Detailed CO_2 Storage Reservoir Site Characterization: The Key to Optimizing Performance and Maximizing Storage Capacity*

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Search and Discovery Article #80318 (2013)**
Posted October 8, 2013

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 19-22, 2013.

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Abstract

This study - funded under U.S. Department of Energy National Energy Technology Laboratory award DE-FE-0002142 - uses outcrop and core observations, a diverse electric log suite, a VSP survey, in-bore testing (i.e., DST, injection tests, and fluid sampling), a variety of rock/fluid analyses, and a wide range of seismic attributes derived from a 3-D seismic survey. The primary data sources used in this study are a 5-mile by 5-mile seismic survey, a 12,810-foot-deep stratigraphic test well, 916 feet of high-quality core, and regional outcrop observations.

The robust databases derived from the sources listed above were designed to optimize the characterization of the potential CO_2 storage site at the Rock Springs Uplift, Wyoming for the Madison Limestone and Weber/Tensleep Sandstone: prime storage reservoirs in the northern Rocky Mountain basins. This study aims to build a realistic 3-D geological property model by combining lithofacies/petrophysical analyses with seismic attribute computations and mapping. Using this approach - along with outstanding correlations between laboratory-measured porosity and permeability, sonic velocity and log porosity, and acoustic impedance and density porosity - geological property models for the Madison and Weber/Tensleep were constructed. Inherent to the geological property models of the targeted reservoir intervals are the heterogeneities observed in outcrop, core, petrophysical logs, and seismic attributes. Three-dimensional computational grids were populated with the geological property models, and the grids were then used to numerically simulate a variety of CO_2 injection scenarios for specific reservoir intervals. These scenarios demonstrate that even in the most favorable reservoir interval - for example, the middle Madison Limestone - injection well sites in the 5-mile by 5-mile study area vary by an order of magnitude both in injection rates and storage capacity. Despite these heterogeneities, the dolomitized middle Madison on the Rock Springs Uplift remains an outstanding potential commercial CO_2 storage site. Siting a commercial-scale CO_2 storage facility requires a comprehensive reservoir/site characterization study similar to that described above for the Rock Springs Uplift, in order to optimize CO_2 injection/storage and reduce risk.

Selected References

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Love, J.D., A.C. Christiansen, and A.J. Ver Ploeg, compilers, 1993, Stratigraphic chart showing the Phanerozoic nomenclature for the state of Wyoming: Geological Survey of Wyoming Map Series 41 (MS-41).

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Detailed CO_2 storage reservoir/site characterization: the key to optimizing performance and maximizing storage capacity

The greatest uncertainty in numerically simulating CO_2 sequestration processes is characterizing geological heterogeneity in 3 dimensions.

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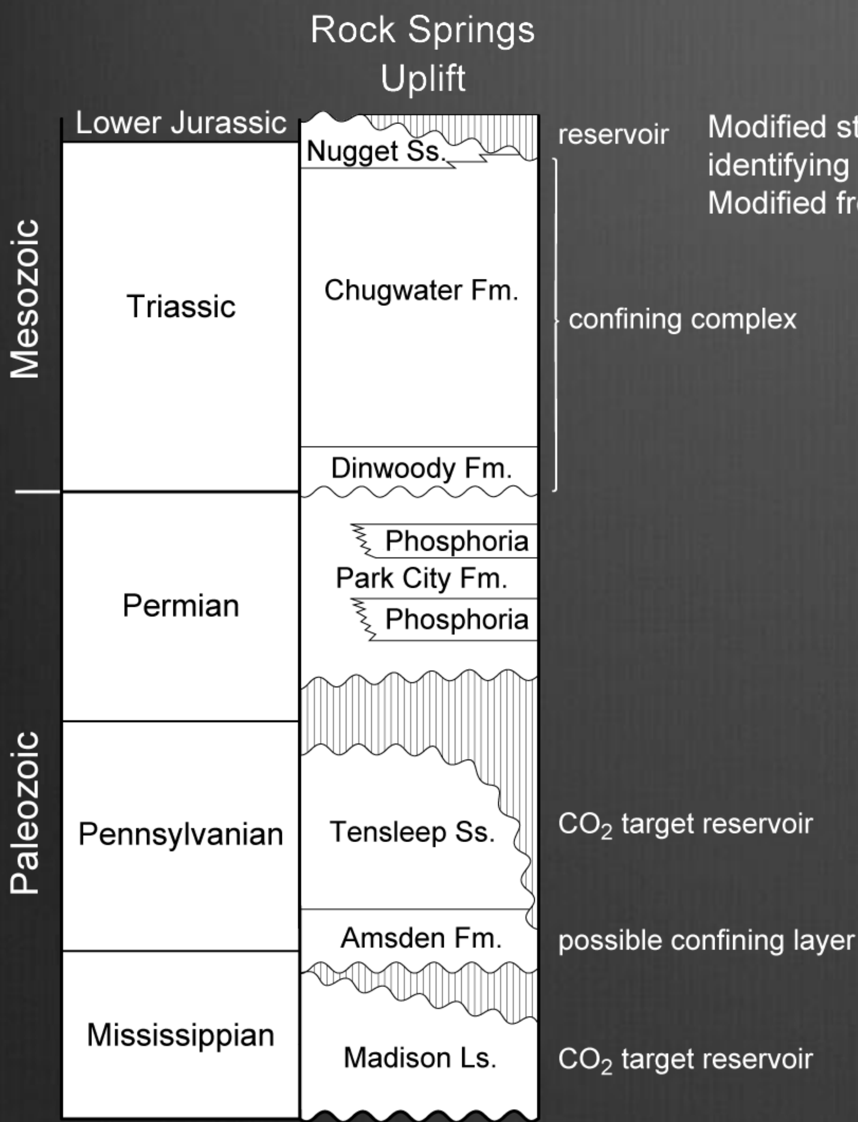
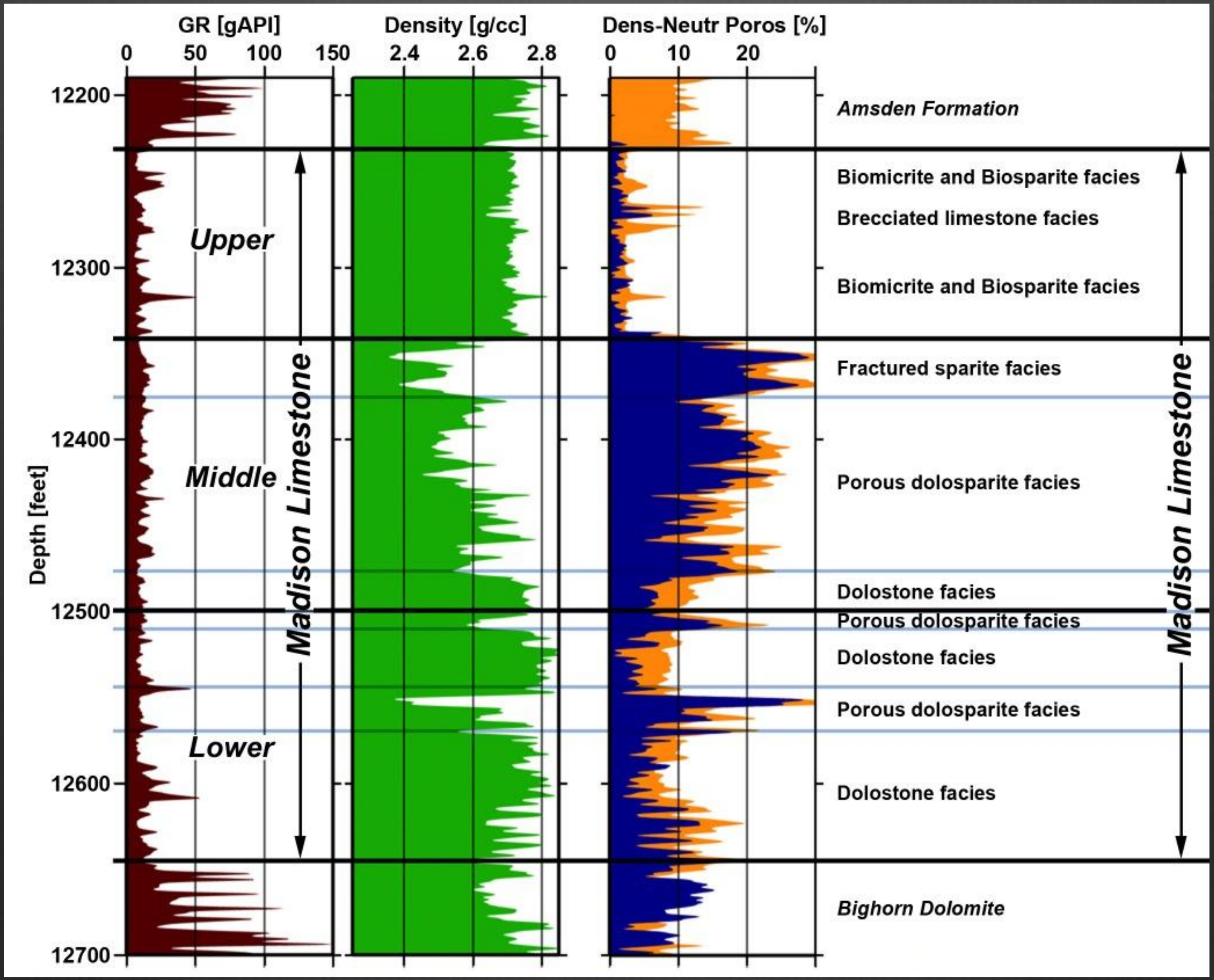
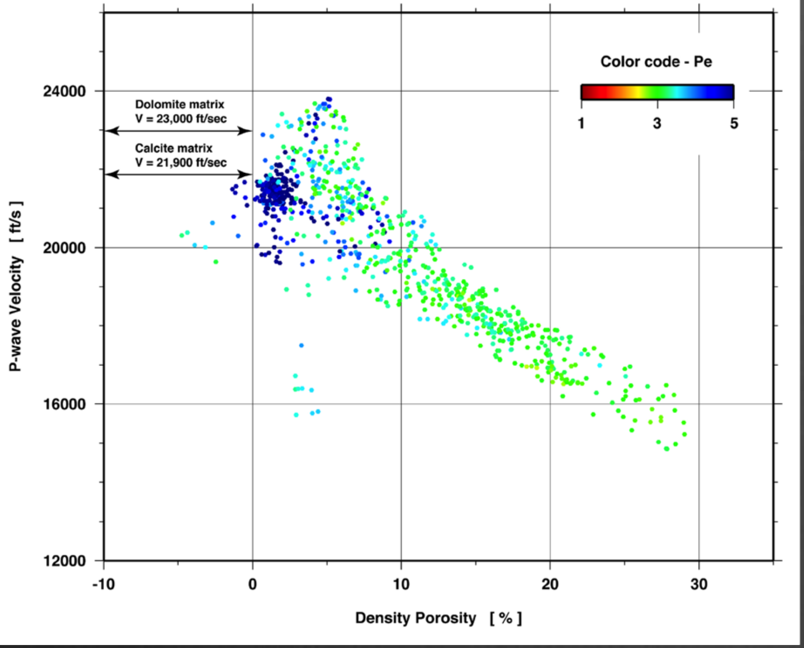


Modified stratigraphic column of the Rock Springs Uplift identifying possible confining layers and CO_2 target reservoirs. Modified from Love, Christiansen, and VerPloeg, 1993.

