Integrated Characterization of CO_2 Storage Reservoirs on the Rock Springs Uplift Combining Geomechanics, Geochemistry, and Flow Modeling

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U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology, Innovation and Collaboration:

Carbon Storage and Natural Gas Technologies Review Meeting

August 16-18, 2016

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.

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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 estimated 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

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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 reacted reservoir rock 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.

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Technical Status

Interdisciplinary Team

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

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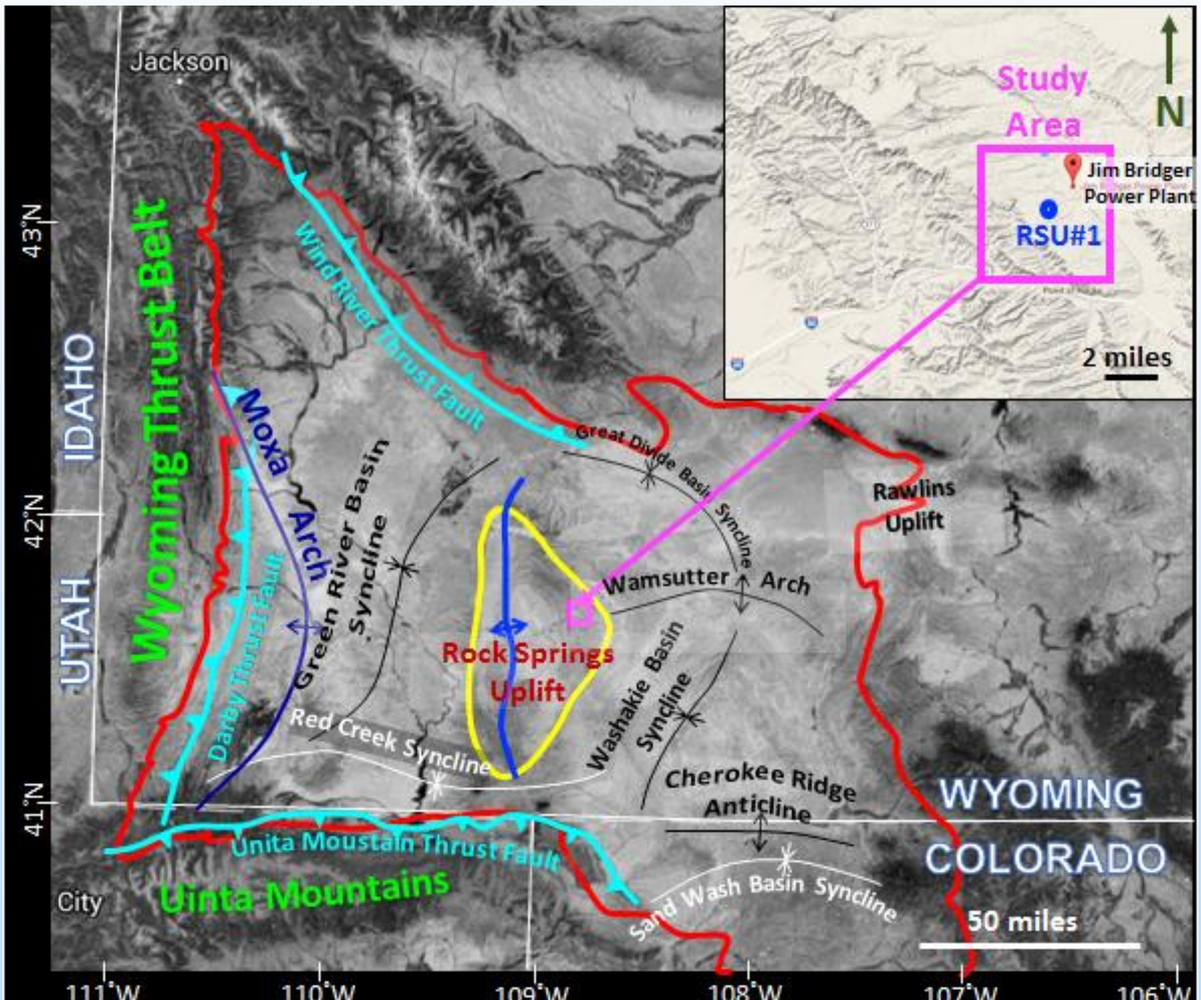
Technical Status

Rock Springs Uplift, WY



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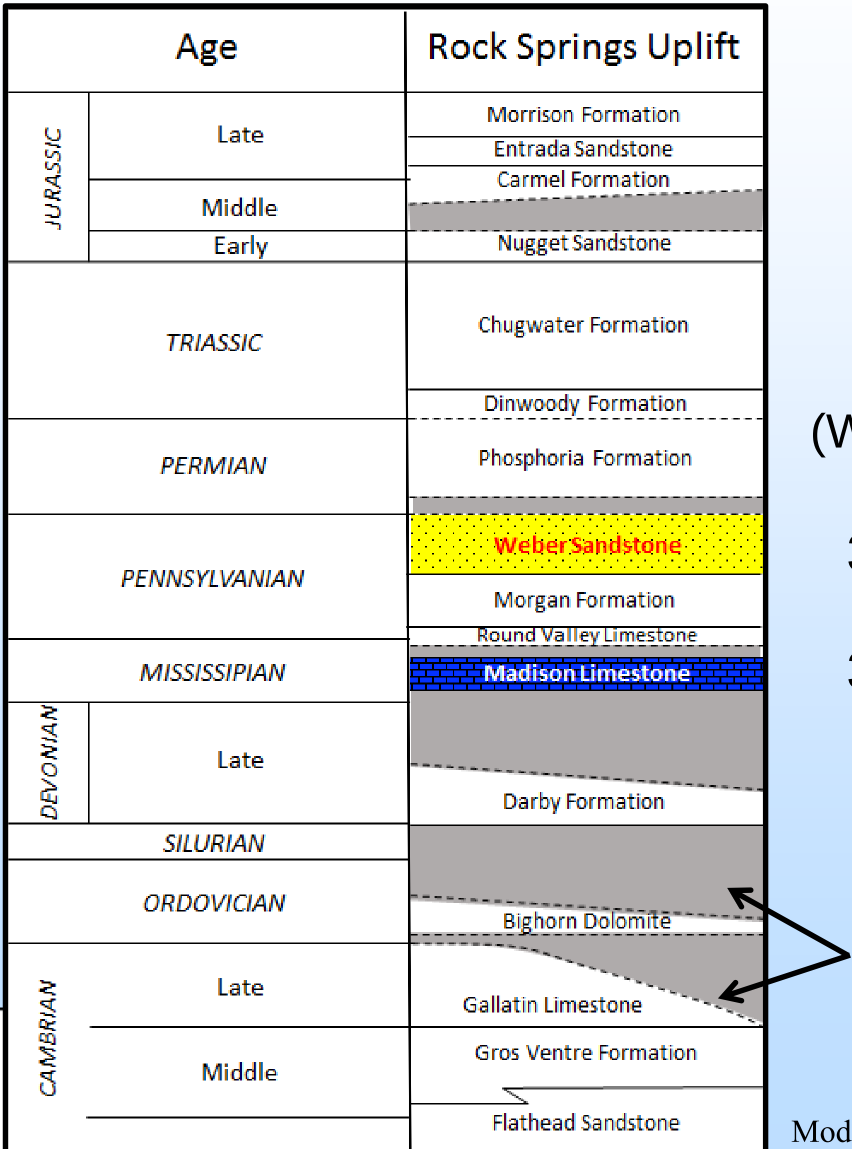


RSU Stratigraphy

Target Reservoirs
(Weber Sandstone & Madison Limestone)

