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

Project Number DE-FE0023328

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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

- Technical status
  - Objectives
  - Rock physics & seismic
  - Petrophysical lab
  - Geomechanical lab
- Accomplishments to date
- Lessons learned
- Synergy opportunities
- Project summary

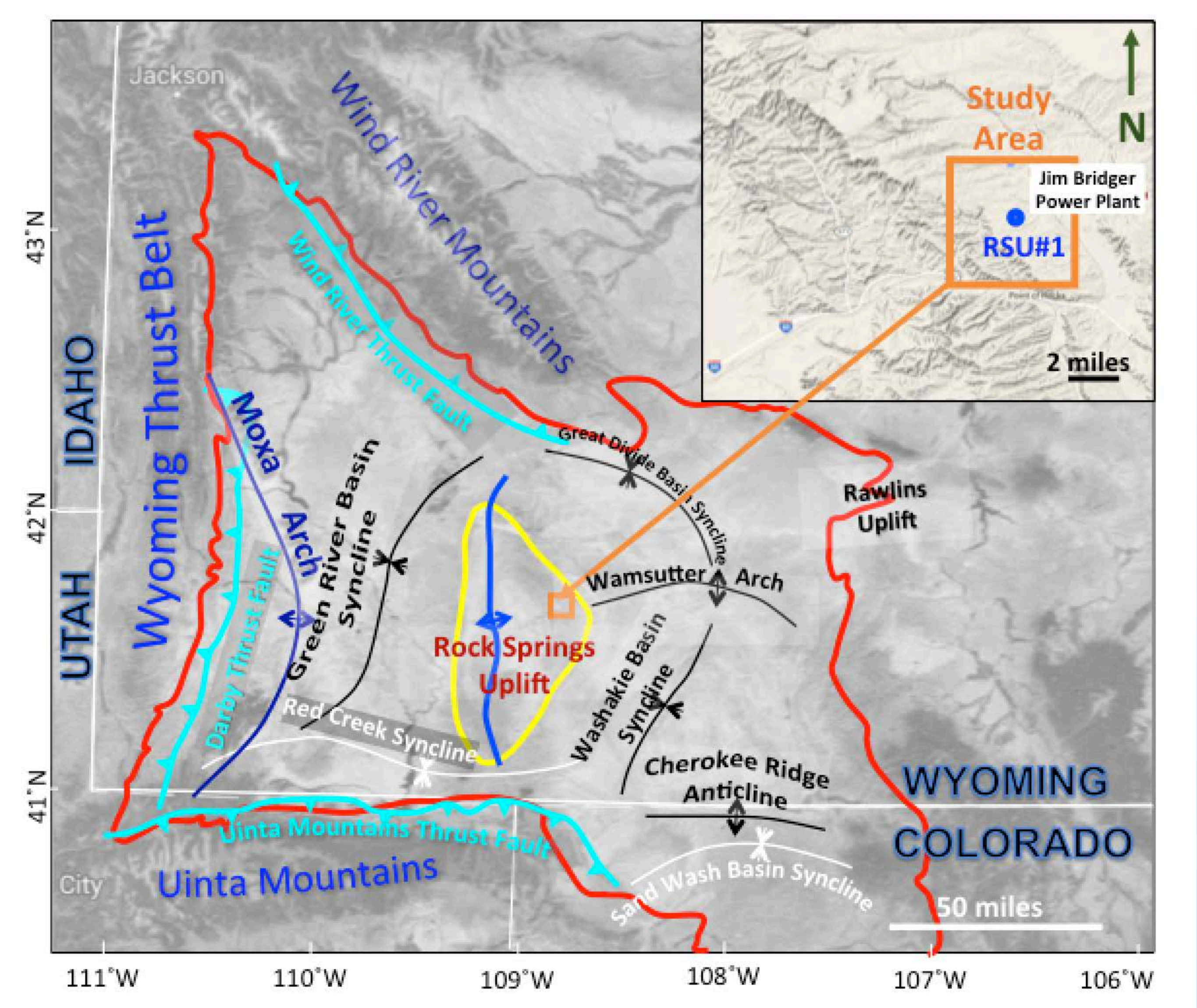
Technical Status

- **Overall Objective**: Improve understanding of the effects of CO_2 injection and storage on geomechanical and petrophysical properties.
  - ➢ Combines integrated, interdisciplinary methodology using existing data sets (Rock Springs Uplift in Wyoming)
  - ➢ Culminates in integrated workflow for potential CO_2 storage operations

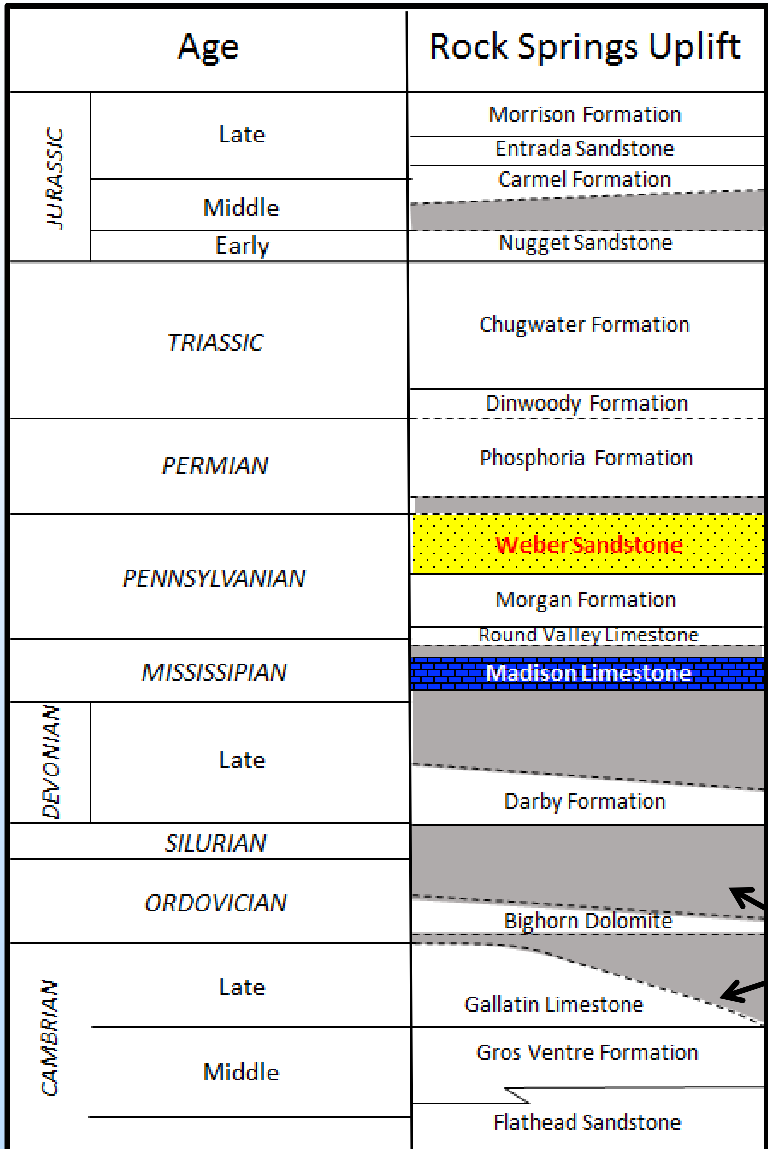
Multidisciplinary Team

- Vladimir Alvarado: Assistant Project Manager, Reservoir Engineering
- Erin Campbell-Stone: Structural Geology, Geomechanics, Wyoming Geology (now at WSGS)
- Dario Grana: Rock Physics
- John Kaszuba: Project Manager, Geochemistry
- Kam Ng: Geomechanics

Rock Springs Uplift, WY



Regional Geology



Target Reservoirs
(Weber Sandstone
& Madison Limestone)

