Characterization of Most Promising Sequestration Formations in the Rocky Mountain Region

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Infrastructure for CCS

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Partners

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Arizona Geological Survey
Schlumberger
New Mexico Bureau of Geology

Presentation Outline

- Program Benefits
- Project / Program Goals
- Technical Status: Finalizing 10-Point Protocol for CO_2 Storage Site Characterization
- Key Accomplishments
- Summary

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Benefit to the Program

Program Goals Being Addressed by this Project

(1) Support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.

(2) Develop and validate technologies to ensure 99 percent storage permanence.

(3) Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.

(4) Develop Best Practice Manual for risk analysis and simulation.

Project Benefits Statement

The main outcome of this study is a 10-point Protocol for CO_2 Storage Site Characterization. Although this protocol is applied to one region (the Rocky Mountains), we've generalized it to be applicable anywhere, and this protocol will support and contribute directly to goals (1), (2) and (3) above (especially (1)).

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Project Overview: Goals and Objectives

- The primary objectives of the Rocky Mountain Site Characterization project, or RMCCS, are
  - to characterize and analyze geologic sequestration formations at a specific set of local sites
  - apply the results to identify the regional significance of those geologic sequestration formations for the southwestern U.S.
- Of particular context is the Programmatic Goal of *supporting industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent* -- our 10-point protocol is intended to provide direct support to this Programmatic Goal

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Finalizing 10-Point Protocol for CO_2 Storage Site Characterization

1. Regional assessment of sedimentary basins, oilfields, and existing data
2. Gathering of existing-data and associated analysis, especially of northwestern Colorado
3. Surface geology reconnaissance, including field mapping and/or helicopter geologic assessment
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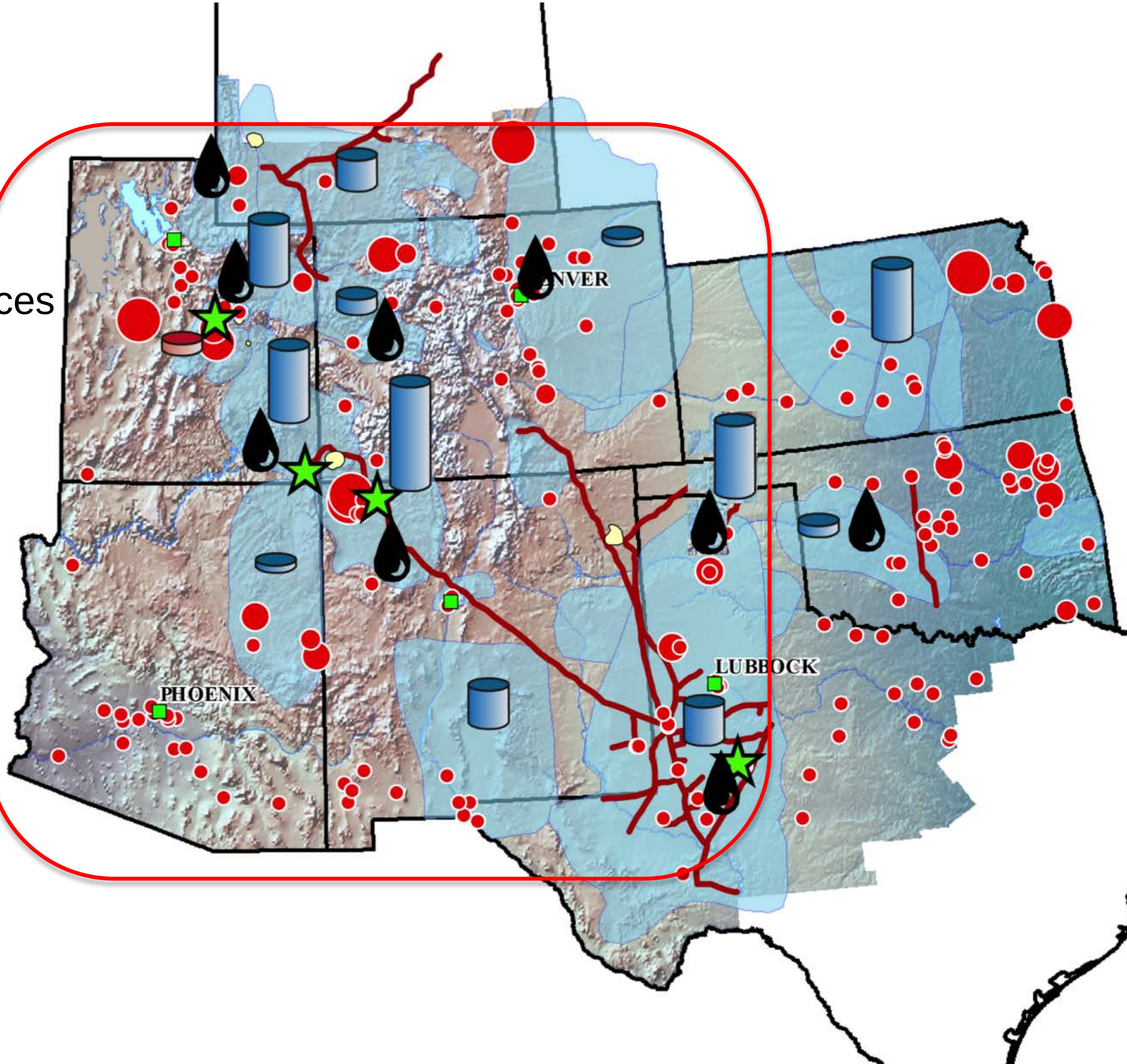
1. Regional Assessment

Optimize Capacity Estimation: Number of Years for Specific Sources



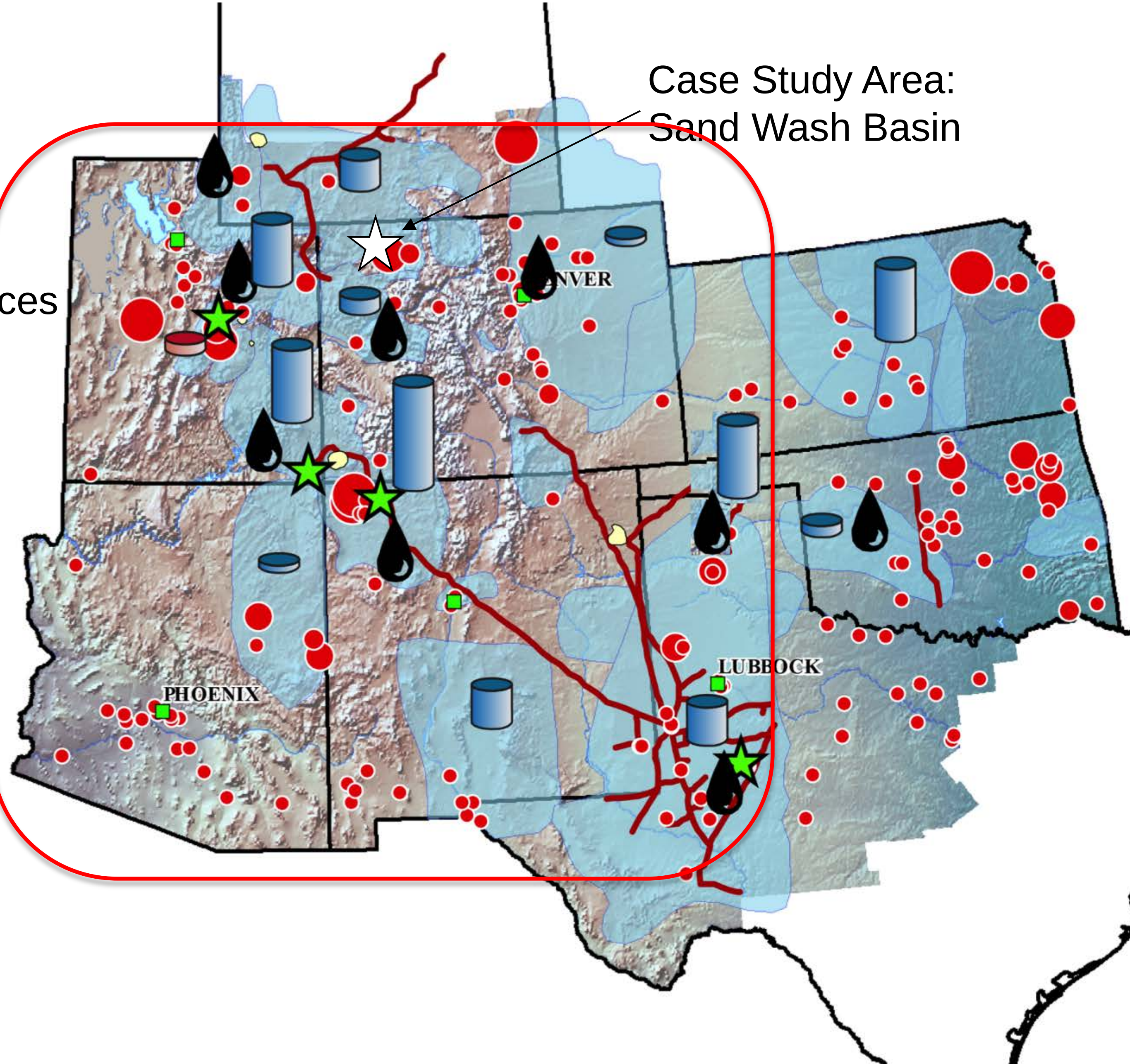
EXAMPLE: Regional Emissions

Point Sources :

~318 million tons CO_2 per year

1. Regional Assessment

Optimize Capacity Estimation: Number of Years for Specific Sources



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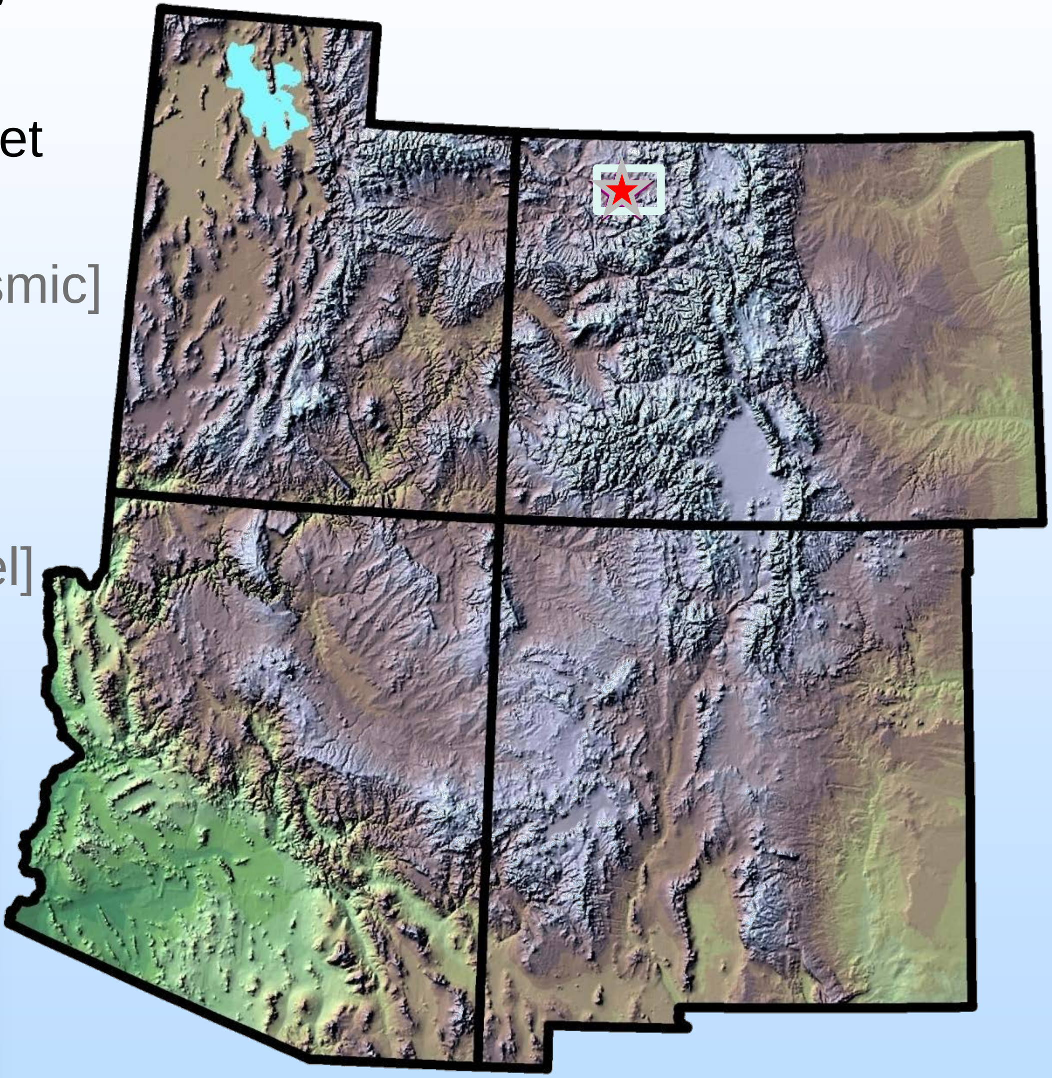
2. Gather/Analyze Existing Data