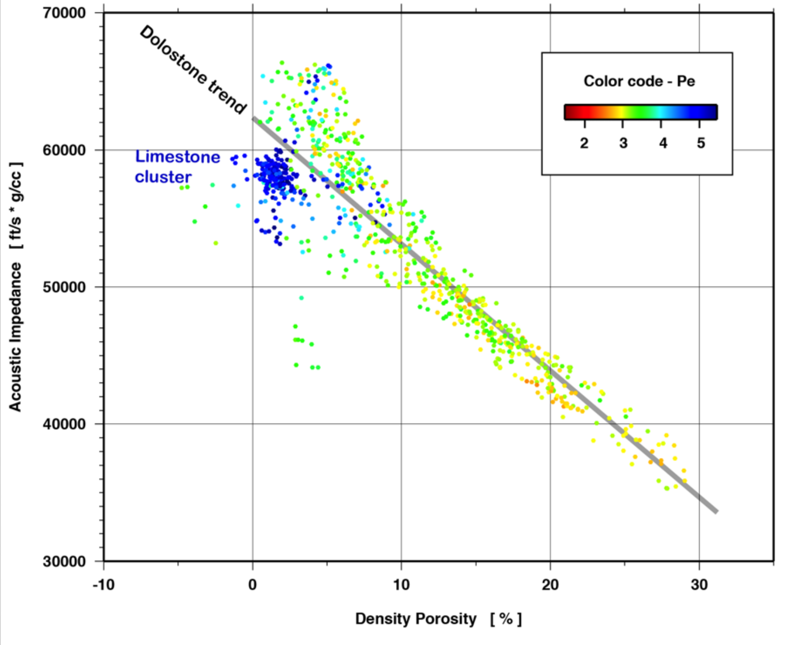
RSU-1 well: Madison Limestone Formation lithofacies zones



Sonic/Seismic velocity vs. density porosity



Madison Limestone



Madison Limestone

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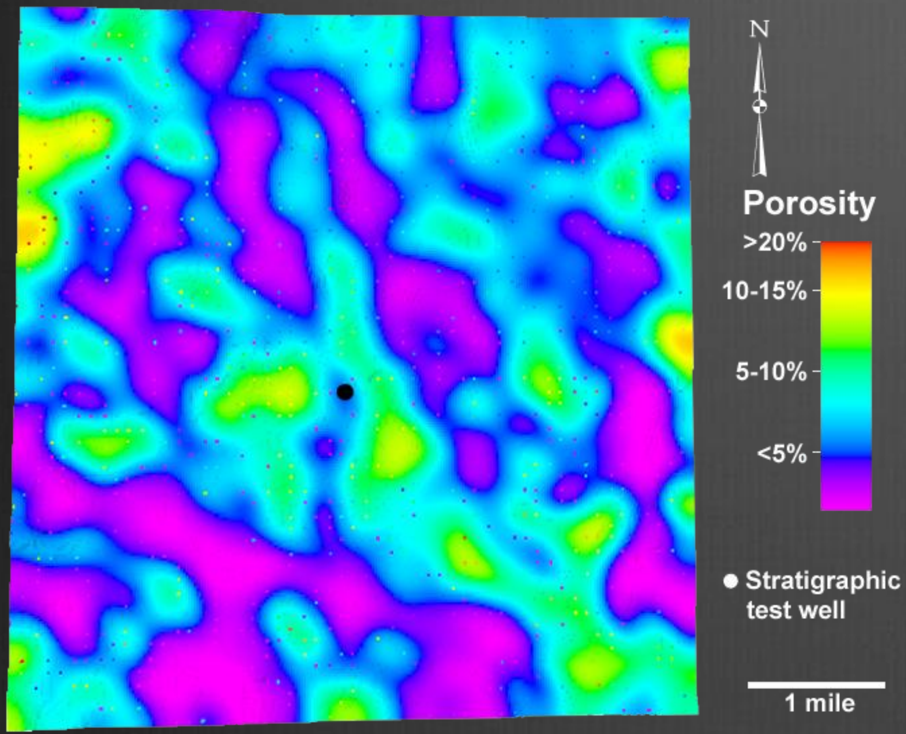
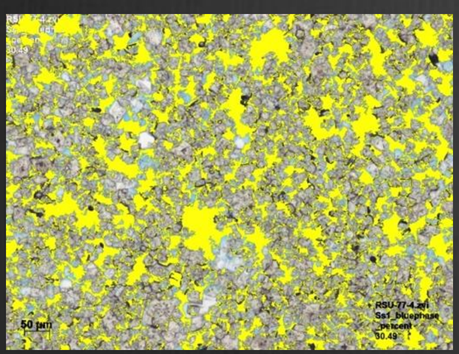
Madison Limestone