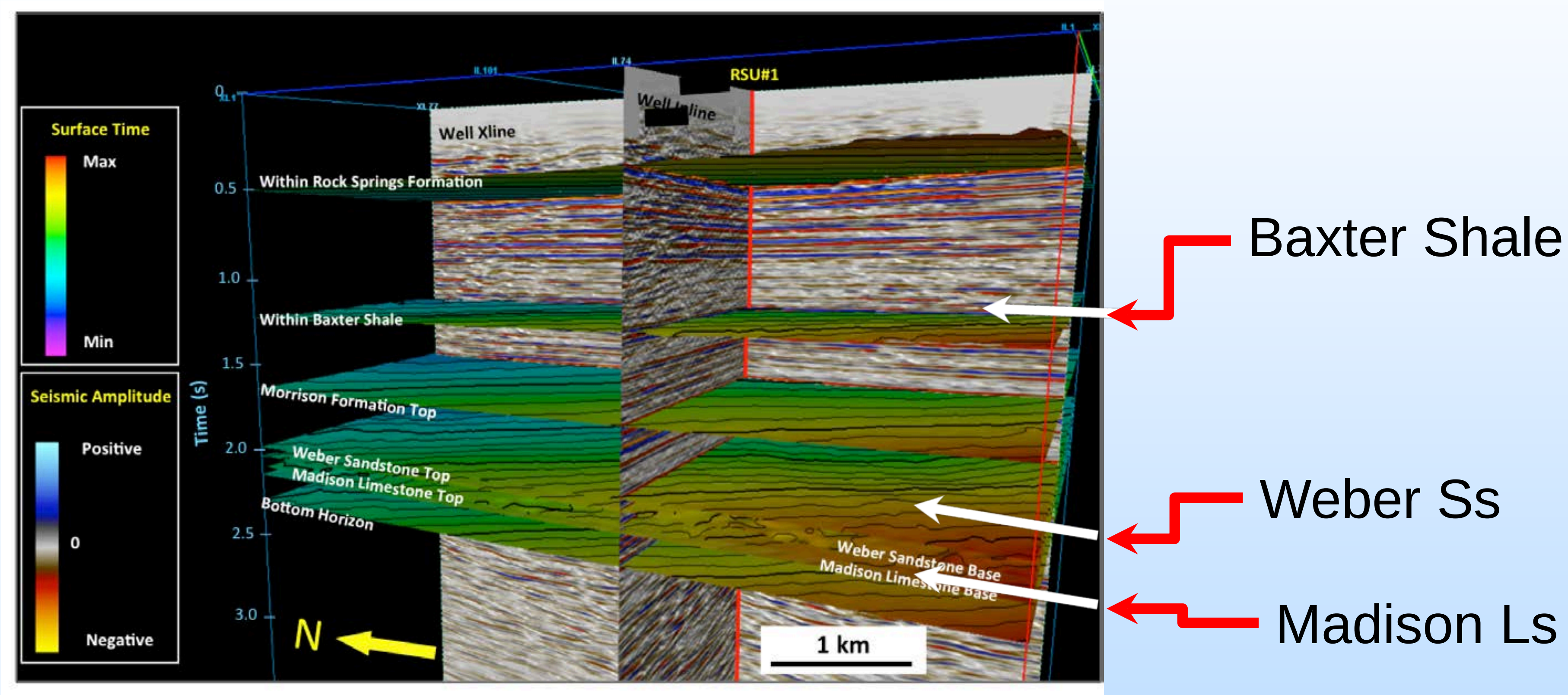
3400 – 3600 m (11150 – 11800 ft)

3725 – 3855 m (12225 – 12650 ft)

Missing Time Intervals

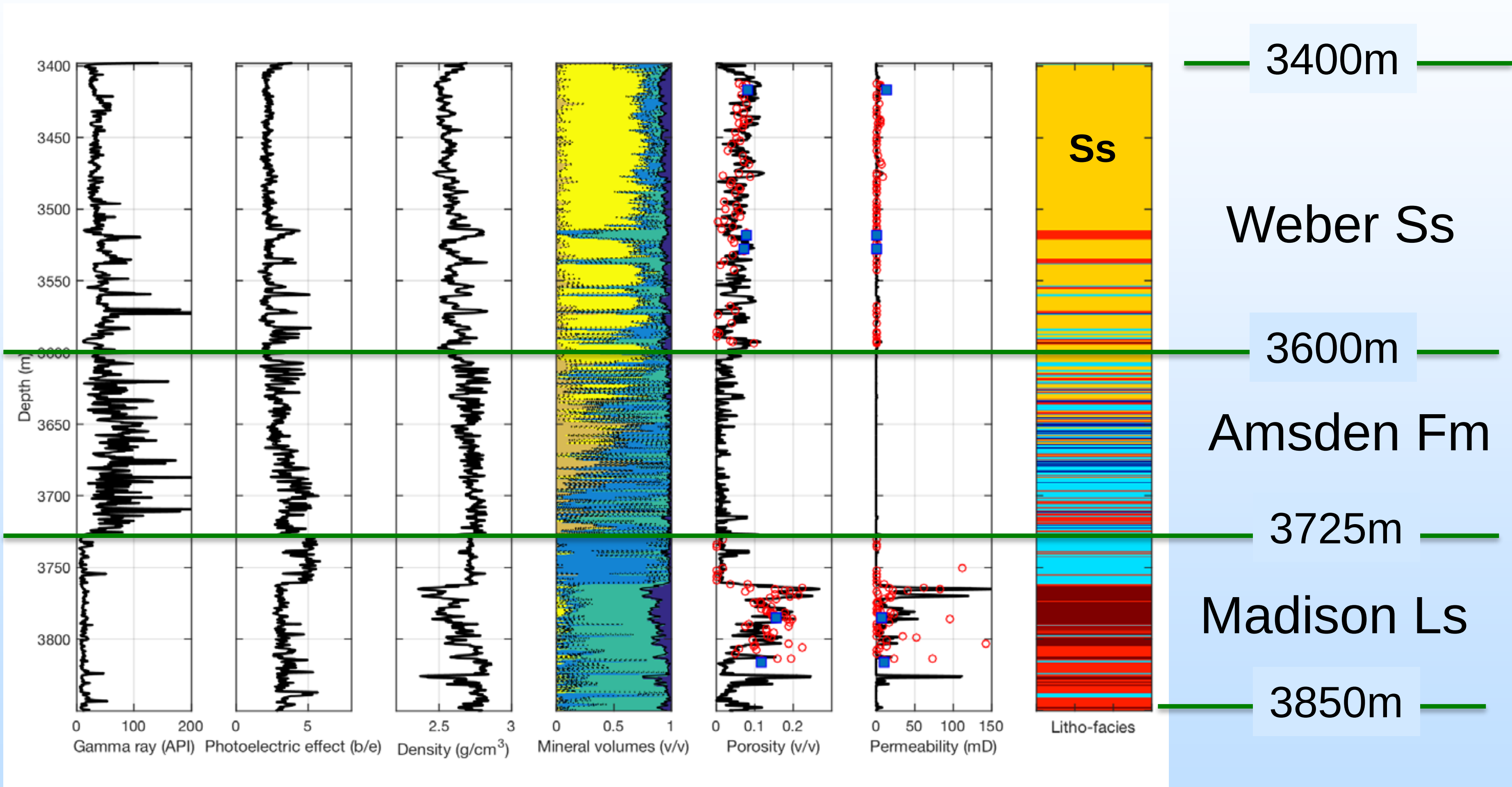
Modified from Love et al. (1993)

Seismic Data (Time Domain)



