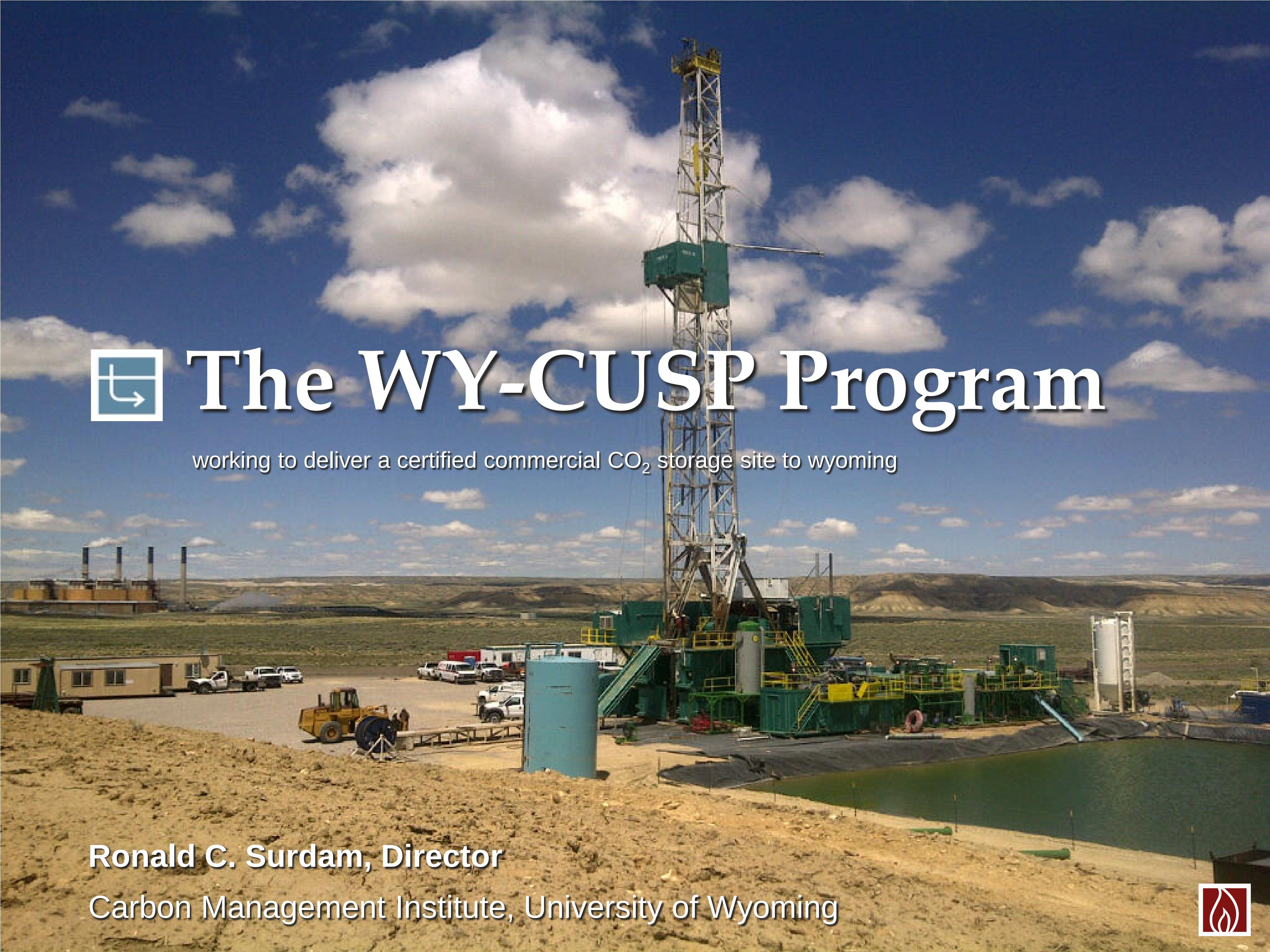


The WY-CUSP Program

working to deliver a certified commercial CO_2 storage site to wyoming

Ronald C. Surdam, Director

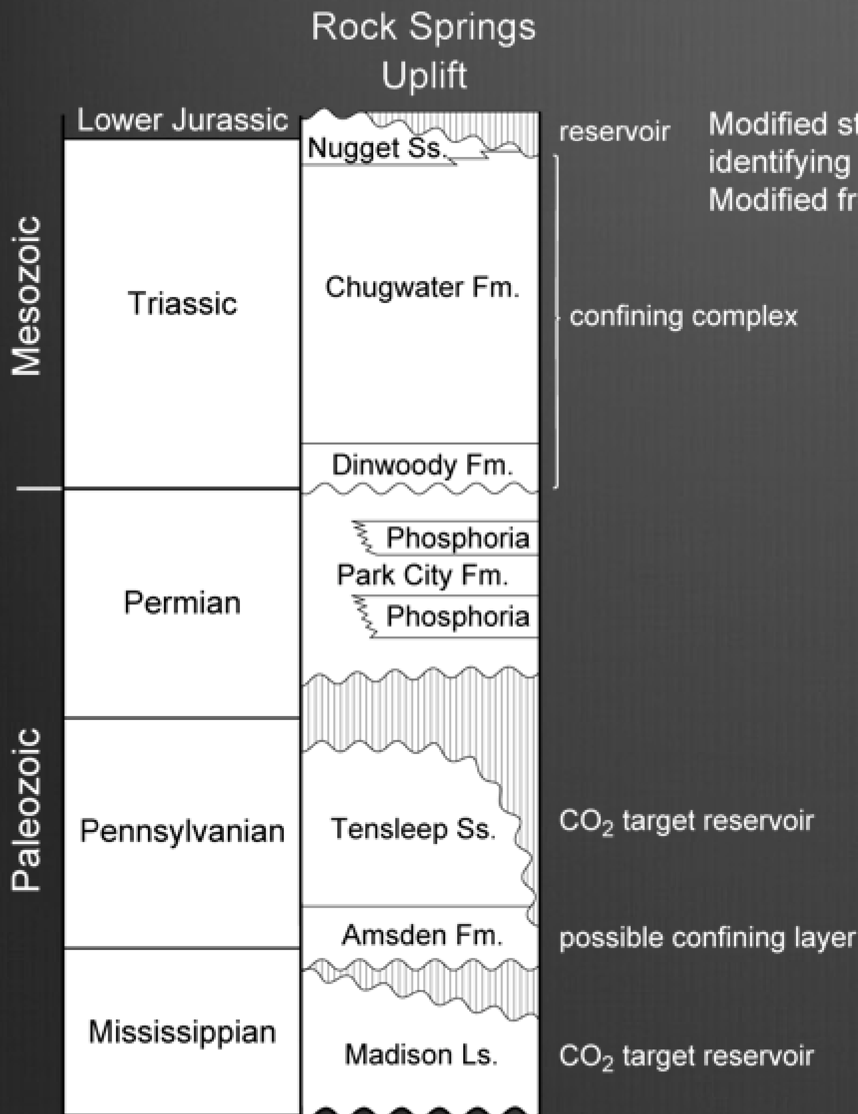
Carbon Management Institute, University of Wyoming

Wyoming Carbon Underground Storage Project (WY-CUSP) Goals

1. To improve estimates of CO_2 reservoir storage capacity at the premier CCUS site in Wyoming.

2. To evaluate the long-term integrity and permanence of confining layers at the Rock Springs Uplift.

3. To manage injection pressures and brine production in order to optimize CO_2 storage efficiency for the most significant storage reservoirs (Tensleep/Weber and Madison formations).



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

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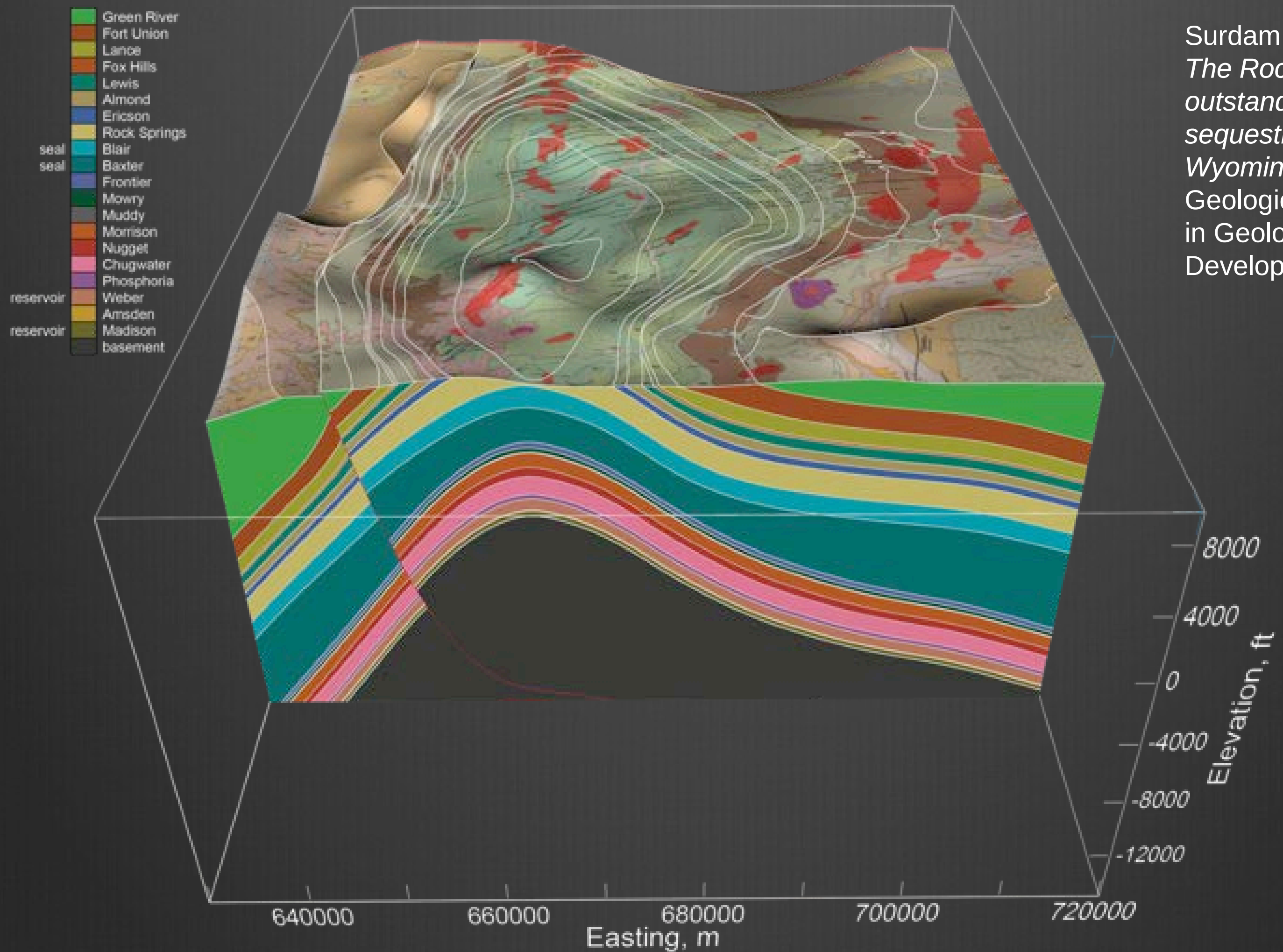
3-D geological model of the Rock Springs Uplift



