Characterization of Petrophysical Properties for CO_2 Sequestration Models in the Mississippian Madison Group, Moxa Arch-La Barge Platform, Southwestern Wyoming*

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Abstract

Petrophysical data for the Mississipian Madison Group in southwestern Wyoming was compiled and evaluated to relate petrophysical properties to stratigraphic facies in the Madison Group. The study was performed to help develop accurate storage estimates and provide baseline data for the geologic model required for carbon sequestration. Public-domain geological and petrophysical data from core analyses, wireline logs and core from wells that penetrate the Madison Group were used to place the wells within the regional structural and sequence-stratigraphic framework, and detail porosity-permeability relationships. The use of log-based porosity calibrated against core-based porosity greatly extended petrophysical characterization. Log-based porosity allowed regional-scale observation of trends in petrophysical properties.

Based on statistical analysis, we characterize the Madison as having three petrophysical facies. The first facies is characterized by low porosity (<4%) with a highly variable permeability to porosity relationship. Preliminary data indicate the low-porosity carbonate facies' highly variable permeability is related to micro-fracturing. Examination of core with accompanying petrophysical data show that the lower porosities are mostly present in micritic to wackestone facies, and also thinly bedded packstones and grainstones. The second petrophysical facies has intermediate porosity (4-12%) with a variable-to-log permeability to porosity relationship. The third petrophysical facies has higher porosity (>12%) with a log permeability to porosity relationship. The higher porosities are present in packstone- to grainstone-dominated facies. The best porosity in the study area is present in the lower portion of the formation in dolomitic packstone-to-grainstone-dominated facies near the top of the trangressive systems tract, with high porosity zones extending over 10's of kilometers. In terms of porosity, all of these petrophysical facies can be related to depositional facies as a first-order control.

References

Garner, H.F., 1974, The Origin of Landscapes; A Synthesis of Geomorphology: Oxford University Press, United Kingdom, 734 p.

Schlumberger Limited (corporate author), 1972, Schlumberger Log Interpretation, Principles Vol. I, Applications Vol. II: Schlumberger, Ltd., New York, 112 p.

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ENHANCED OIL RECOVERY INSTITUTE

UNIVERSITY OF WYOMING

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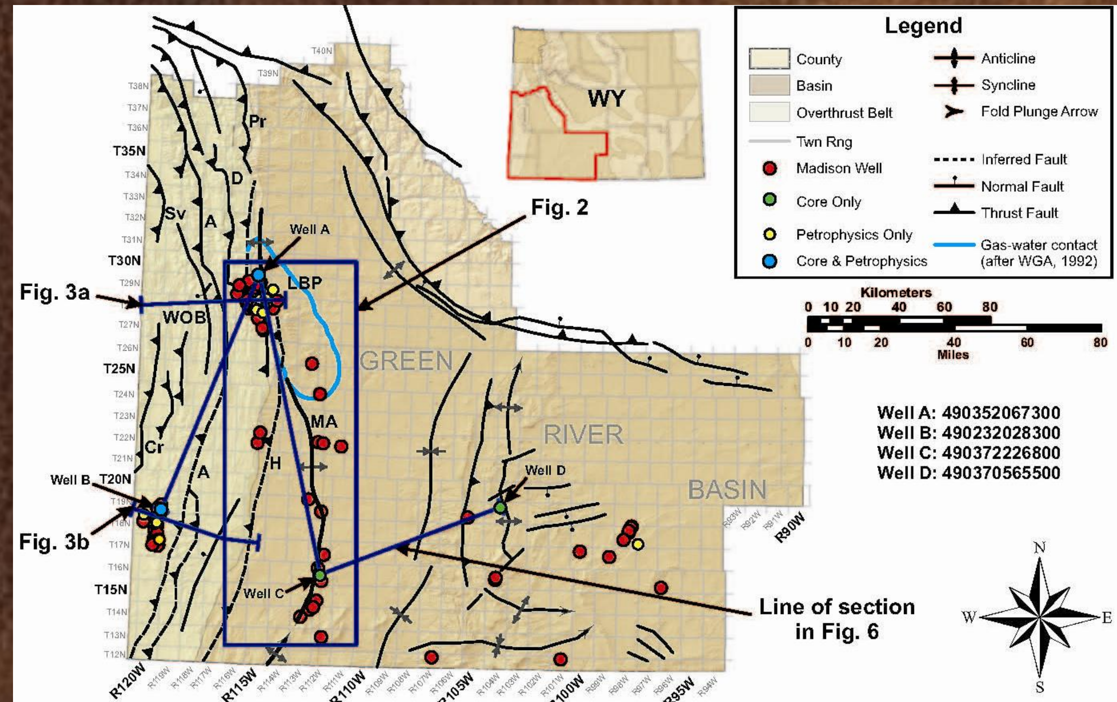
- Cimarex Energy and Triple O Slabbing.
- Schlumberger and Blueback Reservoir.
- ESRI and WyGISC (Wyoming Geographic Information Science Center).

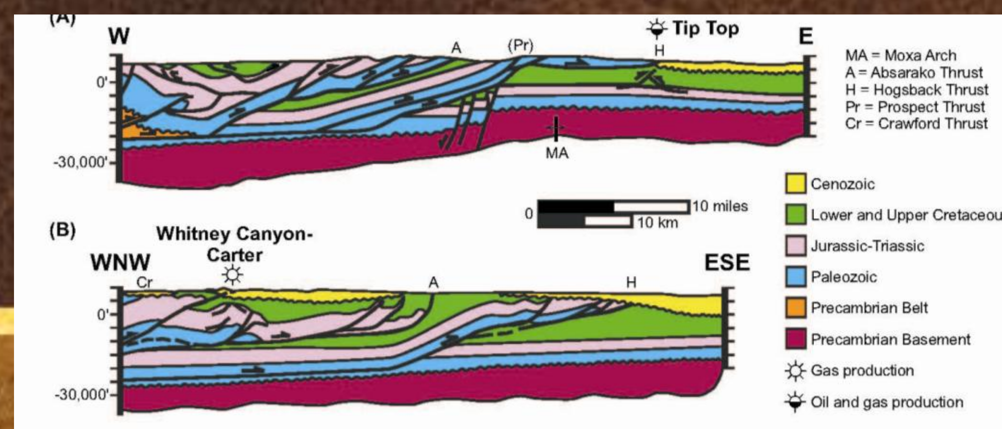
Why do we need a model?

- Carbon sequestration models will be required for screening, scoping and permitting of storage facilities.
- The model requires a geologic framework including stratigraphic, structural and petrophysical data.
- Information will come from public sources (WYOGCC, UGSS, WYGS, scientific literature).
- The primary source for this data are petroleum wells.

