[PS] A Regional Lithostratigraphic Model of the Eau Claire Formation (Cambrian): How Much Shale is in the Confining Unit?*

R. Lahann[1], C. Medina[1], J. Rupp[1], T. Lovell[2], B. Bowen[2], D. Barnes[3], J. Hickman[4], R. Bandy[4], and J. Sminchak[5]

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Abstract

Several studies have been published that evaluate the potential of the Mount Simon Sandstone (Cambrian) to serve as a CO_2 storage reservoir. However, relatively few studies have examined the sealing properties of the overlying Eau Claire Formation (Cambrian) or the regional variation of those sealing properties.

For this study, suites of wireline logs from 77 wells from Michigan, Ohio, Kentucky, Illinois, and Indiana were used to define electrofacies for the Eau Claire interval. The electrofacies were defined using a clustering program, the software "Geological Analysis of Maximum Likelihood System" (GAMLS). One well per county was chosen in an attempt to avoid spatial bias in the clustering process. Many counties were not represented either owing to an absence of drilling or inadequate log control. The wells that were used contained a gamma-ray log and at least two porosity-related logs (sonic, density or neutron). The log data were conditioned within GAMLS prior to clustering. The cluster run was seeded with the gamma-ray logs and then divided into twelve electrofacies, which were assigned to seven lithofacies: (1) argillaceous dolostone/dolomitic sand, (2) dolostone, (3) clean silt, (4) muddy silt, (5) silty shale, (6) dolomitic shale, and (7) clean shale. The choices of lithofacies were based on mean log responses for the cluster mode. The abundance of silt-sized feldspar made differentiation of high-gamma siltstones from shales problematic. The validity of the lithofacies assignments were confirmed by core description, petrology, and inorganic geochemistry for selected sites in Illinois and Indiana. Confirmation using locations in Ohio, Michigan, and Kentucky is in progress.

Examination of the GAMLS models for lithofacies across the five-state region indicated the development of a significant silty package in the lower half of the Eau Claire in NW Indiana. This package thins to the southeast. The other distinctive regional pattern observed was an increase in sandy dolomite from west to east across Kentucky into the laterally equivalent Conasauga Formation or Group in Kentucky and Ohio. Additionally, an increase in shale content was interpreted towards the center of the Michigan basin. How these multiple lithofacies vary both vertically within the interval that is designated as the confining unit and how they vary laterally across the region will control the effectiveness of the seal and control storage practices.

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[1]Indiana Geological Survey, [2]Purdue University, [3]University of Utah, [4]Western Michigan University, [5]University of Kentucky, [6]Battelle Institute

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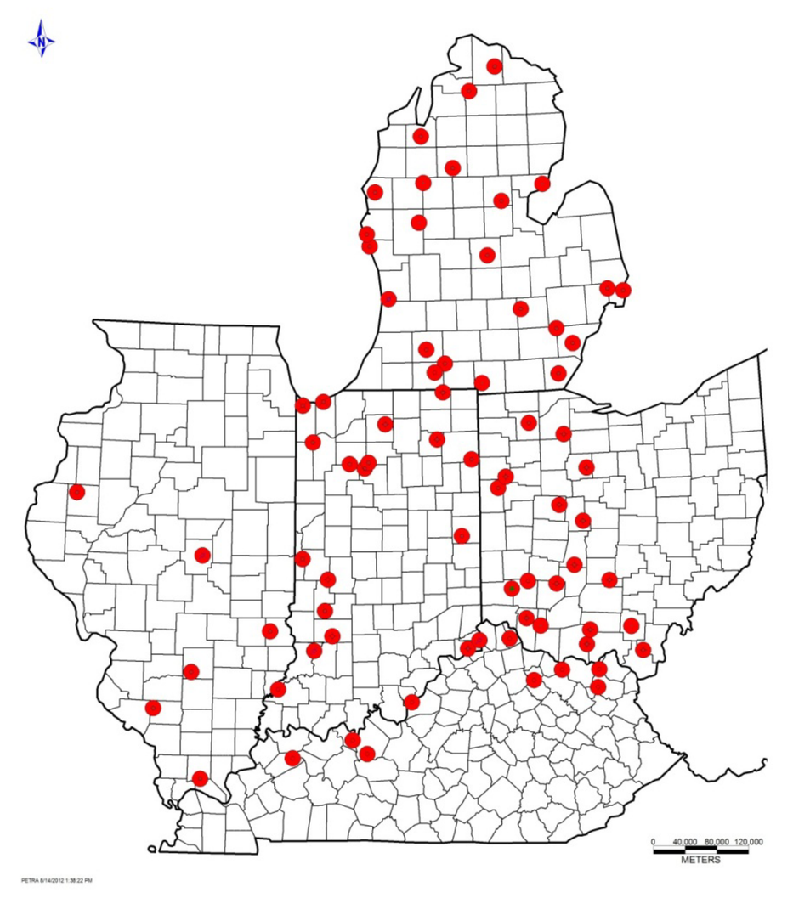
GAMLS