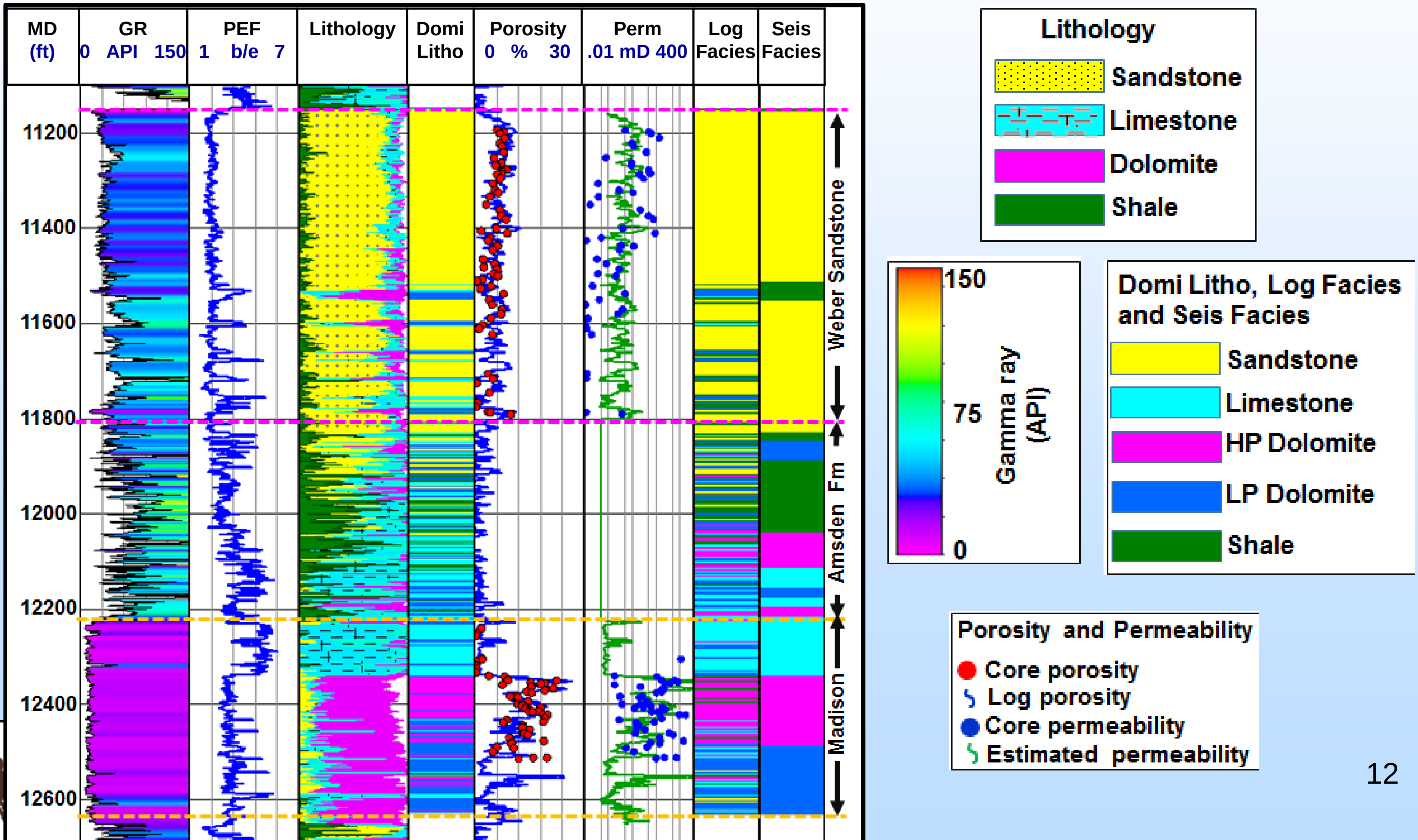
3400 – 3600 m (11150 – 11800 ft)

3725 – 3855 m (12225 – 12650 ft)

Modified from Love et al. (1993)