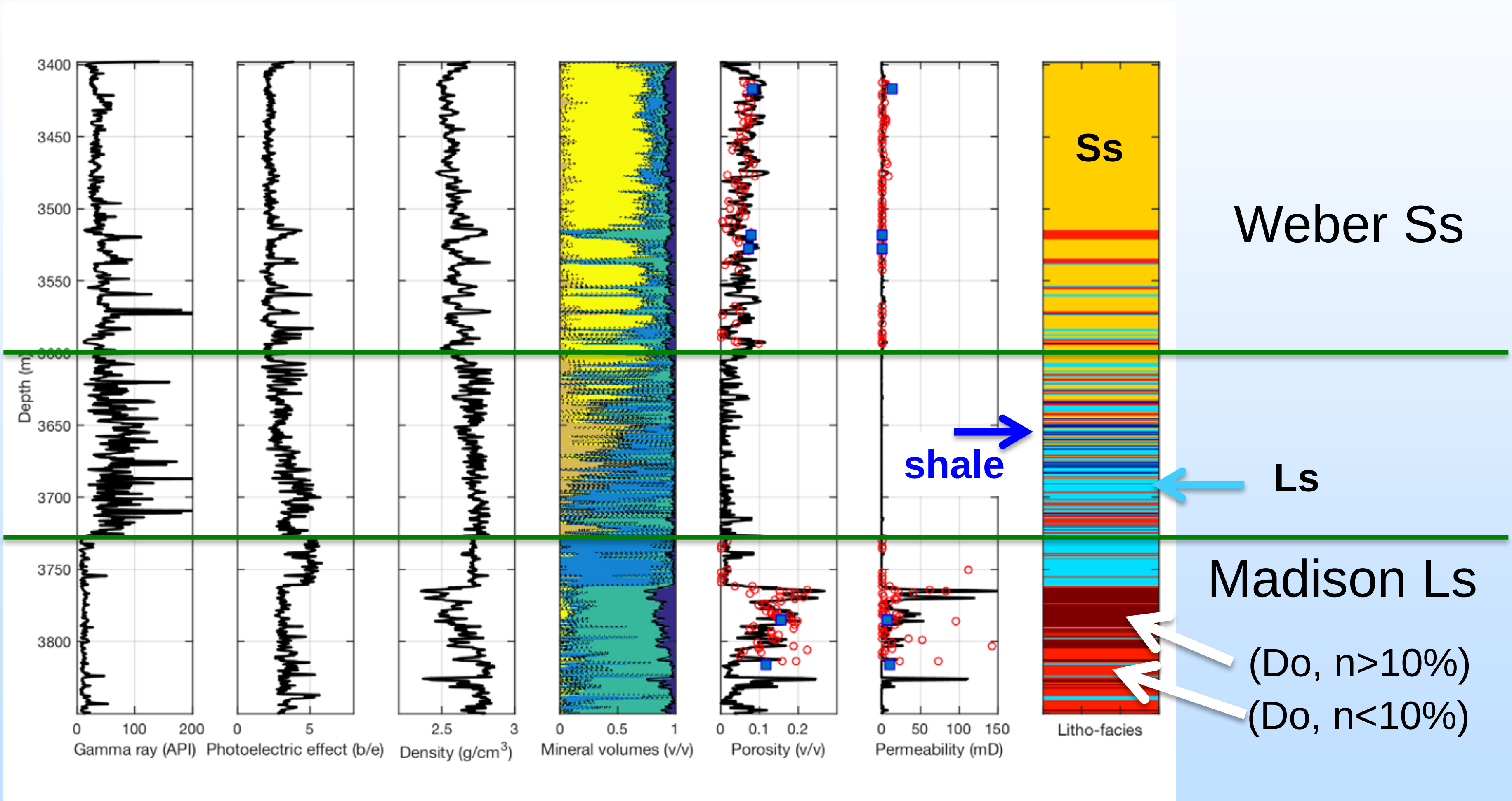
Grana et al., IJGGC, submitted

Petrophysical Logs & Computed Parameters



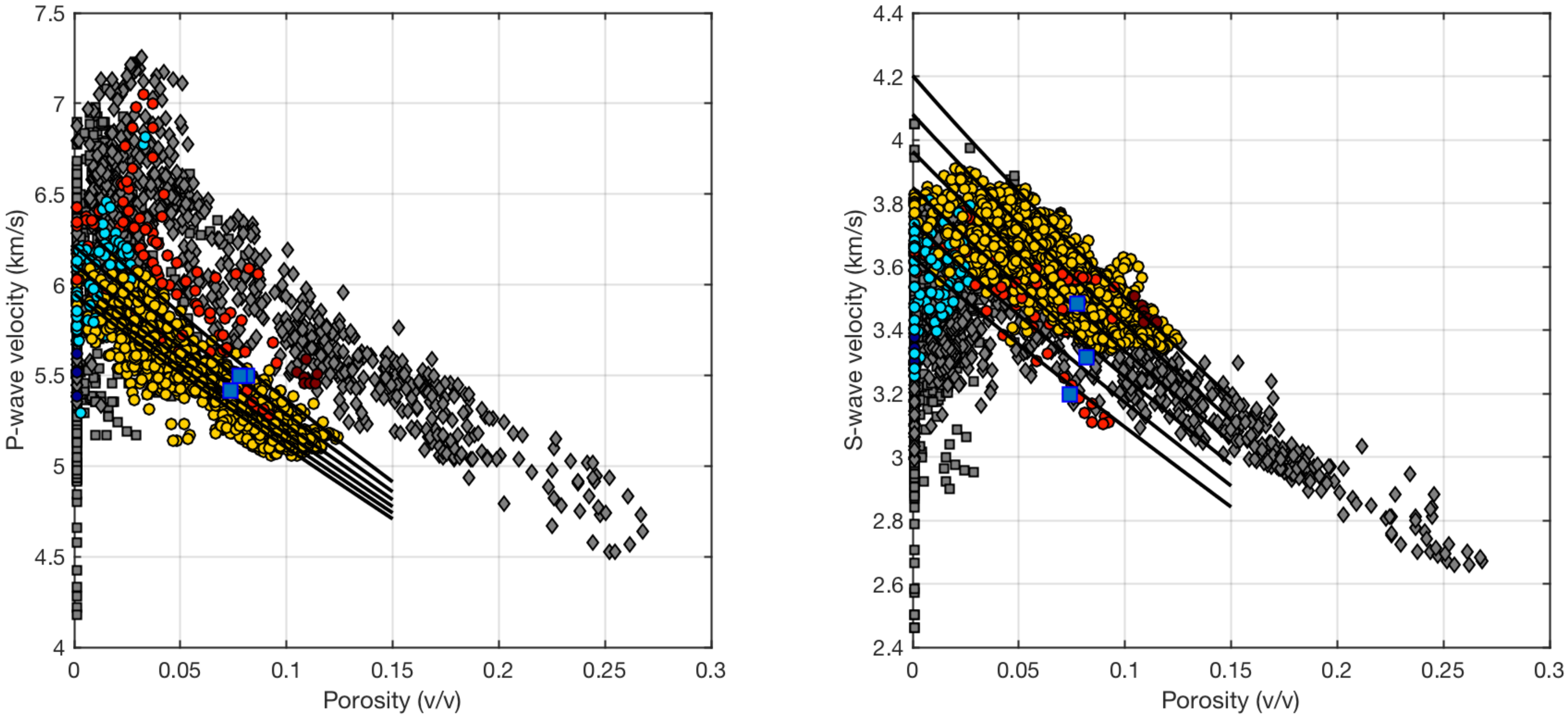
Grana et al., IJGGC, submitted

Petrophysical Logs & Computed Parameters



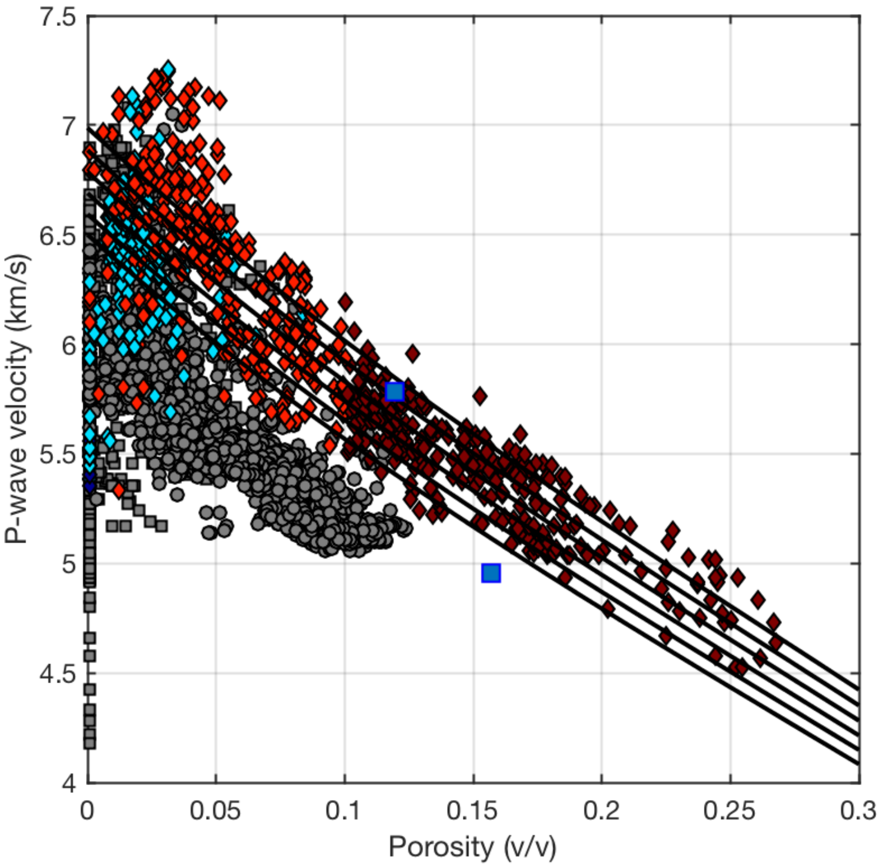