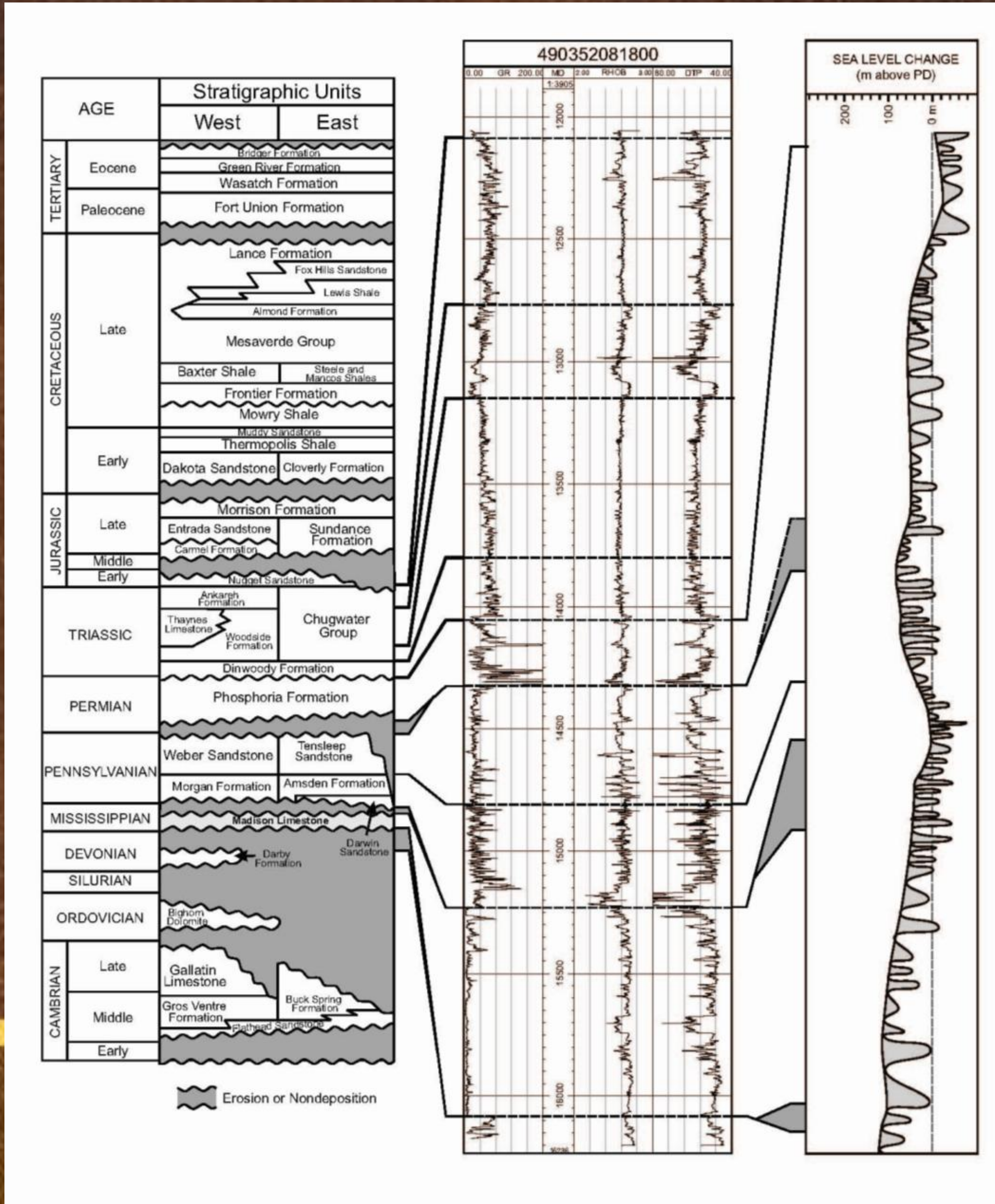
Study Area

- Moxa Arch 140-mile long north-south trending anticline
- Late Cretaceous uplift to create structure
- Extensive trap for hydrocarbons (mostly gas) in Mesozoic and Cenozoic sections
- Paleozoic section contains CO_2, CH_4, H_2S and He
- Zone of interest is Mississippian Madison Formation





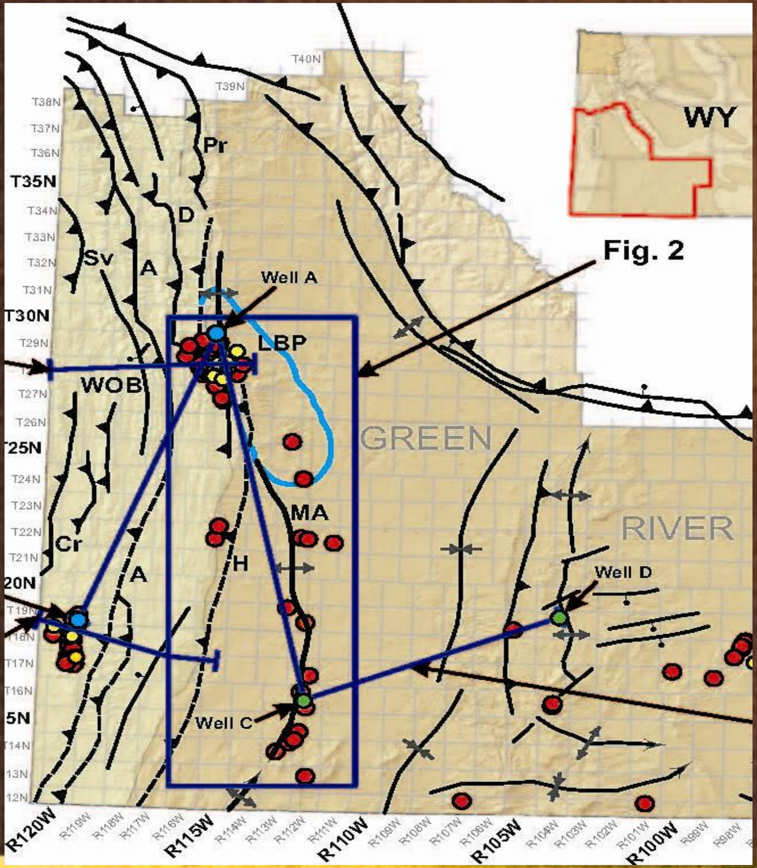
Madison Formation Lithostratigraphy



- Platform carbonate.
- Early dolomitization.
- Six 3rd order sequences.

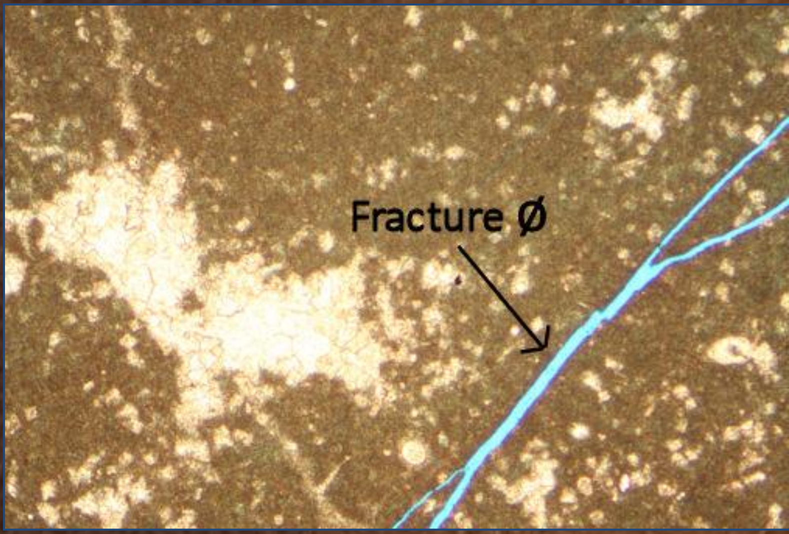
Madison Formation Lithostratigraphy

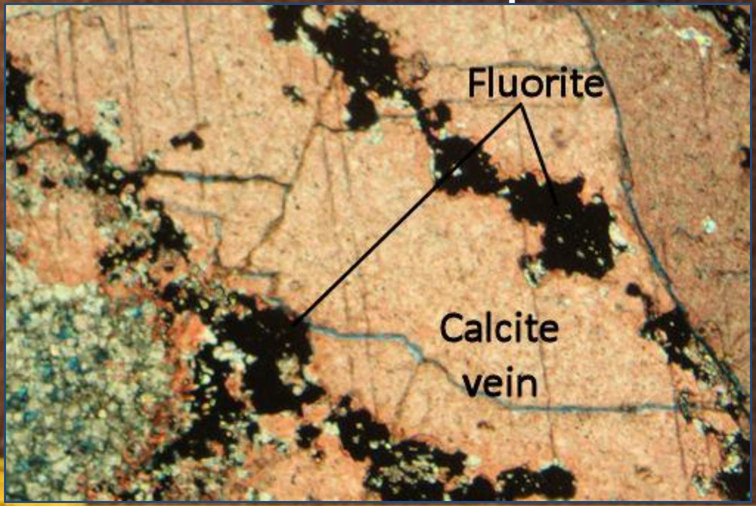
- Primary geological data is from core.
- Four wells with available core (USGS, Cimarex).
- West and east of Arch.
- North and south ends of Arch.