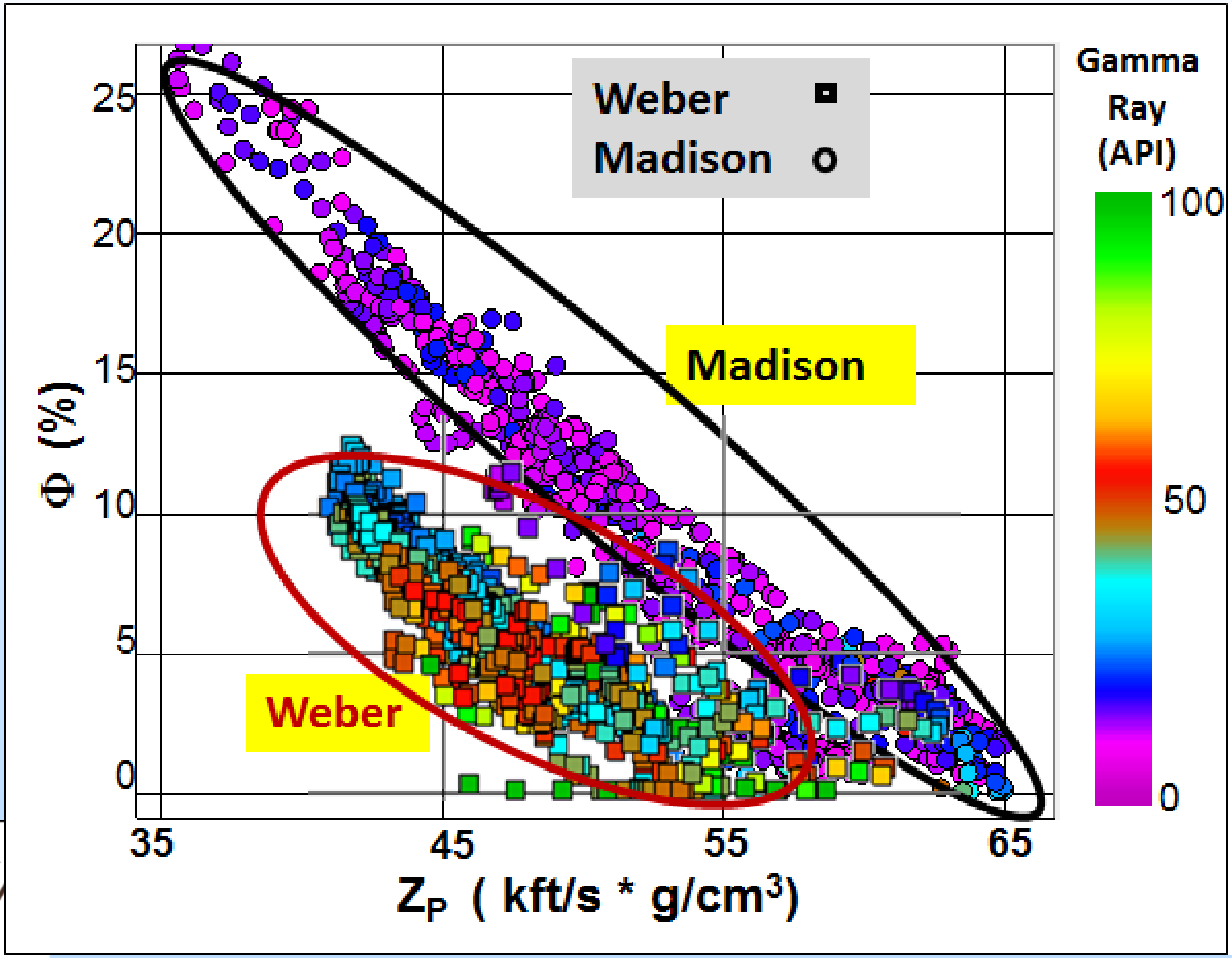
Technical Status

Well Logs & Core Data Analysis



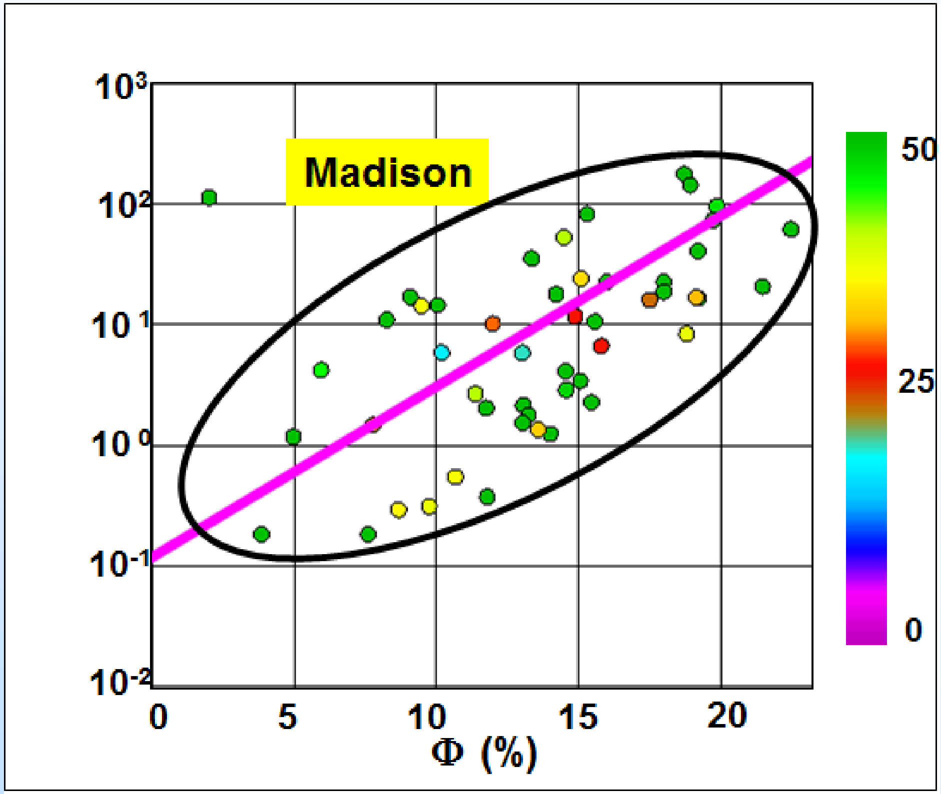
Technical Status

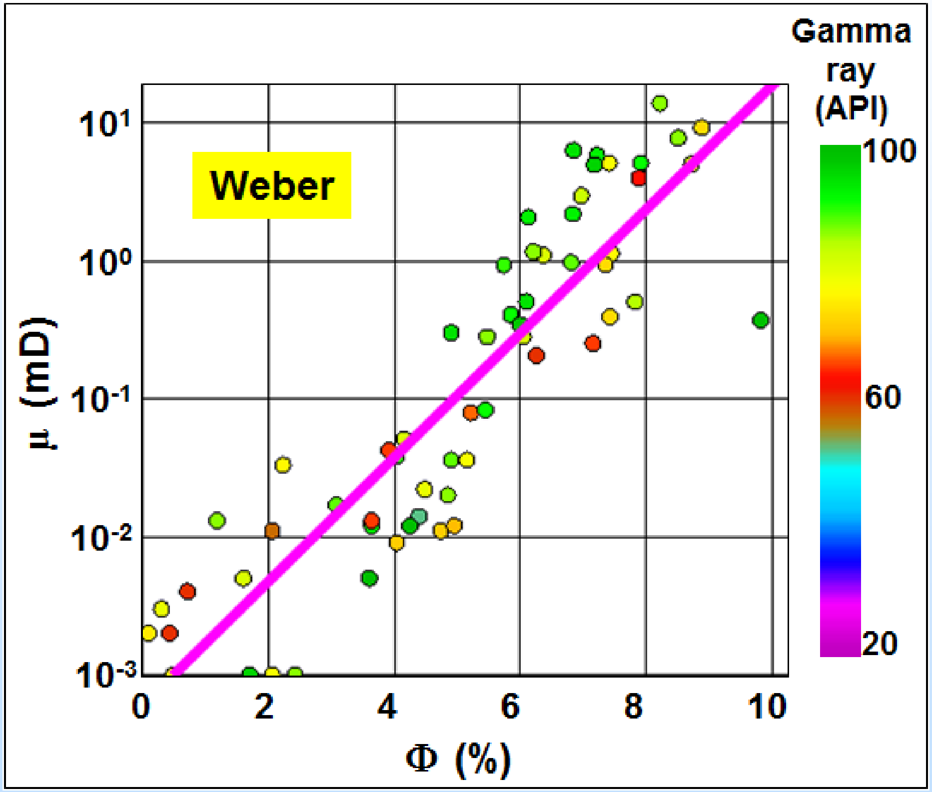
Cross Plot of P-Impedance vs. Porosity



Technical Status

Cross Plots of Porosity vs. Permeability





Correlation= 69.5%