Surdam, R.C. & Jiao, Z., 2007, *The Rock Springs Uplift: An outstanding geological CO_2 sequestration site in southwest Wyoming*: Wyoming State Geological Survey Challenges in Geologic Resource Development No. 2, 31 p.

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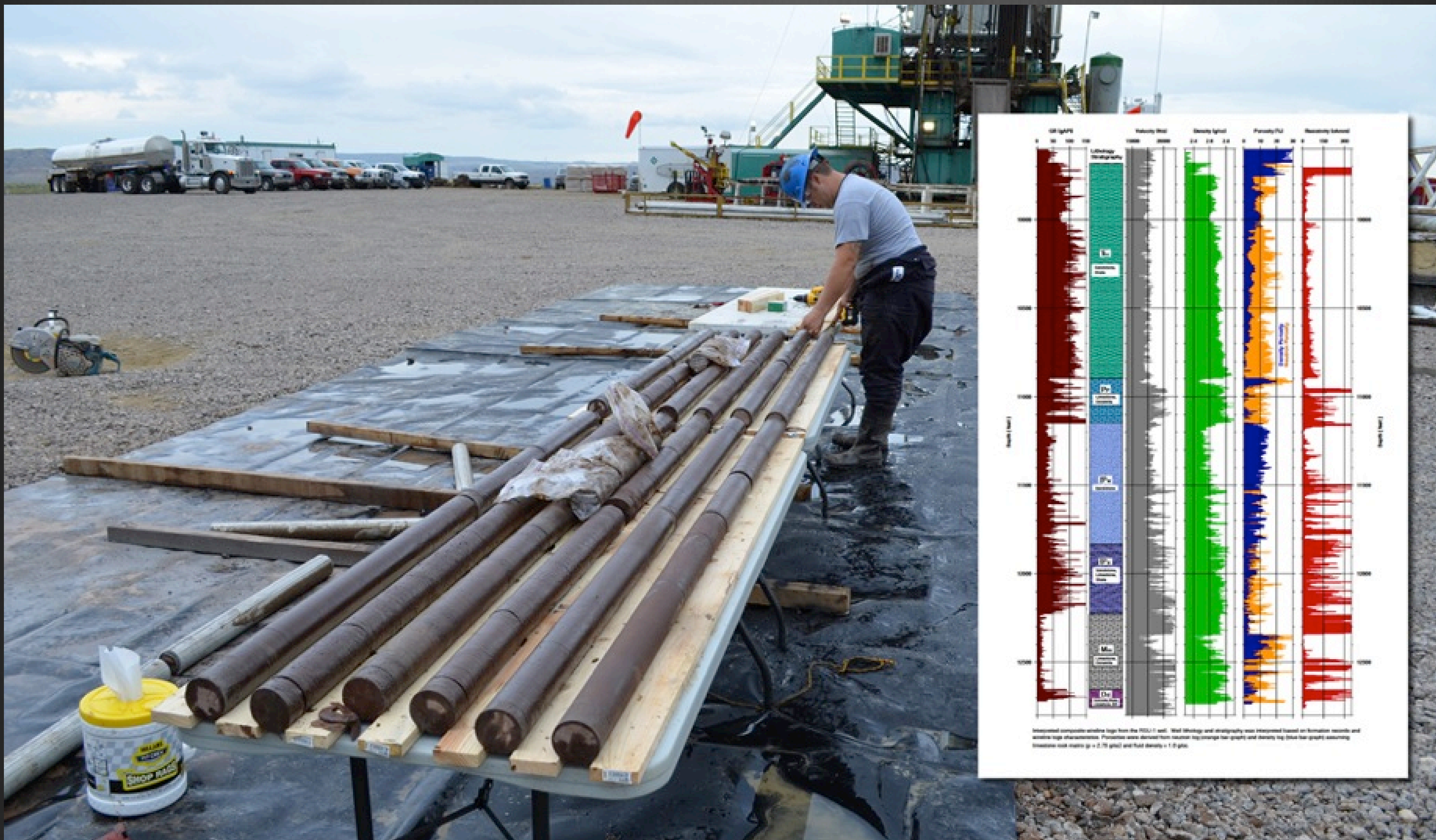
3-D seismic survey, Madison amplitude volume

Interpretation of log suite/core



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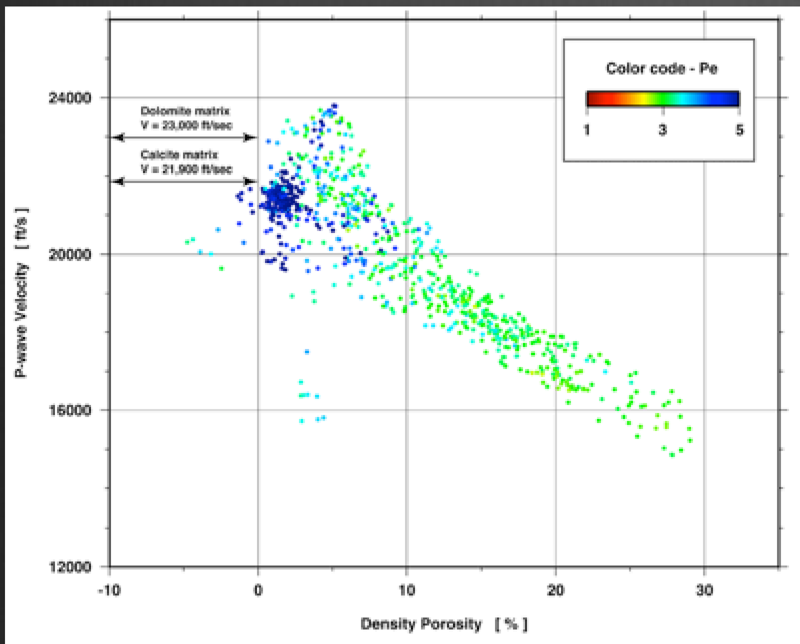
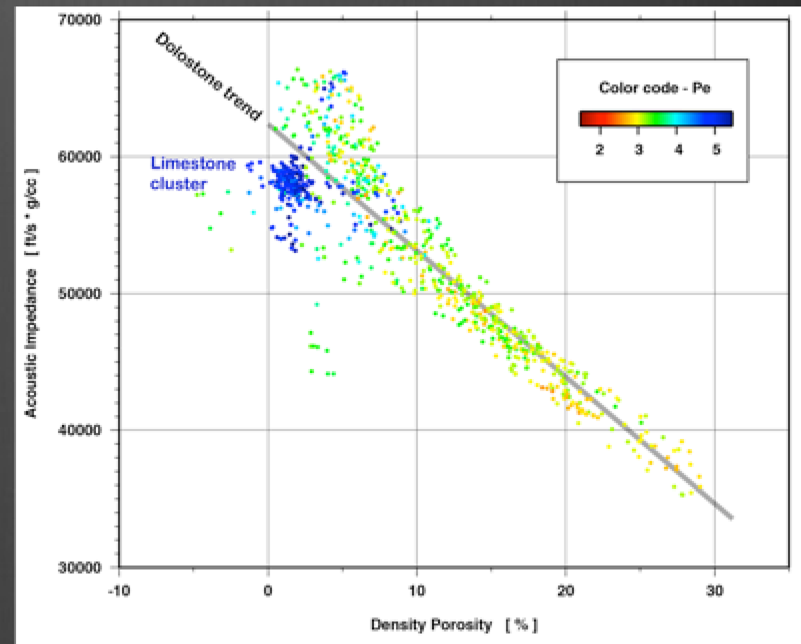
Sonic/Seismic velocity vs. density porosity