Grana et al., IJGGC, submitted

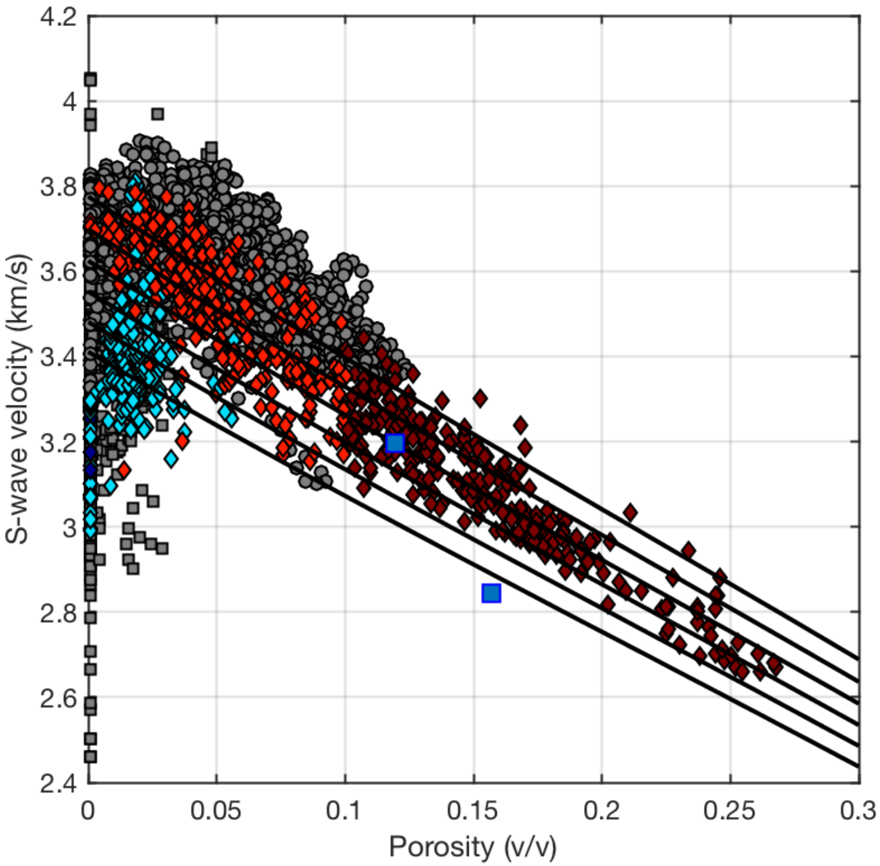
Rock Physics Model – Weber Ss



Grana et al., IJGGC, submitted

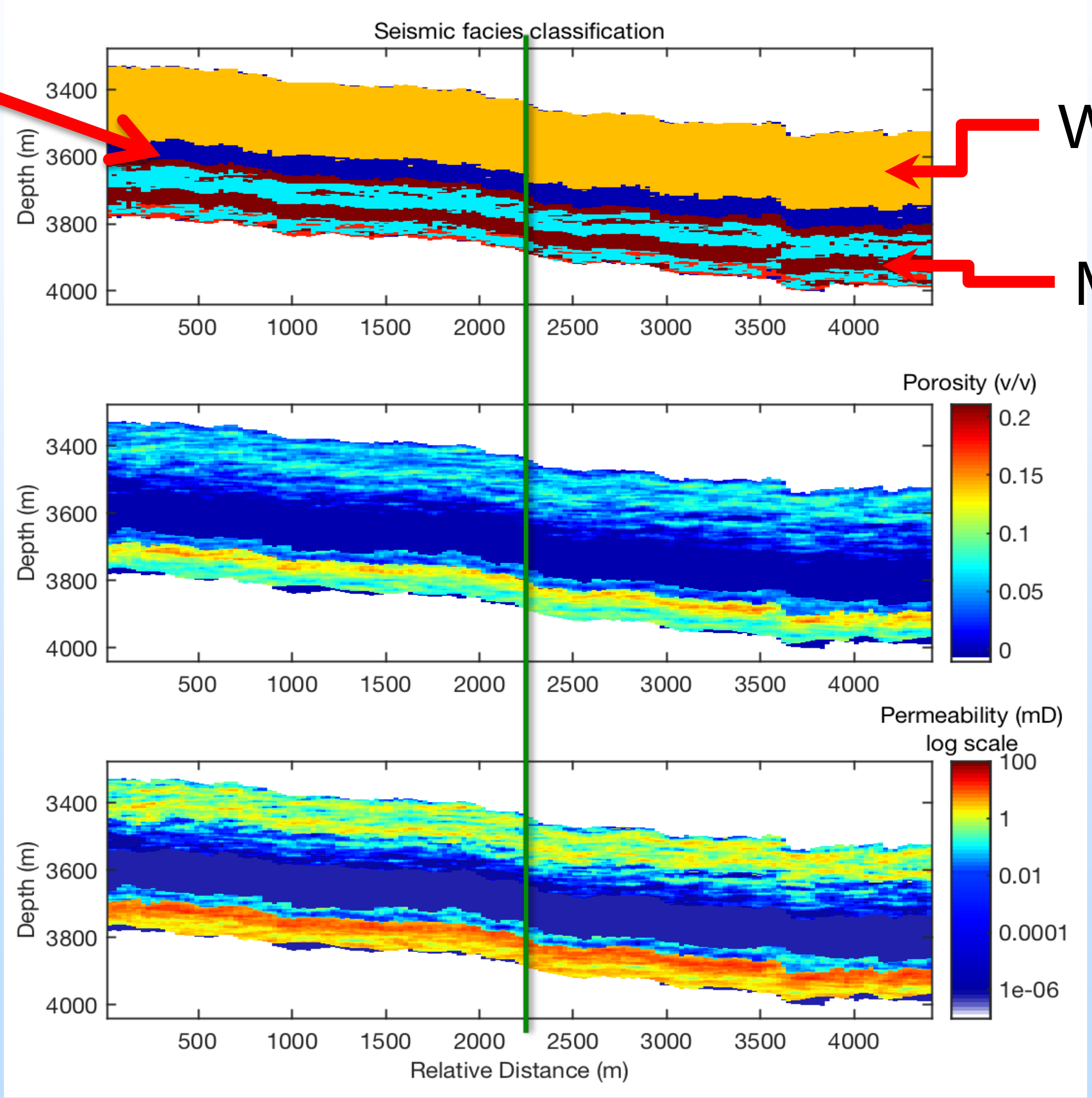
Rock Physics Model – Madison Ls





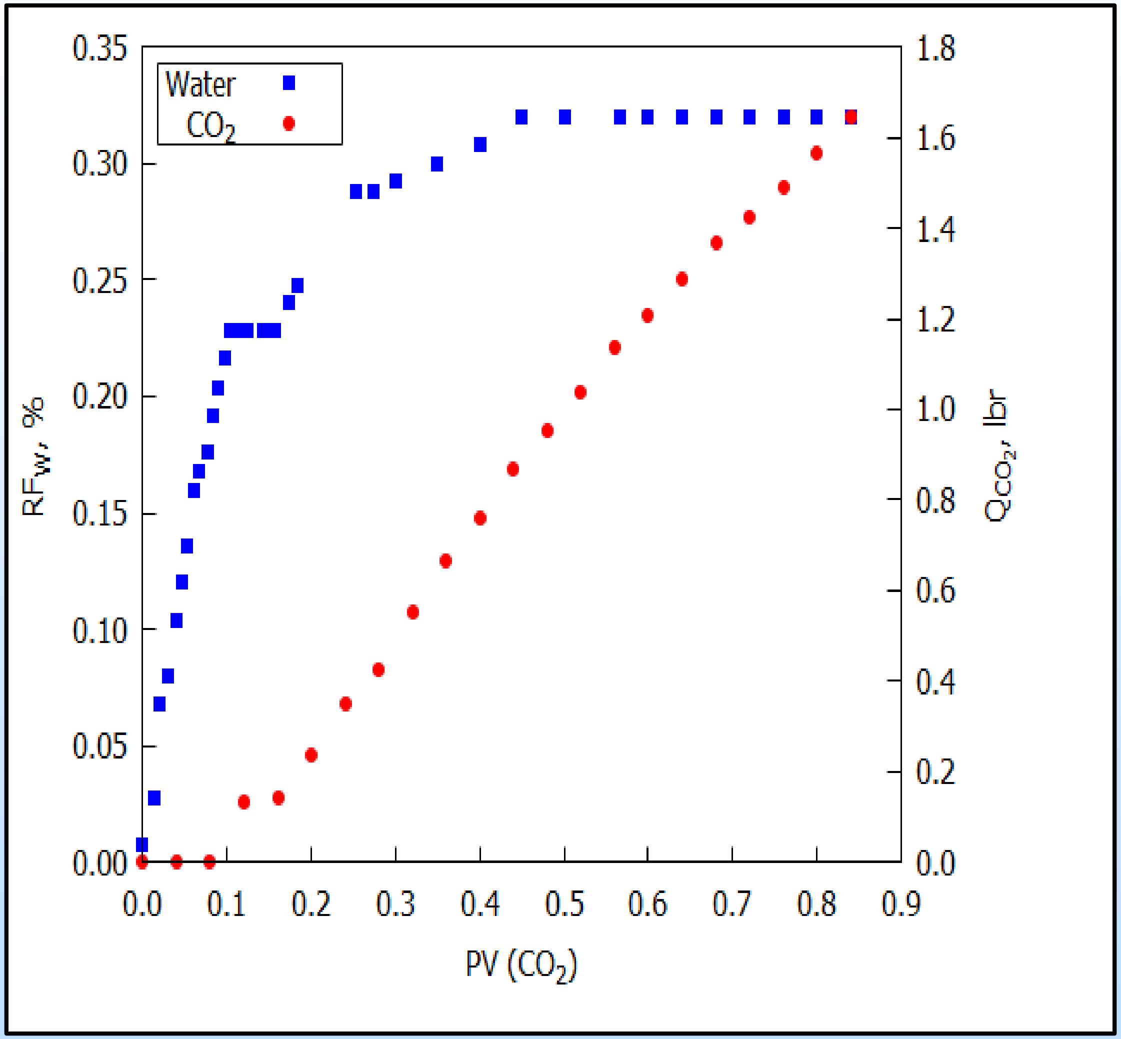
Grana et al., IJGGC, submitted