$\mu = 4.6 \times 10^{-2} \exp^{(0.37*\Phi)}$

Correlation= 90.2%
$\mu = 5.77 \times 10^{-4} \exp^{(1.037*\Phi)}$

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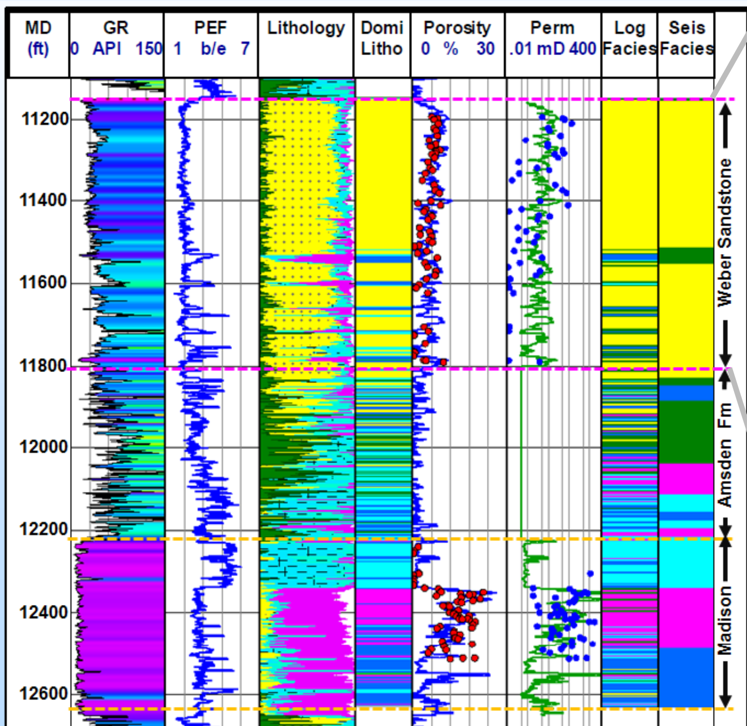
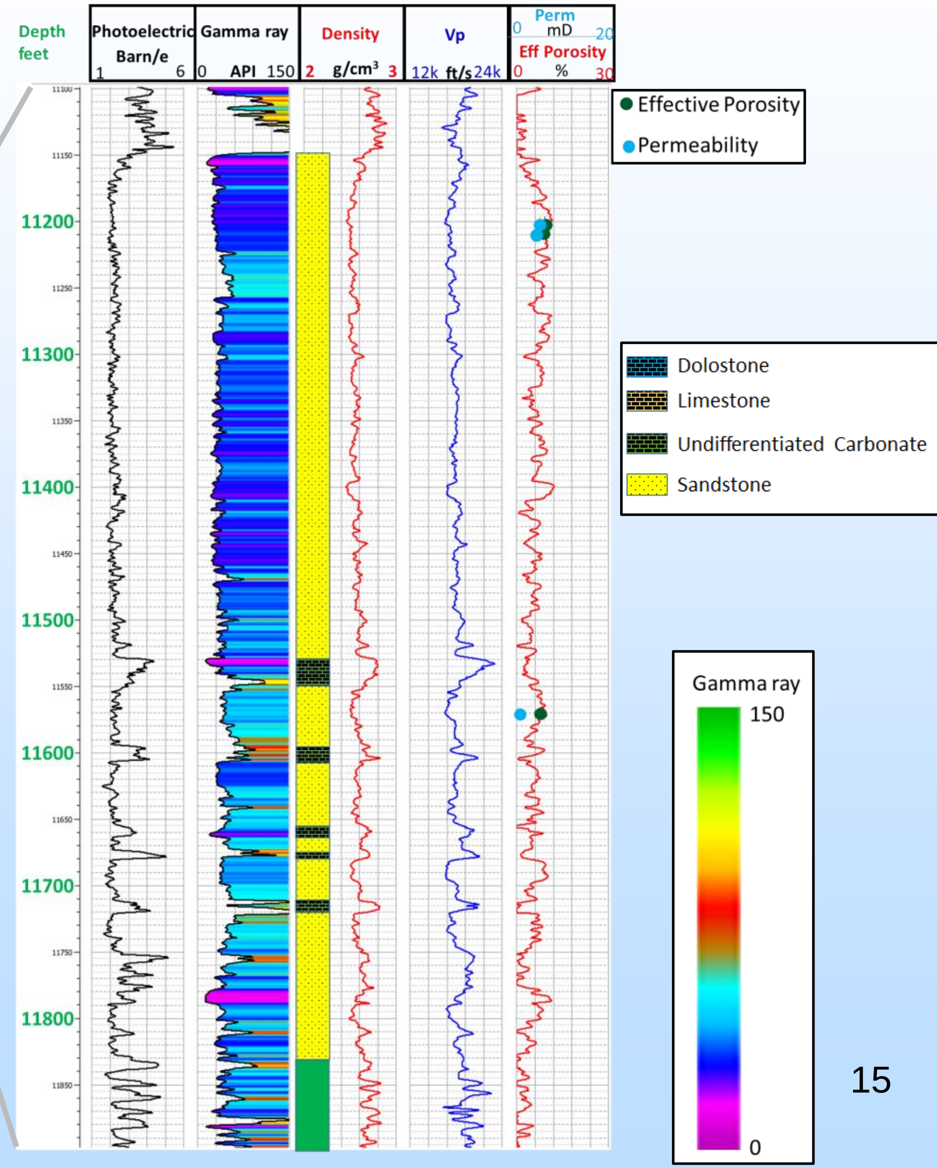
Technical Status

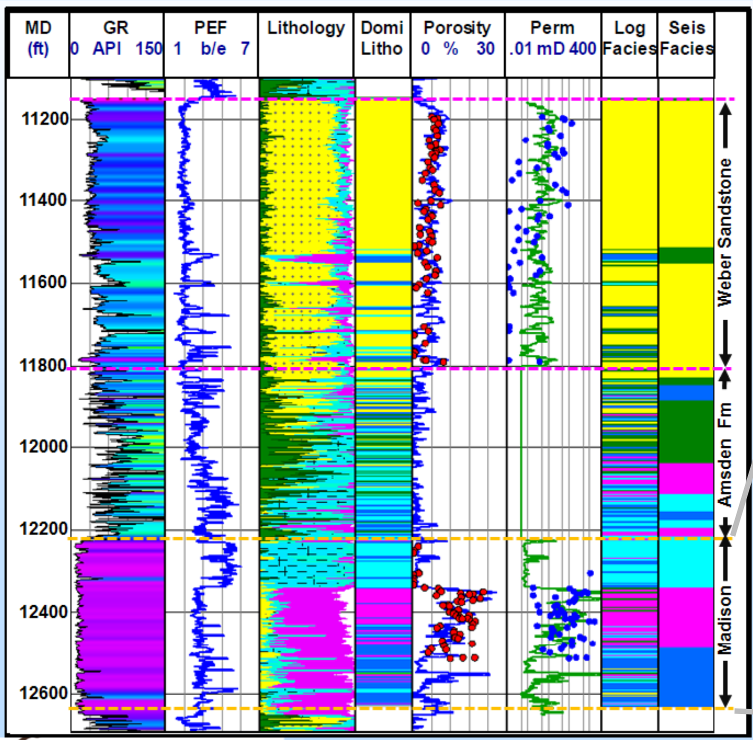
Weber Sandstone – Lithology & Core Samples