Core Information

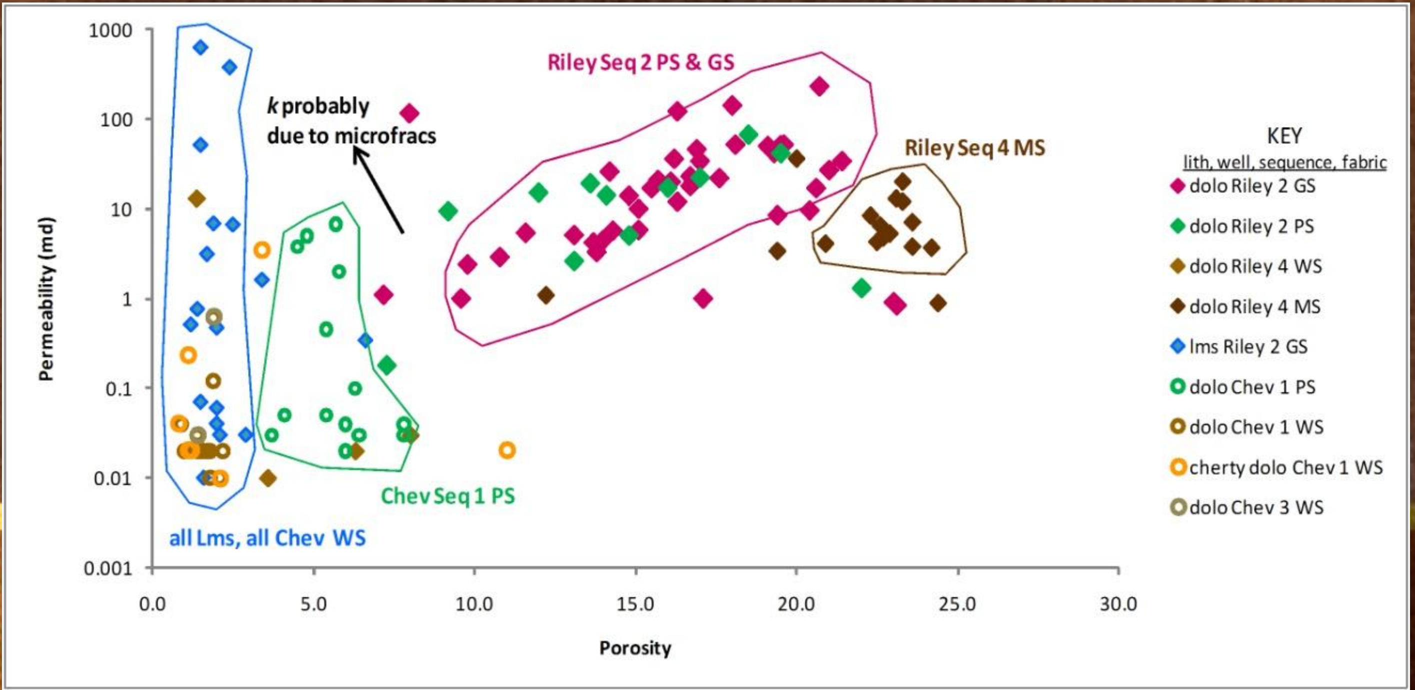
- Detailed descriptions of the four cores.
- Primarily dolomite.
- Thin limestone layers interbedded and near top of sequences.
- Fractures in limestones and dolomite with multiple orientations.





Core Information

- Recognize several facies (karst breccia, micrite, wackestone, packstone, grainstone).
- Two wells have both petrophysical data and core.
- Petrophysical properties related to facies.



More Petrophysical Data

- Standard petrophysical data for 10 more wells at 1-ft. intervals
- Porosity, Kx, Ky and Kz, oil and water saturation, density and mineralogy).

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

023 20361.

CHEVRON U.S.A., INC.
1-30M CHEVRON-FEDERAL
CARTER CREEK FIELD
LINCOLN COUNTY, WYOMING

DATE : 17-JUL-81
FORMATION : MADISON
DRLG. FLUID: N/A
LOCATION : SW SW SEC 30-T19N-119W

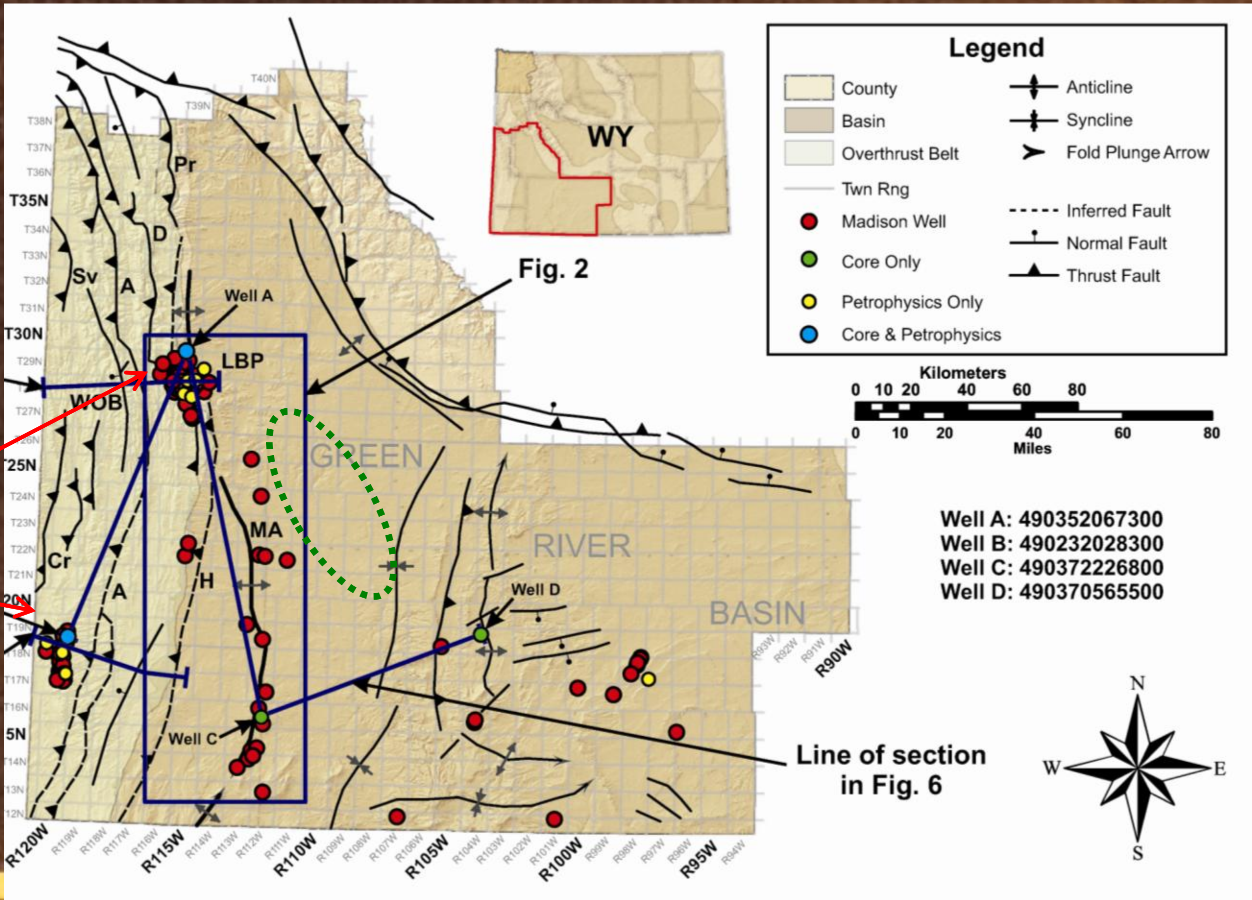
FILE NO : RP-4-6085
ANALYSTS : BERNDT
ELEVATION: 7989 GR.