- ✓ Identify and incorporate existing data (e.g. previous geologic studies, maps, well logs and cores)
- ✓ Purchase, process, and interpret existing seismic
- ✓ [Acquire and interpret new seismic]
- ✓ [Map surface structure]
- ✓ [Map regional rock property trends (i.e. porosity)]
- ✓ [Generate static geologic model]



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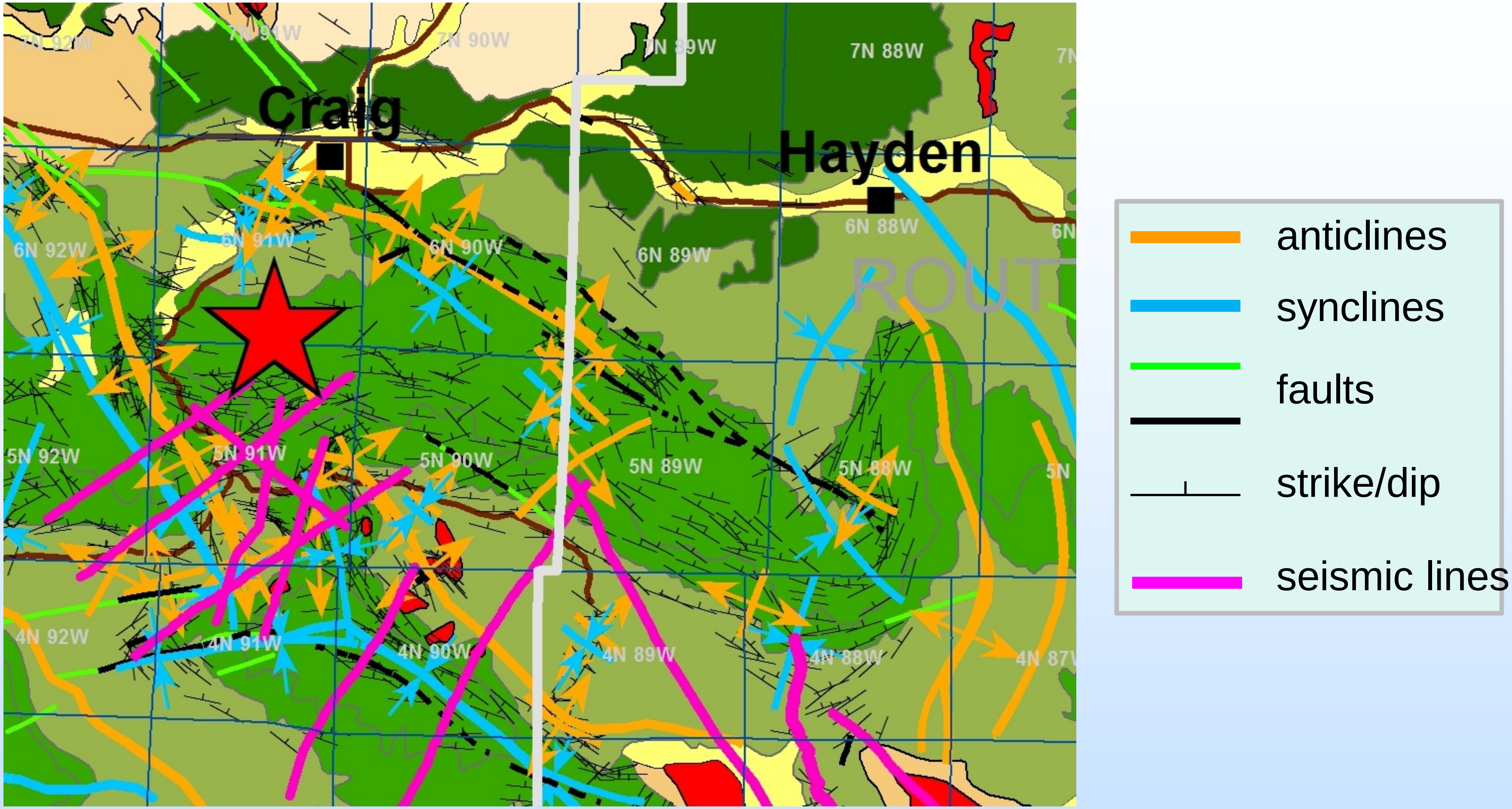
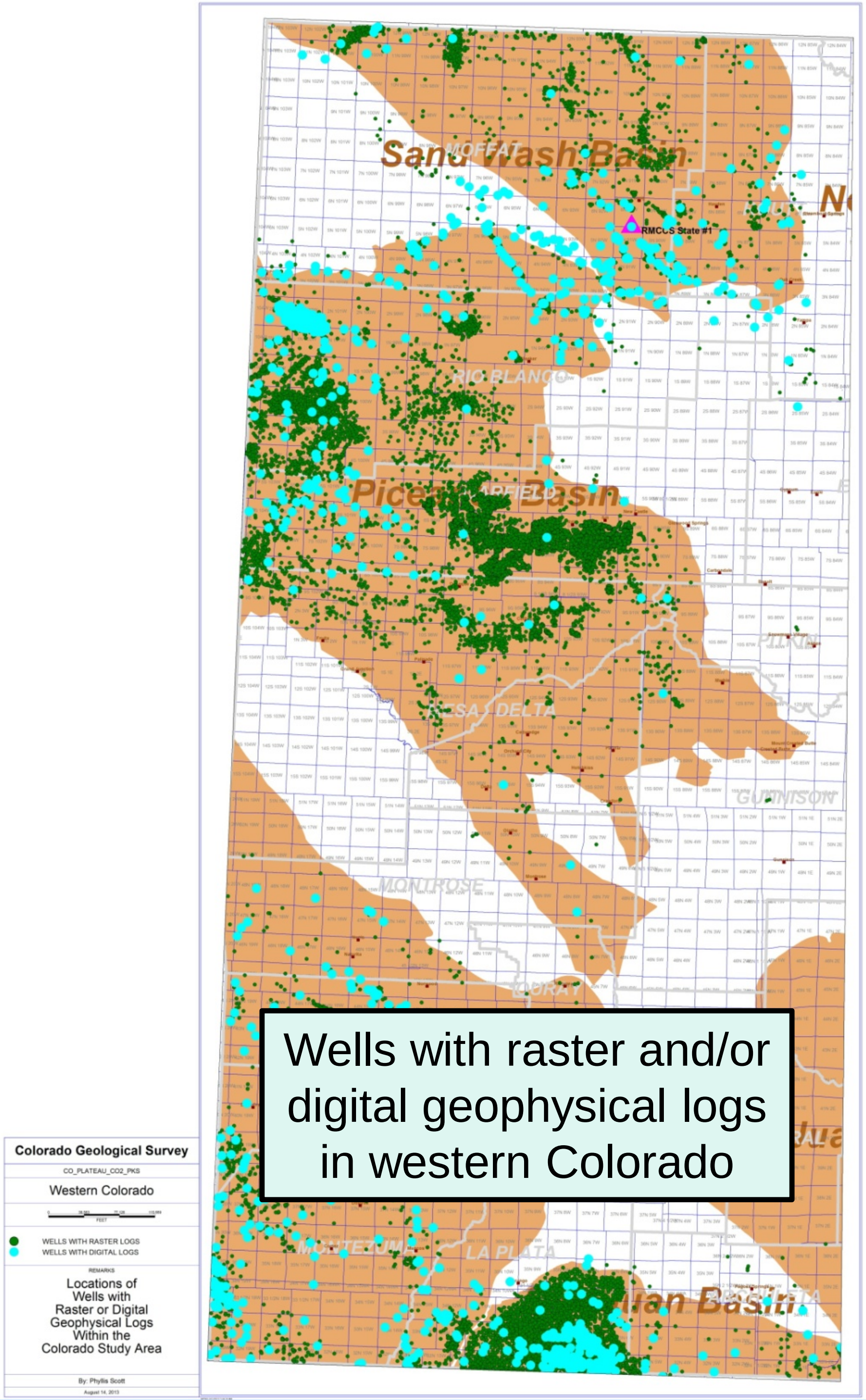
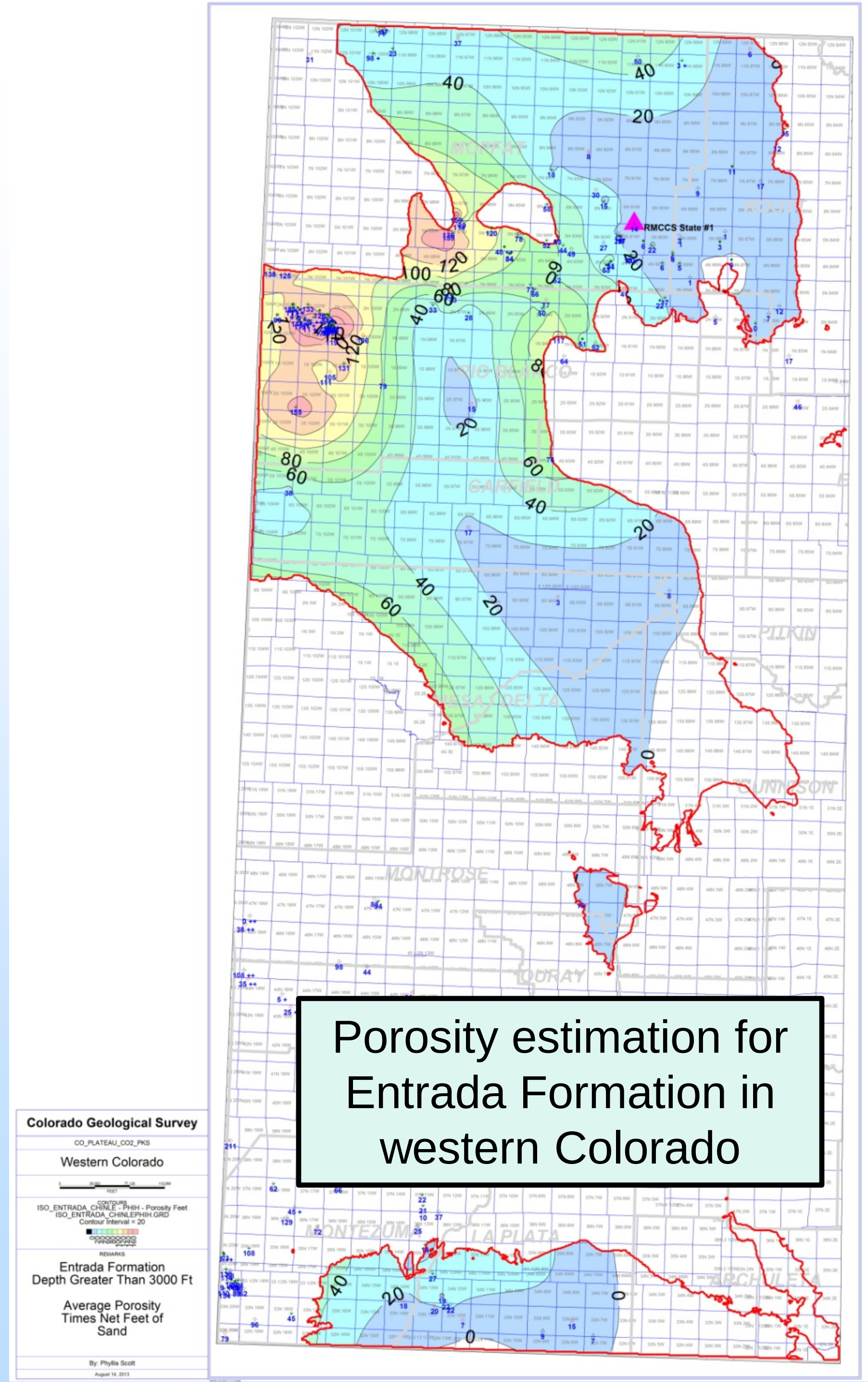


- Surface structural and subsurface geophysical data were used to identify best well location and target formation depths at site. Focus on region near Craig, CO.
- More than 18,000 well logs from 30,000 wells across Western Colorado were initially evaluated. Nearly 50,000 individual formation tops were picked to characterize subsurface geology.