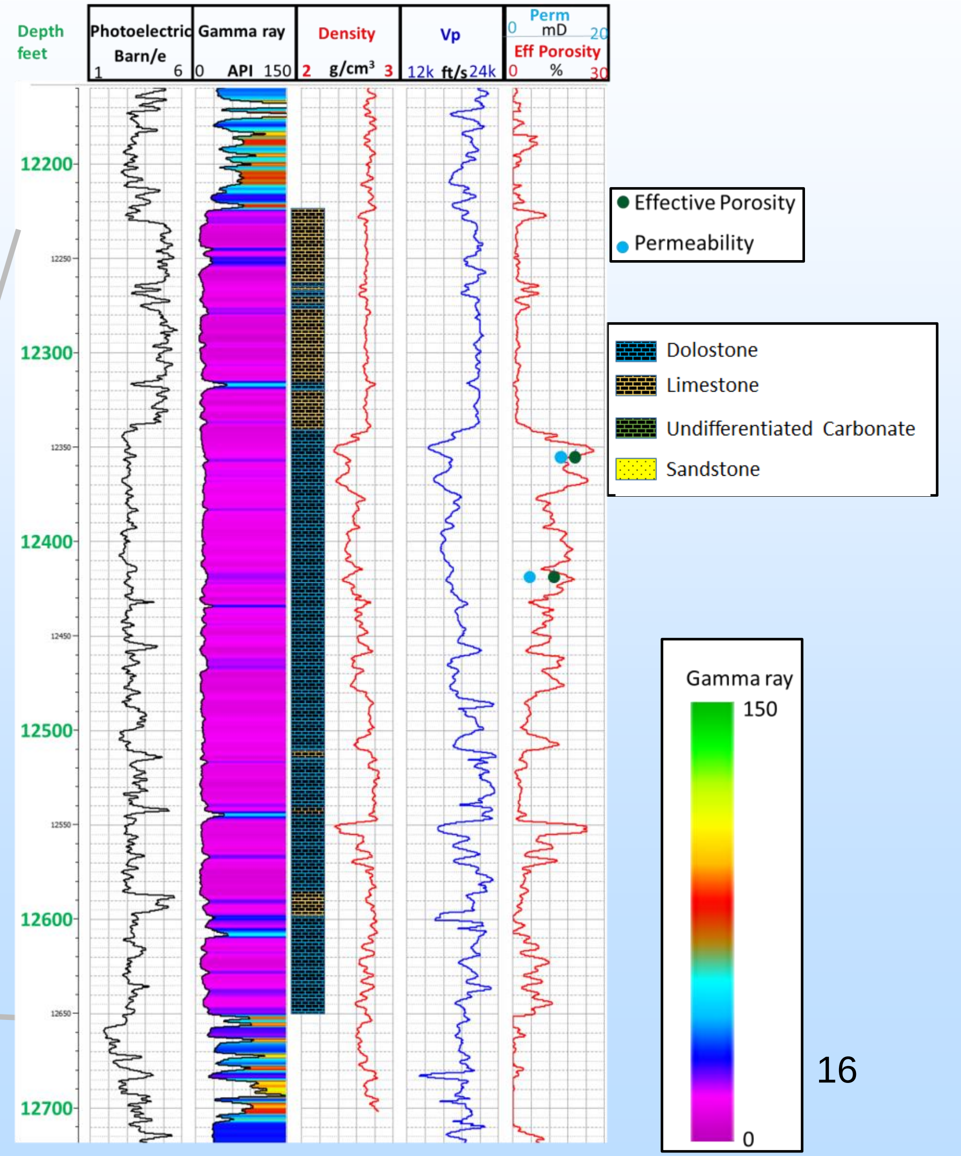




Technical Status

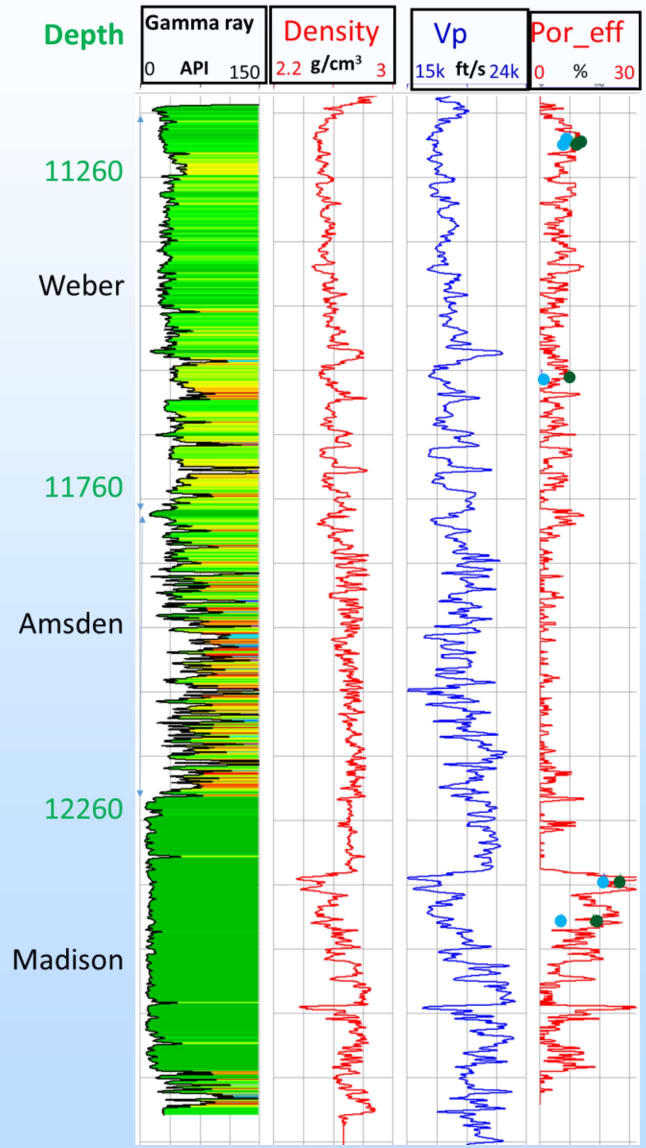
Madison Limestone – Lithology & Core Samples