FULL DIAMETER ANALYSIS--BOYLE'S LAW POROSITY

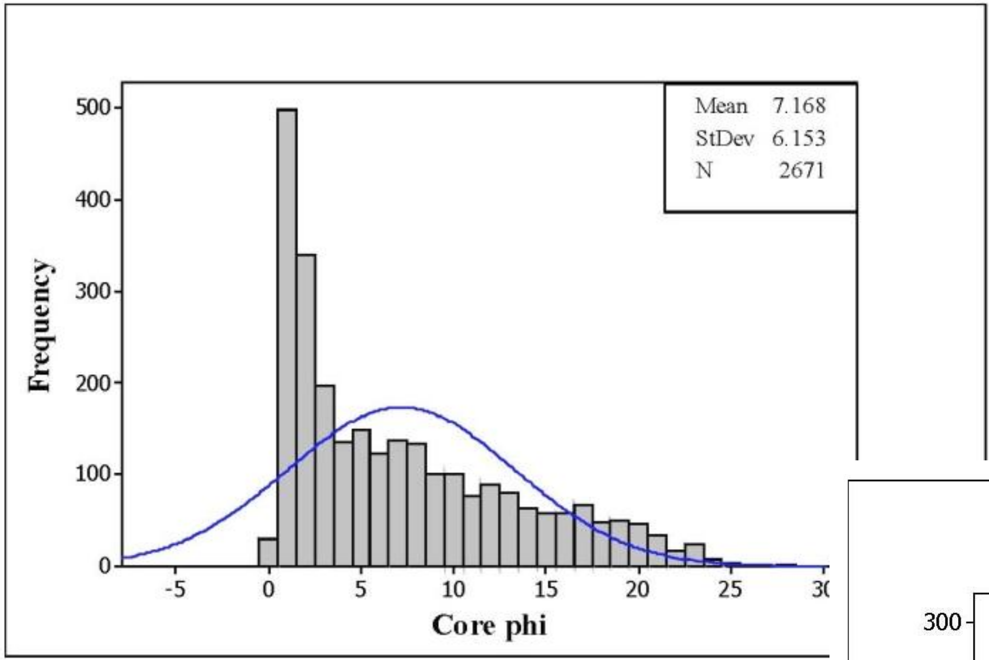
SAMPLE NUMBER	DEPTH	PERM. TO AIR (MD) MAXIMUM	PERM. TO AIR (MD) 90 DEG	PERM. TO AIR (MD) VERTICAL	POR. He	FLUID SATS. OIL	FLUID SATS. WTR	GRAIN DEN	DESCRIPTION
1	15023.0-24.0	0.37	0.26	1.40	7.9	0.0	7.2	2.87	DOL, GY VFXLN ANHY CALC
2	15024.0-25.0	0.14	0.11	0.23	5.8	0.0	31.4	2.86	DOL, GY VFXLN ANHY CALC
3	15025.0-26.0	1.05	0.57	0.31	5.0	0.0	7.1	2.86	DOL, GY VFXLN ANHY CALC STYL
4	15026.0-27.0	0.50	*	0.05	5.2	0.0	62.9	2.86	DOL, GY VFXLN ANHY CALC
5	15027.0-28.0	1.08	0.91	1.12	5.1	0.0	55.5	2.87	DOL, GY VFXLN ANHY CALC V&HF
6	15028.0-29.0	1254.	5.30	14.	9.3	0.0	26.6	2.86	DOL, GY VFXLN ANHY CALC VF
7	15029.0-30.0	1398.	1.91	0.81	2.6	0.0	51.5	2.85	DOL, GY VFXLN ANHY CALC VF
8	15030.0-31.0	11.	1.99	3.72	4.5	0.0	26.4	2.86	DOL, GY VFXLN ANHY CALC
9	15031.0-32.0	6.74	5.06	1.42	2.0	0.0	52.9	2.83	DOL, GY VFXLN ANHY CALC
10	15032.0-33.0	8.63	4.20	2.40	2.2	0.0	45.7	2.87	DOL, GY VFXLN ANHY CALC
11	15033.0-34.0	17.	7.87	0.98	1.7	0.0	67.1	2.83	DOL, GY VFXLN ANHY CALC
12	15034.0-35.0	399.	5.52	2.50	1.5	0.0	60.8	2.84	DOL, GY VFXLN ANHY CALC VF
13	15035.0-36.0	7.52	1.57	0.22	2.3	0.0	69.9	2.84	DOL, GY VFXLN ANHY CALC
14	15036.0-37.0	9.22	5.76	1.20	2.5	0.0	85.3	2.85	DOL, GY VFXLN ANHY CALC
15	15037.0-38.0	4.88	2.66	2.16	2.9	0.0	79.3	2.86	DOL, GY VFXLN ANHY CALC
16	15038.0-39.0	28.	25.	10.	3.7	0.0	55.8	2.86	DOL, GY VFXLN ANHY CALC HF
17	15039.0-40.0	76.	*	0.04	2.6	0.0	81.3	2.83	DOL, GY VFXLN ANHY CALC
18	15040.0-41.0	3.86	1.40	3.28	3.9	0.0	79.0	2.85	DOL, GY VFXLN ANHY CALC HF
19	15041.0-42.0	0.01	*	0.60	1.1	0.0	85.1	2.82	DOL, GY VFXLN ANHY CALC
20	15042.0-43.0	94.	3.46	10.	3.3	0.0	87.2	2.84	DOL, GY VFXLN ANHY CALC
21	15043.0-44.0	361.	0.74	0.16	3.1	0.0	71.9	2.84	DOL, GY VFXLN ANHY CALC
22	15044.0-45.0	10.	6.30	3.01	3.3	0.0	32.9	2.85	DOL, GY VFXLN ANHY CALC
23	15045.0-46.0	38.	3.76	6.88	7.1	0.0	3.2	2.86	DOL, GY VFXLN ANHY CALC
24	15046.0-47.0	1467.	6.16	0.03	7.8	0.0	7.4	2.86	DOL, GY VFXLN ANHY CALC VF
25	15047.0-48.0	4.27	1.42	4.52	7.5	0.0	4.7	2.86	DOL, GY VFXLN ANHY CALC VF
26	15048.0-49.0	224.	2.89	3.36	6.3	0.0	3.7	2.85	DOL, GY VFXLN ANHY CALC VF
27	15049.0-50.0	0.29	0.10	0.19	7.8	0.0	19.7	2.84	DOL, GY VFXLN ANHY CALC
28	15050.0-51.0	0.78	0.49	0.19	8.8	0.0	3.0	2.85	DOL, GY VFXLN ANHY VUG