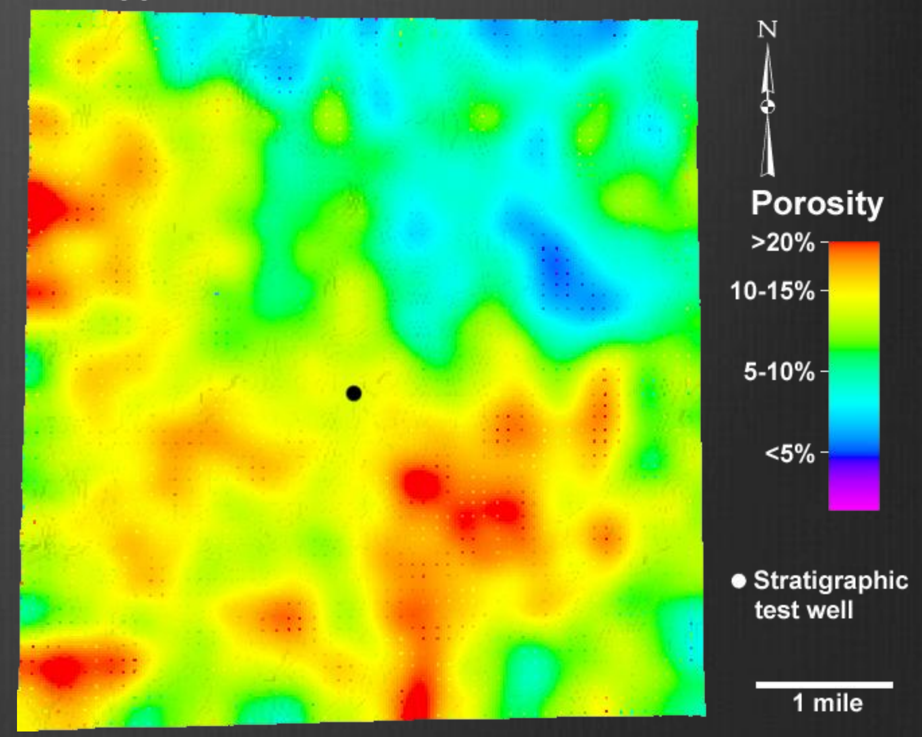
Upper Madison Limestone



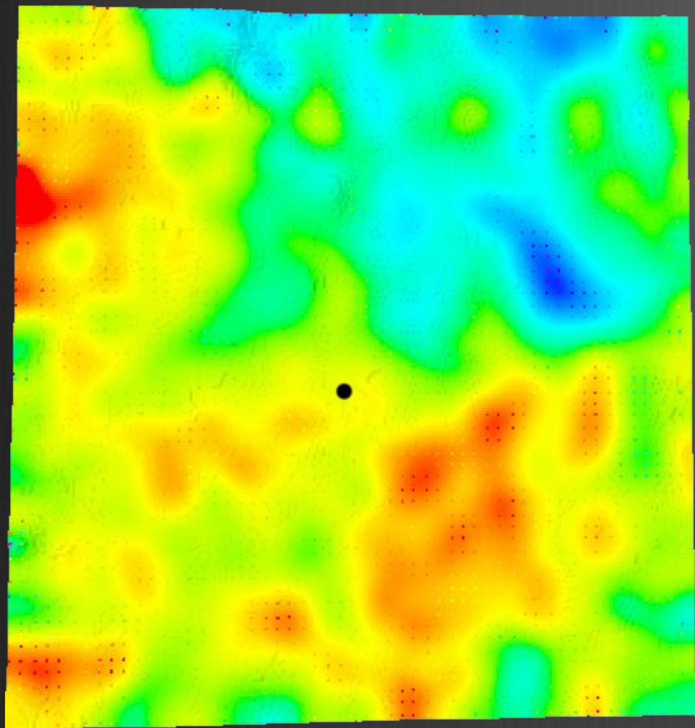


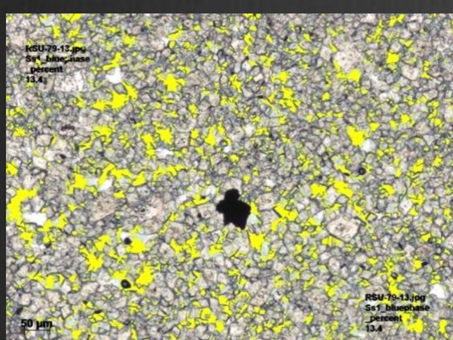
Porosity 30.5%

Upper Middle Madison Limestone

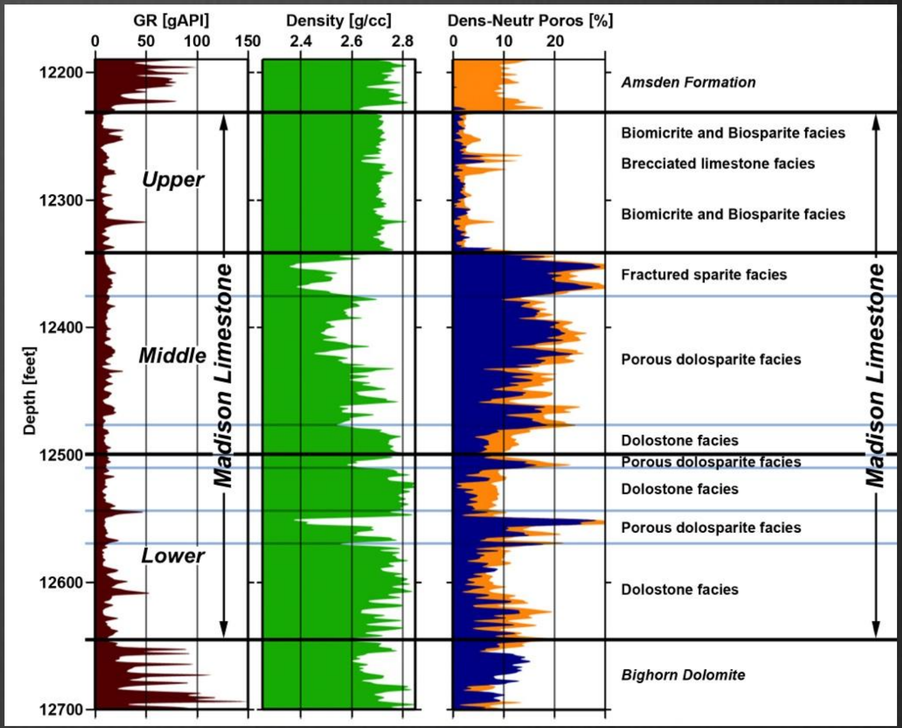


Madison Limestone



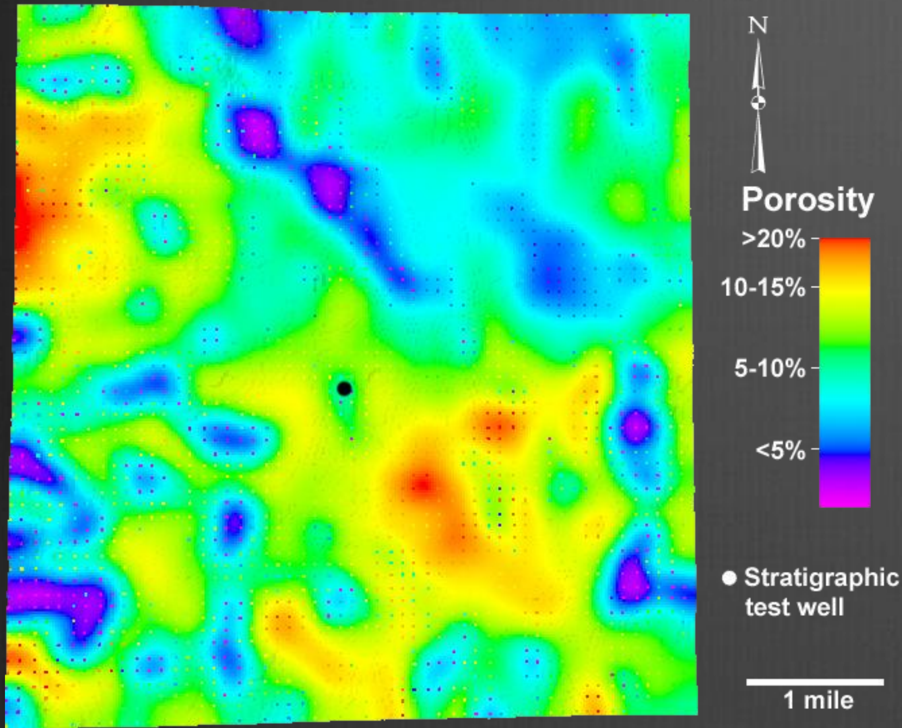


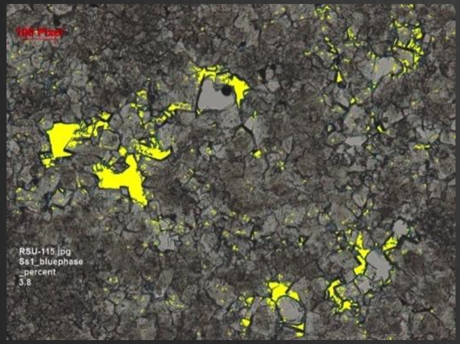
Porosity 13.4%



Madison Limestone

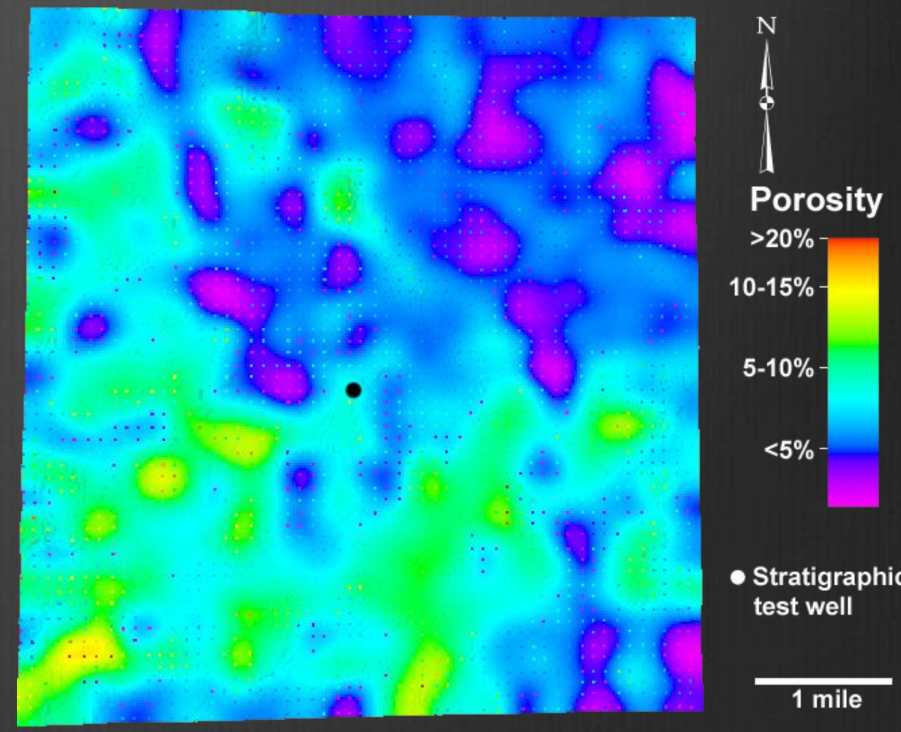
Lower Middle Madison Limestone





Porosity 3.8%

Lower Madison Limestone



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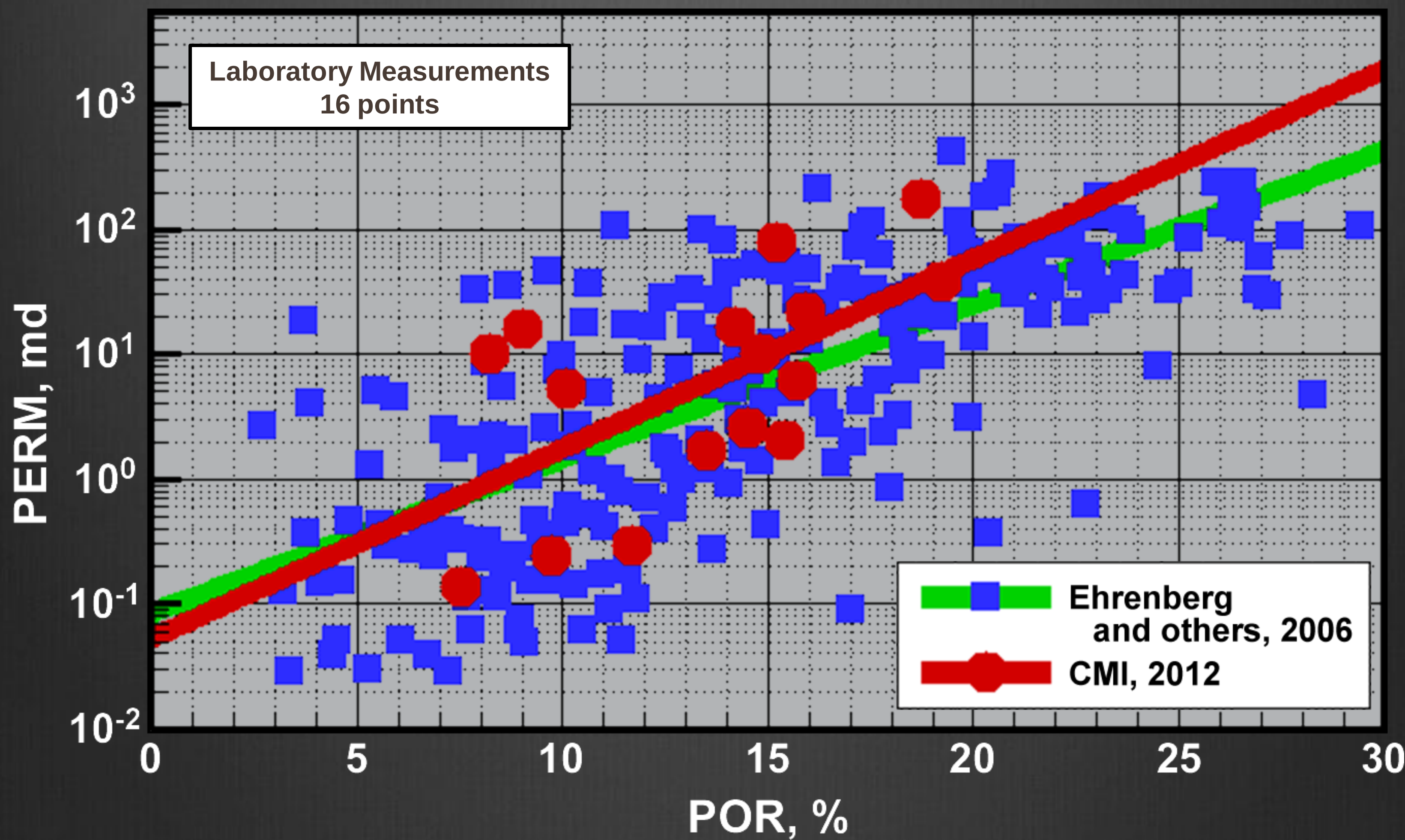
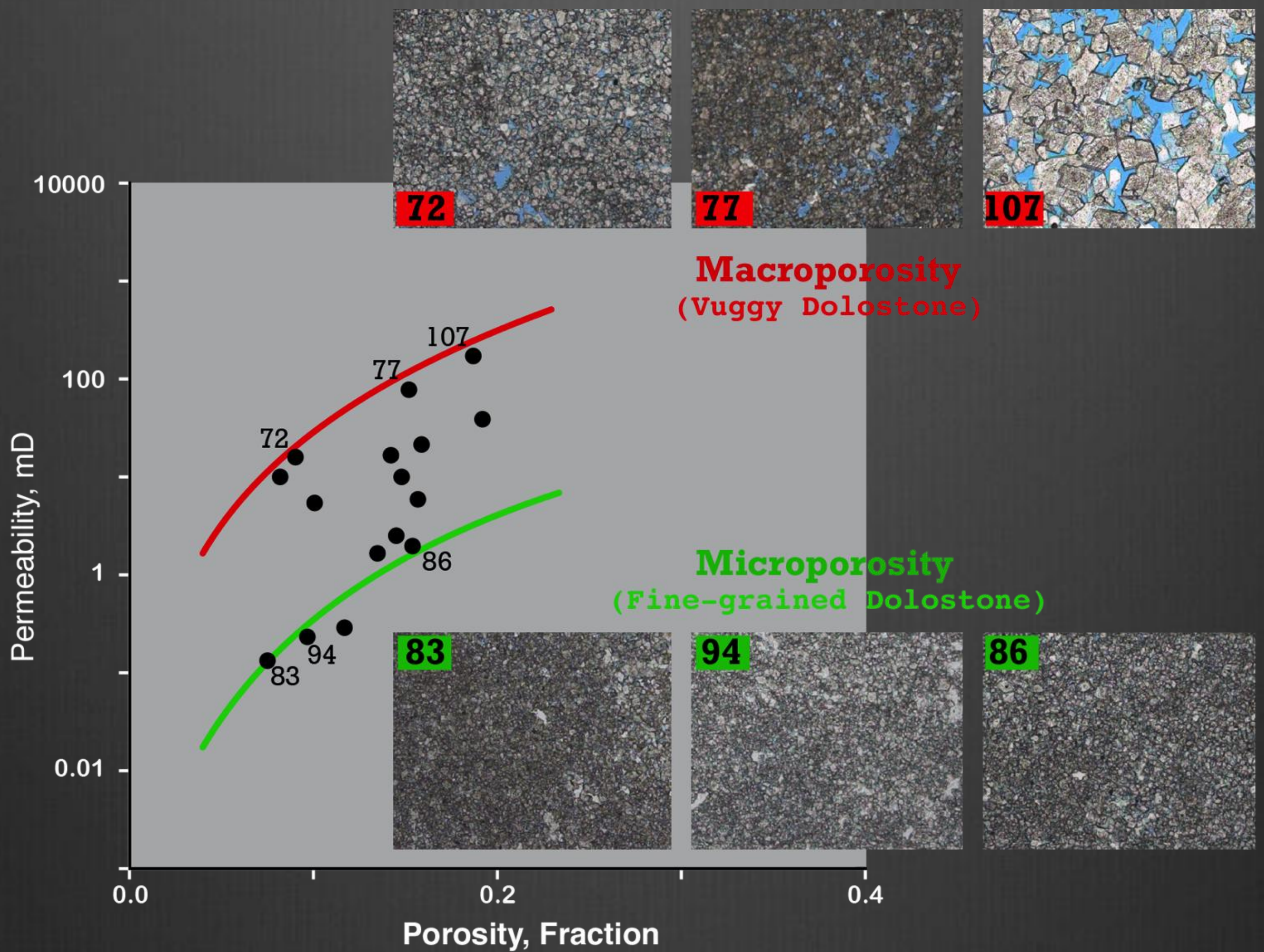
Cross Plot of Porosity vs Permeability for Madison Limestone, Wyoming