Technical Status

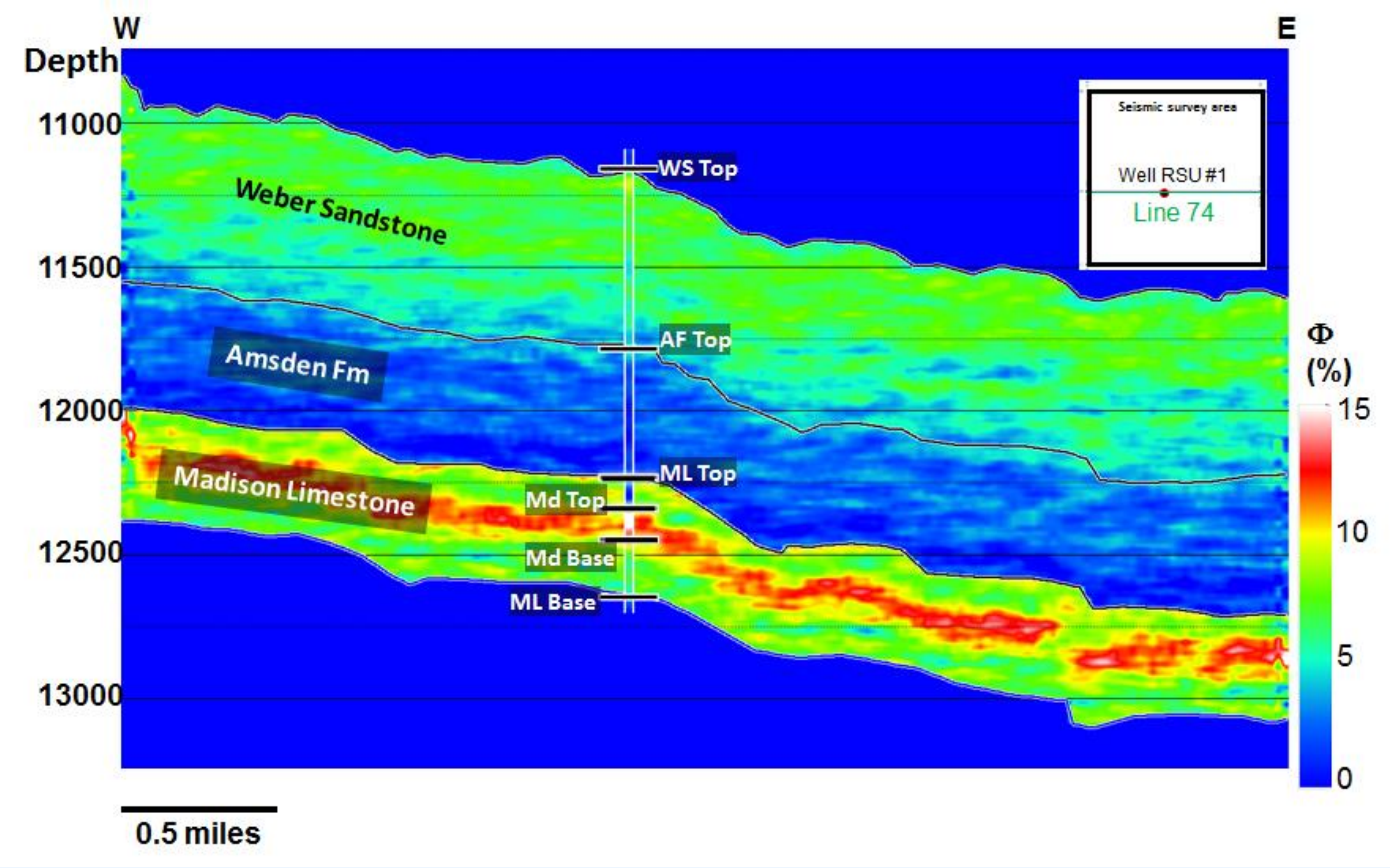
Effective Porosity & Permeability



- Effective Porosity
- Permeability

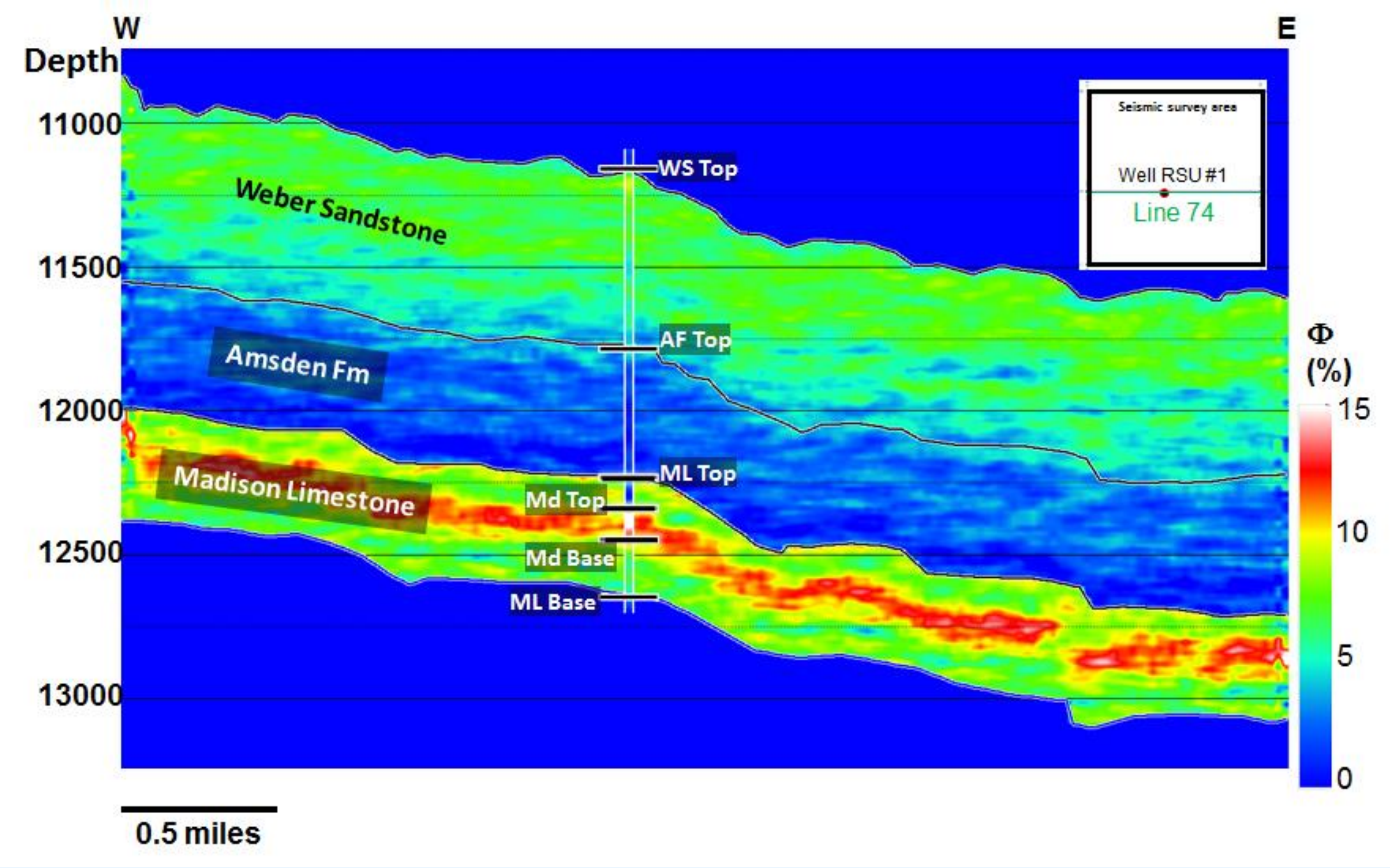
Technical Status

Porosity



Technical Status

Permeability



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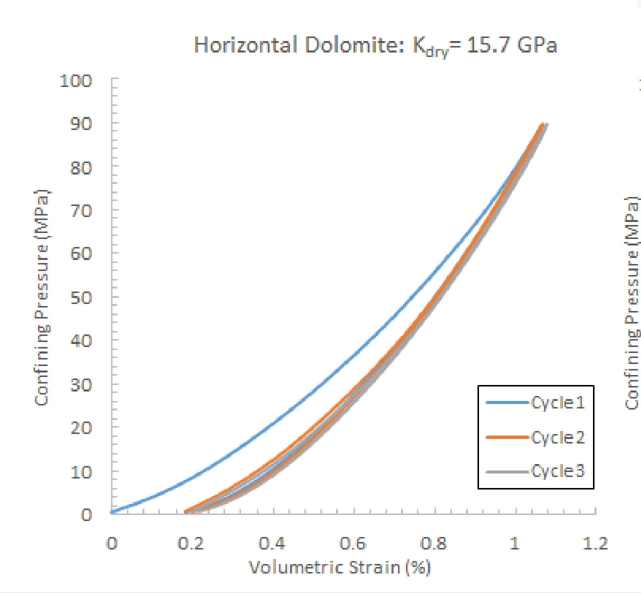
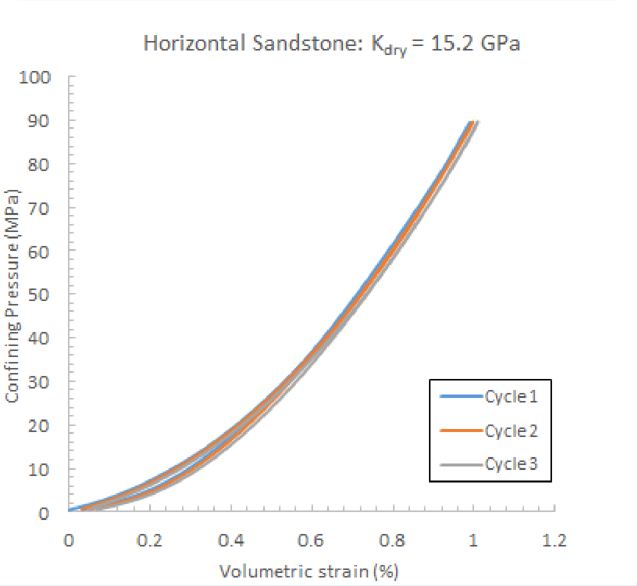
Geomechanical Tests

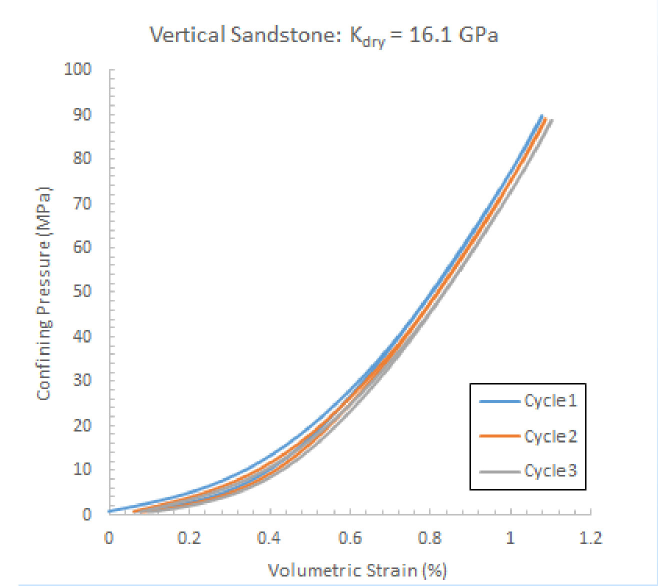
Treatment	Testing Method	Minimum Quantity of Specimens	Temperature (C)	Pore Pressure (psi)	Effective Confining Pressure (psi)
Dry	Unjacketed Hydrostatic Compression (w/ ultrasonic)	1	RT*	0	Ramp to 13,000
	Jacketed Hydrostatic Compression (w/ ultrasonic)	1	RT	0	Ramp to 13,000
Saturated w/ Brine	Uniaxial Test (w/ ultrasonic)	1	90.3 (Sandstone) 93.1 (Carbonate)	5300 (Sandstone) 5750 (Carbonate)	0
	Triaxial Test (w/ ultrasonic)	3	90.3 (Sandstone) 93.1 (Carbonate)	5300 (Sandstone) 5750 (Carbonate)	1000, 5000, 8000
Saturated w/ Brine and CO2	Uniaxial Test (w/ ultrasonic)	1	90.3 (Sandstone) 93.1 (Carbonate)	5300 (Sandstone) 5750 (Carbonate)	0
	Triaxial Test (w/ ultrasonic)	3	90.3 (Sandstone) 93.1 (Carbonate)	5300 (Sandstone) 5750 (Carbonate)	1000, 5000, 8000

Technical Status

Hydrostatic Tests on Jacketed Dry Samples







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Accomplishments to Date

1) Geostatistical inversion of prestack seismic data for the joint estimation of facies and seismic velocities using stochastic sampling from Gaussian mixture posterior distributions was conducted.