Wells with raster and/or digital geophysical logs in western Colorado



Porosity estimation for Entrada Formation in western Colorado

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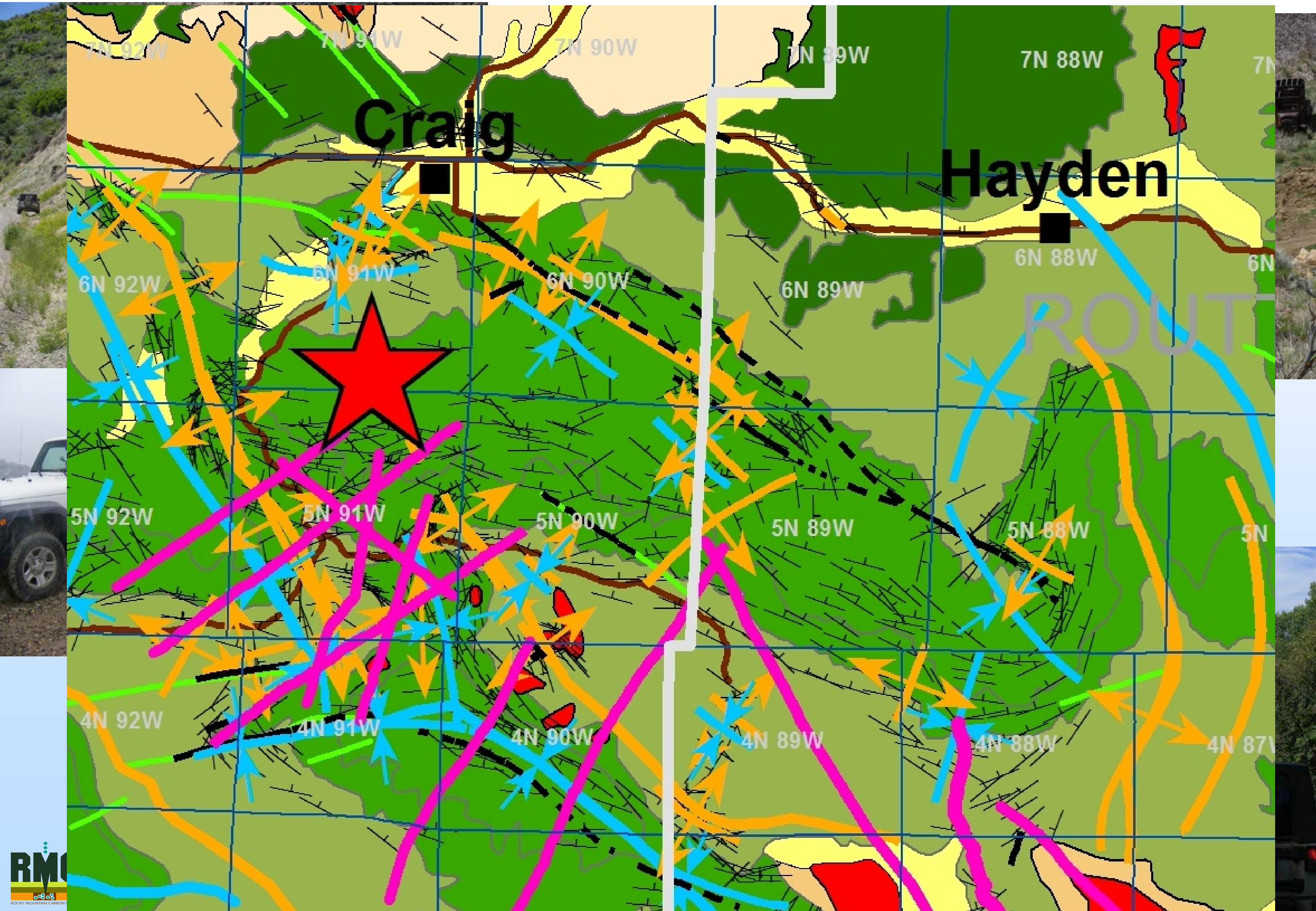
3. Surface Geologic Reconnaissance



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Quantitative Seismic Interpretation through Seismic-Well Ties (SWT)

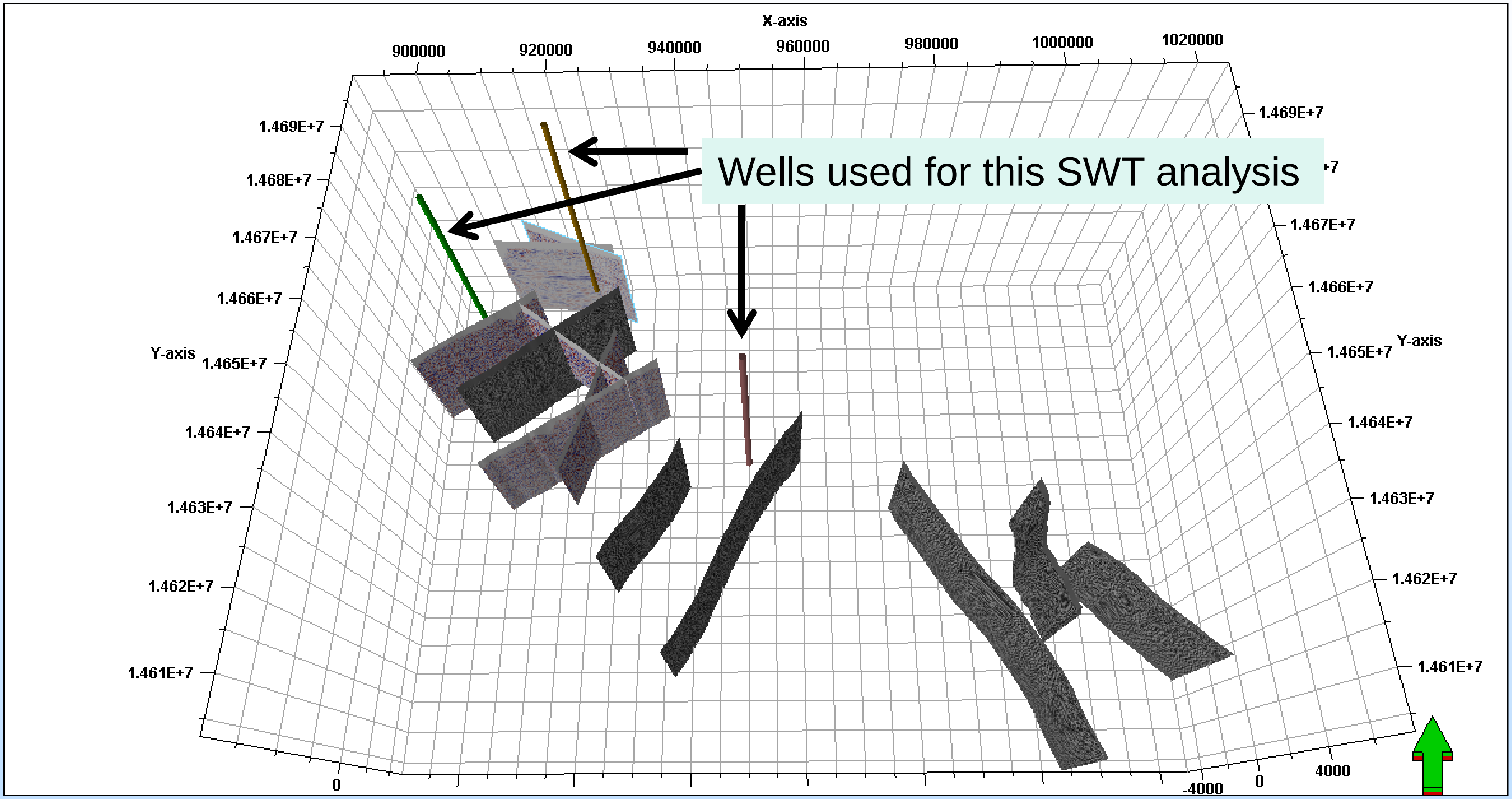
Using sonic and density well logs along with intersecting seismic data to calibrate a time-depth relationship (TDR) for use in depth conversion of seismic interpretations.

SWT based Interpretation Process

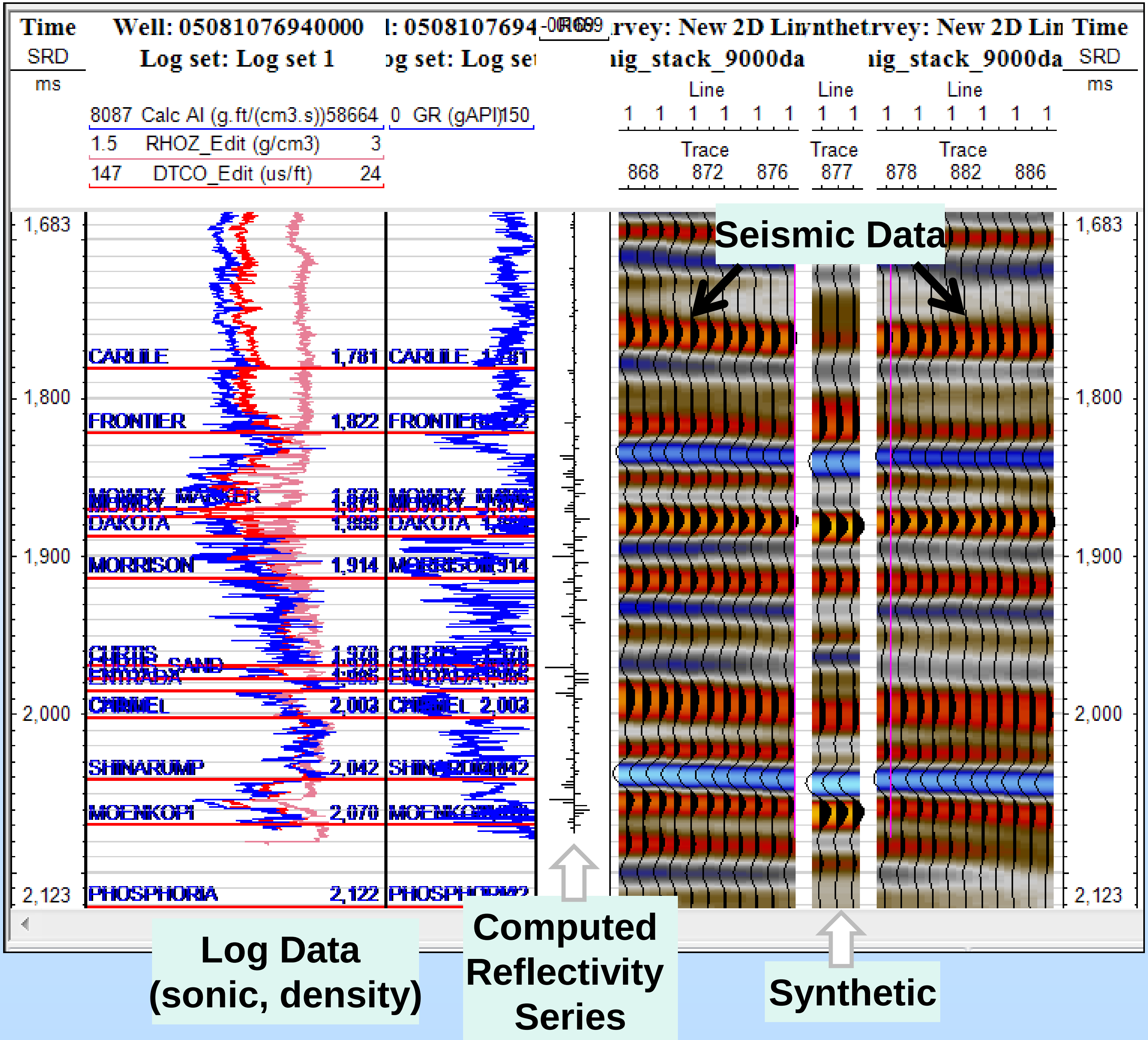
1. Wherever available sonic and density well log data are calibrated to nearby seismic data, creating a TDR for the well.
2. Geologists picks for the well are converted to time using the TDR.
3. Time converted well picks are posted on the seismic data and used as kick-off points for seismic interpretations.
4. TDR's for one or more wells are interpolated to create a 3D velocity model.
5. The 3D velocity model then used to convert seismic time interpretations to depth.
6. Depth converted seismic interpretations are then used, along with well tops, in construction of the 3D geologic model grid.