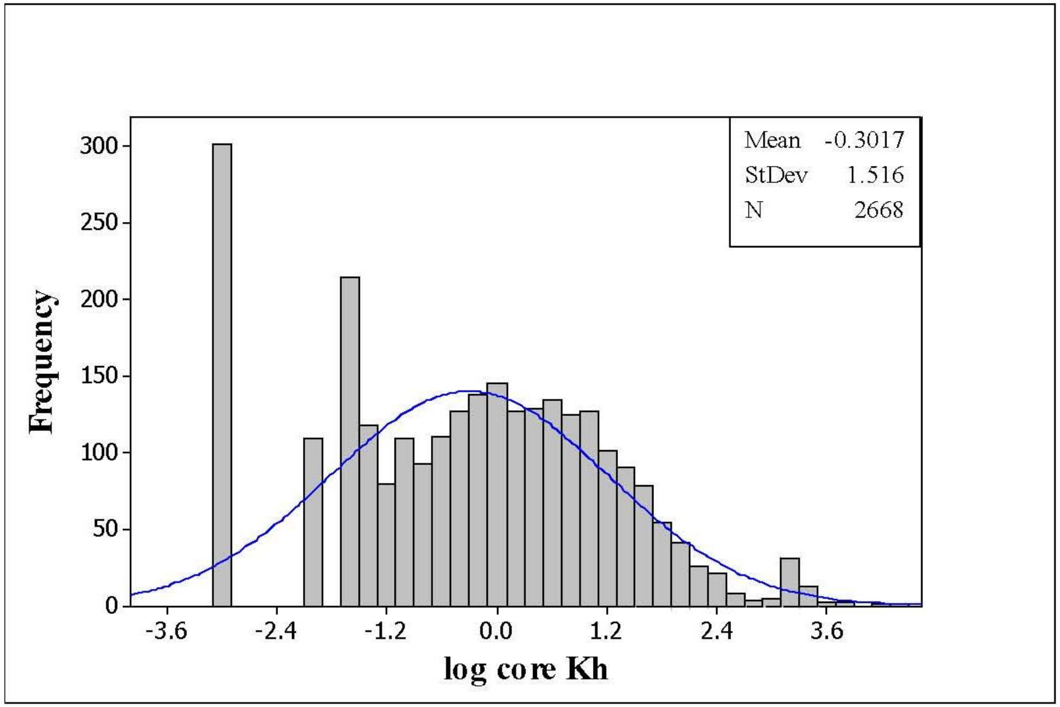
Caveat: Potential Biases in the Petrophysical Data

- Most of the petrophysical data comes from unavailable core.
- May not proportionally represent formation.
- Core-based petrophysical data from only two locations.

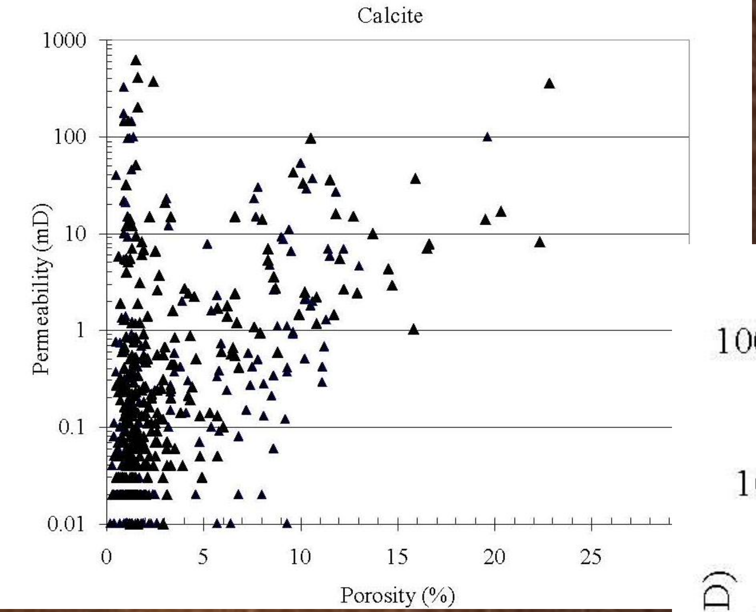


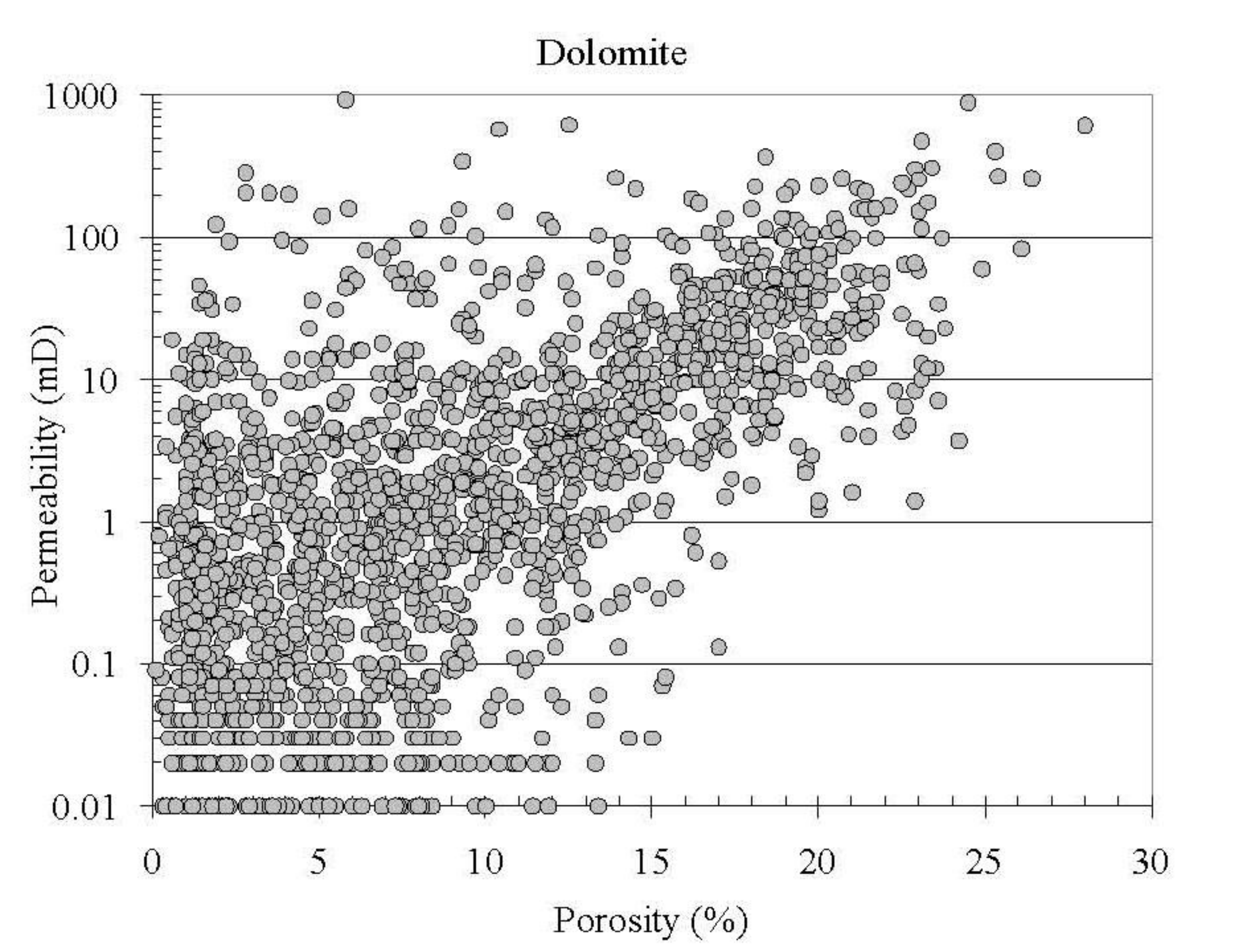
Petrophysical Data from All Cores





Petrophysical Data from All Cores





Core-Based Well Information

- Core-based data show:
  - Mainly dolomite with interbedded calcite and anhydrite.
  - Core descriptions and thin sections show fractures.
  - Porosity distribution skewed toward low values.
  - Permeability is log-normal.
  - Ø vs. log k for higher Ø).
  - Poor correlation between Ø and k in low-porosity rocks.
- This is the primary data to populate model grid.

