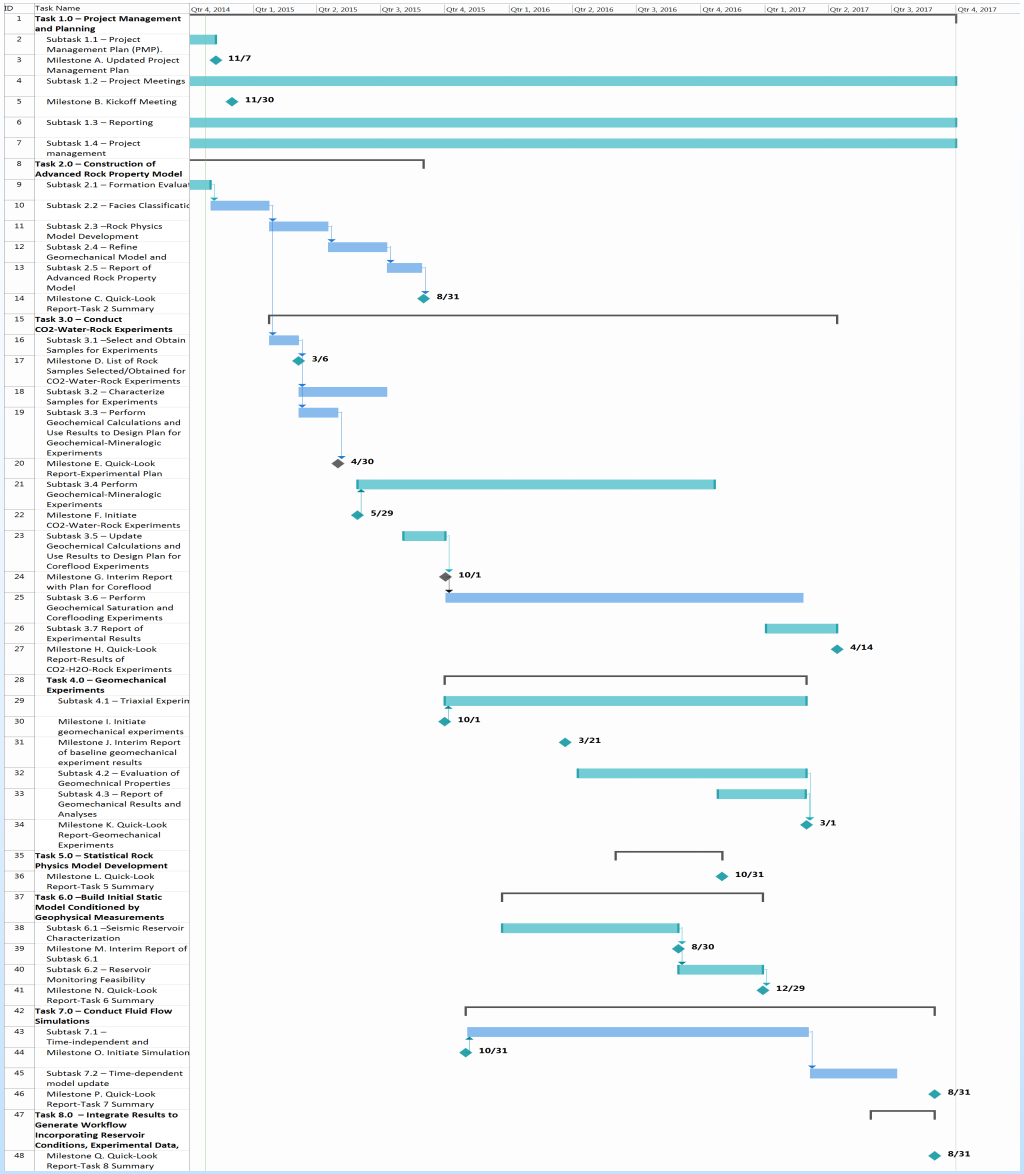
Figure 1. Organizational chart.

Deliverables/Milestones/Decision Points



Task/ Subtask	Milestone ID/Description	Planned Completion	Verification Method*
1.0	A. Updated Project Management Plan	11/07/2014	Project Management Plan file
1.0	B. Kickoff Meeting	11/30/2014	Presentation file
2.0/2.5	**C. Summary of the activities and results from Task 2.0 for the advanced rock property model**	**8/31/2015**	**Quick-look report**
3.0/3.1	**D. List of rock samples selected/obtained for CO2-Water-Rock experiments to include pertinent sample properties (formation, lithology, depth, facies)**	**03/06/2015**	**List**
3.0/3.3	**E. Plan that describes the details of the geochemical-mineralogic experiments to be performed**	**04/30/2015**	**Quick-look report with plan**
3.0/3.4	**F. Initiate CO_2-Water-Rock experiments**	**05/30/2015**	**Email to FPM describing initiation**
3.0/3.5	**G. Plan for coreflood experiments**	**10/01/2015**	**Interim report to FPM with plan for coreflood experiments**
3.0/3.7	H. Report of analyses and results studied in the CO_2-Water-Rock experiments	04/14/2017	Quick-look report
4.0/4.1	**I. Initiate geomechanical experiments**	**10/01/2015**	**Email to FPM describing initiation**
4.0/4.1	**J. Report of baseline geomechanical experiment results**	**03/21/2016**	**Interim report to FPM with results of baseline geomechanical experiments**
4.0/4.3	K. Report of results and analyses of the geomechanical experiments	02/28/2017	Quick-look report
5.0	L. Summary of the activities and results performed in the rock physics model development and analyses in Task 5.0	10/31/2016	Quick-look report
6.0/6.1	**M. Report of Subtask 6.1 seismic reservoir characterization**	**08/30/2016**	**Interim report to FPM describing seismic reservoir characterization**
6.0/6.2	N. Summary of the activities and results performed in development and analyses of the initial static model, and the modeled petrophysical, geomechanical, and elastic response and implications for monitoring, performed in Task 6.0	12/29/2016	Quick-look Report
7.1	**O. Initiate Simulations**	**10/31/2015**	**Email to FPM describing initiation**
7.2	P. Report summarizing the activities and results performed in the simulations in Task 7.0	08/31/2017	Quick-look Report
8.0	Q. Report summarizing the workflow, accompanying documentation, and activities and results performed in Task 8.0 for the workflow definition and accompanying documentation.	08/31/2017	Quick-look Report