Seismic/Rock Physics Model



Grana et al., IJGGC, submitted

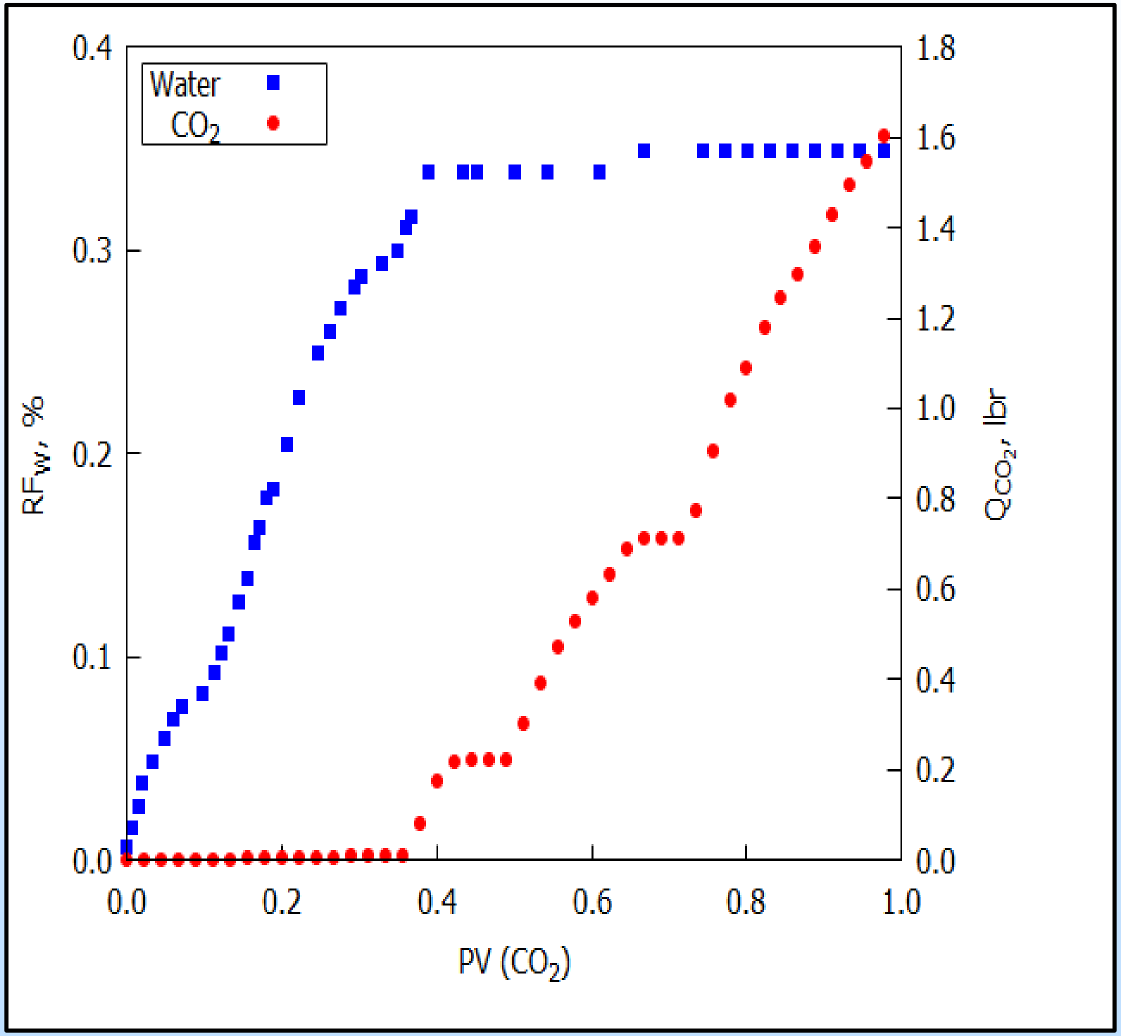
CO_2 Core Flood – Weber Ss



k = 3.0 mD

S_{wir} = 0.68

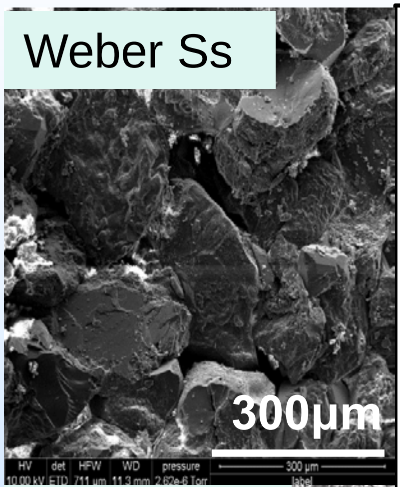
CO_2 Core Flood – Madison Ls

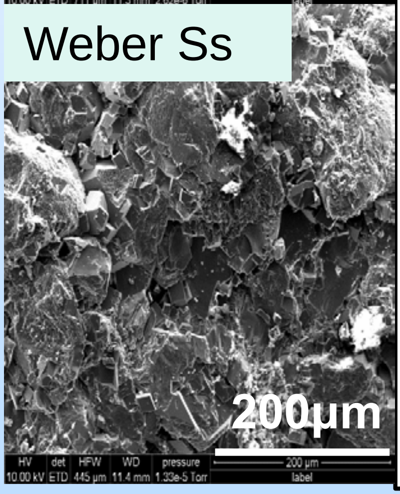


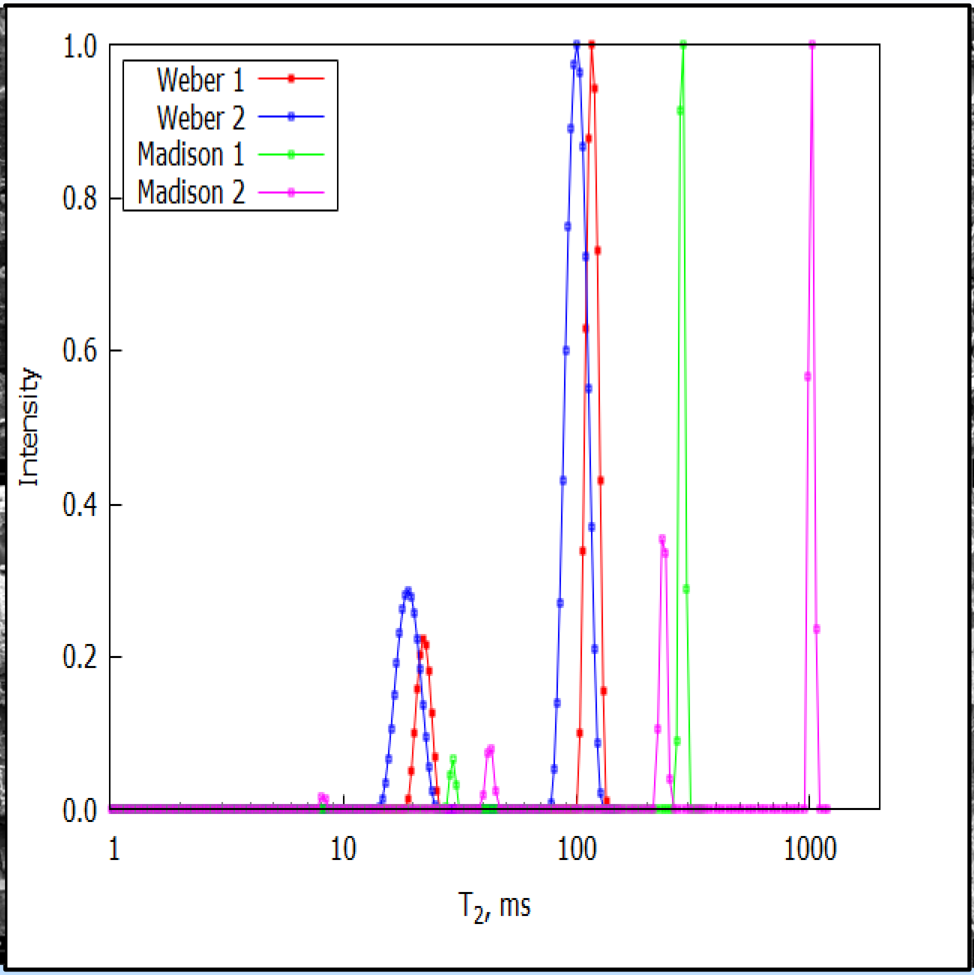