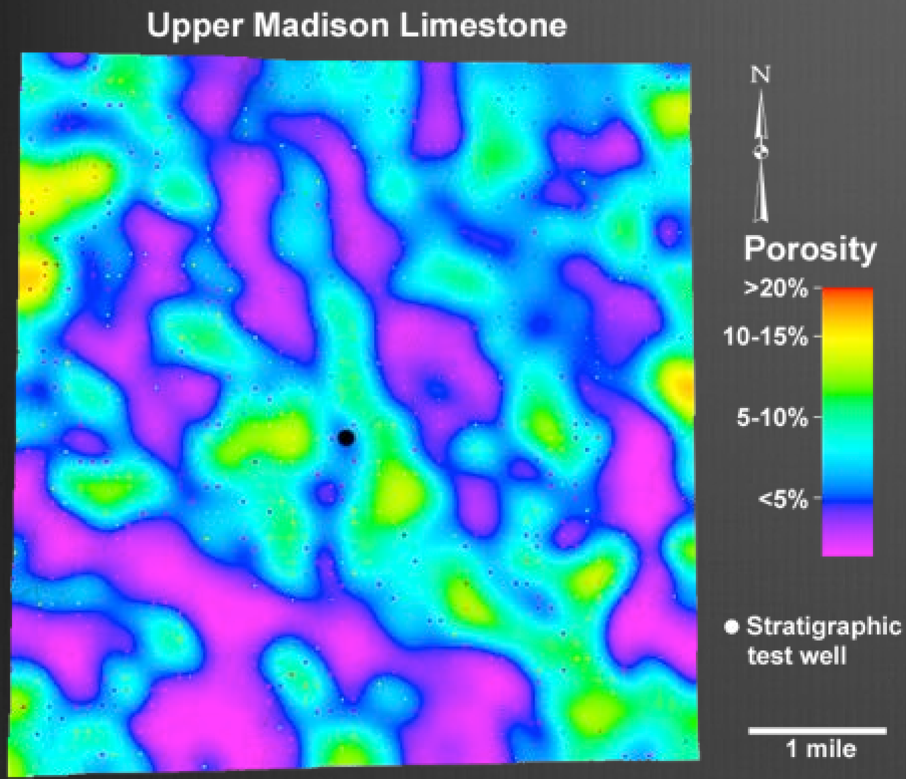


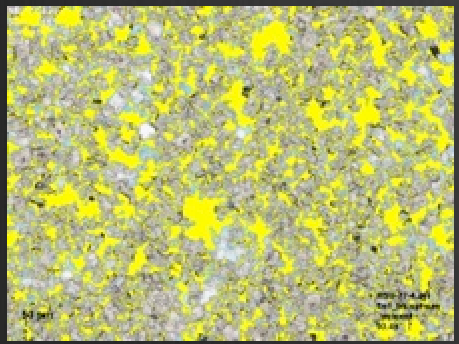
Madison Limestone



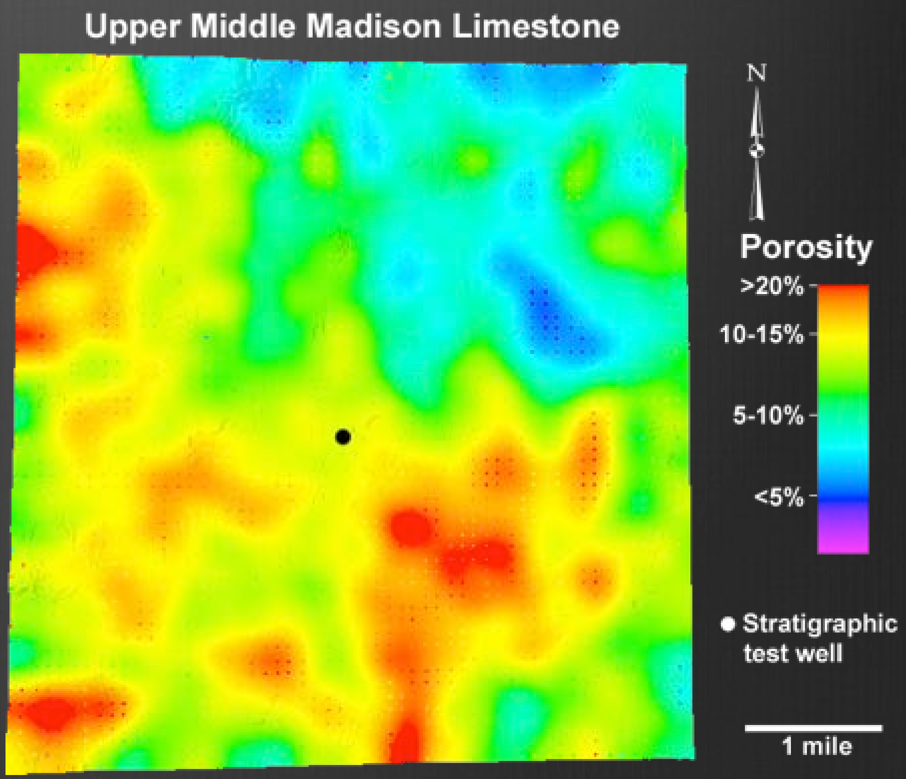
Madison Limestone

Madison Limestone





Porosity 30.5%



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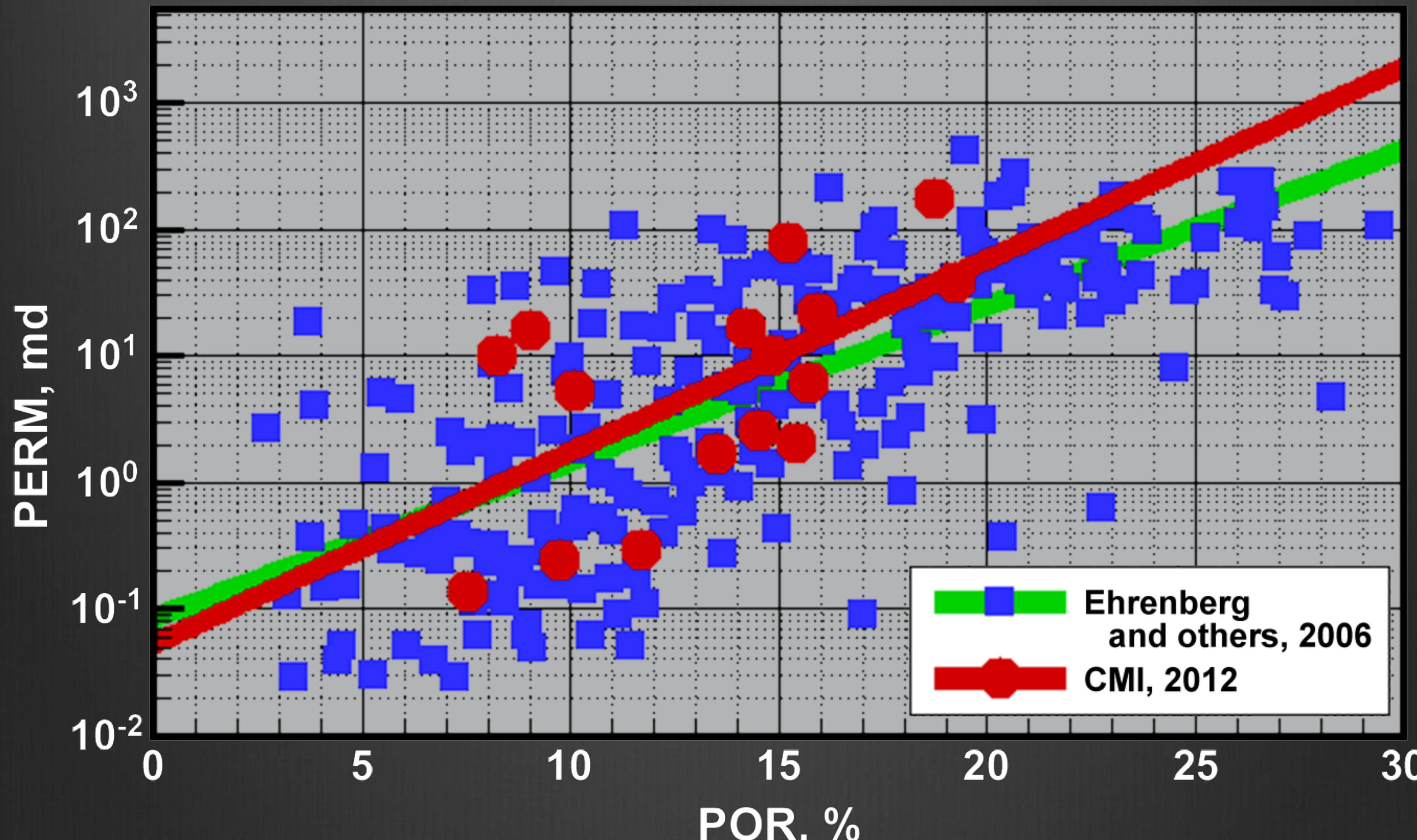
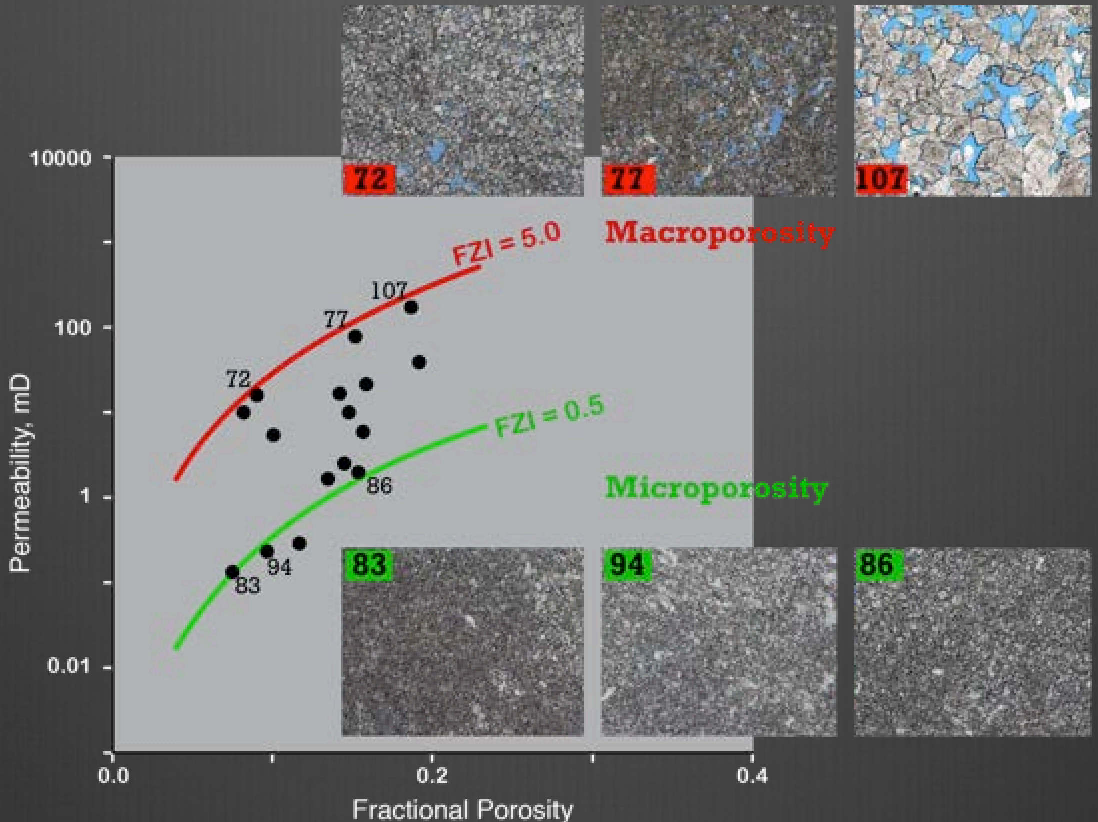
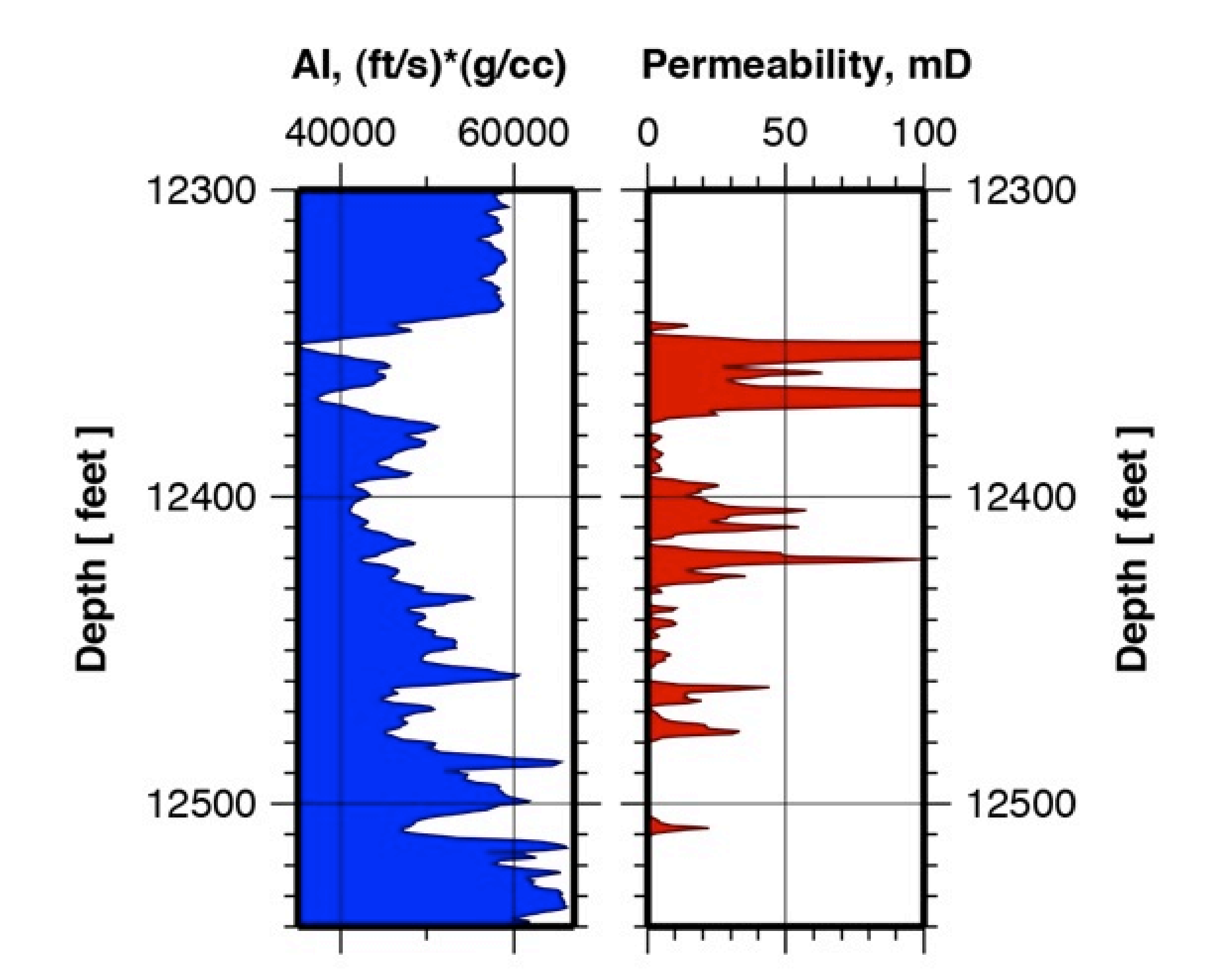
Cross Plot of Porosity vs Permeability for Madison Limestone, Wyoming