4. Surface Seismic Surveys

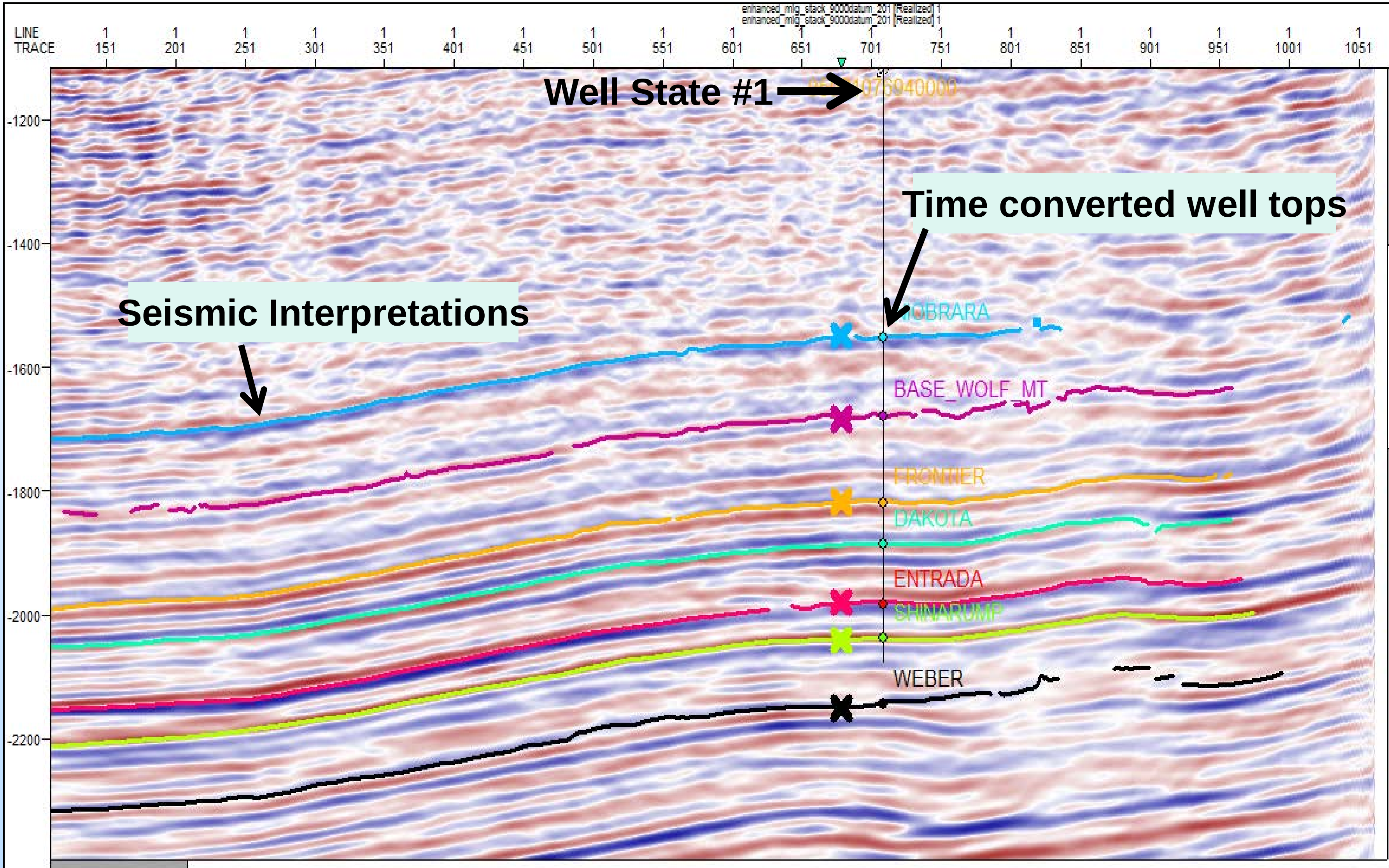
Example: Seismic Line Coverage and Wells in SWT



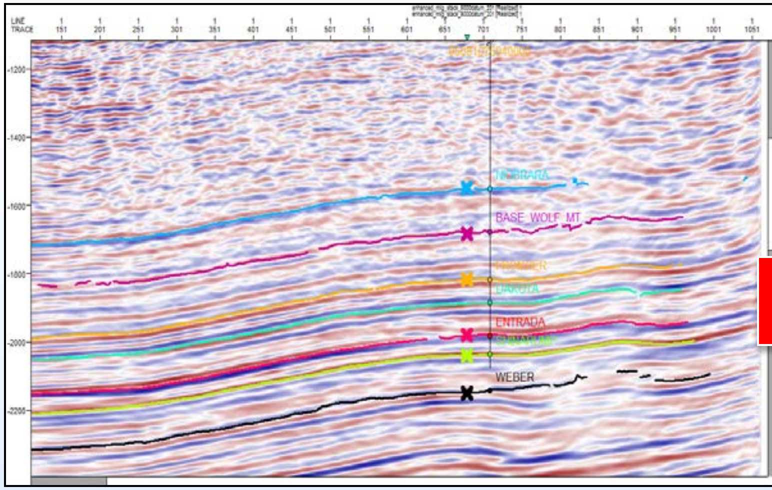
Seismic to Well Tie

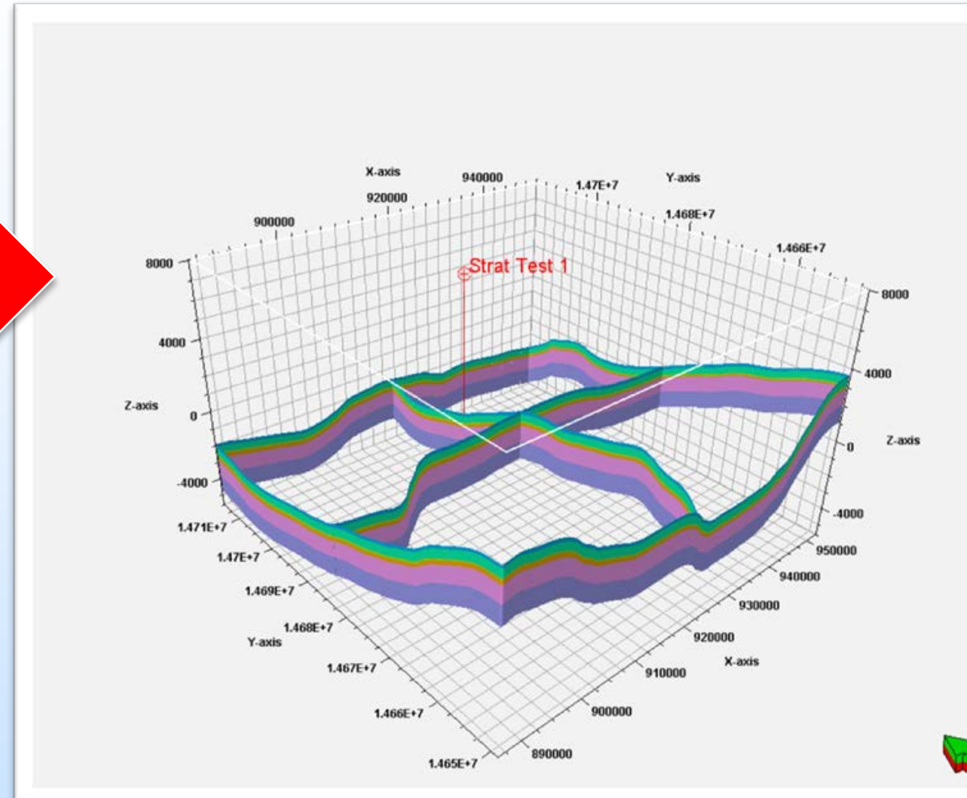


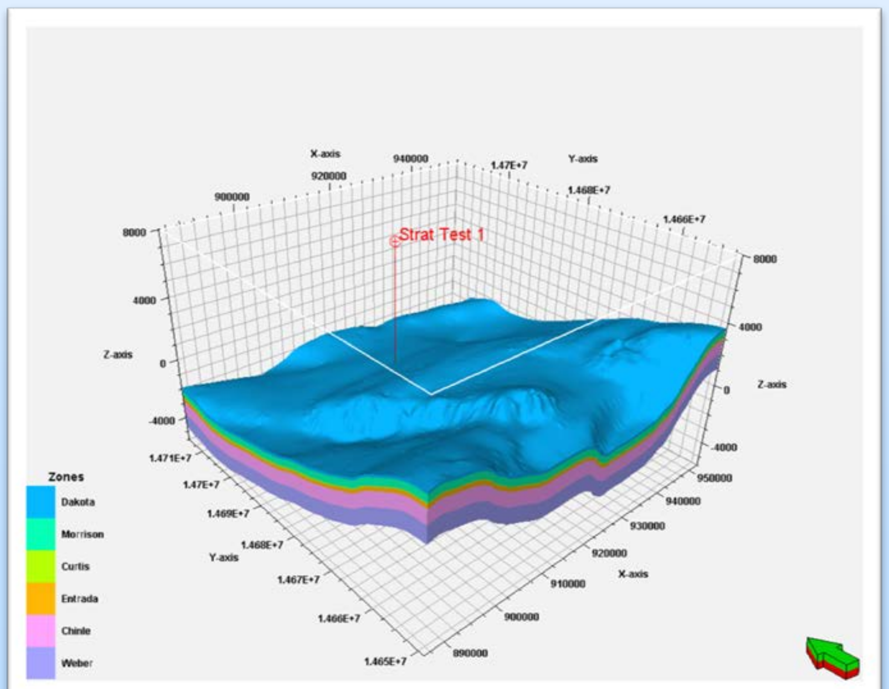
Seismic Time Interpretation From Time Converted Well Tops



Seismic Time Interpretation Ultimately Serves as Basis for Reservoir Model Grid







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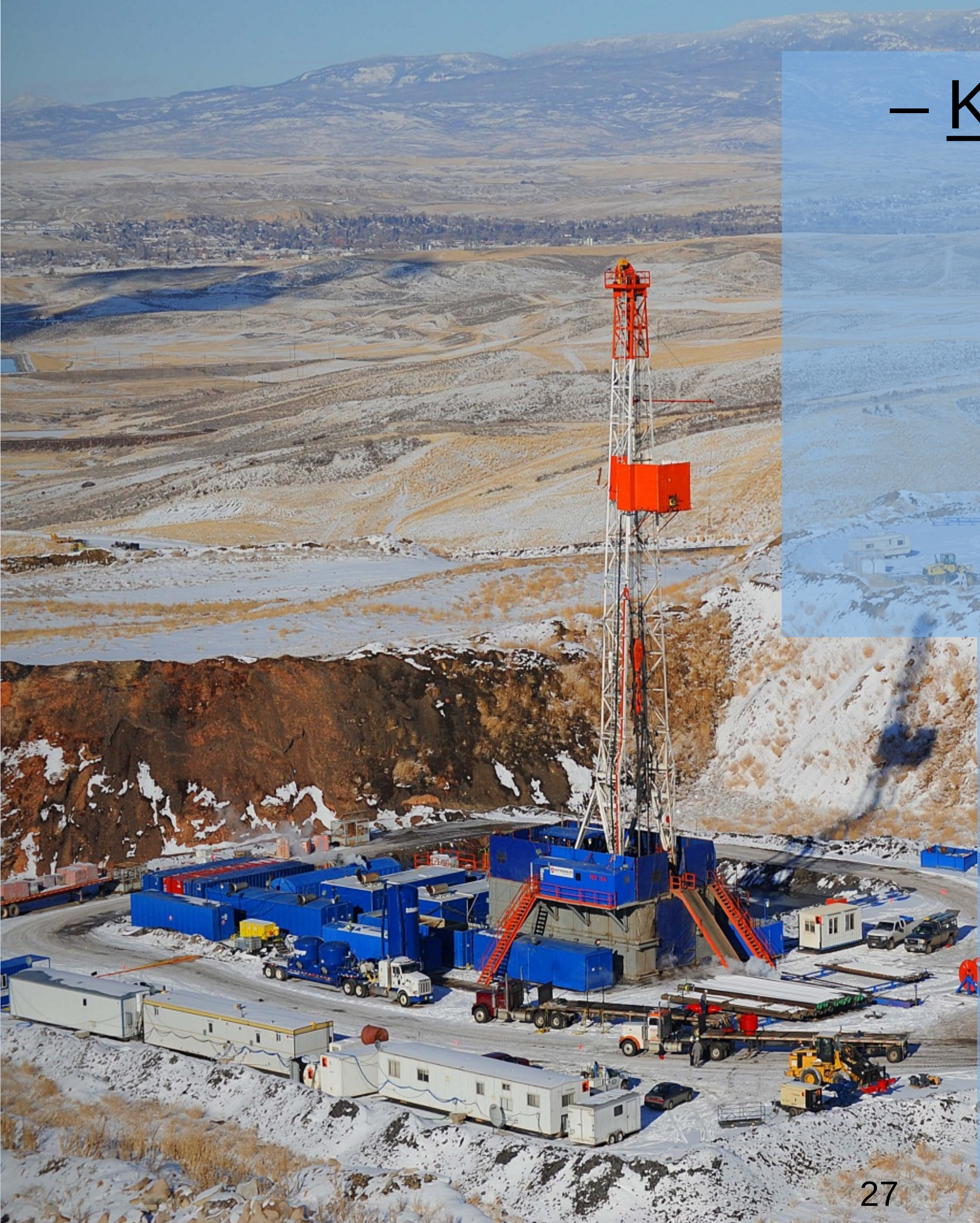
5. Stratigraphic Well Drilling and Coring