k = 17.7 mD

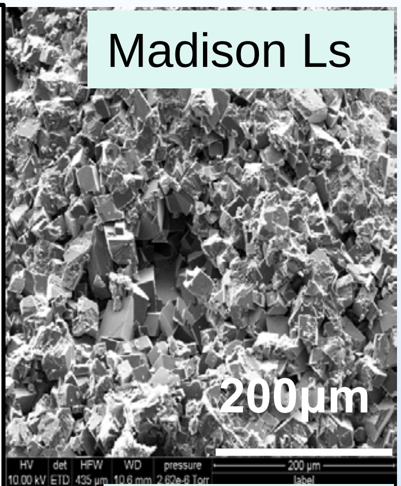
S_{wir} = 0.65

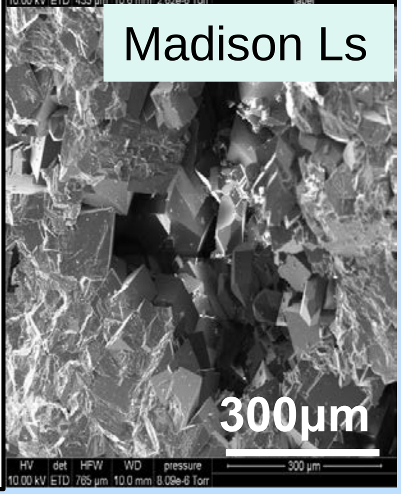
NMR T_2 Distribution Measurements



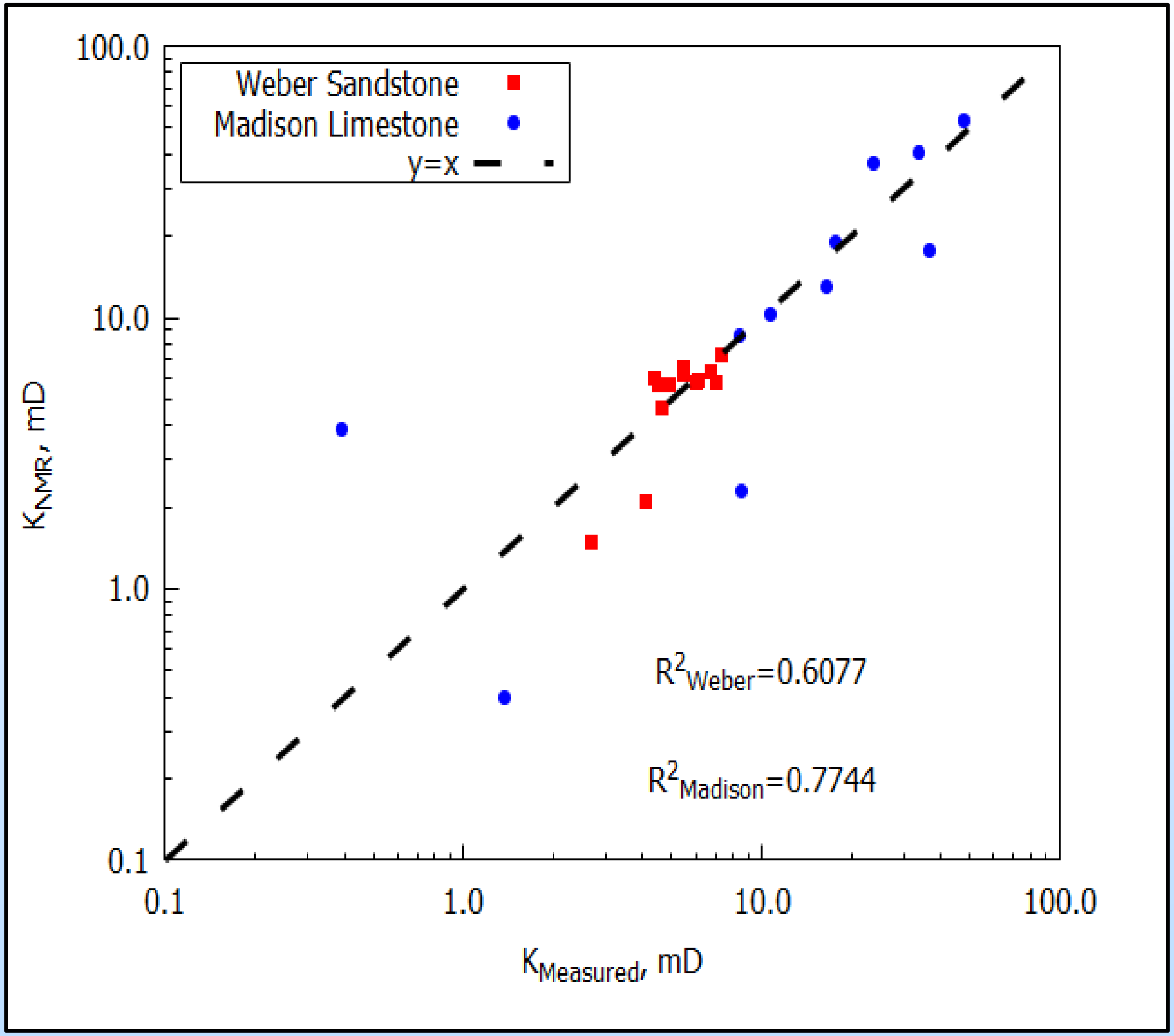








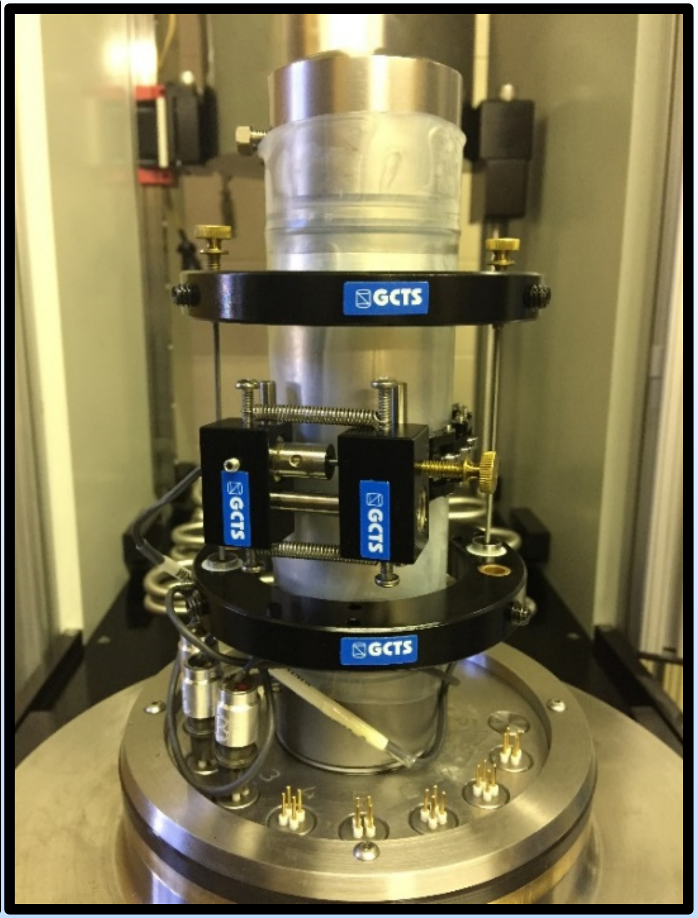
NMR T_2 Distribution Measurements