Semilog plot of permeability vs. porosity for the Madison Limestone samples, RSU #1 well, Rock Springs Uplift, Wyoming. The colored curves indicate constant hydraulic units defined by the FZI value. Thin section images (labeled with the sample ID numbers) demonstrate that permeability of the corresponding dolostone sample is a function of the total porosity and the pore structure. Dolostones dominated by large vuggy pore types (top) show greater permeability than fine-grained dolostones dominated by intergranular microporosity (bottom). For the set of data, the FZI approach shows an r value of 0.835 with the measured permeability values.

Establishing relationships between Seismic attributes and permeability



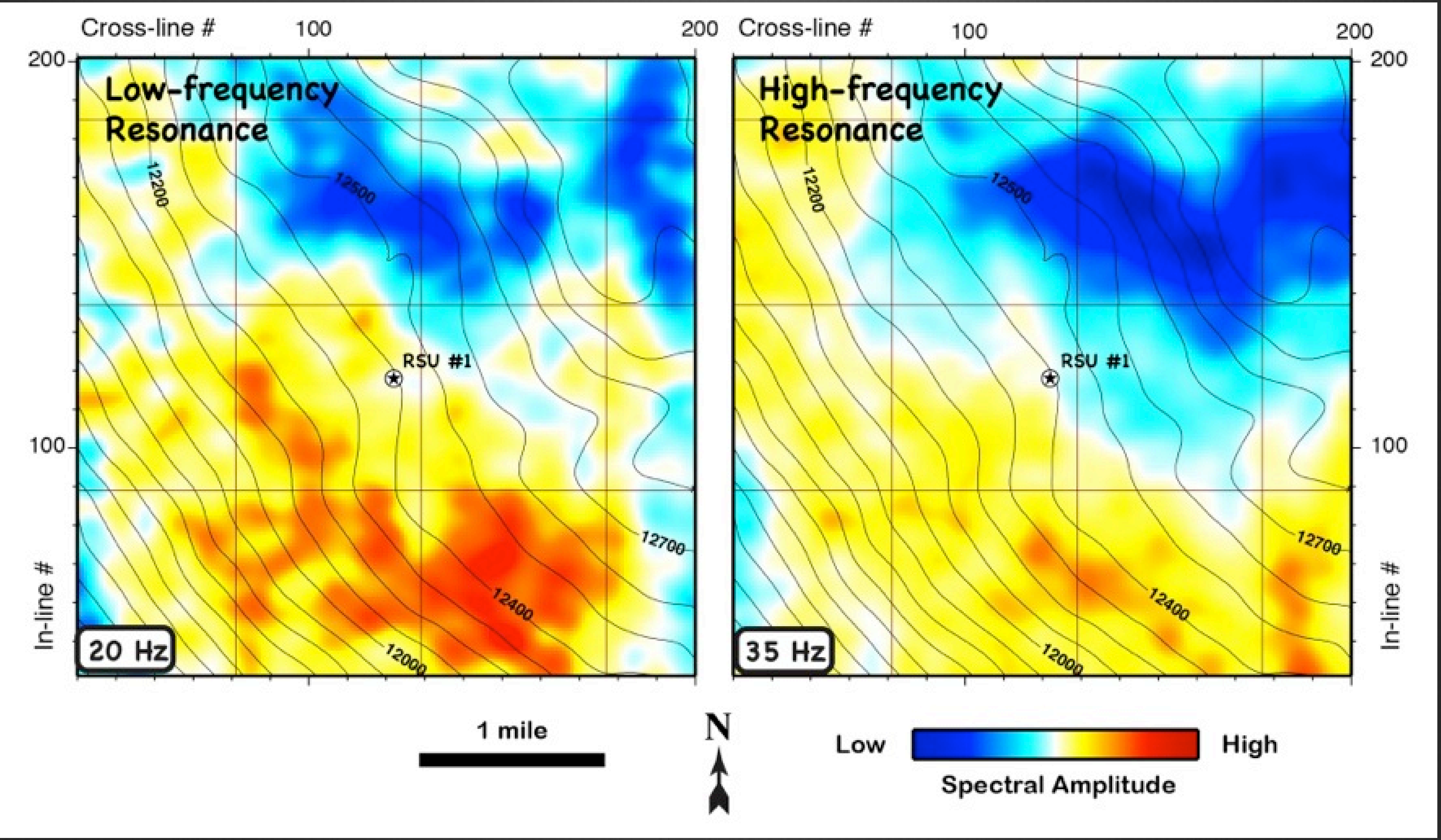
Permeability Attribute

$$\frac{\text{Amplitude (20 Hz)} - \text{Amplitude (35 Hz)}}{\Sigma\,(A_{20} + A_{35})} = \text{Qualitative Permeability}$$