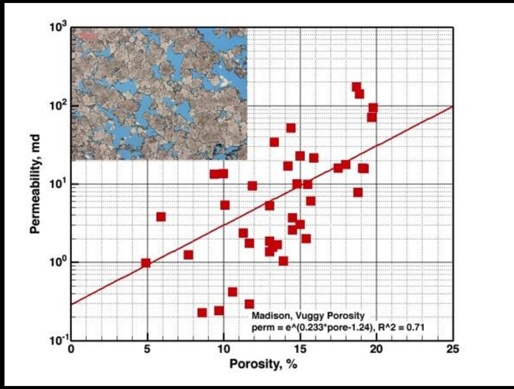


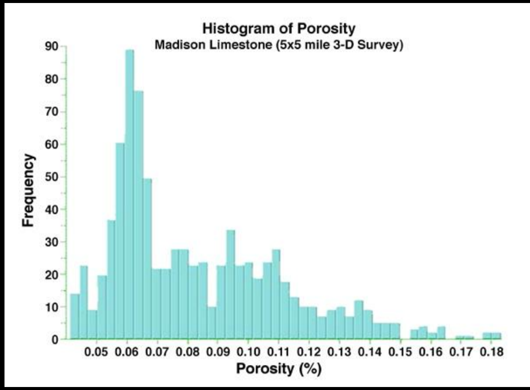
Madison Limestone Dual Porosity System

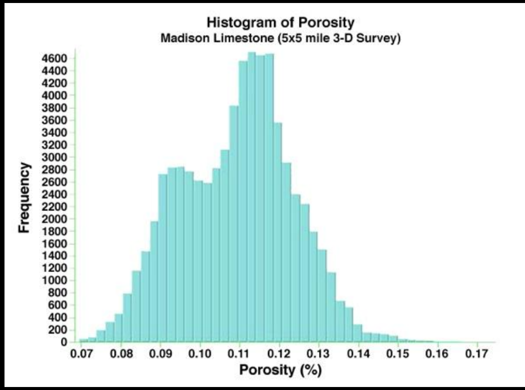


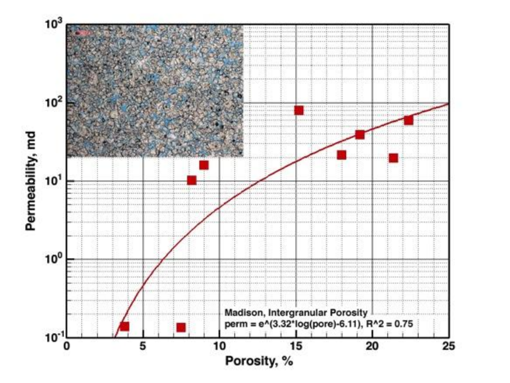
Pathway to Developing
A 3-D Model of Reservoir Heterogeneity

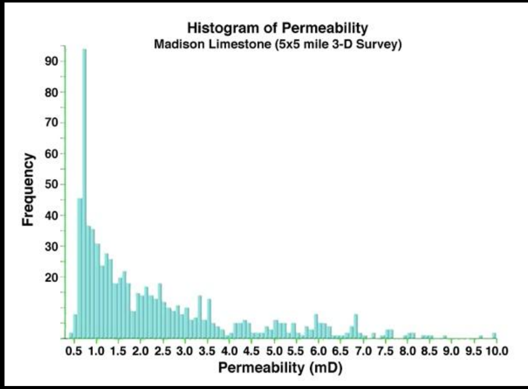
Lab Results Core 50 points	→	Well Logs Continuous Profile 762 points	→	Seismic 3D Domain 69,740 points