Proposed Schedule



ID	Task Name
1	**Task 1.0 – Project Management and Planning**
2	Subtask 1.1 – Project Management Plan (PMP).
3	Milestone A. Updated Project Management Plan
4	Subtask 1.2 – Project Meetings
5	Milestone B. Kickoff Meeting
6	Subtask 1.3 – Reporting
7	Subtask 1.4 – Project management
8	**Task 2.0 – Construction of Advanced Rock Property Model**
9	Subtask 2.1 – Formation Evaluat
10	Subtask 2.2 – Facies Classificatio
11	Subtask 2.3 –Rock Physics Model Development
12	Subtask 2.4 – Refine Geomechanical Model and
13	Subtask 2.5 – Report of Advanced Rock Property Model
14	Milestone C. Quick-Look Report-Task 2 Summary
15	**Task 3.0 – Conduct CO2-Water-Rock Experiments**
16	Subtask 3.1 –Select and Obtain Samples for Experiments
17	Milestone D. List of Rock Samples Selected/Obtained for CO2-Water-Rock Experiments
18	Subtask 3.2 – Characterize Samples for Experiments
19	Subtask 3.3 – Perform Geochemical Calculations and Use Results to Design Plan for Geochemical-Mineralogic Experiments
20	Milestone E. Quick-Look Report-Experimental Plan
21	Subtask 3.4 Perform Geochemical-Mineralogic Experiments
22	Milestone F. Initiate CO2-Water-Rock Experiments
23	Subtask 3.5 – Update Geochemical Calculations and Use Results to Design Plan for Coreflood Experiments
24	Milestone G. Interim Report with Plan for Coreflood
25	Subtask 3.6 – Perform Geochemical Saturation and Coreflooding Experiments
26	Subtask 3.7 Report of Experimental Results
27	Milestone H. Quick-Look Report-Results of CO2-H2O-Rock Experiments
28	**Task 4.0 – Geomechanical Experiments**
29	Subtask 4.1 – Triaxial Experim
30	Milestone I. Initiate geomechanical experiments
31	Milestone J. Interim Report of baseline geomechanical experiment results
32	Subtask 4.2 – Evaluation of Geomechnical Properties
33	Subtask 4.3 – Report of Geomechanical Results and Analyses
34	Milestone K. Quick-Look Report-Geomechanical Experiments
35	**Task 5.0 – Statistical Rock Physics Model Development**
36	Milestone L. Quick-Look Report-Task 5 Summary
37	**Task 6.0 –Build Initial Static Model Conditioned by Geophysical Measurements**
38	Subtask 6.1 –Seismic Reservoir Characterization
39	Milestone M. Interim Report of Subtask 6.1
40	Subtask 6.2 – Reservoir Monitoring Feasibility
41	Milestone N. Quick-Look Report-Task 6 Summary
42	**Task 7.0 – Conduct Fluid Flow Simulations**
43	Subtask 7.1 – Time-independent and
44	Milestone O. Initiate Simulation
45	Subtask 7.2 – Time-dependent model update
46	Milestone P. Quick-Look Report-Task 7 Summary
47	**Task 8.0 – Integrate Results to Generate Workflow Incorporating Reservoir Conditions, Experimental Data,**
48	Milestone Q. Quick-Look Report-Task 8 Summary

Bibliography

No peer reviewed publications to date

References Cited

Shafer, L.R., 2013, Assessing injection zone fracture permeability through identification of critically stressed fractures at the Rock Springs Uplift CO_2 sequestration site, SW Wyoming, M.S. Thesis, Department of Geology and Geophysics, University of Wyoming, 118 p.

Spaeth, Lynsey J., Analysis of Triassic formations as potential confining units for carbon sequestration in southwestern Wyoming, M.S. Thesis, Department of Geology and Geophysics, University of Wyoming, 138 p.

Surdam, R.C., editor, 2013, Geological CO_2 Storage Characterization: The Key to Deploying Clean Fossil Energy Technology: New York, Springer-Verlag, 310 p.

Surdam, R.C., Bentley, R., Campbell-Stone, E., Deiss, A., Ganshin, Y., Jiao, Z., Kaszuba, J., Mallick, S., 2013, Site characterization of the highest-priority geologic formations for CO_2 storage in Wyoming: Final Report to U.S. Department of Energy, DOE Award Number DE-FE0002142, 606 p.