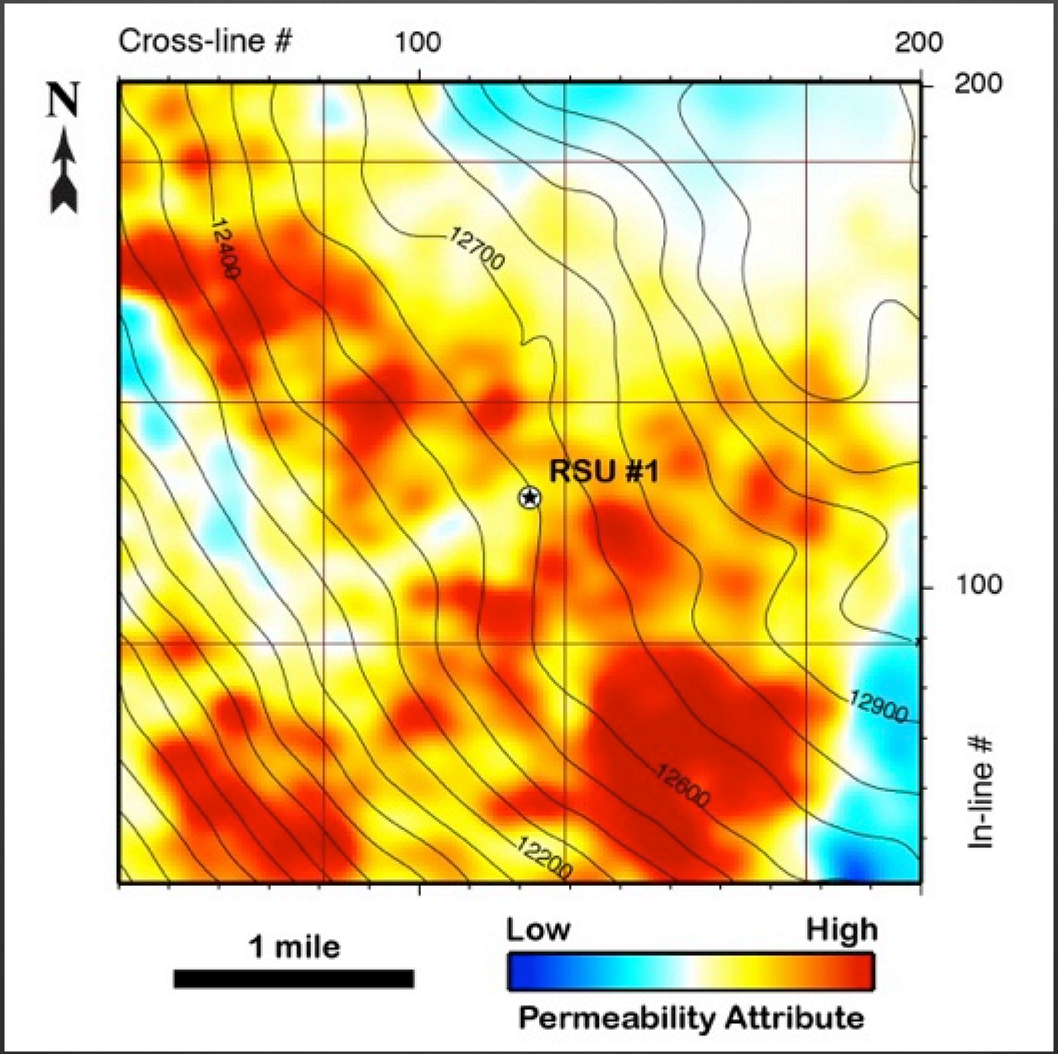
Derived from seismic spectral decomposition.

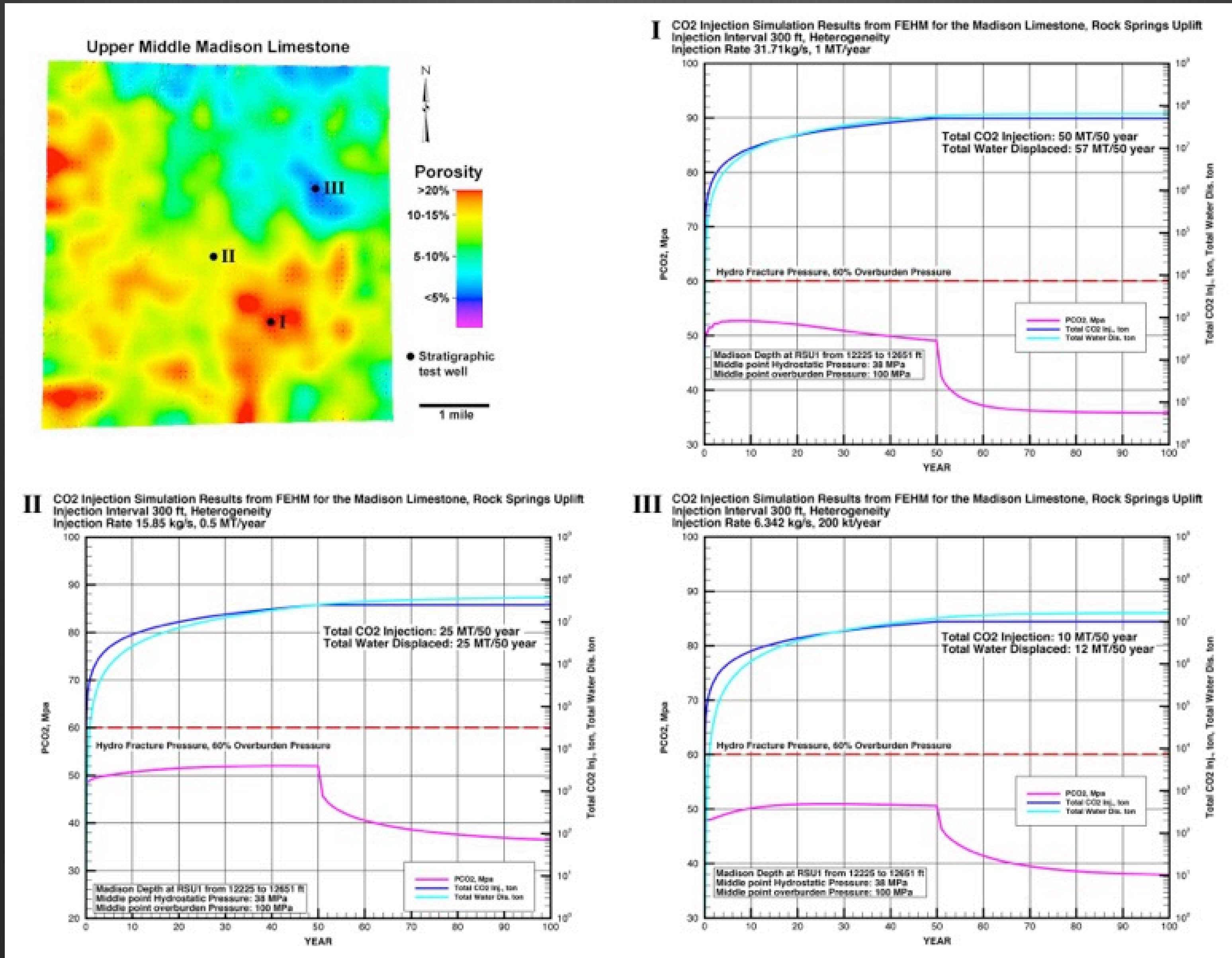
Specific to the Madison Limestone within the Rock Springs Uplift.

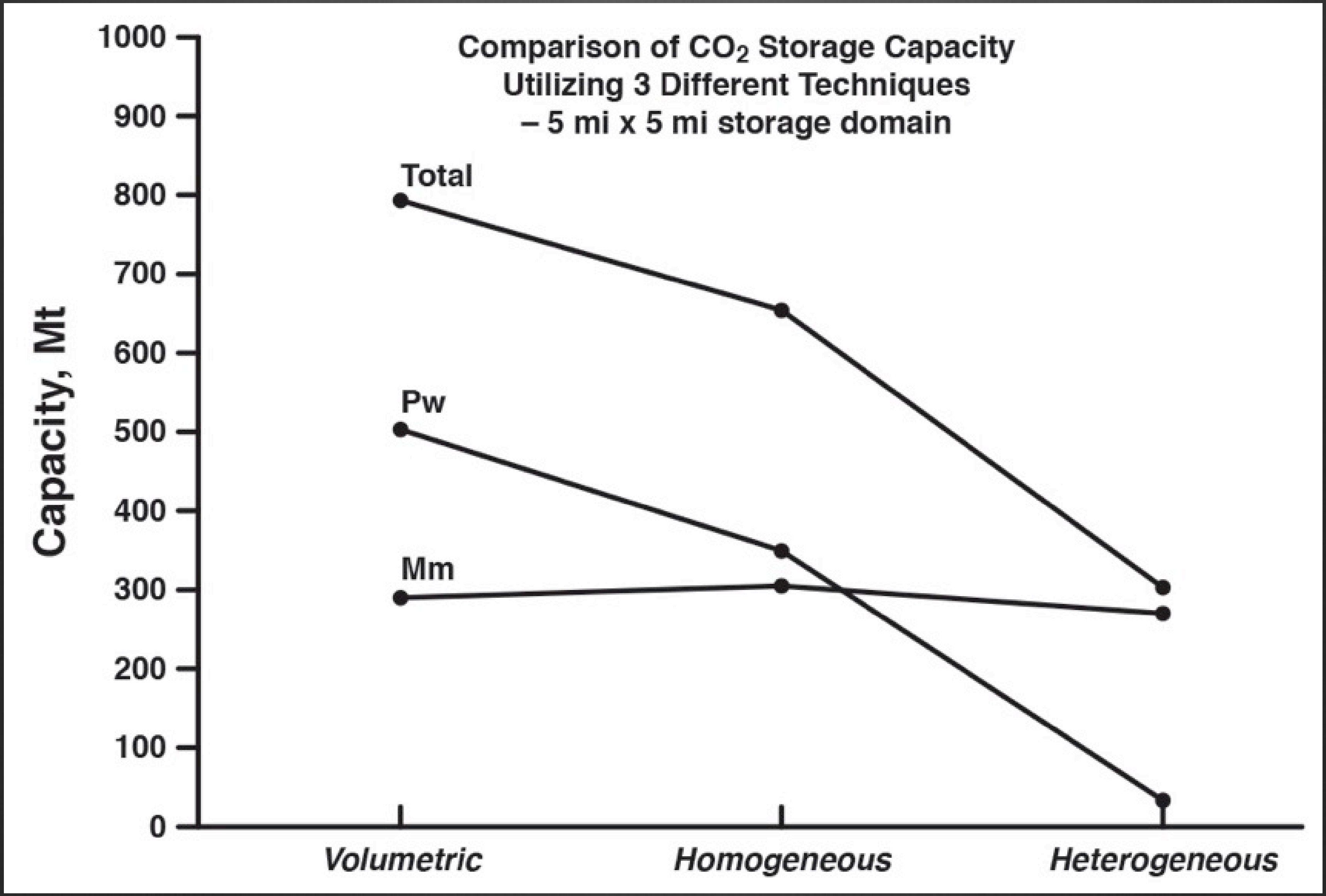
Middle Madison Horizon



Middle Madison Horizon
(qualitative permeability from seismic attribute)