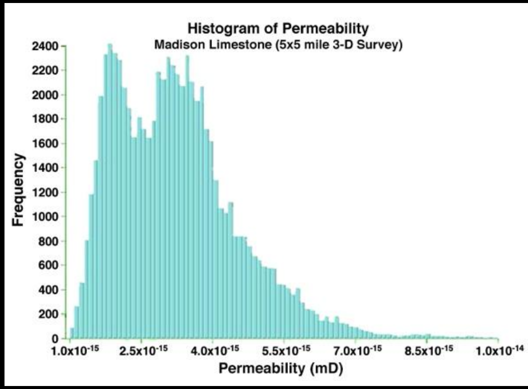




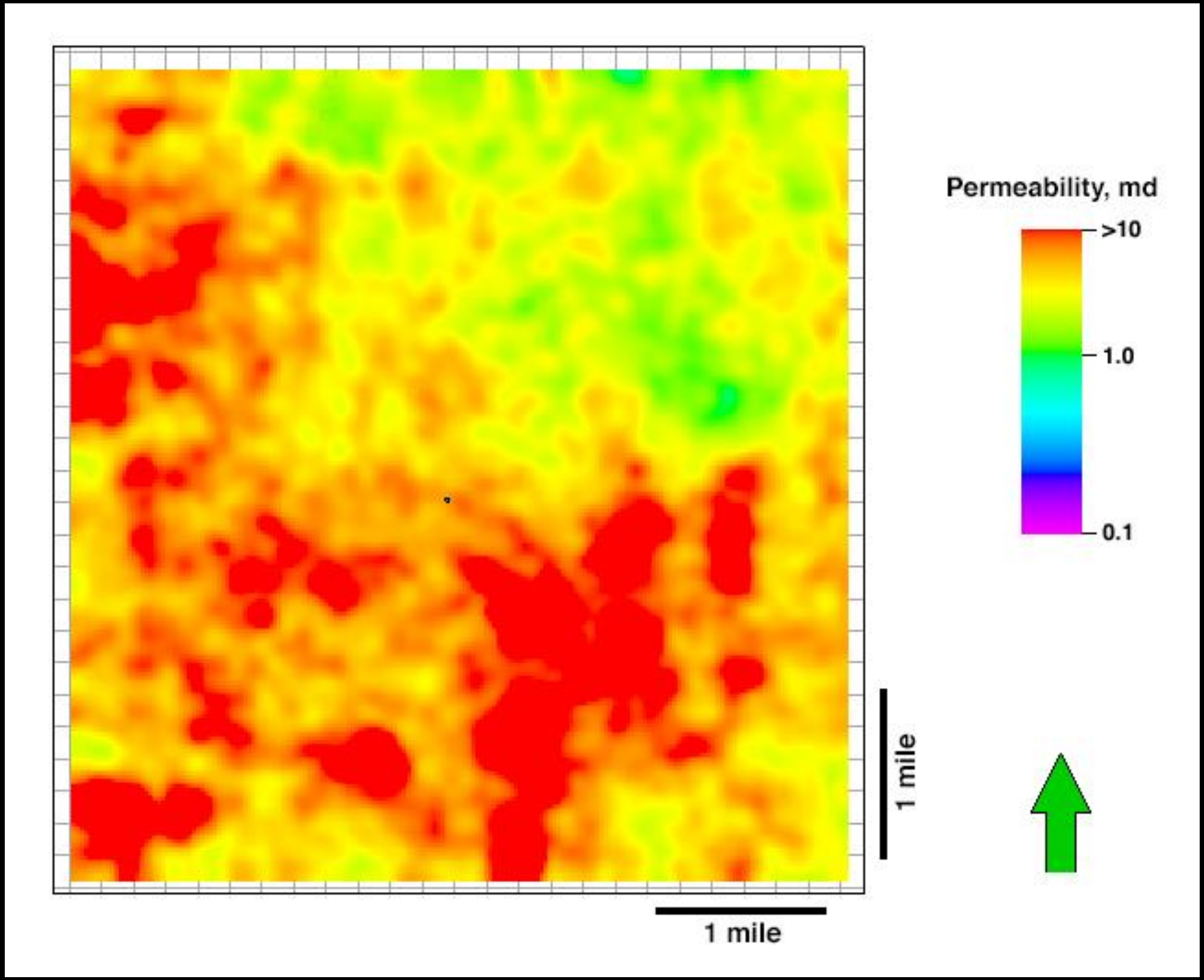


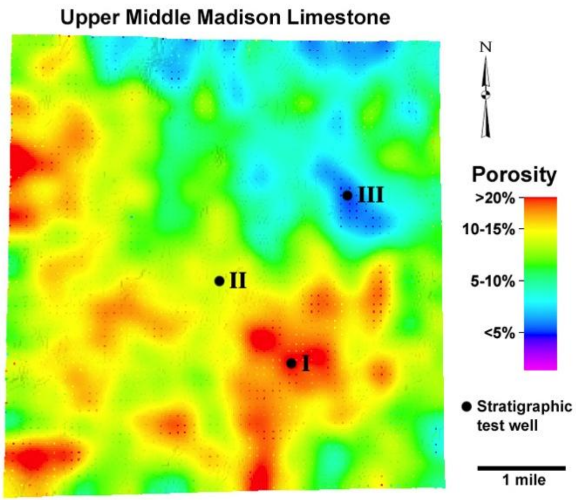


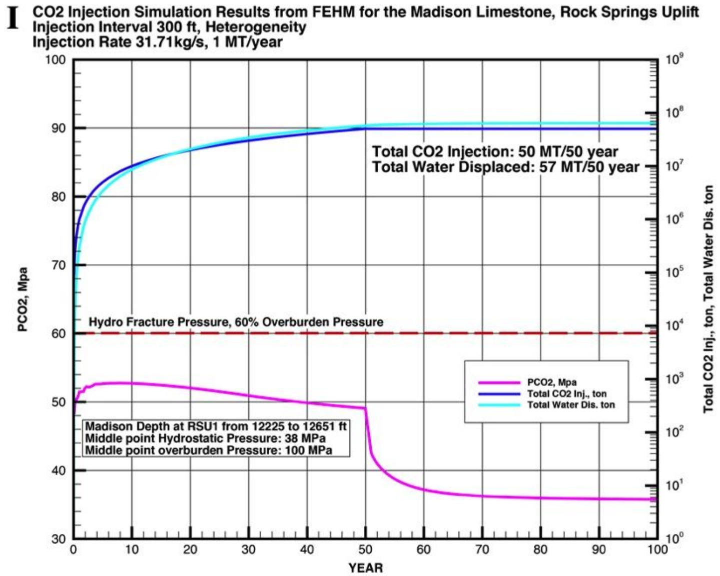


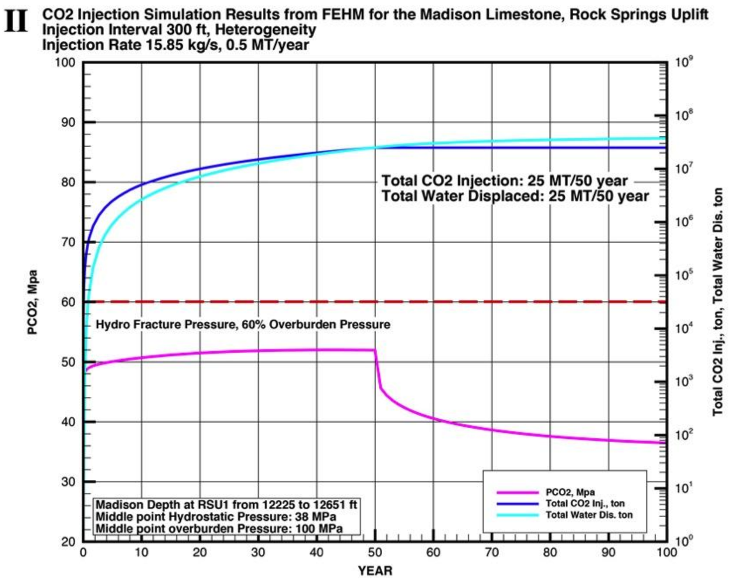


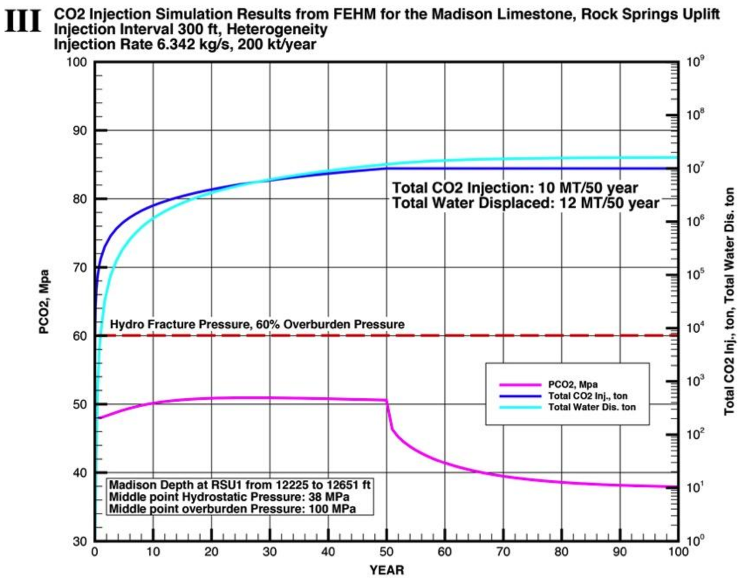
Permeability model of the Madison Limestone



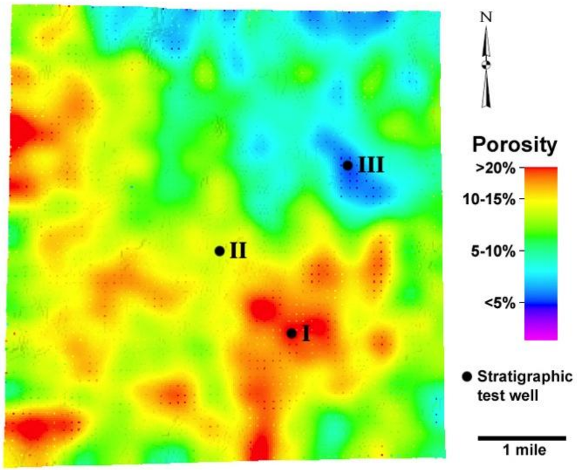

Upper Middle Madison Limestone
III
II
I
N
Porosity
>20%
10-15%
5-10%
<5%
● Stratigraphic test well
1 mile


I
CO2 Injection Simulation Results from FEHM for the Madison Limestone, Rock Springs Uplift
Injection Interval 300 ft, Heterogeneity
Injection Rate 31.71kg/s, 1 MT/year
Total CO2 Injection: 50 MT/50 year
Total Water Displaced: 57 MT/50 year
Hydro Fracture Pressure, 60% Overburden Pressure
PCO2, Mpa
Total CO2 Inj., ton
Total Water Dis. ton
Madison Depth at RSU1 from 12225 to 12651 ft
Middle point Hydrostatic Pressure: 38 MPa
Middle point overburden Pressure: 100 MPa
PCO2, Mpa
Total CO2 Inj., ton, Total Water Dis. ton
YEAR

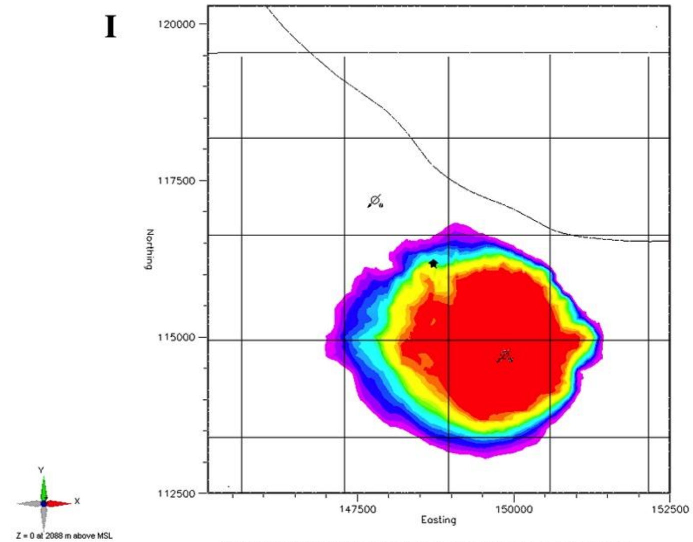

II
CO2 Injection Simulation Results from FEHM for the Madison Limestone, Rock Springs Uplift
Injection Interval 300 ft, Heterogeneity
Injection Rate 15.85 kg/s, 0.5 MT/year
Total CO2 Injection: 25 MT/50 year
Total Water Displaced: 25 MT/50 year
Hydro Fracture Pressure, 60% Overburden Pressure
Madison Depth at RSU1 from 12225 to 12651 ft
Middle point Hydrostatic Pressure: 38 MPa
Middle point overburden Pressure: 100 MPa
PCO2, Mpa
Total CO2 Inj., ton
Total Water Dis. ton
PCO2, Mpa
Total CO2 Inj., ton, Total Water Dis. ton
YEAR


III
CO2 Injection Simulation Results from FEHM for the Madison Limestone, Rock Springs Uplift
Injection Interval 300 ft, Heterogeneity
Injection Rate 6.342 kg/s, 200 kt/year
Total CO2 Injection: 10 MT/50 year
Total Water Displaced: 12 MT/50 year
Hydro Fracture Pressure, 60% Overburden Pressure
PCO2, Mpa
Total CO2 Inj., ton
Total Water Dis. ton
Madison Depth at RSU1 from 12225 to 12651 ft
Middle point Hydrostatic Pressure: 38 MPa
Middle point overburden Pressure: 100 MPa
PCO2, Mpa
Total CO2 Inj., ton, Total Water Dis. ton
YEAR