– Key Findings

- Dakota Formation at 8,275’
  – 34’ net sand >0.1 md
- Entrada Formation at 9,000’
  – 28’ net Sand >1 md
- Ave porosity 10% to 15%
- Sealing Formations Excellent

– Lessons Learned

- Drilling on operating mine best practices developed
- Drilling “Wildcat” area on fixed budget best practices developed

5. Stratigraphic Well Drilling and Coring

– Key Findings

- Niobrara contained natural fractures and oil
- Entrada storage formation average permeability 1-5 md with as much as 300 md
- Mowry sealing formation average permeabilty .001 md creating an excellent seal

– Lessons Learned

- Coring shale can be problematic with water based drilling fluid
- Critical to have good formation top estimates
- Wireline coring used effectively coring to fill in gaps of primary core

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5. Stratigraphic Well Drilling and Coring

FIGURE 2. PERMEABILITY PROFILE WITH DEPTH

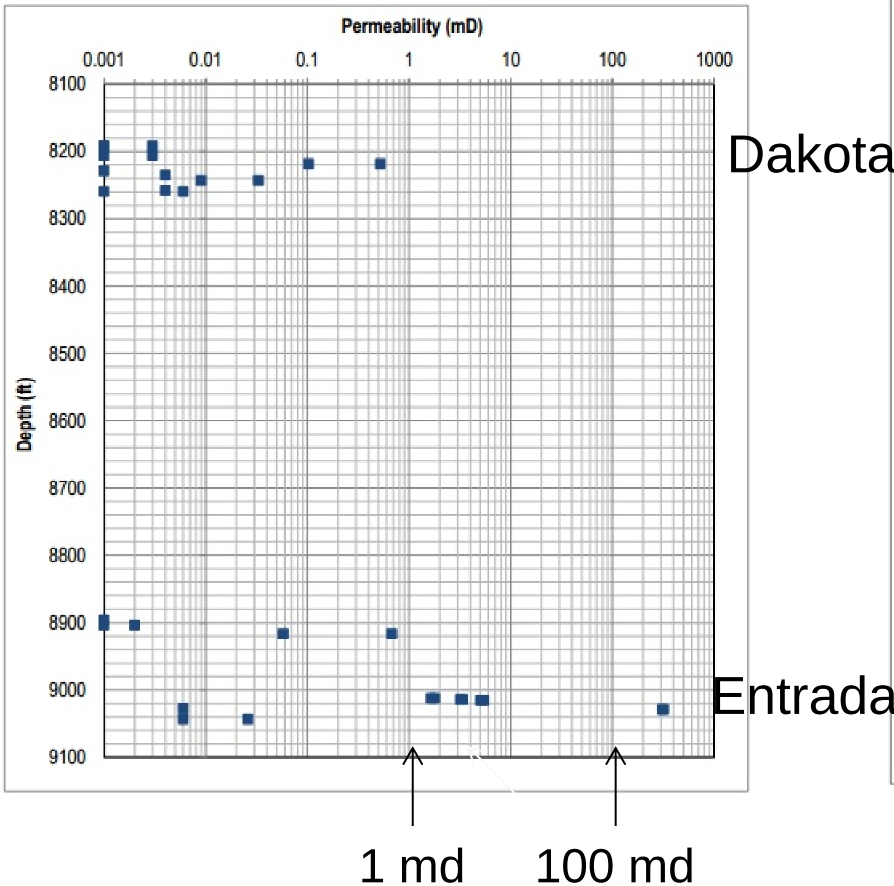
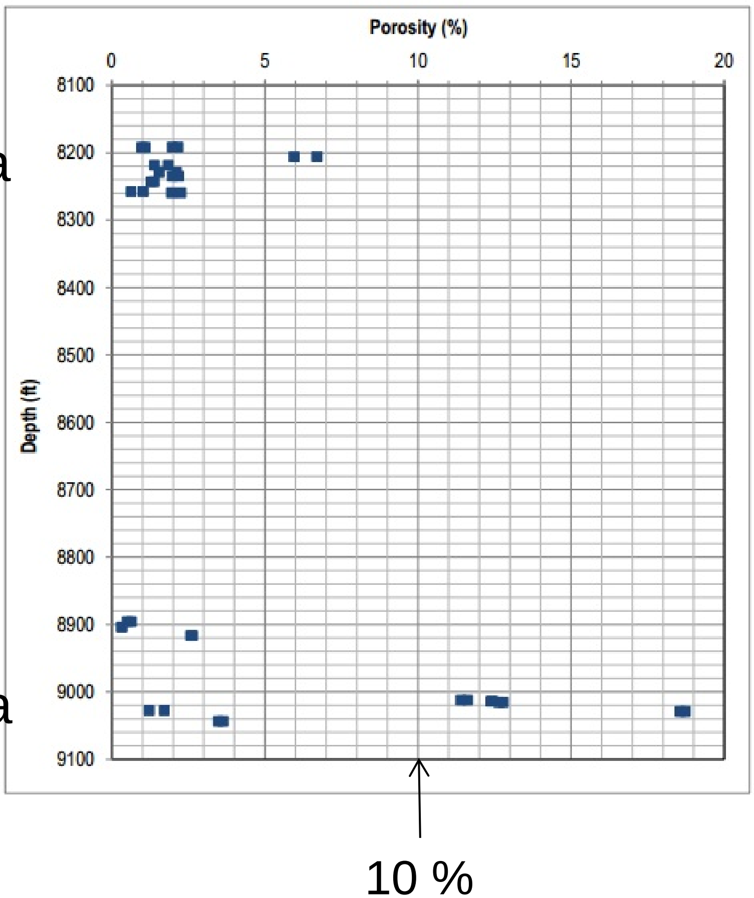


FIGURE 3. POROSITY PROFILE WITH DEPTH



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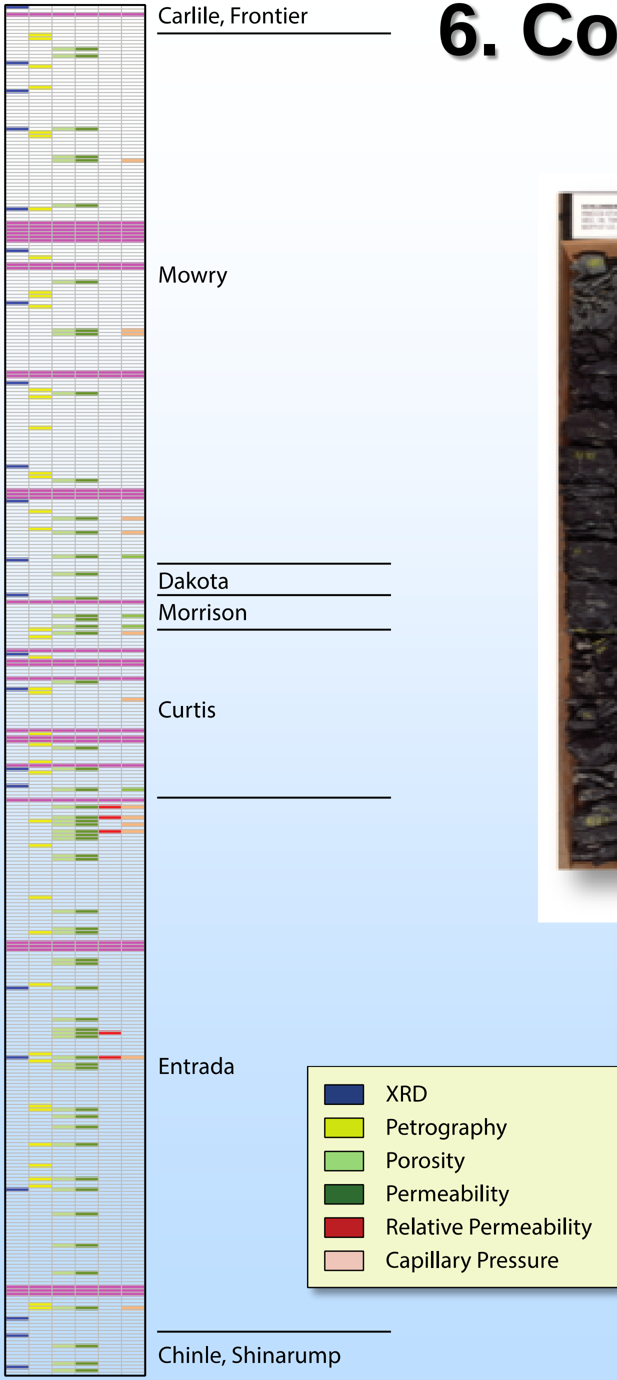
6. Core Analysis and Interpretation

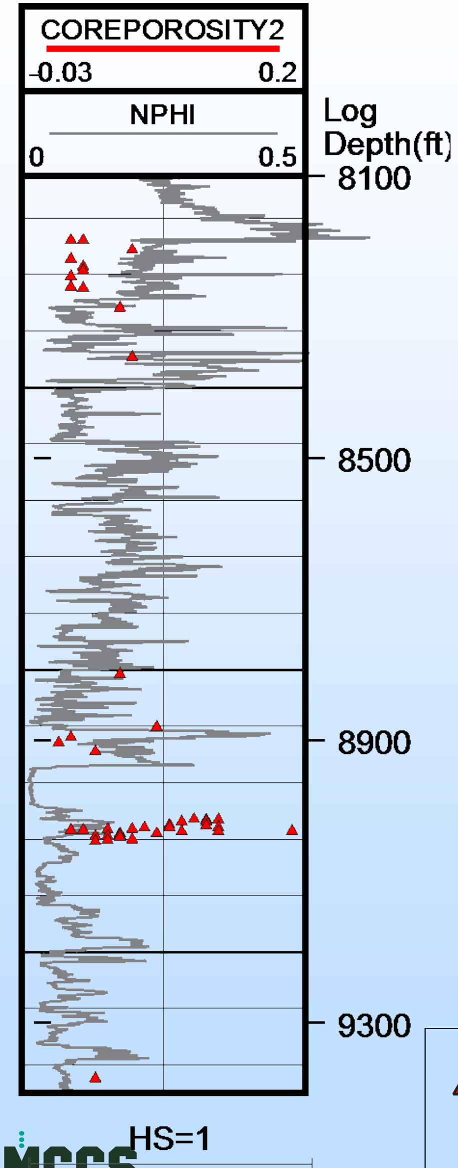


1 of 7 boxes of slabbed core from the RMCCS well

Core & Plugs collected

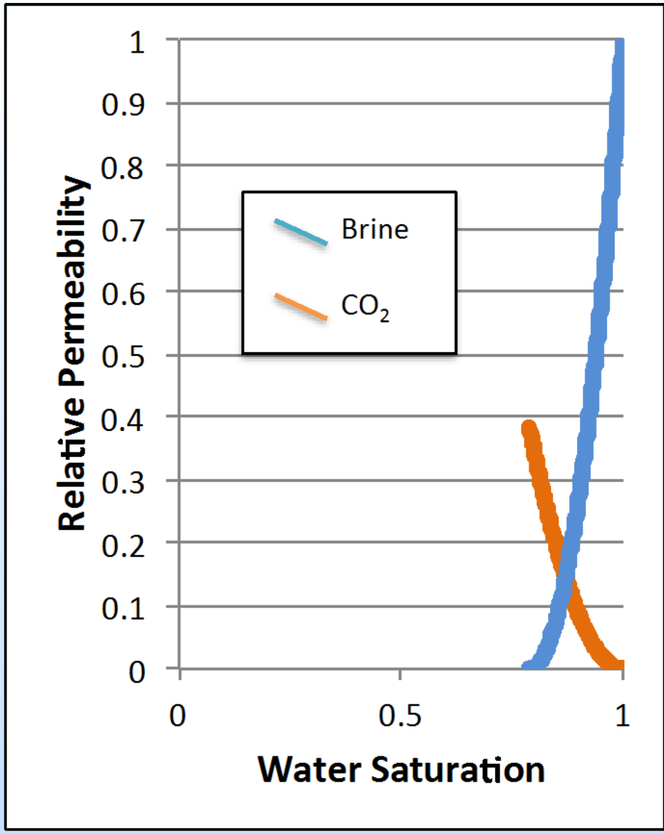
- 131 feet of whole core collected
  - 70 feet from the Mowry
  - 26 feet from the Curtis
  - 35 feet from the Entrada
- 313 plugs sampled from whole core
  - 127 plugs from the Mowry
  - 37 plugs from the Curtis
  - 149 plugs from the Entrada
- 50 rotary sidewall cores collected
  - 1 Carlile Shale
  - 6 Frontier Sandstone
  - 10 Dakota Sandstone
  - 11 Morrison Sandstone
  - 4 Curtis Sandstone
  - 4 Entrada Sandstone
  - 7 Chinle (shale)
  - 4 Shinarump (sandstone and shale)
  - 3 Moenkopi (shale)