Upper Middle Madison Limestone
N
III
II
I
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
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
YEAR
Total CO2 Inj., ton, Total Water Dis. ton
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
YEAR
Total CO2 Inj., ton, Total Water Dis. ton
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
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
YEAR
Total CO2 Inj., ton, Total Water Dis. ton



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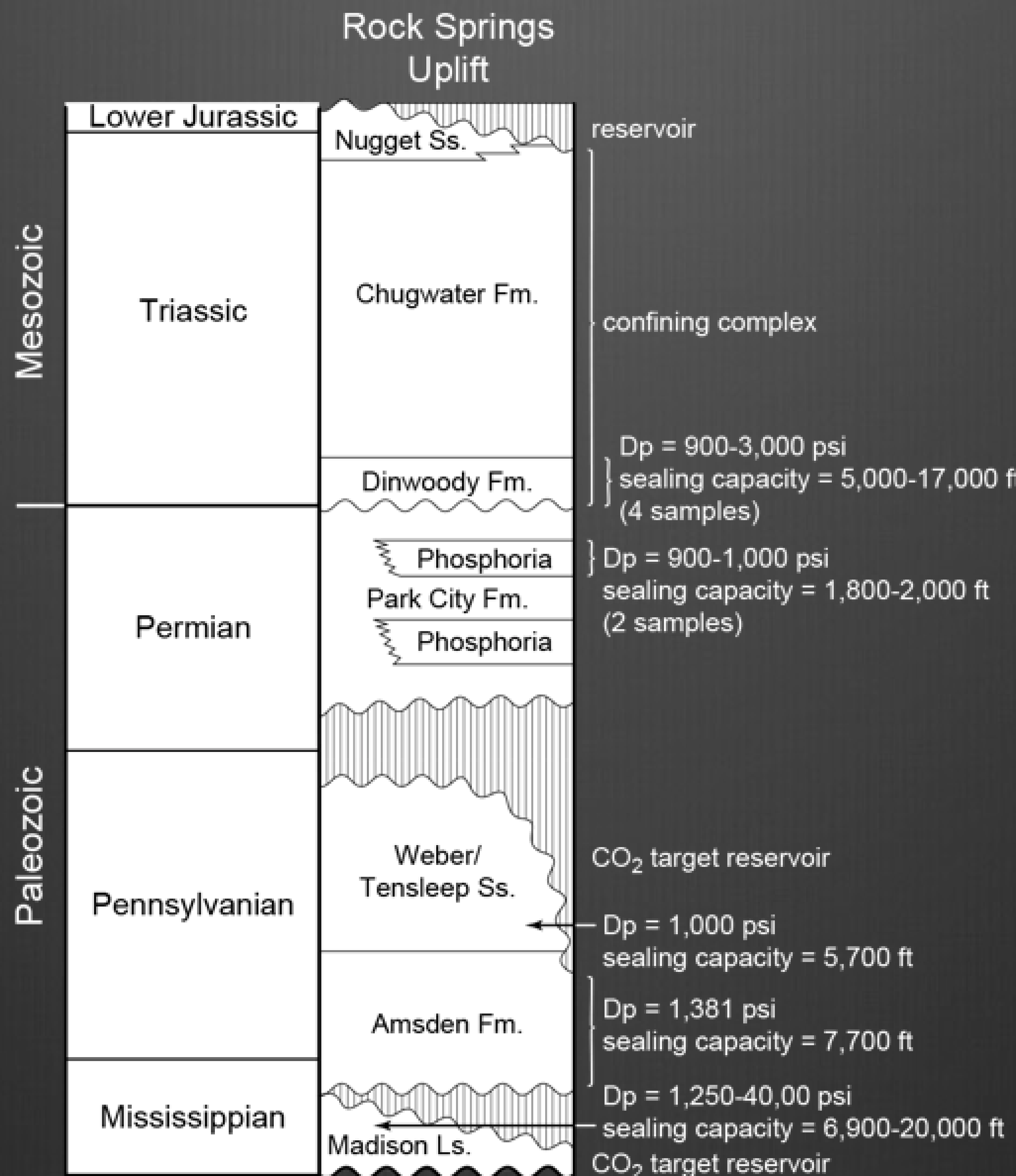
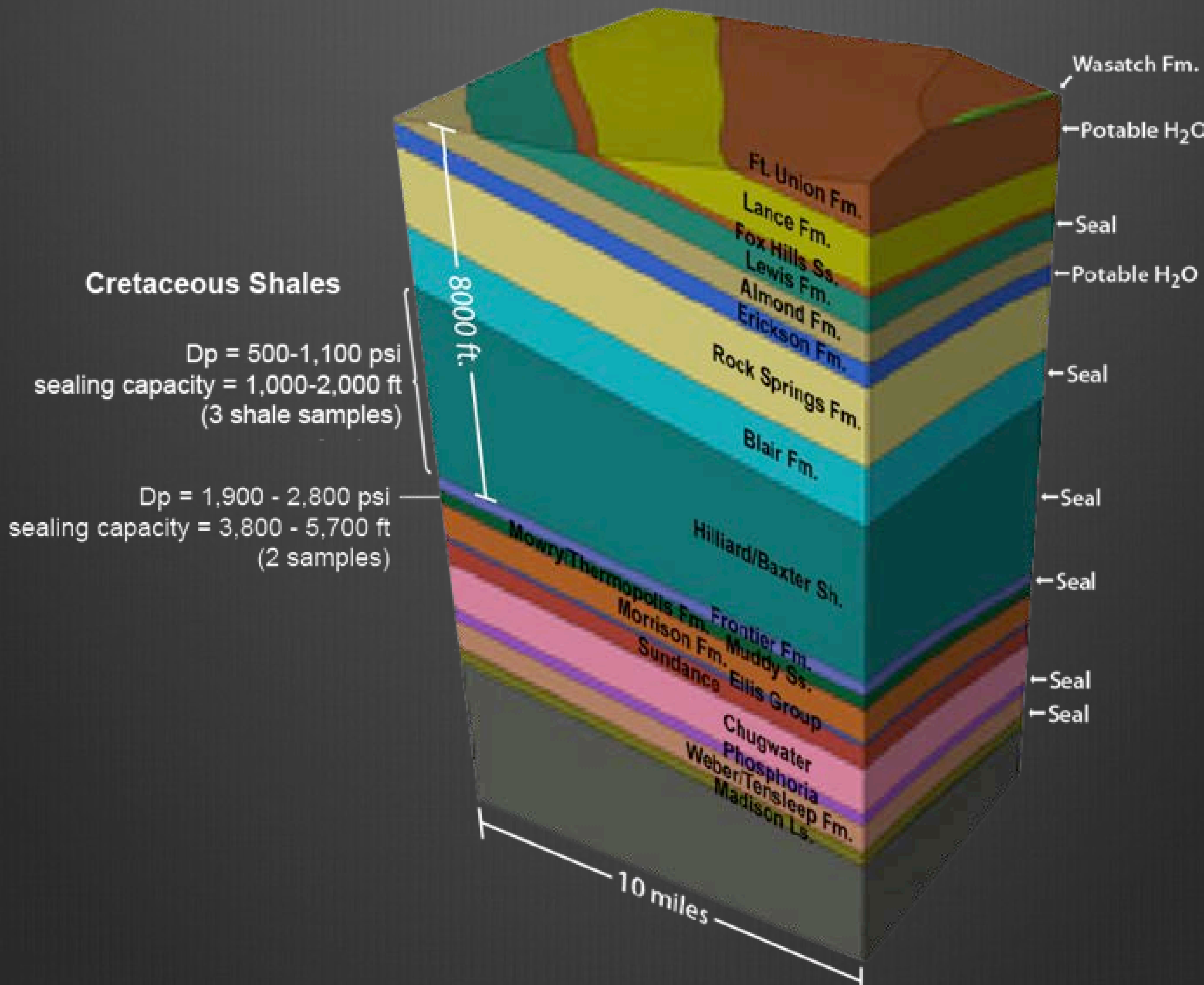
Primary Seals



Rock Springs Uplift hydrostratigraphic system



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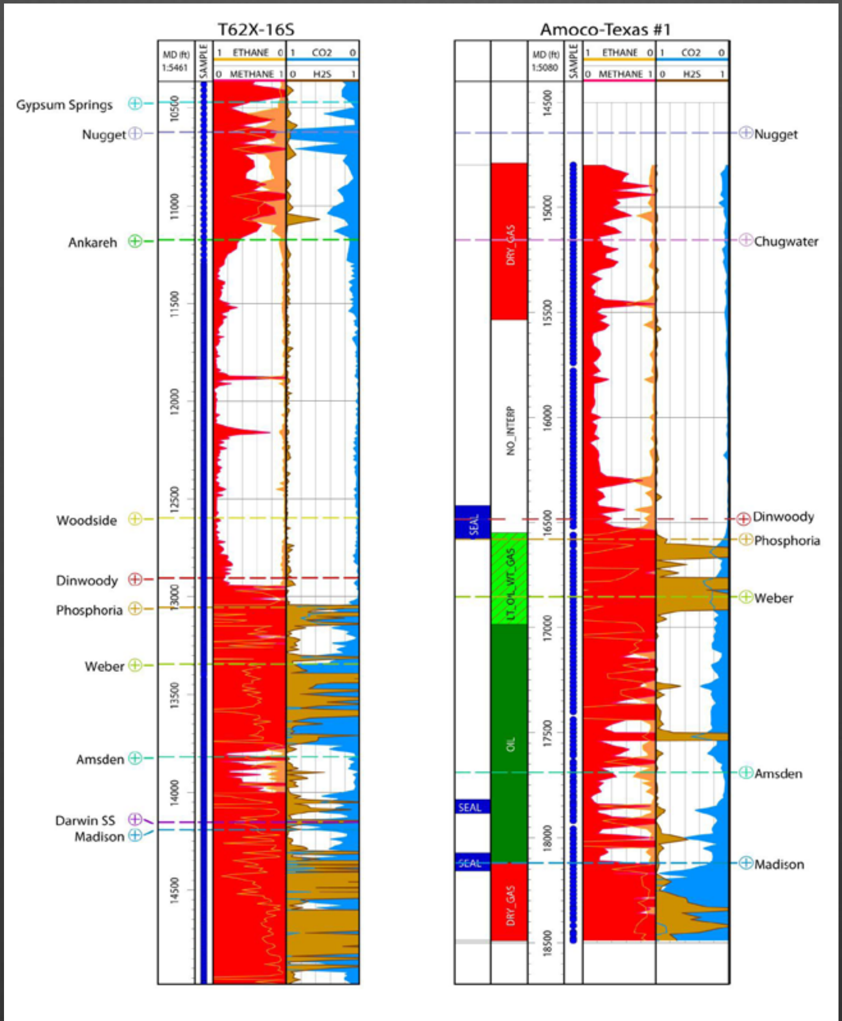