2) Seismic-based, coarse scale porosity models have been generated. Porosity-permeability correlations have been obtained based on core data.

3) Weber Sandstone and Madison Limestone plugs were characterized for gas porosity and permeability, and time-domain NMR.

4) Hydrostatic geomechanical tests have been completed.

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Synergy Opportunities

INTERPRETATION Call-for-Papers

- Issue Date: November 2017
- Submission Deadline: January 20, 2017

Topic: Multidisciplinary studies for geological and geophysical characterization of CO2 storage reservoirs

Organizer: Dario Grana, University of Wyoming

Co-Editors: John Kaszuba, University of Wyoming
Vladimir Alvarado, University of Wyoming
Mary Wheeler, University of Texas
Manika Prasad, Colorado School of Mines
Sumit Verma, University of Texas Permian Basin

Summary – Key Findings 2015-2016

- Two distinguishable correlations between impedance and porosity are applicable to the Madison Limestone and the Weber Sandstone.
- Core-log correlation works well for the Madison Limestone and for most of the Weber Sandstone, except perhaps for the bottom, least porous portion of the interval.
- Refinement of the seismic-based static model needs to use reprocessed seismic survey to increase resolution.

Summary – Future Plans

- Continue geochemical tests
- Begin coreflood tests
- Begin capillary pressure 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 a 3D static model of the reservoir

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Summary – Future Plans

Preliminary Workflow

- Perform formation evaluation analysis
- Classify facies
- Evaluate regional Geomechanical and Rock Physics Models

- Obtain samples . Measure ϕ, K, NMR-T2, & Cp
- Classify rock types. Compare with facies
- Assign samples for different experiments

Build Static Model

- Geochemical calculations
- Perform geochemical mineralogical experiments

- Perform Saturation and Coreflooding Experiments

- Perform triaxial Experiments
- Evaluate Geo-properties
- Analyze and provide geo-data needed for simulations

- Develop Statistical Rock-Physics Model
- Build Static Model
- Evaluate Monitoring Feasibility Study

Dynamic Model

- Conduct time-dependent geomechanic-fluid flow coupled simulation
- Evaluate coupled geochem-geomechanic

- Evaluate coupled effects of geochemistry, geomechanics and fluid flow on CO2 storage

Organizational Chart

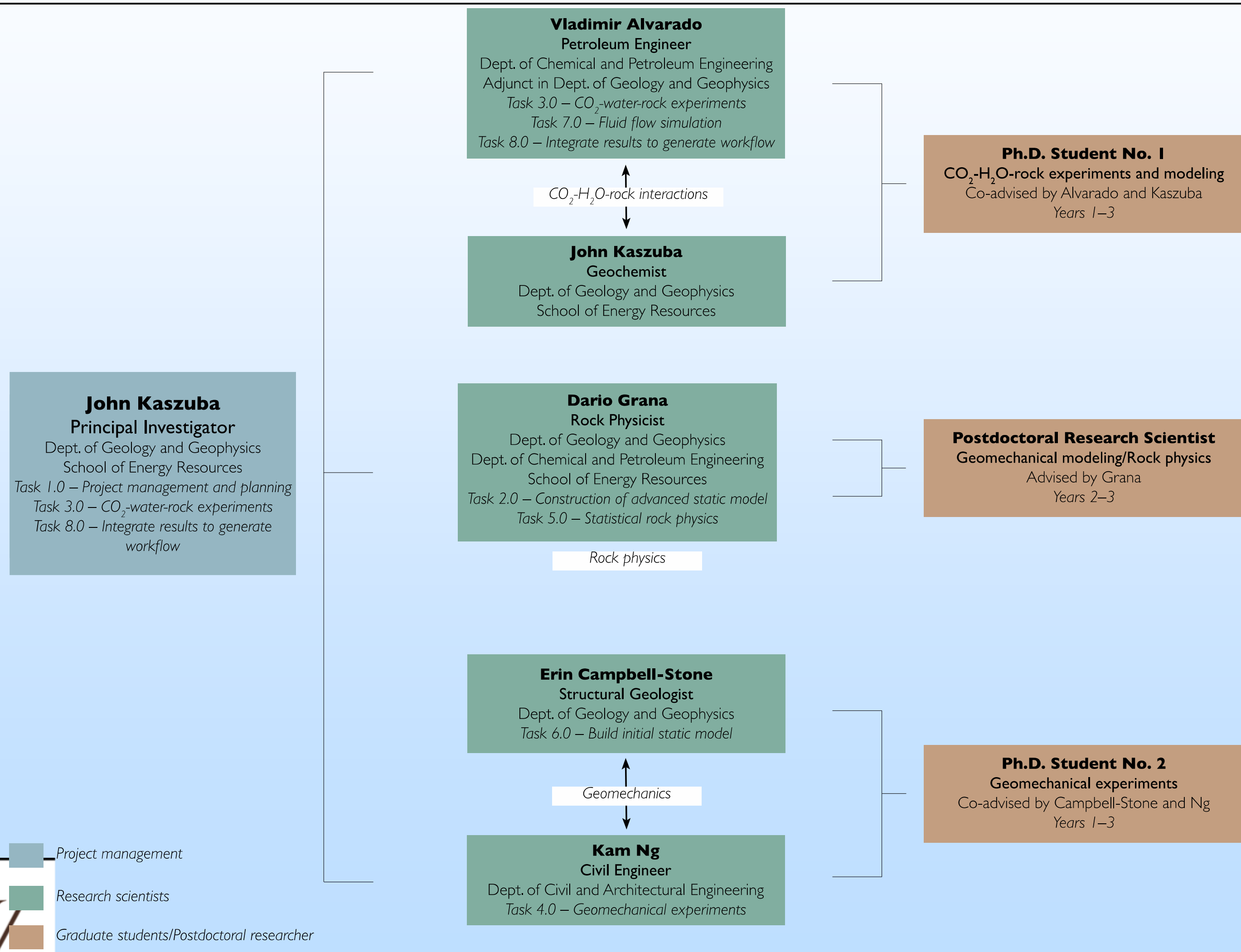
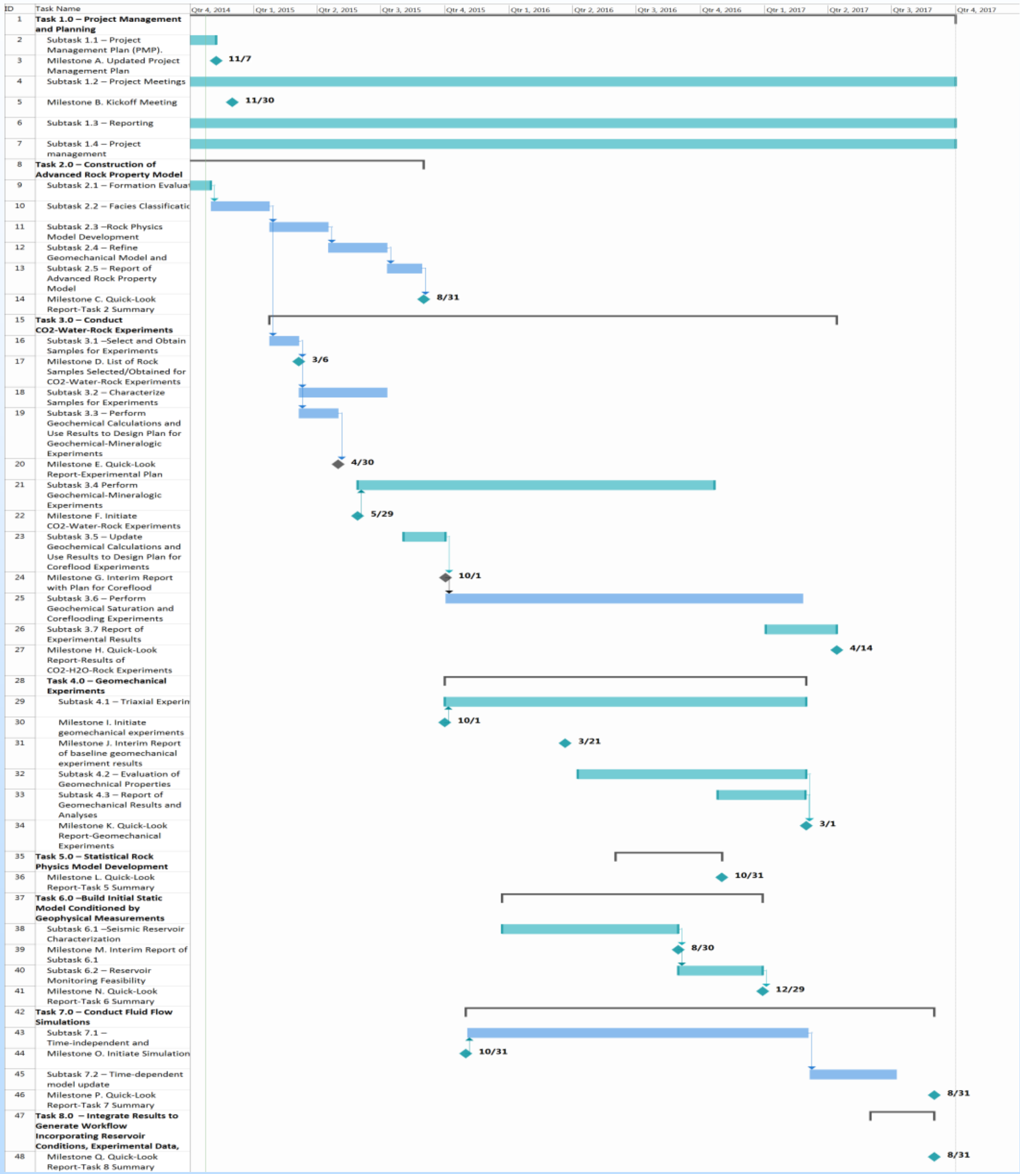