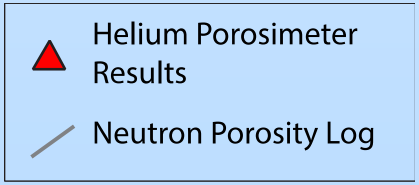
6. Core Analysis and Interpretation



Core & Plugs analyzed

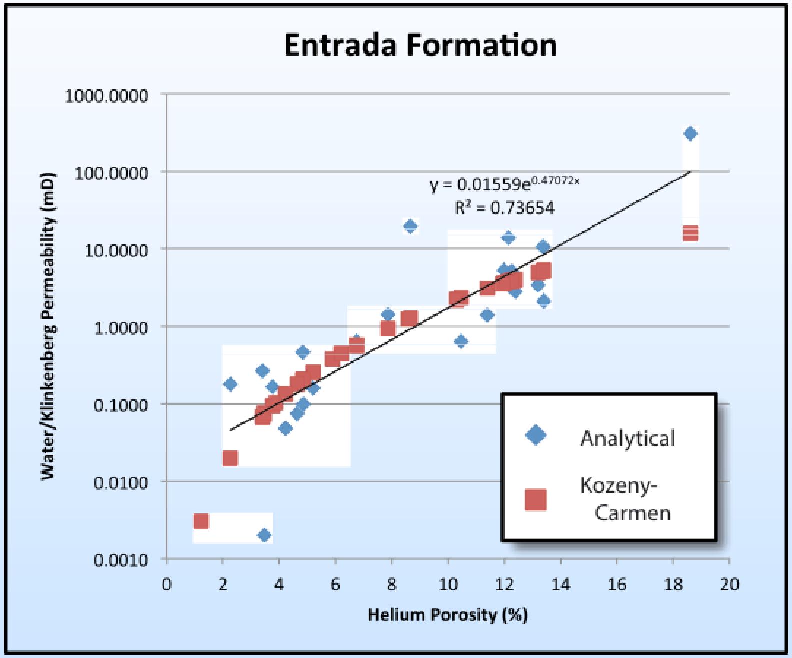
- 22 XRD (bulk and clay) for reactive transport simulation
- 42 Petrographic descriptions for fundamental lithologic characterization
- 55 Porosity analyses for calibration of downhole geophysical logs (see left), model development and CO_2 capacity
- 55 Permeability analyses for model development and simulation
- 6 Relative Permeability analyses for multiphase simulations (see right)
- 13 Capillary Pressure tests for multiphase simulations





6. Core Analysis and Interpretation

Permeability Model from Porosity Data



- Entrada Formation chosen as reservoir because wealth of core samples
- Porosity and Permeability were measured by TerraTek, CoreLab, and the University of Utah and combined

- Kozeny-Carman Equation has been used and tested many times for relating porosity and permeability

  k = permeability [mD]
  Ø = porosity [fraction]
  S_o = particle surface area/volume [m^{-1}]
  S_o ~6/D [where D=mean particle diameter]
- Empirical data was used to back-calculate S_o

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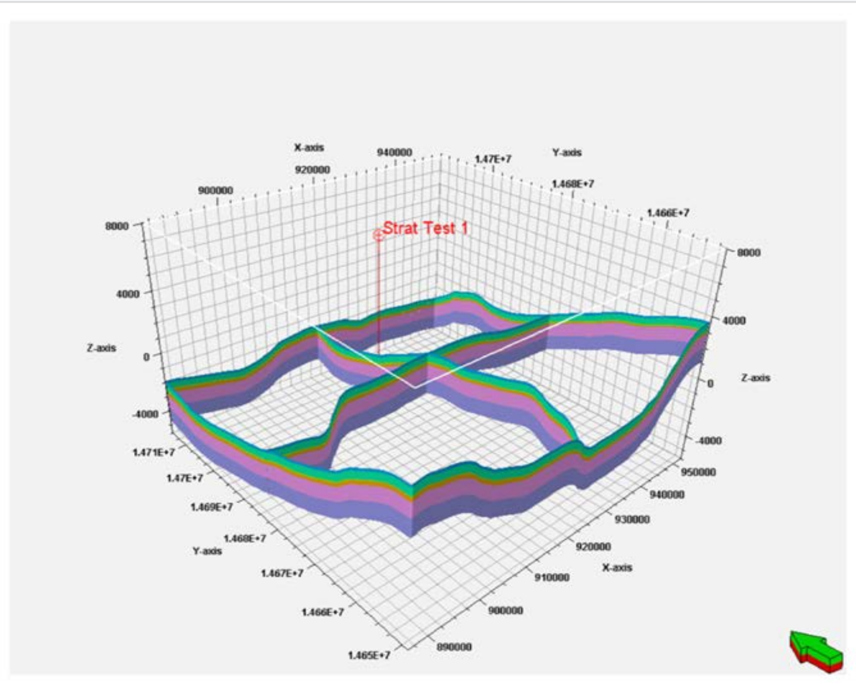
7. Database and Model (Grid) Development

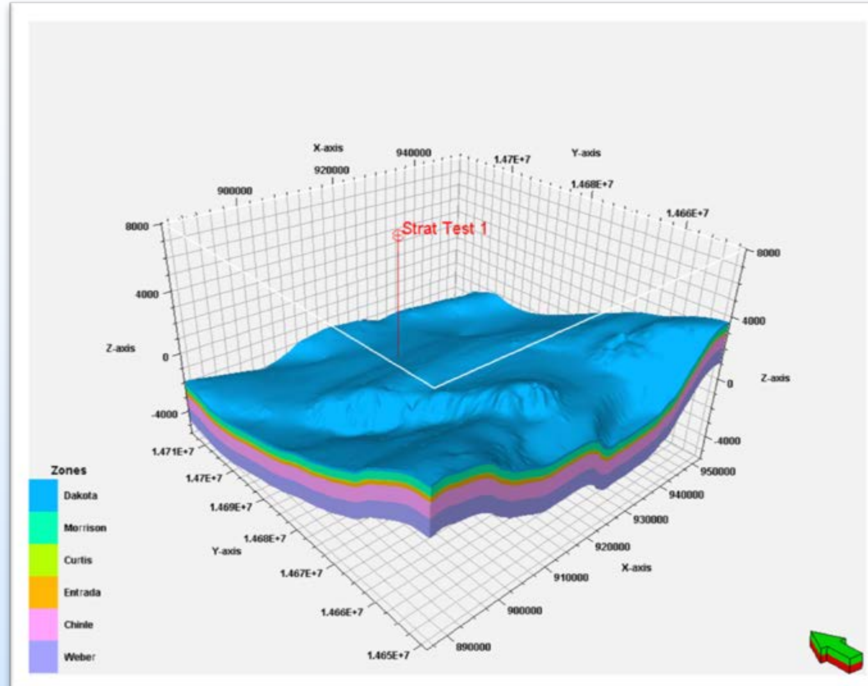
- Collect all available well, core, seismic and other geoscience data from a large region of Northwestern Colorado and Southwestern Wyoming focusing on the Sand Wash Basin;
- Assemble comprehensive database of all pre-existing data, new seismic data, and new well data (Petrel);
- With all data in place, continue interpretation of these data for stratigraphic and structural elements important to project storage and containment goals;
- Identify gaps, or borehole and surface geological and geophysical data in-fill needs (if possible to acquire);
- Integrate all available data into a geologically-representative 3D geocellular model grid;

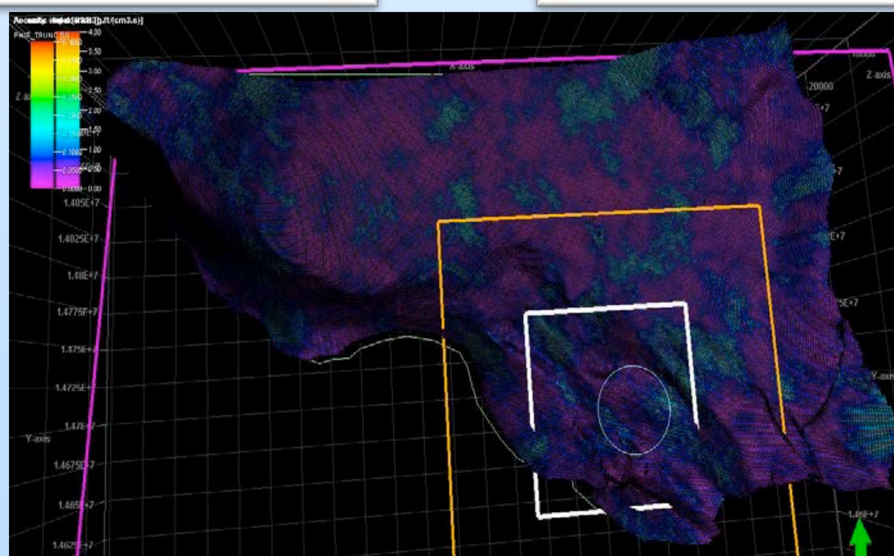
7. Database and Model (Grid) Development

- 4000+ regionally distributed public domain wells with geologic formation top picks
- 200+ wells within the Sand Wash Basin model area with geologic formation top picks
- 20 public wells within the Sand Wash model area with petrophysical analysis
- New logs and core from the RMCCS strat test well.
- 14 reprocessed legacy 2D seismic lines and 2 new acquisition 2D seismic lines.
- Extensive field geological outcrop studies

7. Database and Model (Grid) Development







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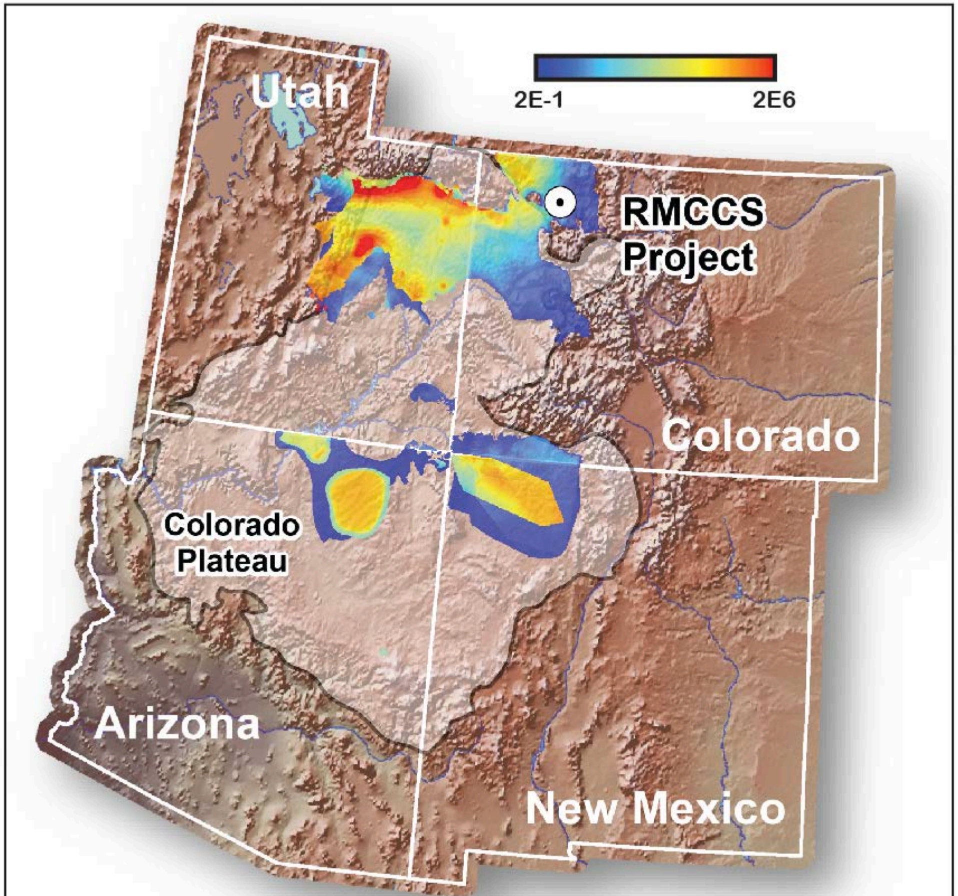
8. Storage Capacity Assessment