From Erin Campbell-Stone et al., 2010

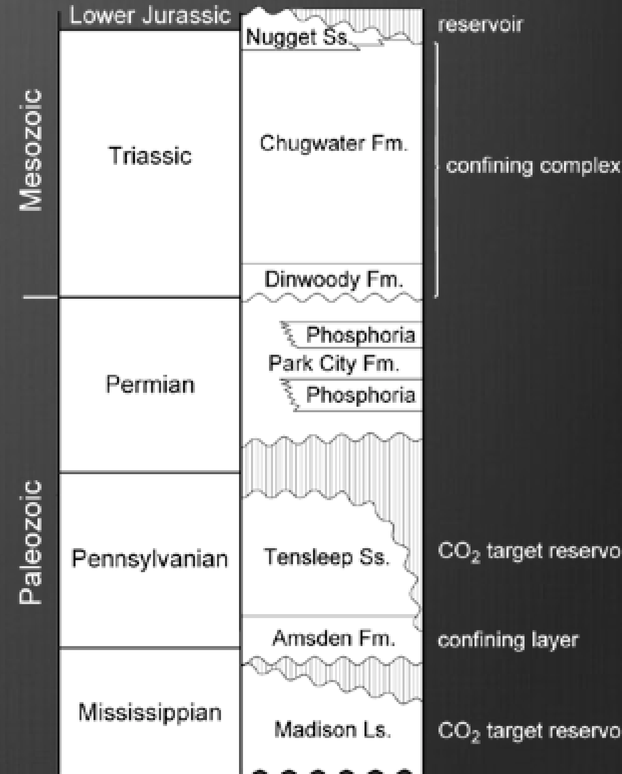
Dinwoody

10,656.4 ft.

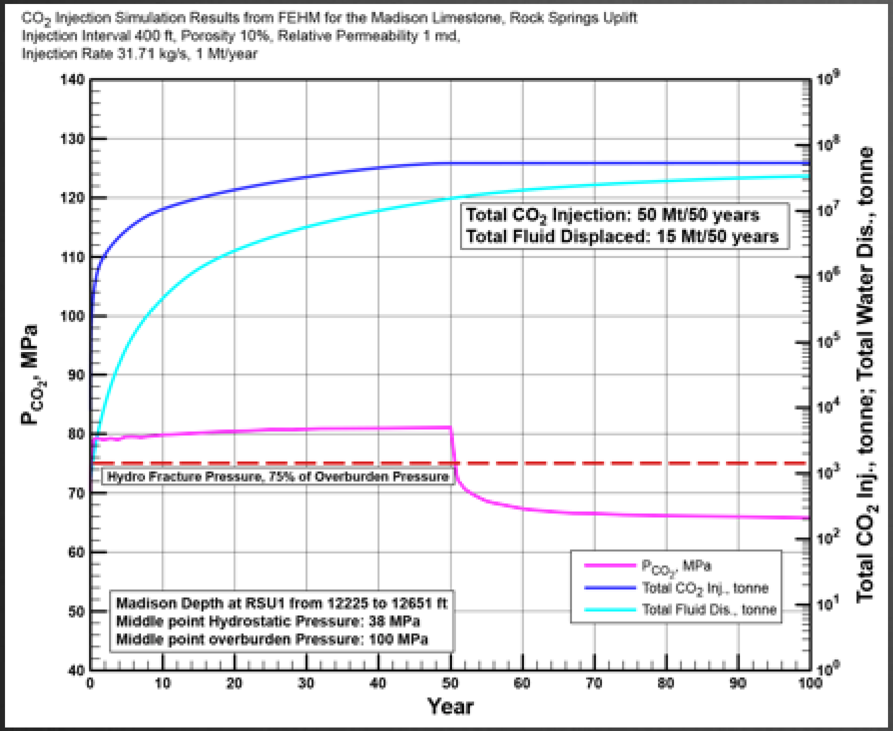
RSU-16

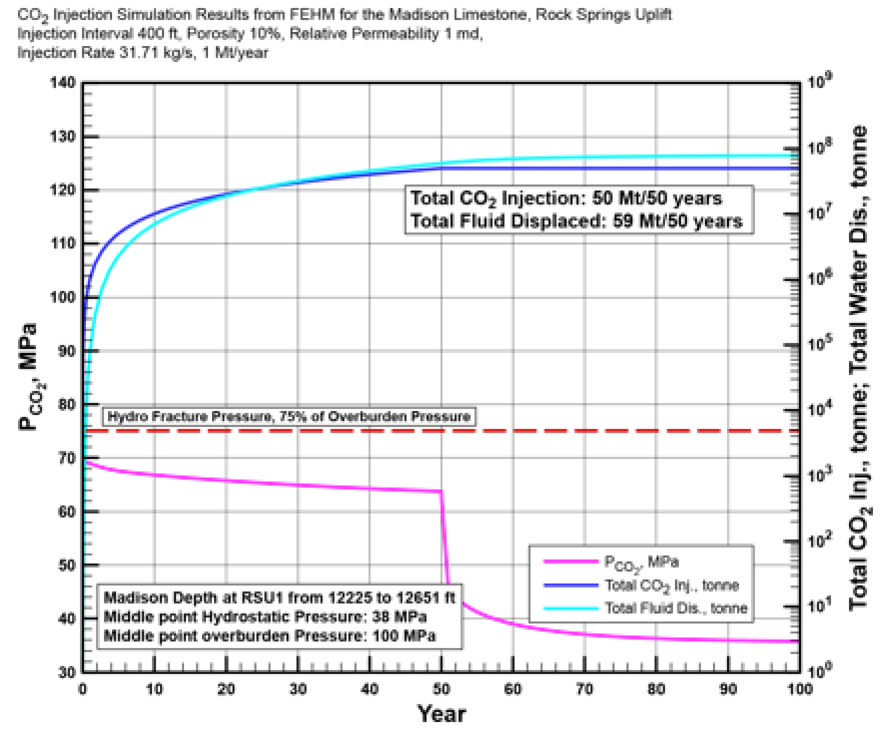
Porosity (Hg) = ND
Permeability = <0.001 mD
Displacement pressure = 3000 psi
Calculated CO_2 sealing capacity* = 16,000 ft.
Scale bar = 200 microns

*Vavra et al., 1992



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





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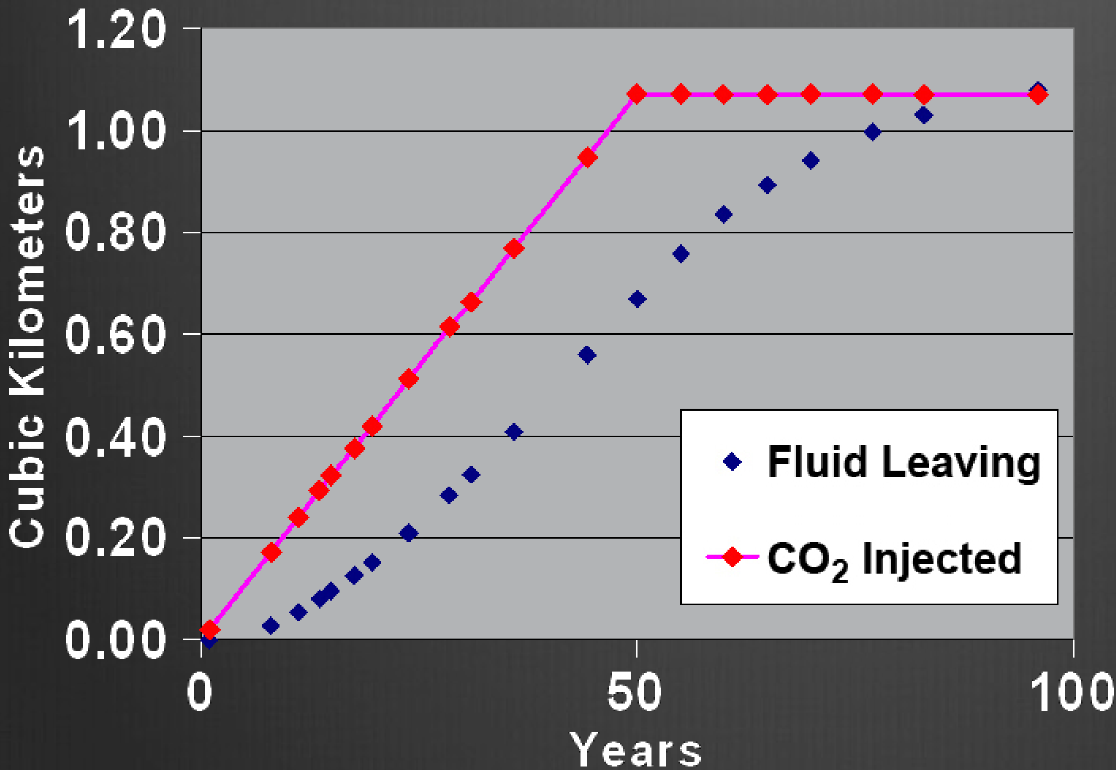
Injected CO_2 versus fluid leaving the domain



Scale:

750 Mt of CO_2 displaces ~1 cubic kilometer.

1 cubic kilometer of displaced fluids is ~6,000,000,000 barrels.