k Measured w/ N_2
vs
k calculated by T_{2gm}

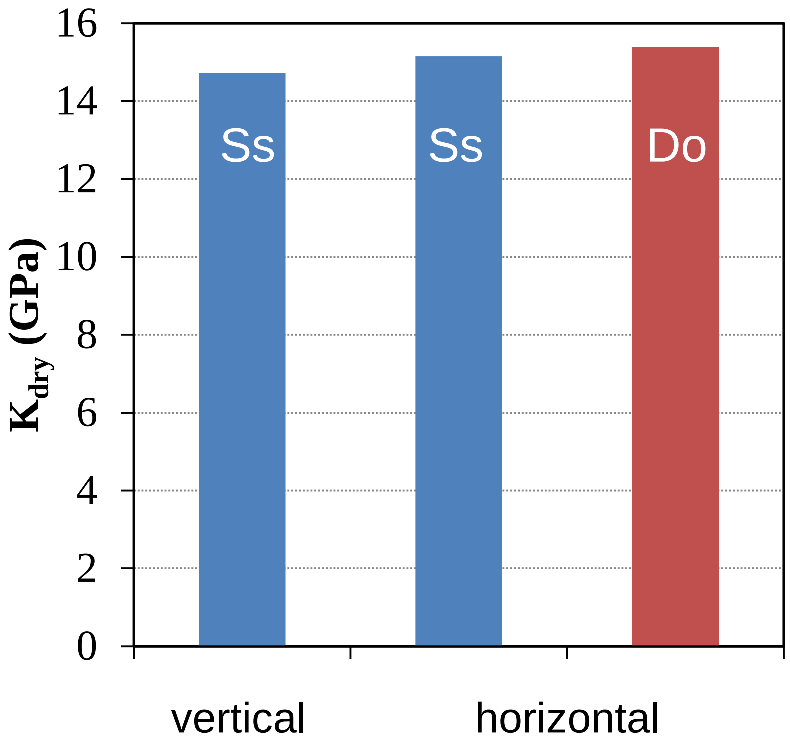
Schlumberger-Doll Research Model

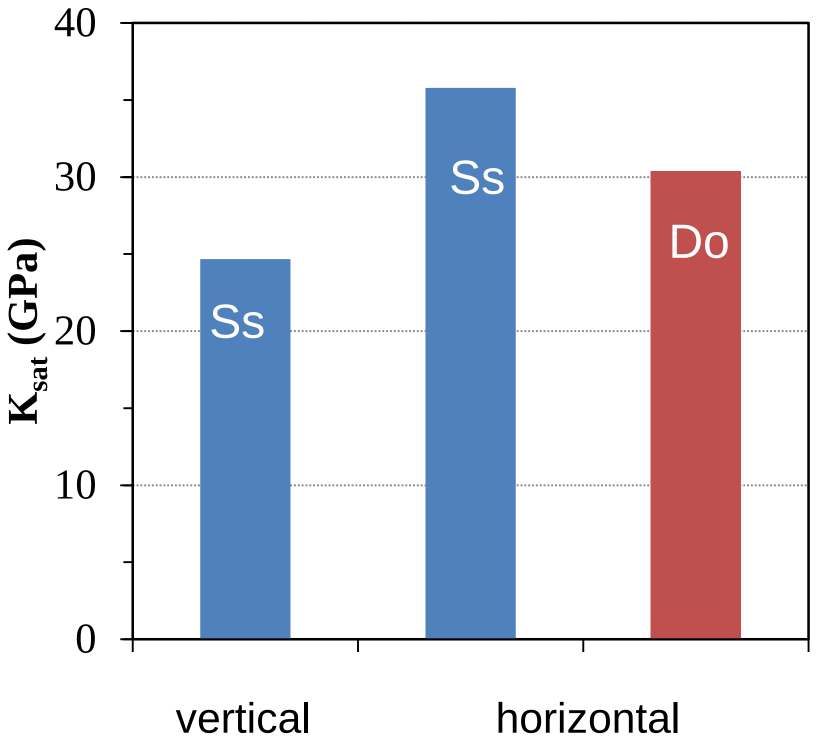
Geomechanics



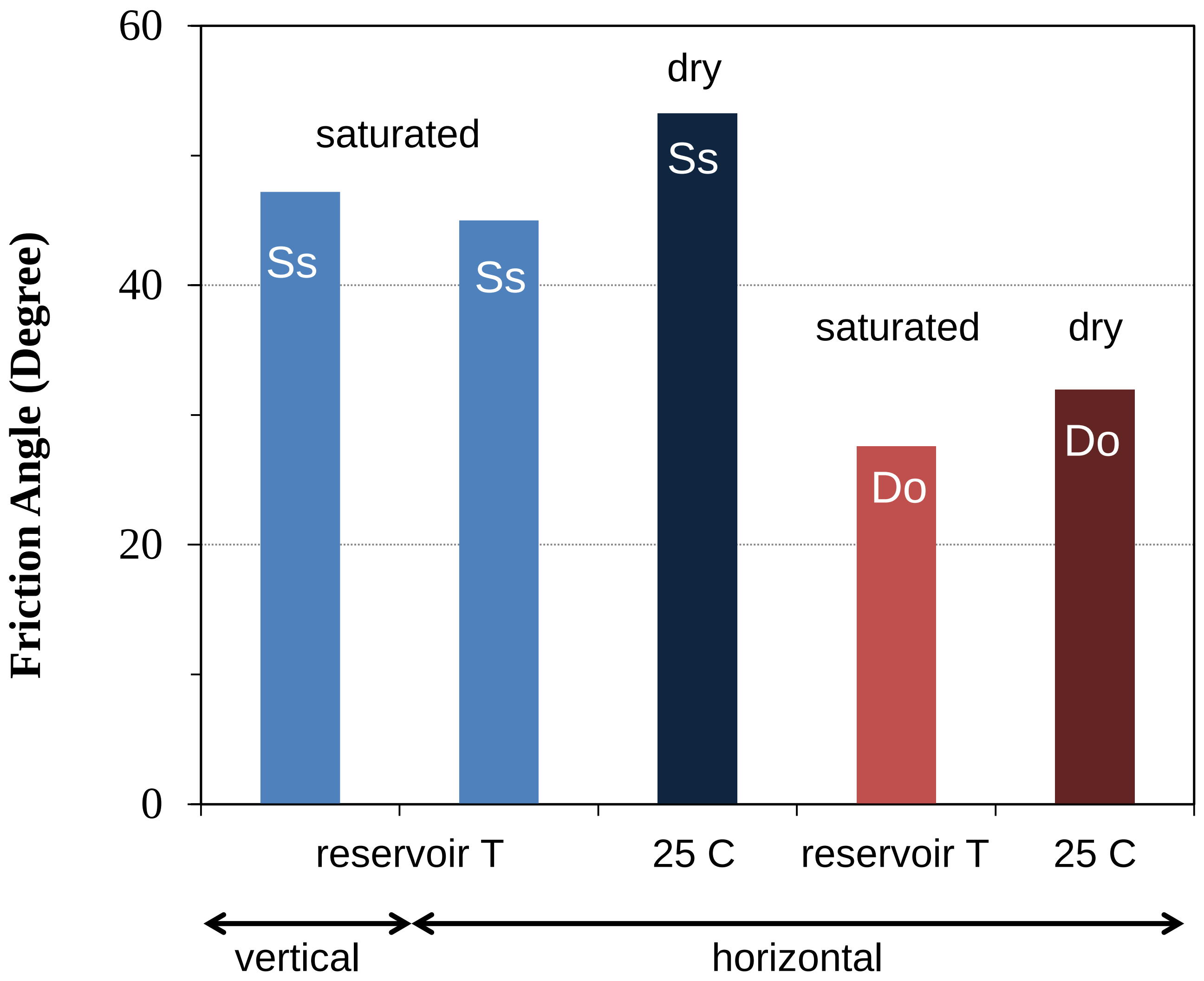
servo-controlled triaxial press (RTR-1500) manufactured by GCTS