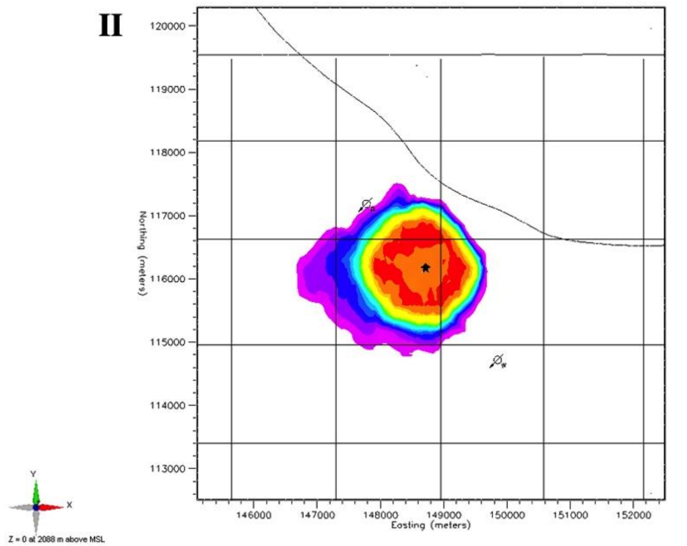
Upper Middle Madison Limestone



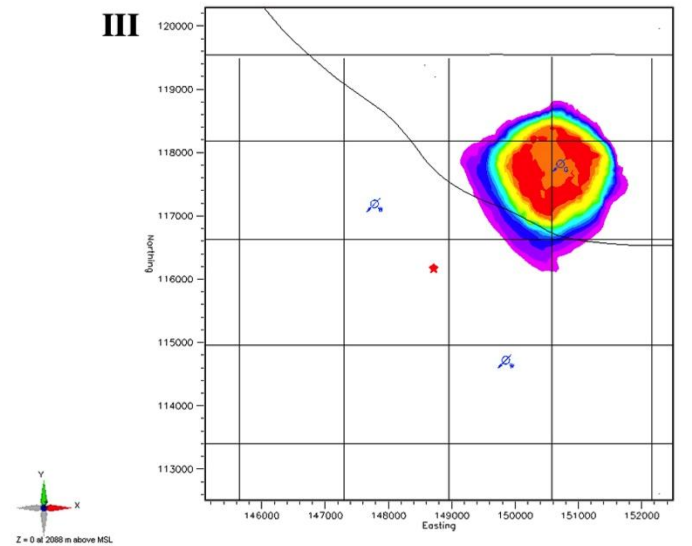
FEHM CO2 Injection Simulation Results for the Madison Limestone
1 mt/y for 50 Years, Heterogenous Properties (High phi and K Area)

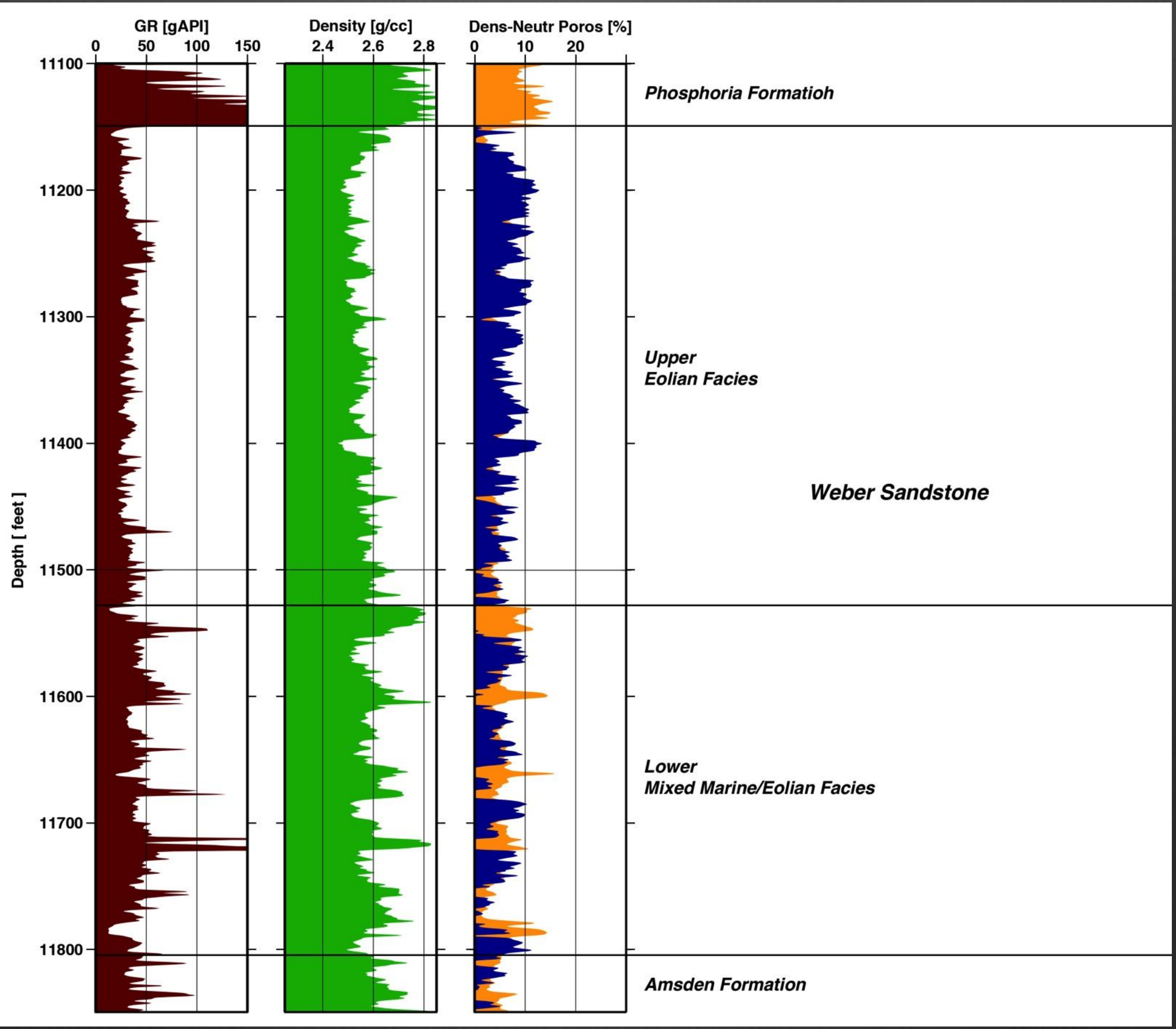


FEHM CO2 Injection Results for the Madison Limestone
500 kt/y for 50 Years, Heterogenous Properties (Low phi and k Area)

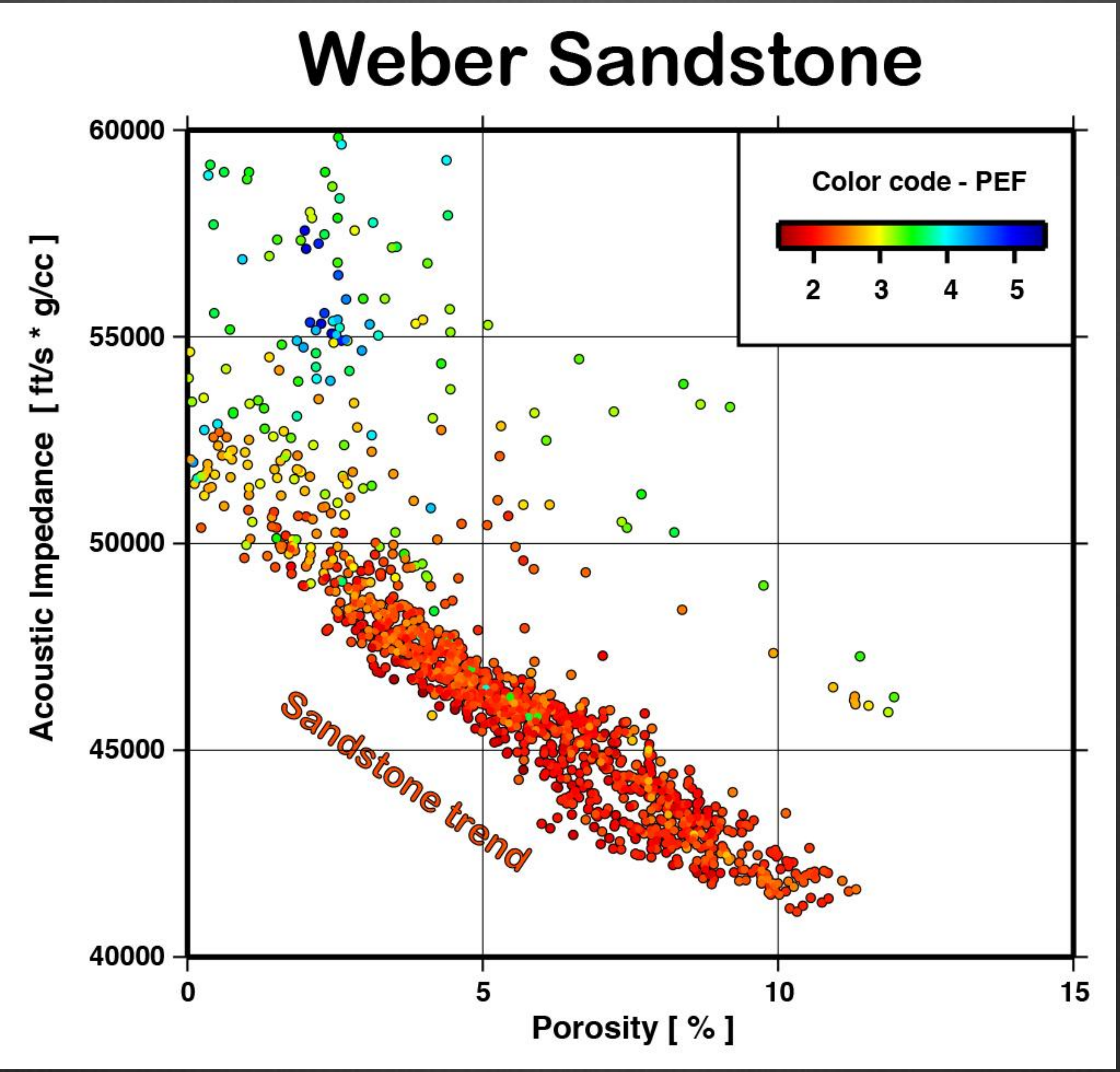


FEHM CO2 Injection Results for the Madison Limestone
200 kt/y for 50 Years, Heterogenous Properties (Low phi and k Area)