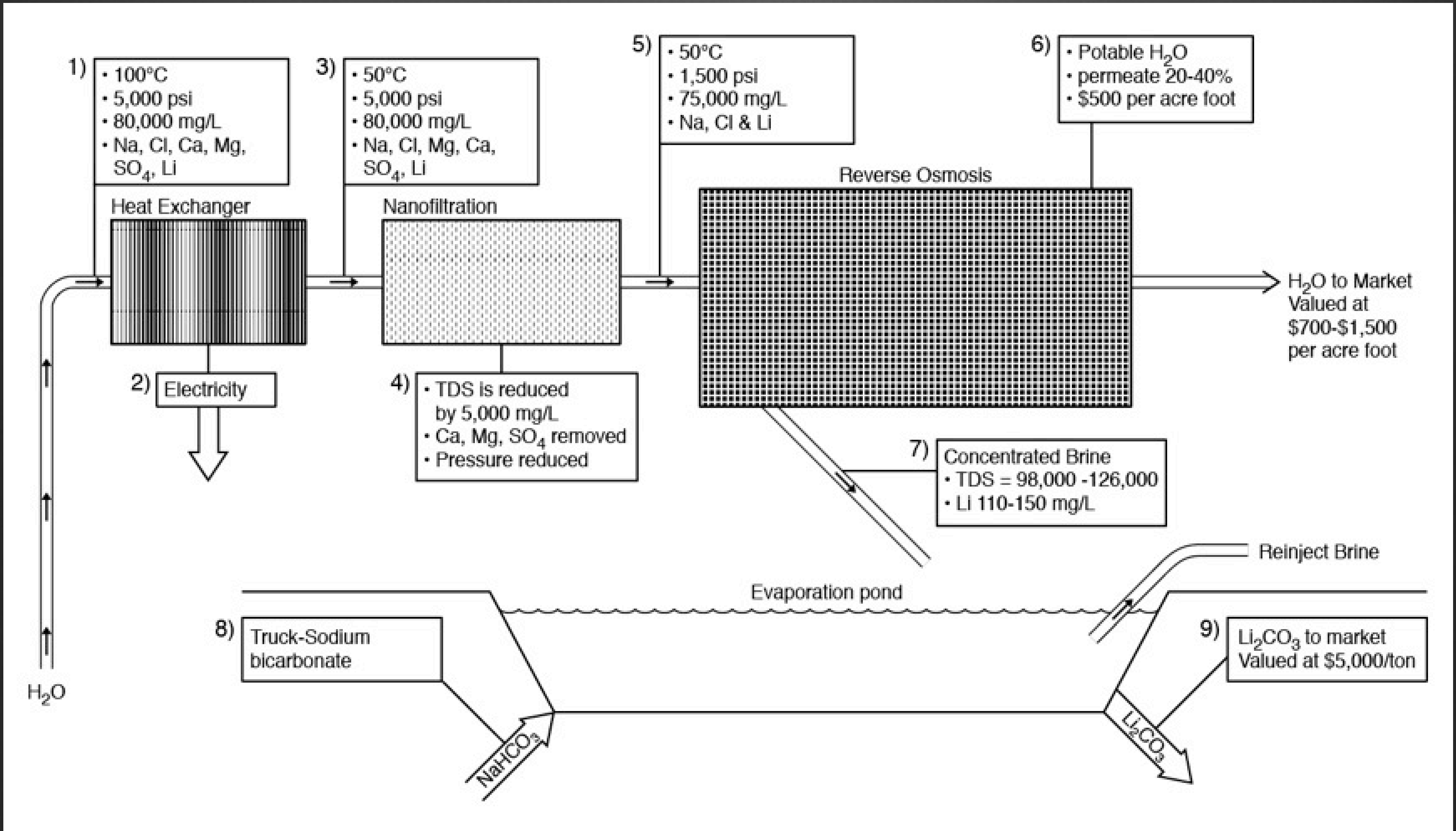
Salt Creek oil production (the largest oil field in Wyoming) is ~680,000,000 barrels (120 years).

1 cubic kilometer of water is ~710,000 acre-feet.

Boysen Reservoir is 792,000 acre-feet.

Modified from Surdam, R.C., Jiao, Z., Stauffer, P., & Miller, T., 2009, An integrated strategy for carbon management combining geological CO_2 sequestration, displaced fluid production, and water treatment: Wyoming State Geological Survey Challenges in Geologic Resource Development No. 8, 25 p.

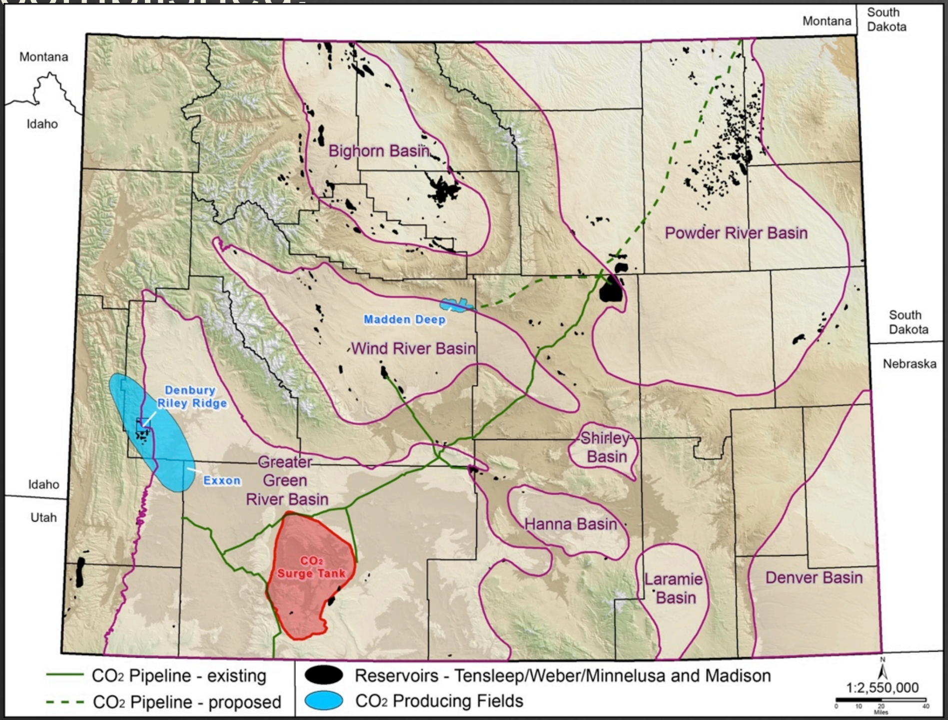
Sample Type	Units	Weber1a	Weber1b	Weber2	Madison1a	Madison1b	Madison2
B	mg/L	14	61	72	21	95	101
K+	mg/L	1,940	--	1,910	4,210	--	3,780
Li+	**mg/L**	**100**	**92.8**	**90.5**	**105**	**91.9**	**91.6**
Ca++	mg/L	705	734	539	1,280	1,190	1,630
Mg++	mg/L	40	37	45	170	158	195
Na+	mg/L	43,250	40,700	36,500	32,820	29,000	27,900
Br-	mg/L	94	--	99	115	--	140
Cl-	mg/L	61,830	60,900	57,400	52,290	50,300	51,600
F-	mg/L	8.4	11.5	6.1	13	3.5	2.8
HCO_3-	mg/L	720	621	3,690	1,610	1,420	3,190
SO_4--	mg/L	10,320	11,600	6,030	2,280	2,800	1,820
pH	unitless	7.11	7.54	6.46	6.01	7.36	6.43
Carbonate alkalinity	mg/L (as CaCO3)	--	509	3,030	--	1,170	2,620
SiO_2(aq)	mg/L (as Si)	55.62	--	96.7	77.02	--	127.3
Dissolved solids	mg/kg	111,668	108,061	102,311	89,932	81,436	87,931
Ionic strength	molal	2.029	1.948	1.767	1.613	1.443	1.497
Water type	unitless	Na-Cl	Na-Cl	Na-Cl	Na-Cl	Na-Cl	Na-Cl
Hardness	mg/L (as CaCO3)	1925	1985	1531	3897	3622	4874



1)
• 100°C
• 5,000 psi
• 80,000 mg/L
• Na, Cl, Ca, Mg, SO4, Li
Heat Exchanger
2) Electricity
3)
• 50°C
• 5,000 psi
• 80,000 mg/L
• Na, Cl, Mg, Ca, SO4, Li
Nanofiltration
4)
• TDS is reduced by 5,000 mg/L
• Ca, Mg, SO4 removed
• Pressure reduced
5)
• 50°C
• 1,500 psi
• 75,000 mg/L
• Na, Cl & Li
Reverse Osmosis
6)
• Potable H2O
• permeate 20-40%
• $500 per acre foot
H2O to Market Valued at $700-$1,500 per acre foot
7) Concentrated Brine
• TDS = 98,000 -126,000
• Li 110-150 mg/L
Reinject Brine
Evaporation pond
8) Truck-Sodium bicarbonate
NaHCO3
9) Li2CO3 to market Valued at $5,000/ton
Li2CO3
H2O

WY-CUSP Deliverables

The ultimate mission of the WY-CUSP program, managed by the University of Wyoming Carbon Management Institute – delivery of a certified commercial CO_2 storage site in Wyoming that could be used as a surge tank for CO_2 utilization – is being accomplished.



Tensleep and Madison oil and gas fields in Wyoming: 2 – 4 billion barrels of stranded oil

Partners and contributors

- Thank you to the crew from Baker Hughes, Inc., including Paul Williams, Sam Zettle, Dana Dale, and Danny Dorsey
- TRUE Drilling Co. of Casper, WY provided the large rig and an excellent drilling crew.
- The WY-CUSP characterization project is funded in part by DOE NETL (Project DE-FE0002142). CMI would like to thank DOE Project Manager Bill Aljoe.
- Other contributors include Los Alamos National Laboratory, Lawrence Livermore National Laboratory, PetroArc International, New England Research, Geokinetics, EMTek, and the Wyoming State Geological Survey.