Geomechanics

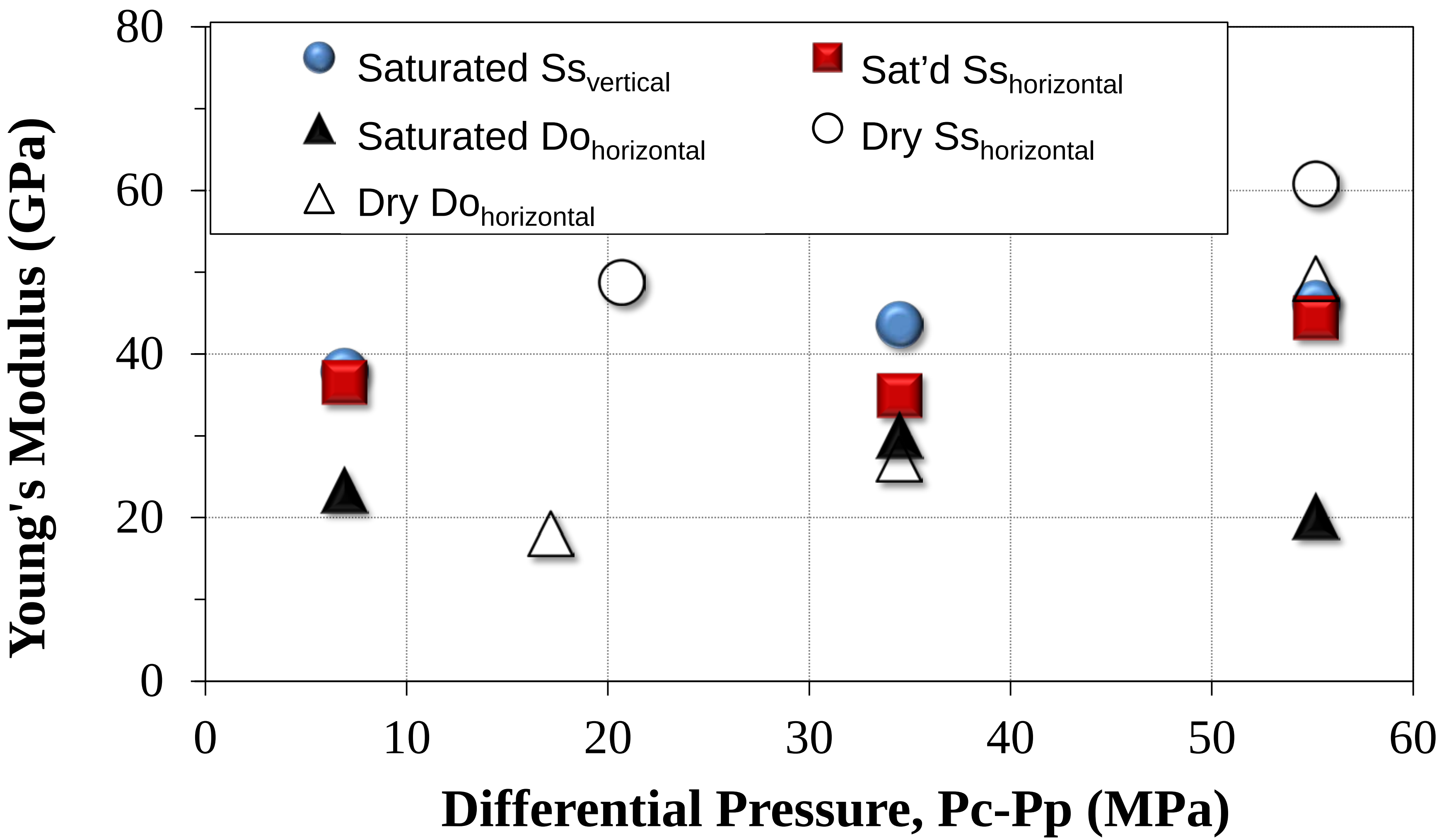




Geomechanics



Geomechanics



Accomplishments to Date

- Submitted 2 manuscripts and published 1 conference proceedings
- Completed statistical rock physics models
- Completed ~80% of capillary pressure tests
- Completed dry and brine-saturated geomechanical tests
- Verified feasibility of using seismic data to monitor CO_2 displacement during injection

Lessons Learned

- Largest technical challenges:
  - Maintaining triaxial press (fortunately, Weatherford is nearby)
  - Performing geomechanical tests on dolostone
- Largest leadership challenges
  - Personnel – lost one PhD student and one postdoc
  - Co-investigators – one left UW and one is now Dept. Head
- Re-affirmation – multidisciplinary is challenging

Synergy Opportunities

- Special Issue of Interpretation for November 2017
  - Topic: Multidisciplinary studies for geological and geophysical characterization of CO_2 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

Project Summary – Key Findings

- Complete reservoir characterization w/ recently-developed techniques: Bayesian elastic inversion of pre-stack seismic data and Bayesian petrophysical inversion of seismic attributes for the estimation of seismic facies, porosity, and permeability.
- Geomechanical tests yield expected results
  - Dry specimens have higher modulus and strength properties than saturated
  - Modulus increases with differential pressures while Poisson ratio decreases
  - Strength properties and Young's modulus of Ss > Do
- Effect of porosity is more significant than mineralogy in these rocks

Project Summary – Next Steps

- Finish geochemical tests (biggest challenge, from PM perspective)
- Condition remaining samples for geomechanics lab (2 Weber Ss and 4 Madison Ls)
- Finish capillary pressure tests (2 Madison Ls)
- Finish geomechanical tests (CO_2-reacted samples)
- Verify feasibility of using EM data to monitor CO_2 displacement during injection
- Conduct fluid flow simulations
- Integrate results to generate workflow incorporating reservoir conditions, experimental data, and fluid flow simulations

Questions?

Appendix

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.

Benefit to the Program

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

Project Overview
Goals and Objectives

- Specific Objectives (continued)
  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
  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.

Organization Chart

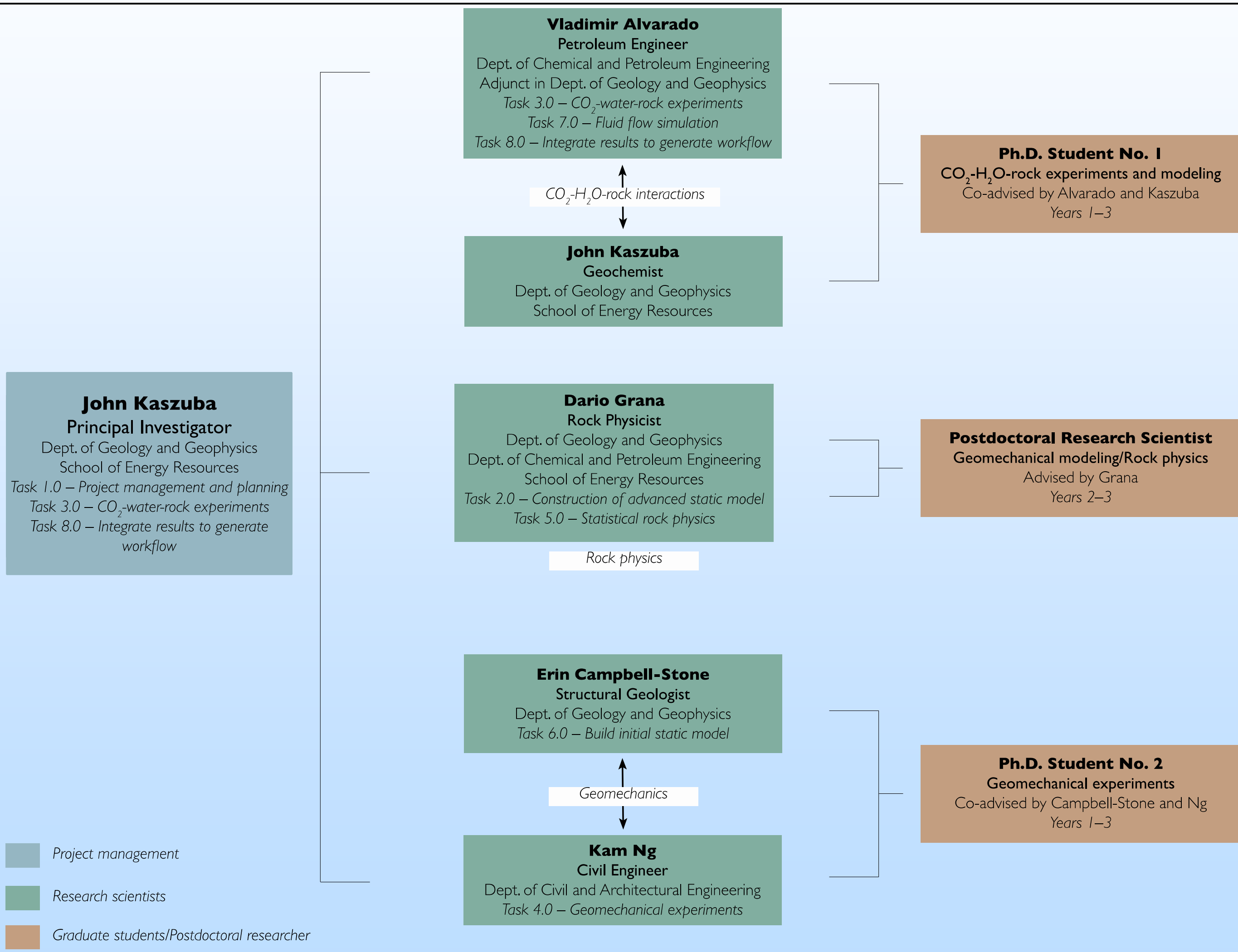


Figure 1. Organizational chart.

Gantt Chart

ID	Task Name	r 2, 2018	Qtr 3, 2018
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		

Bibliography

Grana, D., Verma, S., Pafeng, J., Lang, X., Sharma, H., Wu, W. McLaughlin, F., Campbell-Stone, E., Ng, K., Alvarado, V., Mallick, S., and Kaszuba, J., 2017, A rock physics and seismic reservoir characterization study of the Rock Springs Uplift, a carbon dioxide sequestration site in Southwestern Wyoming: International Journal of Greenhouse Gas Control, submitted.

Wang, H., and Alvarado, V., 2017, Ionic strength-dependent pre-asymptotic diffusion coefficient distribution in porous media – Determination through the pulsed field gradient technique: Journal of Physical Chemistry B, submitted.