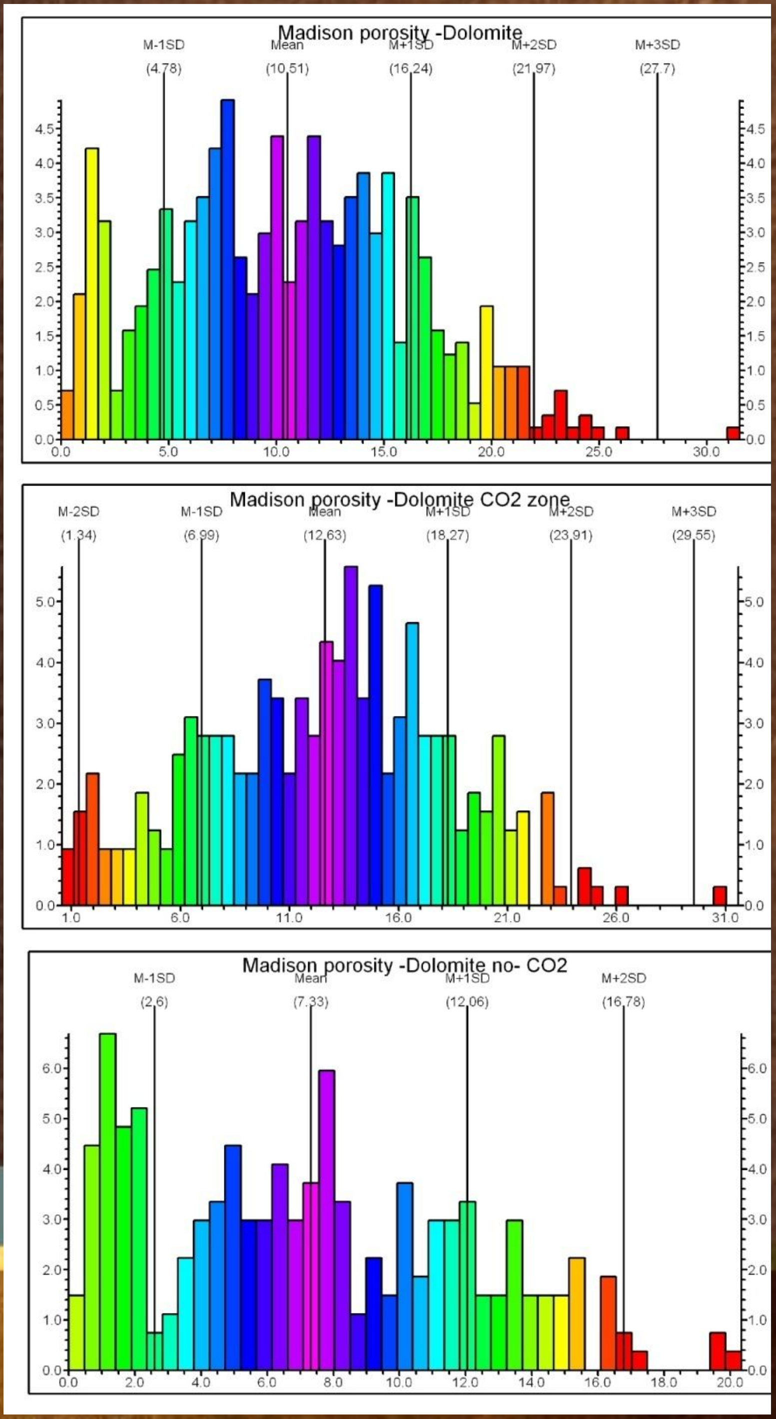
Dolomite Porosity by Location

CO_2 versus no CO_2

Average porosity = 10.5

Average porosity in gas cap = 12.6

Average porosity outside gas cap = 7.33

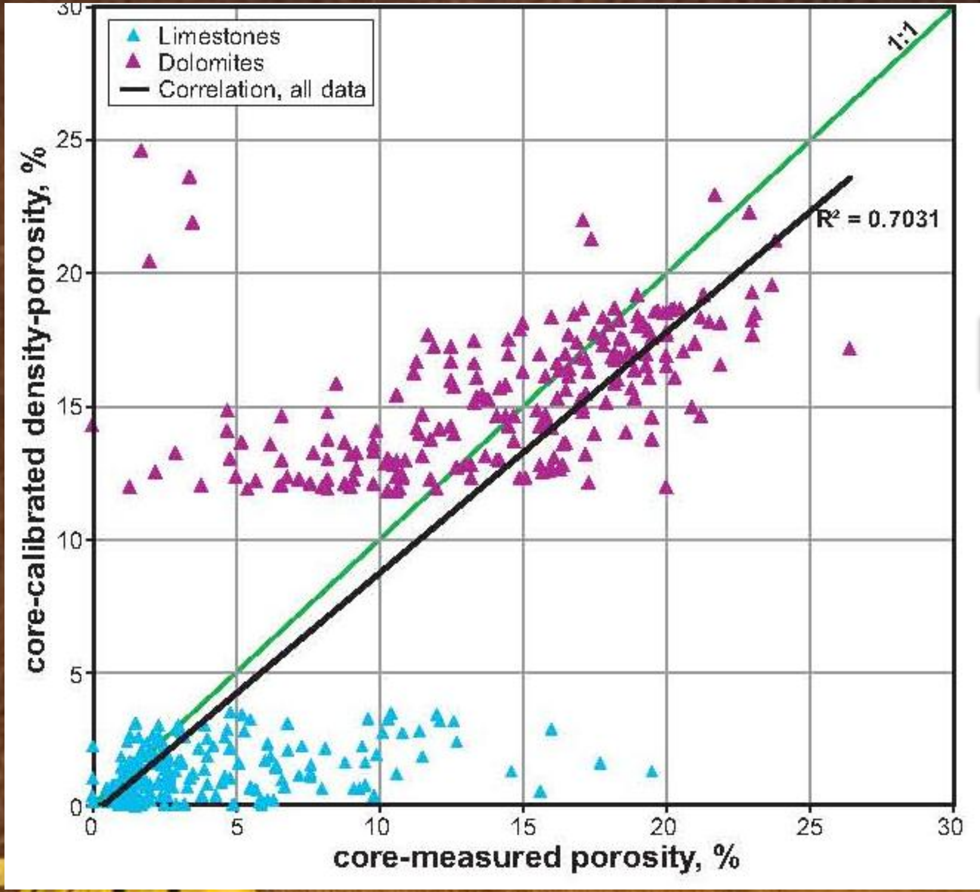


Extending the Data

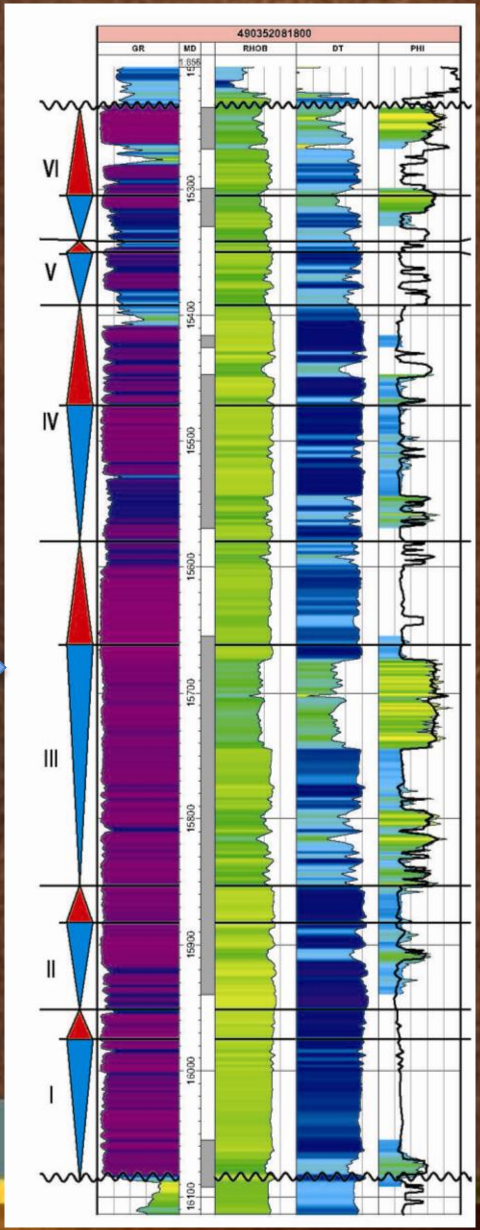
- There are 95 wells that penetrate the Madison Formation in the study area.
- Most have geophysical logs through entire section.
- Use sonic logs to reconstruct bulk density where necessary (Gardner et al. 1974), and bulk density logs to calculate porosity (Schlumberger 1972).
- Calibrate relationship by comparing log-based and measured porosity.
- Used calculated values every 0.5 feet to generate porosity for wells with logs.
- Extend petrophysical database (n = 2,671) by calculating log-based porosity for nine wells (n = 11,959).

Log-Based versus Core Porosity

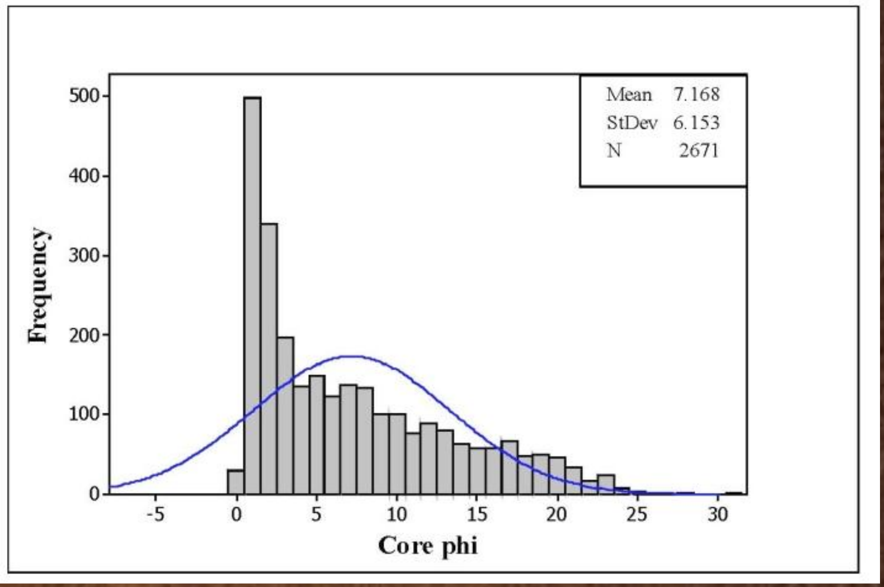
Low-porosity samples do not have a strong correlation.