Figure 1. Organizational chart.

Gantt Chart


ID
Task Name
Qtr 4, 2014
Qtr 1, 2015
Qtr 2, 2015
Qtr 3, 2015
Qtr 4, 2015
Qtr 1, 2016
Qtr 2, 2016
Qtr 3, 2016
Qtr 4, 2016
Qtr 1, 2017
Qtr 2, 2017
Qtr 3, 2017
Qtr 4, 2017
1 Task 1.0 – Project Management and Planning
2 Subtask 1.1 – Project Management Plan (PMP).
3 Milestone A. Updated Project Management Plan
11/7
4 Subtask 1.2 – Project Meetings
5 Milestone B. Kickoff Meeting
11/30
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
8/31
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
3/6
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
4/30
21 Subtask 3.4 Perform Geochemical-Mineralogic Experiments
22 Milestone F. Initiate CO2-Water-Rock Experiments
5/29
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
10/1
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
4/14
28 Task 4.0 – Geomechanical Experiments
29 Subtask 4.1 – Triaxial Experin
30 Milestone I. Initiate geomechanical experiments
10/1
31 Milestone J. Interim Report of baseline geomechanical experiment results
3/21
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
3/1
35 Task 5.0 – Statistical Rock Physics Model Development
36 Milestone L. Quick-Look Report-Task 5 Summary
10/31
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
8/30
40 Subtask 6.2 – Reservoir Monitoring Feasibility
41 Milestone N. Quick-Look Report-Task 6 Summary
12/29
42 Task 7.0 – Conduct Fluid Flow Simulations
43 Subtask 7.1 – Time-independent and
44 Milestone O. Initiate Simulation
10/31
45 Subtask 7.2 – Time-dependent model update
46 Milestone P. Quick-Look Report-Task 7 Summary
8/31
47 Task 8.0 – Integrate Results to Generate Workflow Incorporating Reservoir Conditions, Experimental Data,
48 Milestone Q. Quick-Look Report-Task 8 Summary
8/31

Milestone Chart

"Integrated Characterization of CO2 Storage Reservoirs on the Rock Springs Uplift Combining Geomechanics, Geochemistry, and Flow Modeling" - DE-FE0023328				
Budget Period	Task/Subtask	Milestone ID/Description	Planned Completion	Verification Method
1	1.0	A. Updated Project Management Plan	11/7/2014	Project Management Plan file
1	1.0	B. Kickoff Meeting	11/30/2014	Presentation file
1	**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)**	**3/6/2015**	**List**
1	**3.0/3.3**	**E. Plan that describes the details of the geochemical-mineralogic experiments to be performed**	**4/30/2015**	**Quick-look report with plan**
1	**3.0/3.4**	**F. Initiate CO2-Water-Rock experiments**	**5/29/2015**	**Email to FMP describing initiation**
1	**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**
2	**3.0/3.5**	**G. Plan for coreflood experiments**	**10/1/2015**	**Interim report to FMP with plan for coreflood experiments**
2	**7.1**	**O. Initiate Simulations**	**10/31/2015**	**Email to FMP describing initiation**
2	**4.0/4.1**	**I. Initiate geomechanical experiments**	**12/1/2015**	**Email to FMP describing initiation**
2	**4.0/4.1**	**J. Report of baseline geomechanical experiment results**	**3/21/2016**	**Interim report to FMP with results of baseline geomechanical experiments**
2	**6.0/6.1**	**M. Report of Subtask 6.1 seismic reservoir characterization**	**8/30/2016**	**Interim report to FMP describing seismic reservoir characterization**
3	5.0	L. Summary of the activities and results performed in the rock physics model development and analysis in Task 5.0.	10/31/2016	Quick-look report
3	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
3	4.0/4.3	K. Report of results and analyses of the geomechanical experiments	2/28/2017	Quick-look report
3	3.0/3.7	H. Report of analyses and results studied in the CO2-Water-Rock experiments	4/14/2017	Quick-look report
3	7.2	P. Report summarizing the activities and results performed in the simulations in Task 7.0.	8/31/2017	Quick-look report
3	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.	8/31/2017	Quick-look report

Bibliography

1. Lang, X. and Grana, D., 2015, Geostatistical inversion of prestack seismic data for the joint estimation of facies and seismic velocities using stochastic sampling from Gaussian mixture posterior distributions, SEG Annual Meeting, accepted for oral presentation.

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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 CO2 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 CO2 storage in Wyoming: Final Report to U.S. Department of Energy, DOE Award Number DE-FE0002142, 606 p.