– CO_2 Regional Storage Capacity Assessment:
  - Focus on saline formations: Dakota, Entrada and Weber sandstones occurring mainly on the northern Colorado Plateau
  - Stratigraphic equivalent formations occurring in the southern part of the Colorado Plateau: Hermosa, De Chelly, Cedar Mesa and Leadville



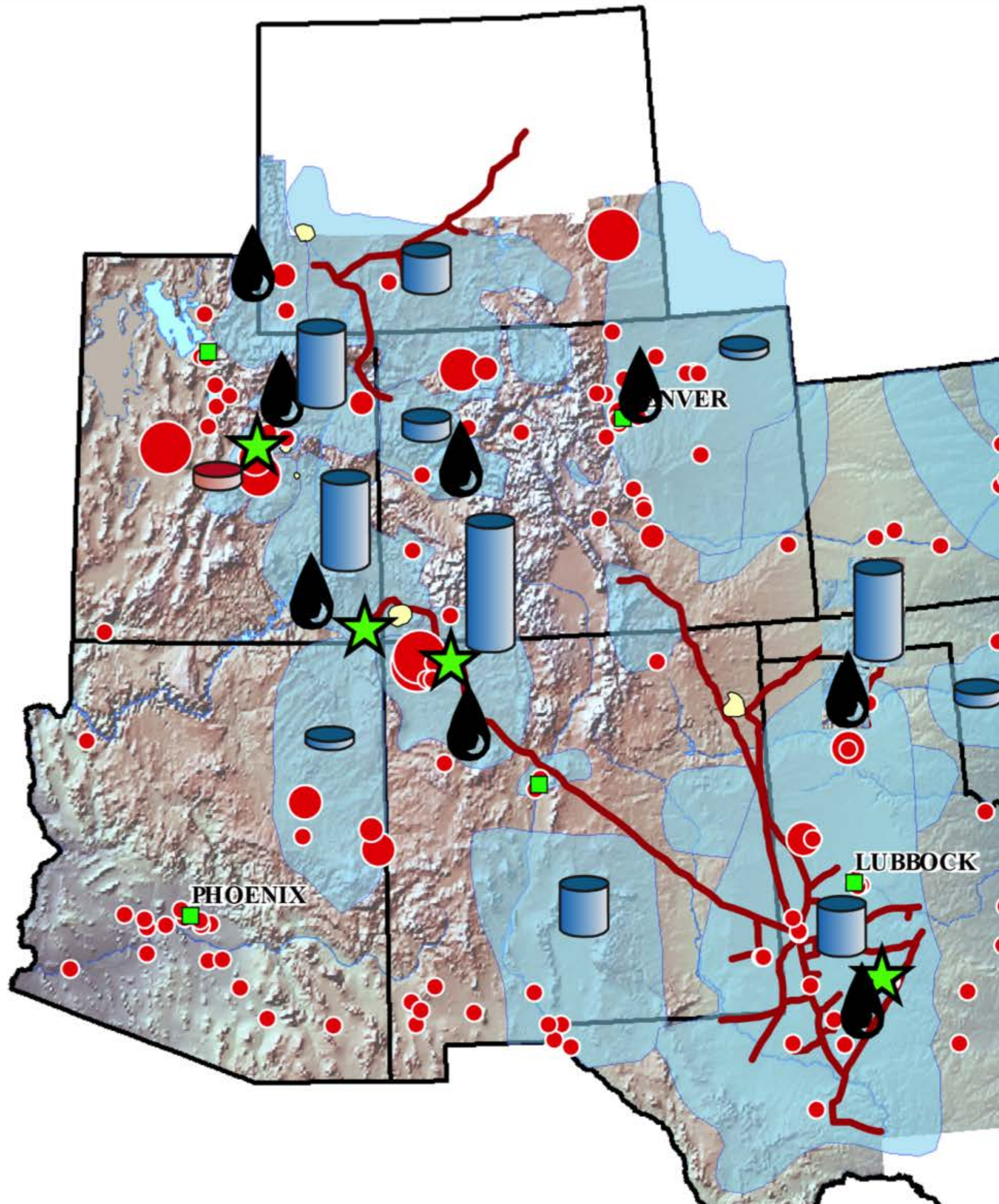
CO_2 Storage Capacity - metric Tonnes/km^2

Data prepared by the AGS, CGS, NMBMR, UGS and UU

8. Storage Capacity Assessment

– CO_2 Regional Storage

	CO_2 Stora
Formation	Low Efficiency (0.51%)
Dakota	1.23
Entrada	6.68
Weber	1.91
Partial Total:	**9.82**
Hermosa	1.67
Cedar Mesa	0.17
De Chelly	1.87
Leadville	0.04
Total:	**13.57**



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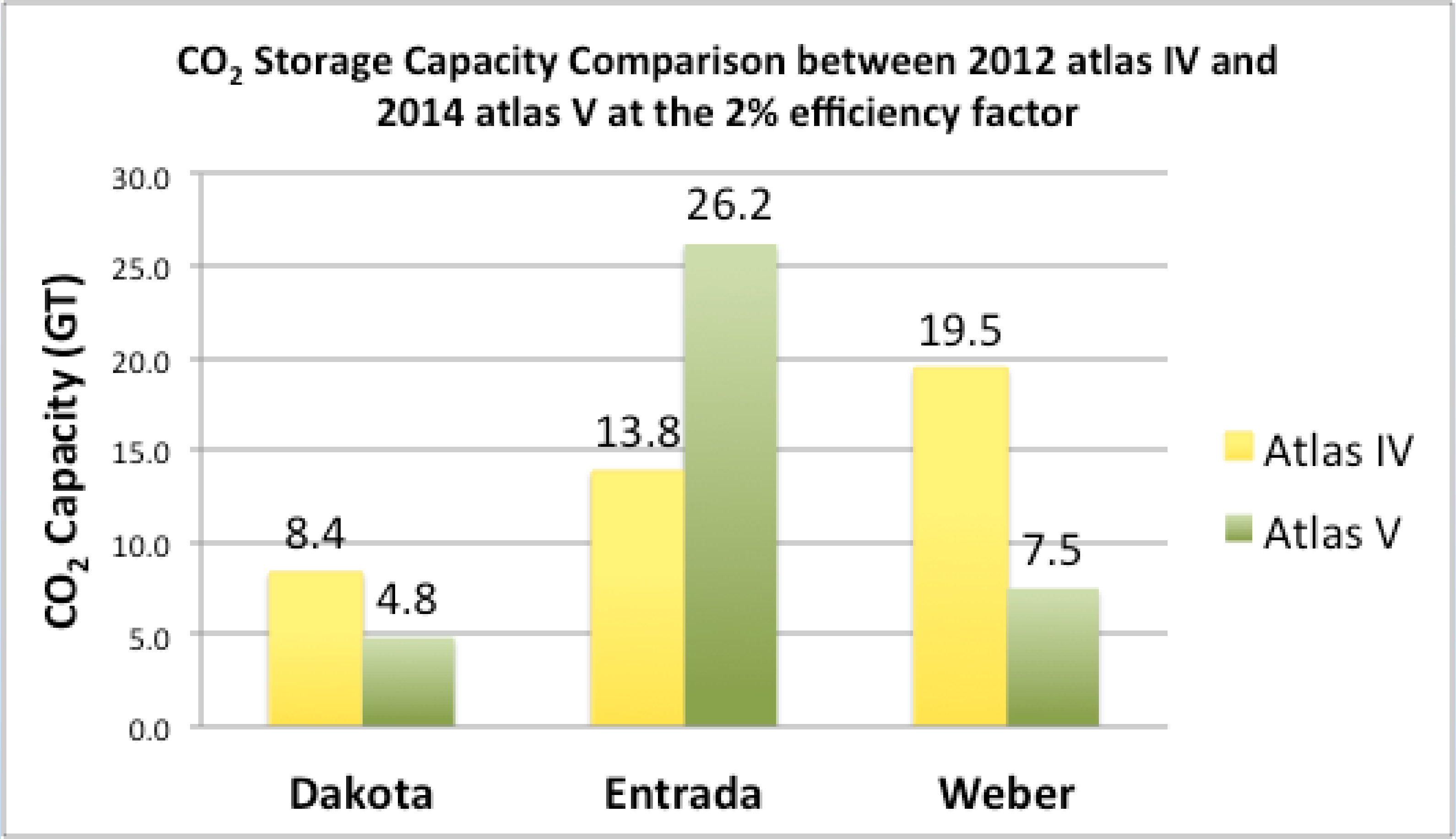
8. Storage Capacity Assessment

- Contrast between Atlas IV and V results



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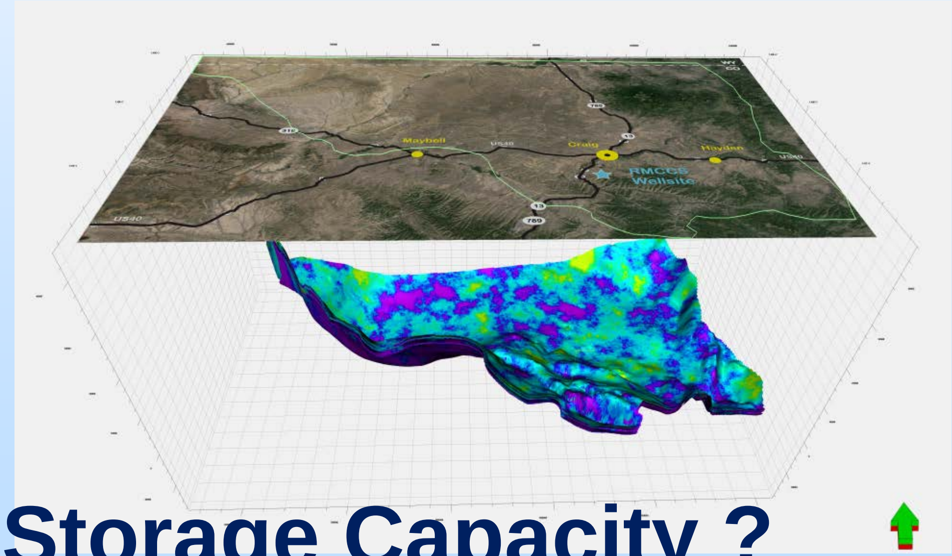
9. Uncertainty (Simulation) Assessment

- Primary uncertainty mechanism: how the local data (e.g., well data quality, number of wells, and location of wells) affect the quality of storage capacity estimates
- In particular: what degree of well density (number of wells) might be required to estimate capacity within a specified degree of confidence



Storage Capacity ?