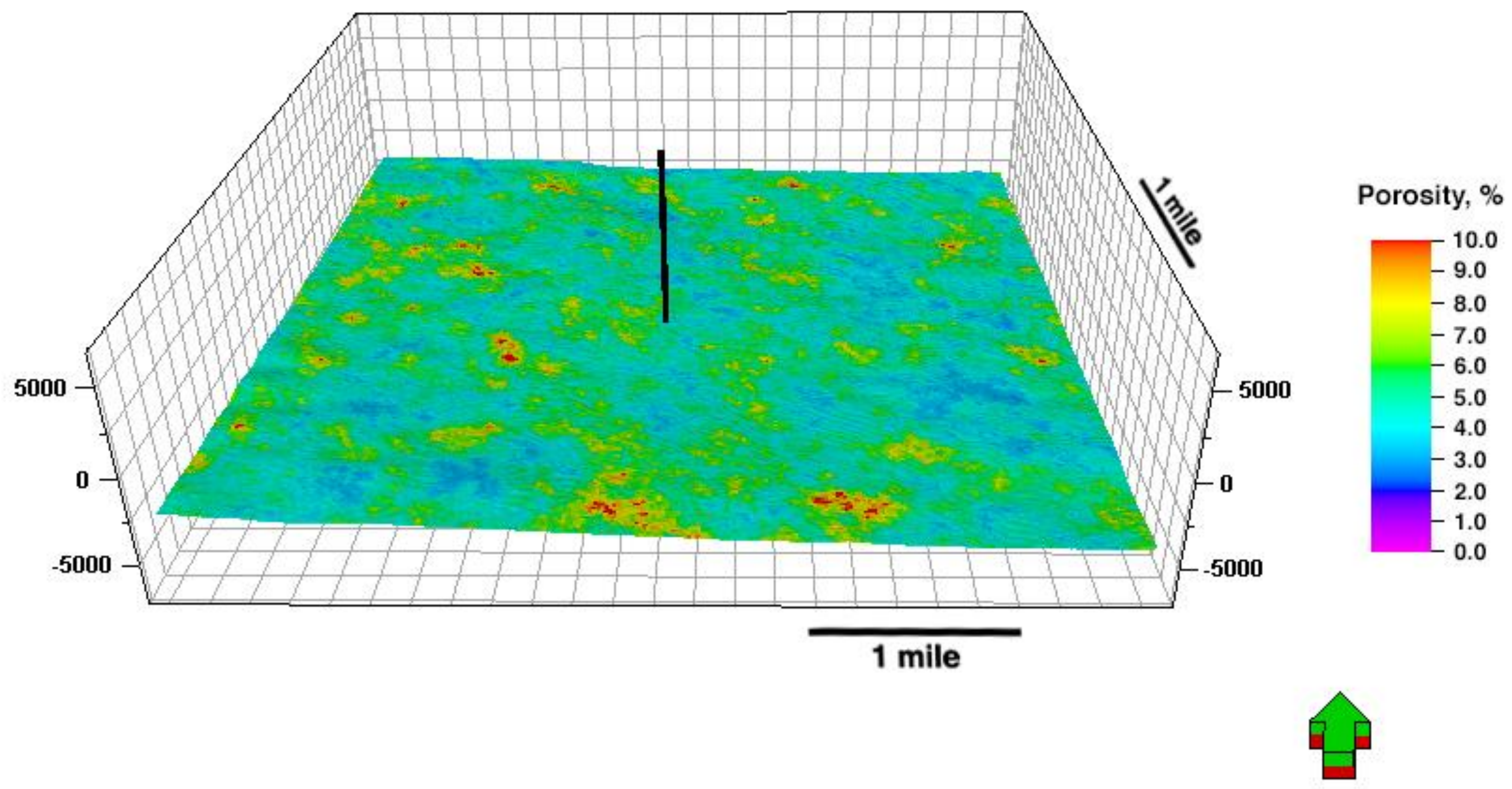




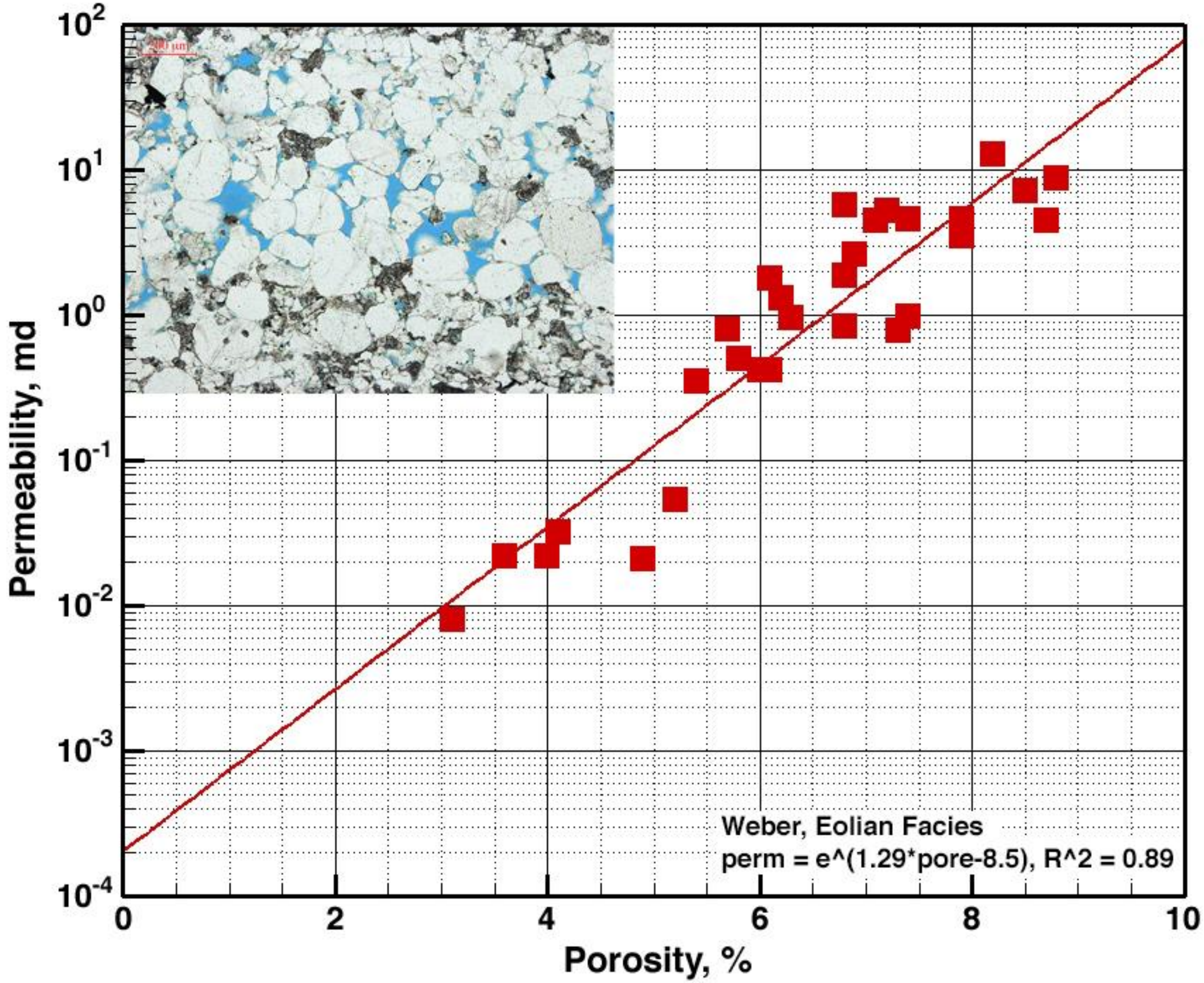
GR [gAPI]
0
50
100
150
Density [g/cc]
2.4
2.6
2.8
Dens-Neutr Poros [%]
0
10
20
Depth [feet]
11100
11200
11300
11400
11500
11600
11700
11800
Phosphoria Formatioh
Upper
Eolian Facies
Weber Sandstone
Lower
Mixed Marine/Eolian Facies
Amsden Formation



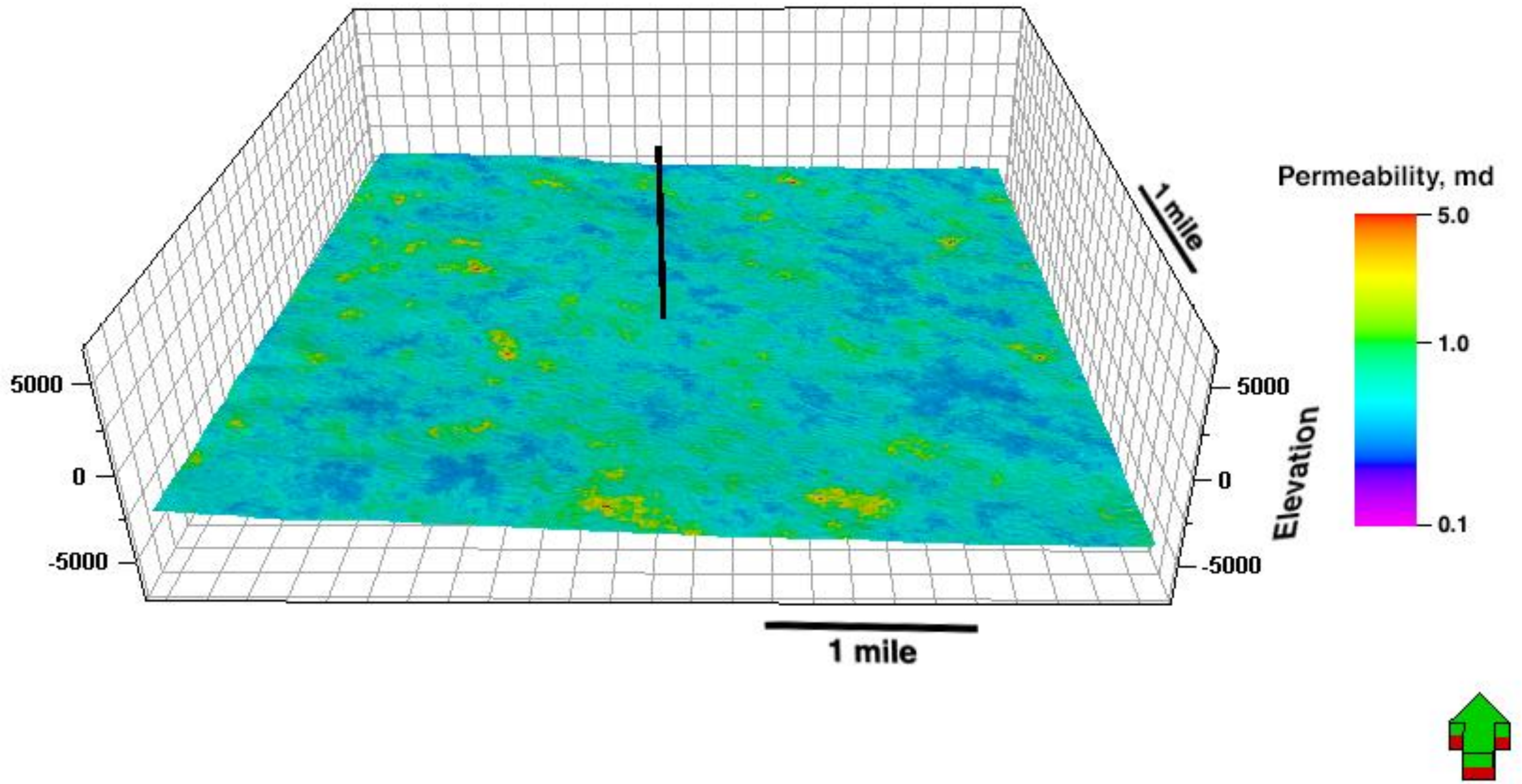
Weber Sandstone
Color code - PEF
2
3
4
5
60000
55000
50000
45000
40000
Acoustic Impedance [ft/s * g/cc]
0
5
10
15
Porosity [%]
Sandstone trend