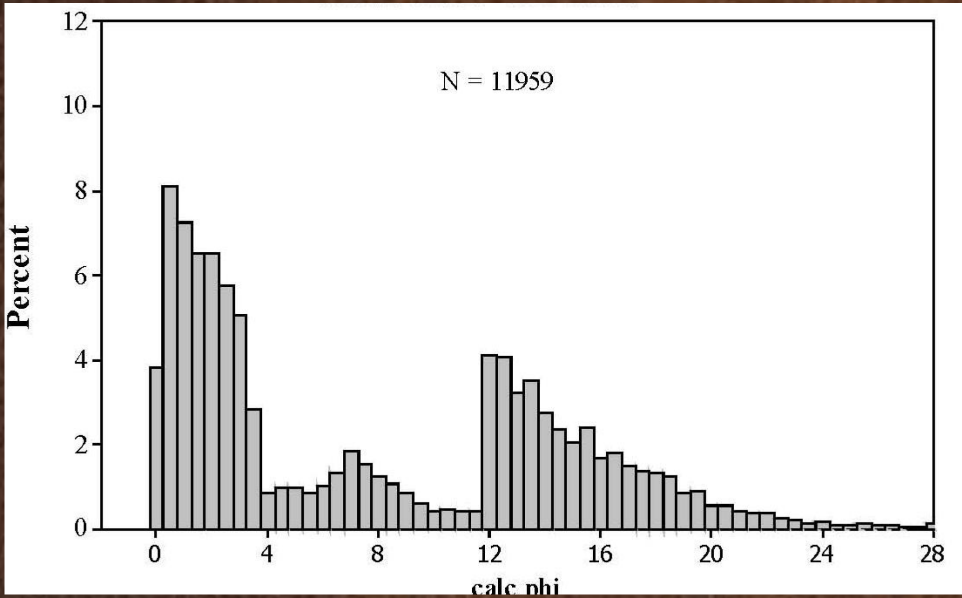


Synthetic Porosity

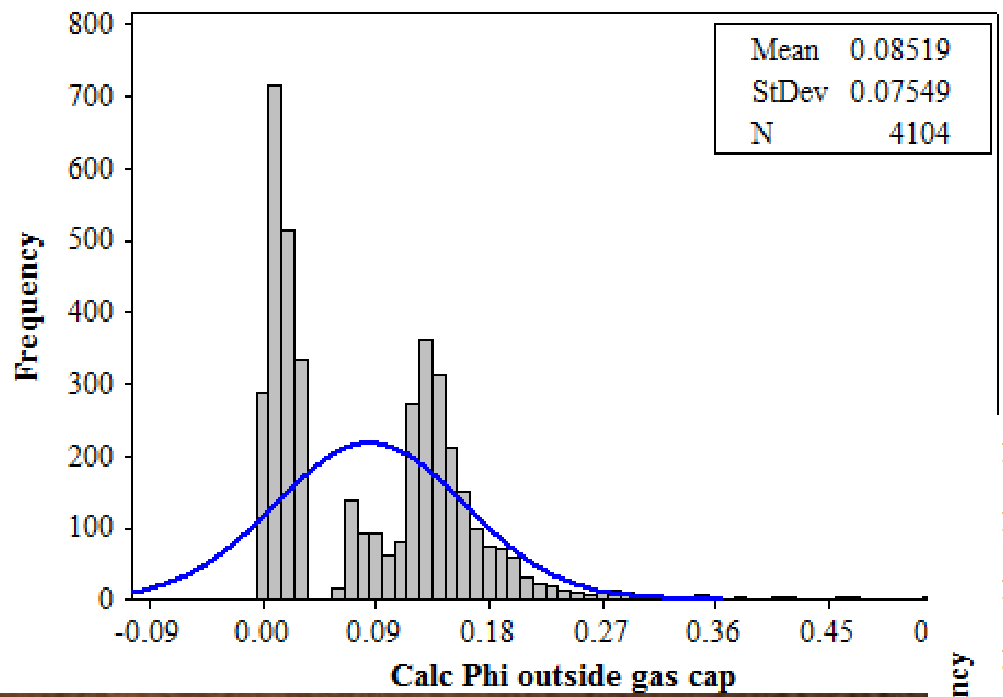


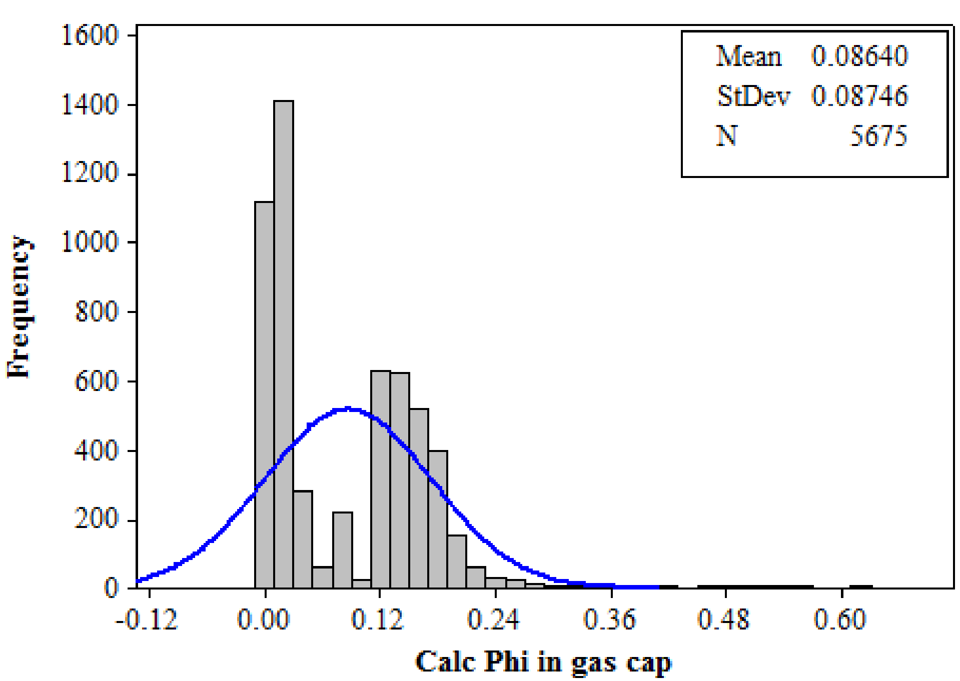
Petrophysical data
core versus log



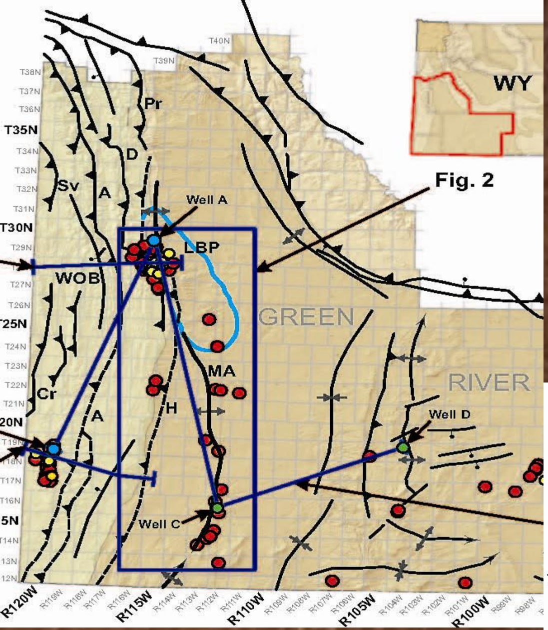


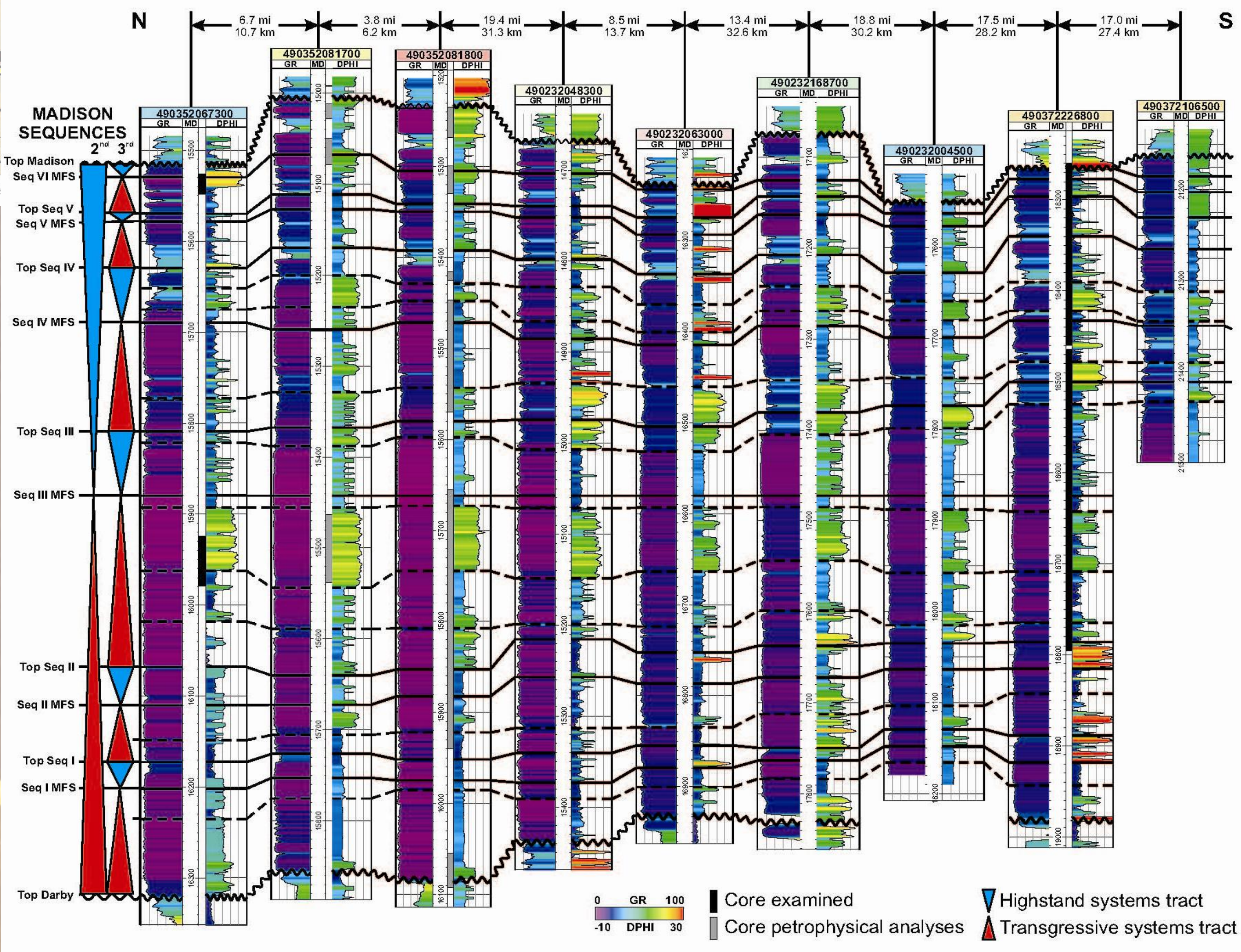
Petrophysical data
log-based shows no location bias





Can Now Generate North-South Transect Non-typical Madison Reservoir





Log-Based Petrophysical Data

- Good reservoir intervals are in third and fourth sequences (still facies controlled).
- High-porosity zones extend over 10's miles.
- Trimodal porosity distribution?
- Three Ø classes in formation.
- <4%, Mean = 2%, (45%).
- 4 – 12%, Mean = 7.5%, (16.5%).
- >12%, Mean = 14%, (37.7%).

Conclusions

- Core-based petrophysical data is primary source to characterize the Madison in the study area.
- Core-based petrophysical data is somewhat biased, (not representative of entire formation).
- We can extend the Ø data using geophysical logs to create calibrated synthetic porosity logs.
- Extended data shows different distribution of reservoir quality than previous work in Wyoming.
- Further refinement of synthetic porosity indicated.