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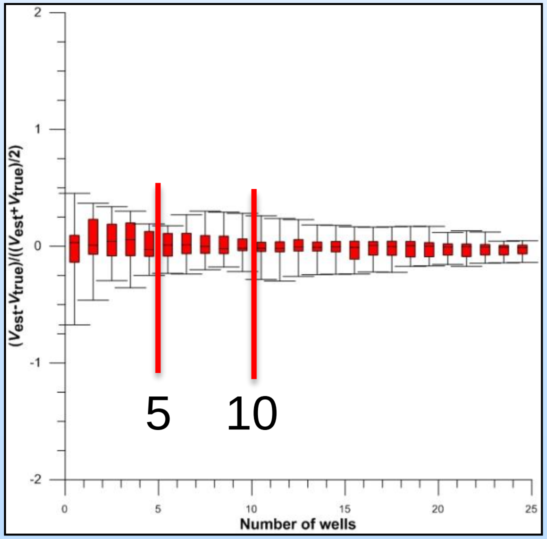
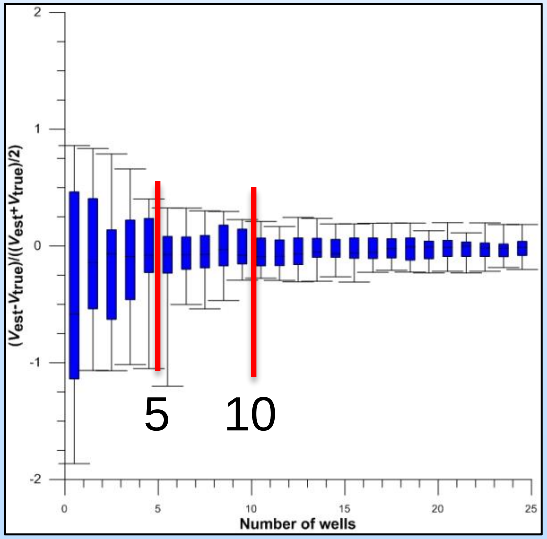
9. Uncertainty (Simulation) Assessment

- Developed new workflow for evaluating storage capacity estimation and associated uncertainty
- Completed the application of the workflow to the Sand Wash Basin geocellular model for estimation of capacity (and associated uncertainty) of the Dakota, Entrada, and Weber formations

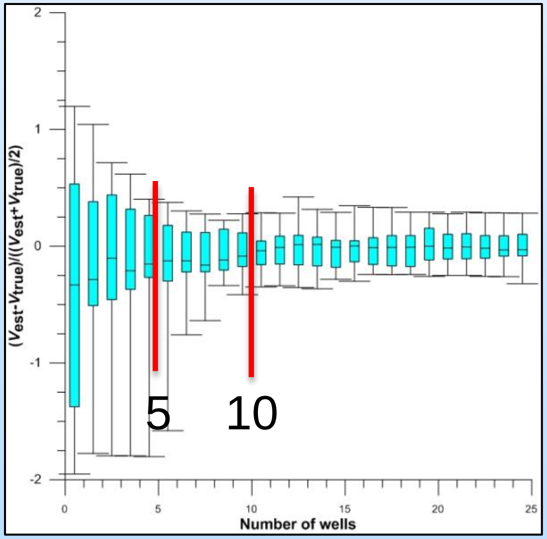
Plots of variance versus well density:



Dakota



Entrada



Weber

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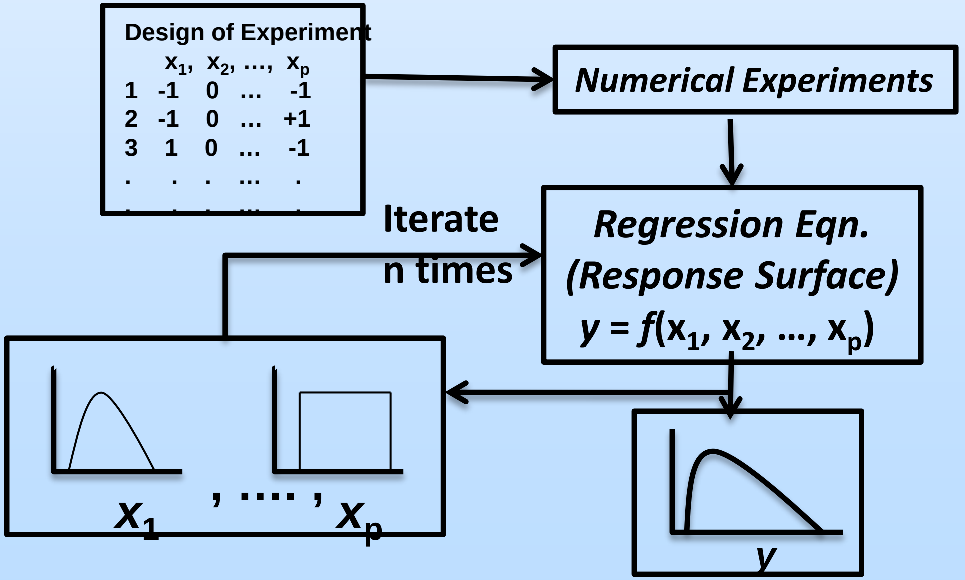
10. **Risk assessment**

10. Risk Assessment

- Apply a response-surface method – combined Monte Carlo sampling – to quantify major risk features, events, processes (FEPs)
- Example: Delineate the spatiotemporal responses (such as injection-induced pressure buildup and associated AOR) due to the CO_2 injection



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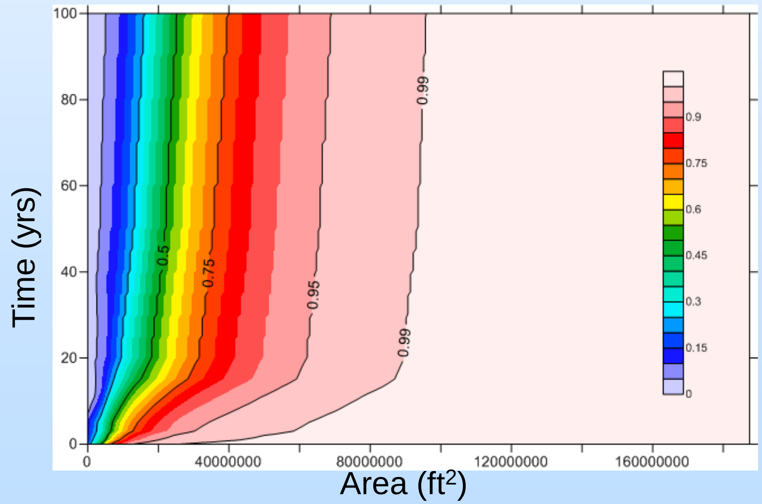
10. Risk Assessment

- The project team’s RSM approach allows effective risk quantification during site selection (pre-injection) stage and to update the results upon acquisition of additional data throughout a project (during- and post-injection stage).
- The approach can also be applied for development of general risk mitigation plans, given the uncertainty in the input parameters (previous step in protocol)

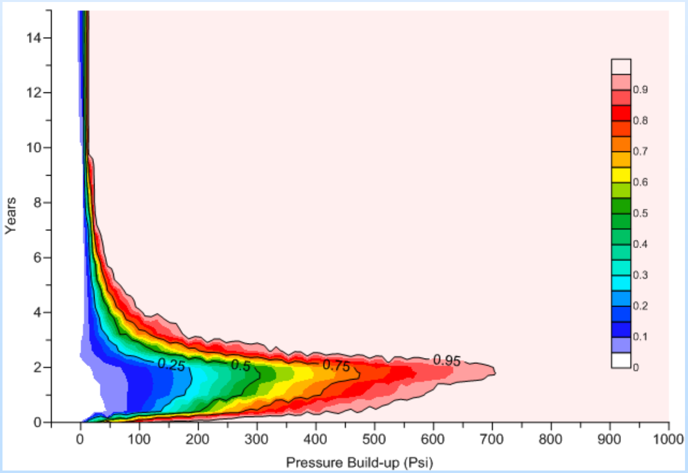
10. Risk Assessment: Example of Results

- Developed probability distributions that characterize uncertainty of specific risks events;
- Shown below are CDFs for the AOR and pressure build-up south of the injection well

CDF: Area of Review (ft^2)



CDF: Pressure build-up @ 500 m south of inj. well



RMCCS
ROCKY MOUNTAIN CARBON CAPTURE AND SEQUESTRATION

NETL

Presentation Outline

- Program Benefits
- Project / Program Goals
- Technical Status: Finalizing 10-Point Protocol for CO_2 Storage Site Characterization
- **Key Accomplishments**
- Summary

Accomplishments to Date

- Site and region characterization completed
- Risk assessment, outreach, mitigation planning and geologic analysis completed
- Detailed geologic modeling completed
- Detailed regional capacities estimated
- Automated workflow (algorithm) for assessing uncertainties developed
- 10-point Protocol for CO_2 Storage Site Characterization Developed

Presentation Outline

- Program Benefits
- Project / Program Goals
- Technical Status: Finalizing 10-Point Protocol for CO_2 Storage Site Characterization
- Key Accomplishments
- **Summary**

Summary

- Key Findings: a 10-Point Protocol for Site Characterization
- Primary Lesson Learned: Uncertainty and project risk both depend data density and quality
- Future Plans: deliver the formal 10-point protocol to NETL in October

Appendix

- These slides will not be discussed during the presentation, but are mandatory

Characterization of Most Promising Sequestration Formations in the Rocky Mountain Region

Organizational Chart

US DOE/NETL
Project Manager

PI: Brian McPherson
EGI, University of Utah
Co-PI: Vince Matthews
Colorado Geologic Surv.

Partners

- Tri-State Generation and Transmission Association, Inc.
- Colorado Geological Survey
- Southwest Carbon Partnership
- Shell
- The University of Utah
- Utah Geological Survey
- Arizona Geological Survey
- Schlumberger
- New Mexico Bureau of Geology

1. Project Management (Task 1)
Brian McPherson
Denise Laes
The University of Utah

2. Assess Regional Significance (Task 2)
Craig Morgan
Vince Matthews
Brian McPherson

3. Site-specific Evaluation (Task 3)
Wayne Rowe
Brian McPherson
Vince Matthews
Schlumberger

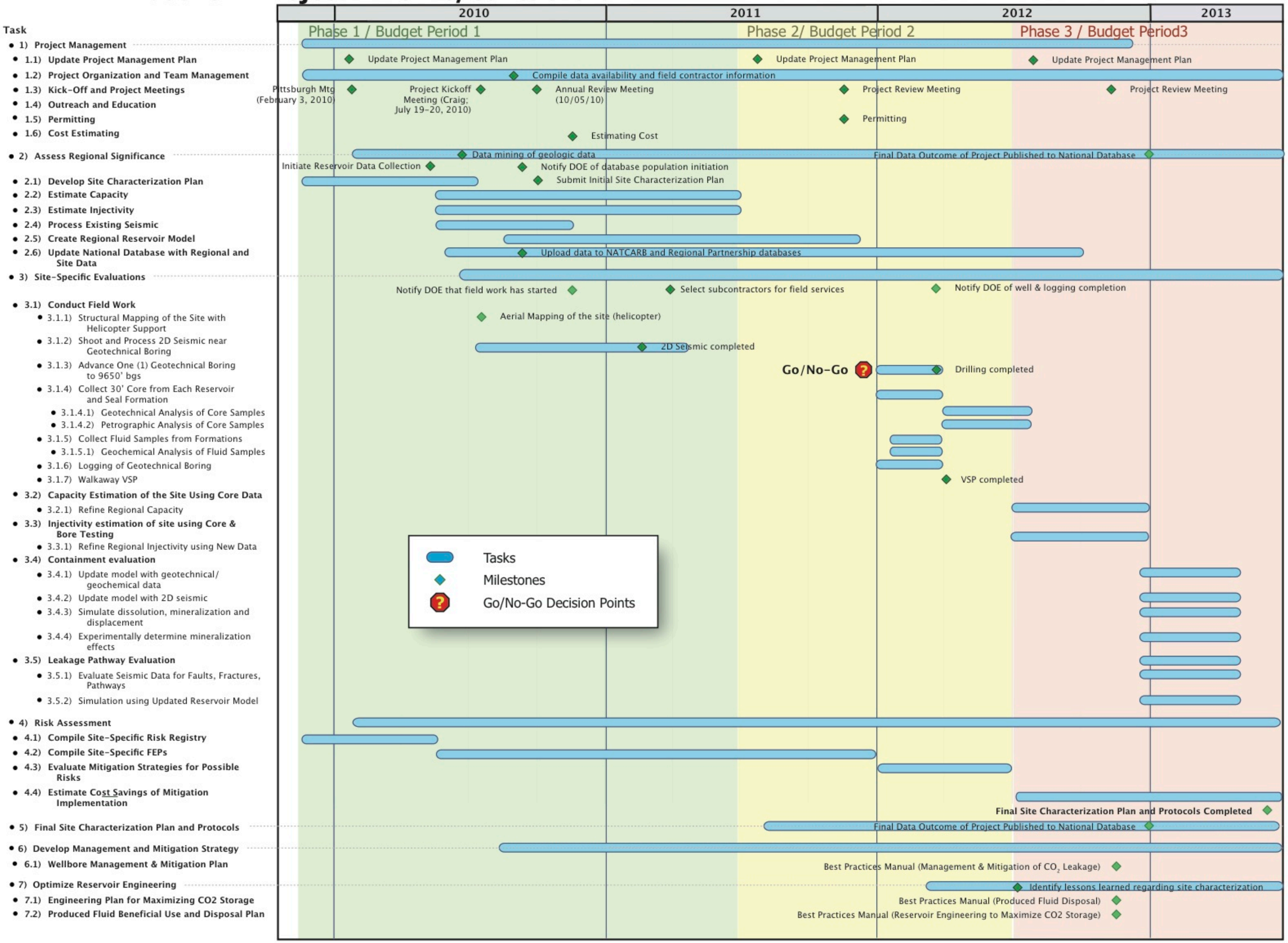
4. Risk Assessment (Task 4)
Brian McPherson
Si-Yong Lee
The University of Utah

5. Site Selection (Task 5)
Vince Matthews
Craig Morgan
Dana Ulmer-Scholle
Jon Spencer

6. Well-bore Management (Task 6)
Brian McPherson
The University of Utah

7. Reservoir Engineering (Task 7)
Brian McPherson
The University of Utah

DE-FE0001812 Project Timeline/Gantt Chart



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