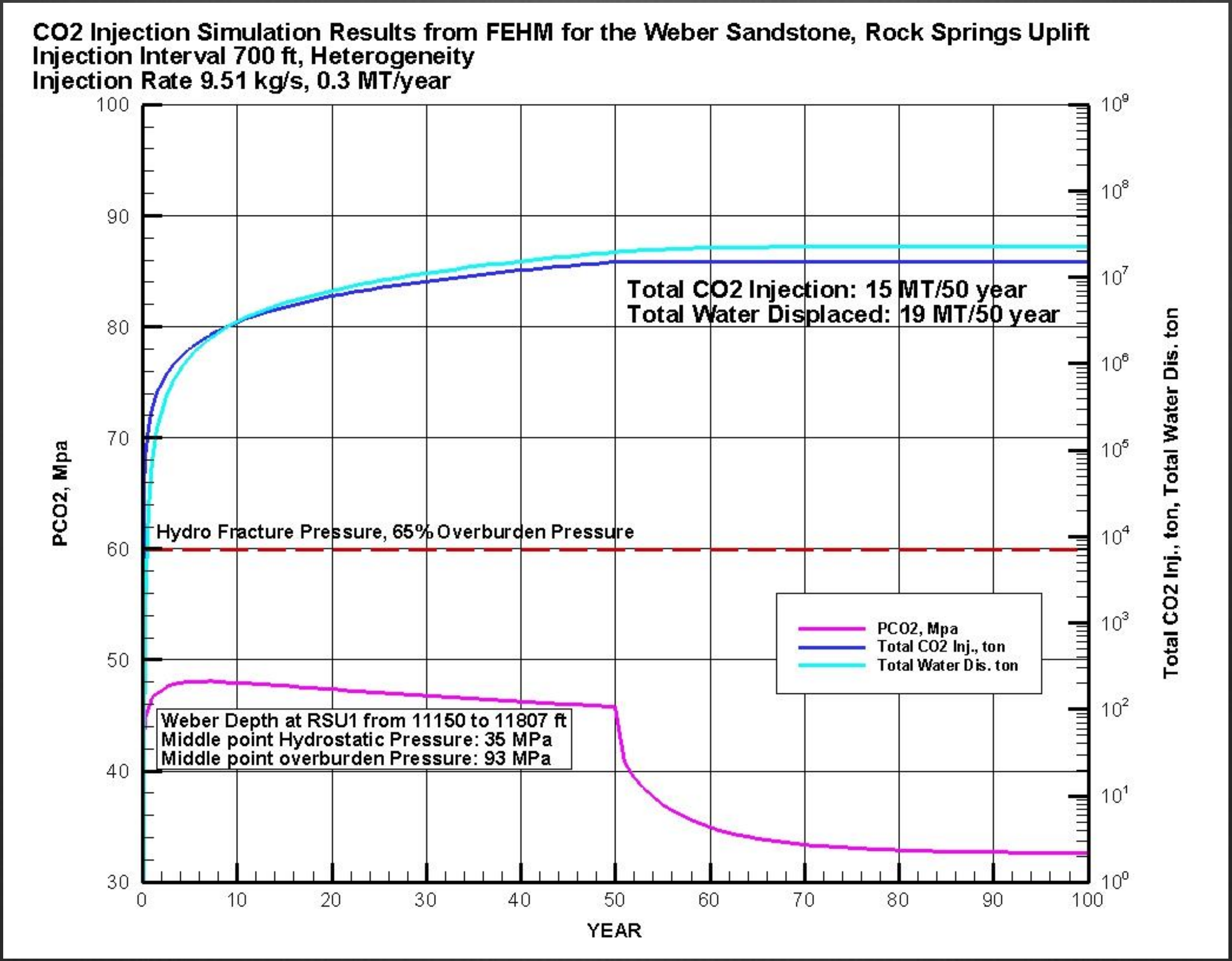


Porosity, %
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
5000
0
-5000
5000
0
-5000
1 mile
1 mile

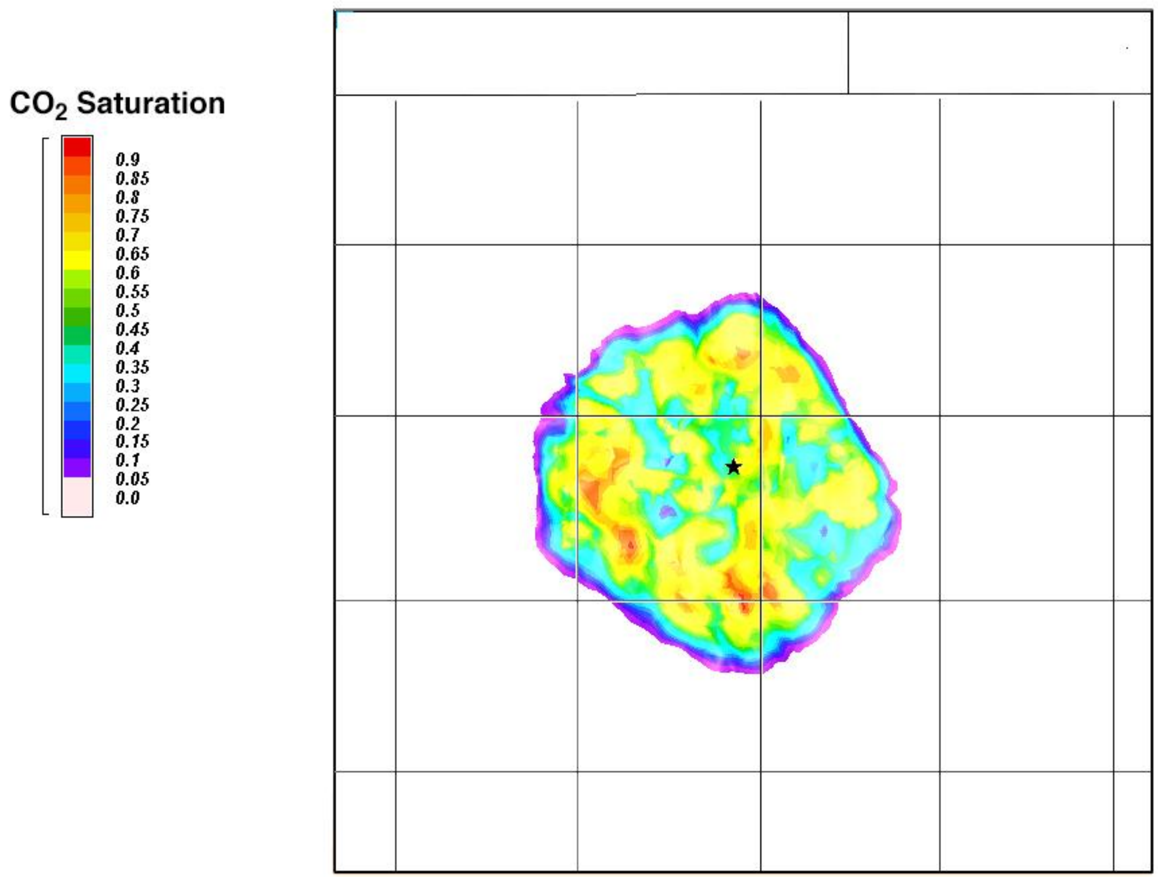


Weber, Eolian Facies
perm = e^(1.29*pore-8.5), R^2 = 0.89
Permeability, md
Porosity, %
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
0
2
4
6
8
10


Permeability, md
5.0
1.0
0.1
5000
0
-5000
5000
0
-5000
Elevation
1 mile
1 mile


CO2 Injection Simulation Results from FEHM for the Weber Sandstone, Rock Springs Uplift
Injection Interval 700 ft, Heterogeneity
Injection Rate 9.51 kg/s, 0.3 MT/year
PCO2, Mpa
Total CO2 Inj., ton, Total Water Dis. ton
YEAR
Total CO2 Injection: 15 MT/50 year
Total Water Displaced: 19 MT/50 year
Hydro Fracture Pressure, 65% Overburden Pressure
PCO2, Mpa
Total CO2 Inj., ton
Total Water Dis. ton
Weber Depth at RSU1 from 11150 to 11807 ft
Middle point Hydrostatic Pressure: 35 MPa
Middle point overburden Pressure: 93 MPa

CO2 Plume After 0.3 Mt Injected To The Weber Sandstone For 50 Years
Heterogeneity Reservoir Properties



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Comparison of CO_2 Storage Capacity Utilizing 3 Different Techniques – 5 mi x 5 mi storage domain

			Static Volumetric Approach[1]	*Dynamic Numerical Simulation*[2] *Homogenous Reservoir Model*			*Dynamic Numerical Simulation*[2] *Heterogeneous Reservoir Model*		
Formation	Area, km^2	Thickness, m	Storage Capacity, Mt	Injection Rate, Mt/y	Storage Capacity, Mt	Injection Wells	Injection Rate, Mt/y	Storage Capacity, Mt	Injection Wells
Weber	64	210	503	1.0	350	7	0.3	33	7
Madison	64	120	290	1.0	305	6	1.0	270	6

1 – USGS Open File Report 2009-1035
2 – FEHM, Los Alomos National Laboratory

Comparison of CO_2 Storage Parameters for 15 and 30 Mt/year for 50 years CO_2 Injection Scenarios

	Static Volumetric Approach	*Dynamic Numerical Simulation Homogenous Reservoir Model*	*Dynamic Numerical Simulation Heterogeneous Reservoir Model*
15 Mt/yr (750 Mt/50yr)			
Area, $miles^2$ (Storage Domain)	24	29	62
Dimensions, mi	5x5	5.5x5.5	8x8
# Injection Wells	1	8	18
30 Mt/yr (1500 Mt/50yr)			
Area, $miles^2$ (Storage Domain)	47	57	124
Dimensions, mi	7x7	7.5x7.5	11x11
# Injection Wells	2	16	35

Acknowledgements

The WY-CUSP site characterization project is funded in part by the U.S. Department of Energy's National Energy Technology Laboratory (Project DE-FE0002142), and the authors would like to thank Project Manager Bill Aljoe. We acknowledge the help of Terry Miller in set up of the finite volume grids; and Phil Stauffer and Hailing Deng for help with details of FEHM. In addition, thanks to Dynamic Graphics, Inc. for allowing us to use their EarthVision software and to Schlumberger for allowing us access to their Eclipse and Petrel software packages. Also, we acknowledge the support provided by the Wyoming Oil and Gas Conservation Commission and the Department of Environmental Quality. Lastly, but very importantly, we thank Shanna Dahl, Shauna Bury, Meg Ewald, and Allory Deiss – all colleagues at CMI – for their support.