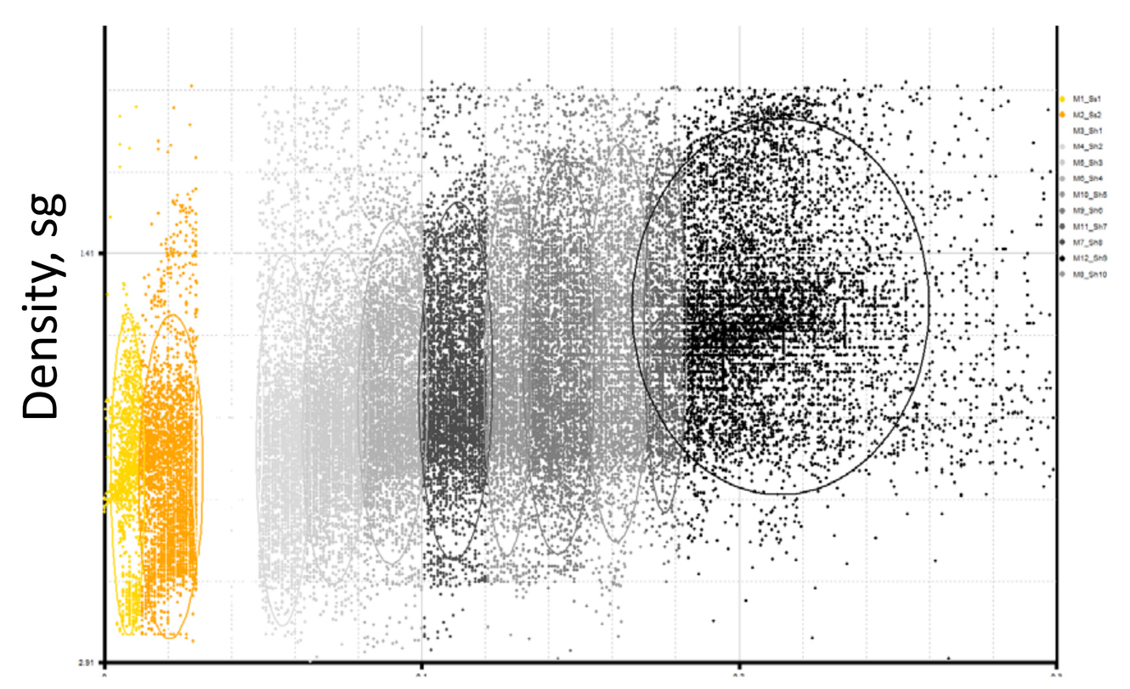
"Geologic Analysis of Maximum Likelihood System" (GAMLS)

- Clustering program for geologic data
- 80 wells clustered from Indiana, Kentucky, Illinois, Ohio and Michigan. One well/county.
- Logs: Gamma Ray, Density, Neutron, and Sonic. Gamma and at least 2 of the 3 porosity logs must be present for inclusion of well.
- Resistivity was tested and found to not be useful in discriminating lithofacies within this interval.

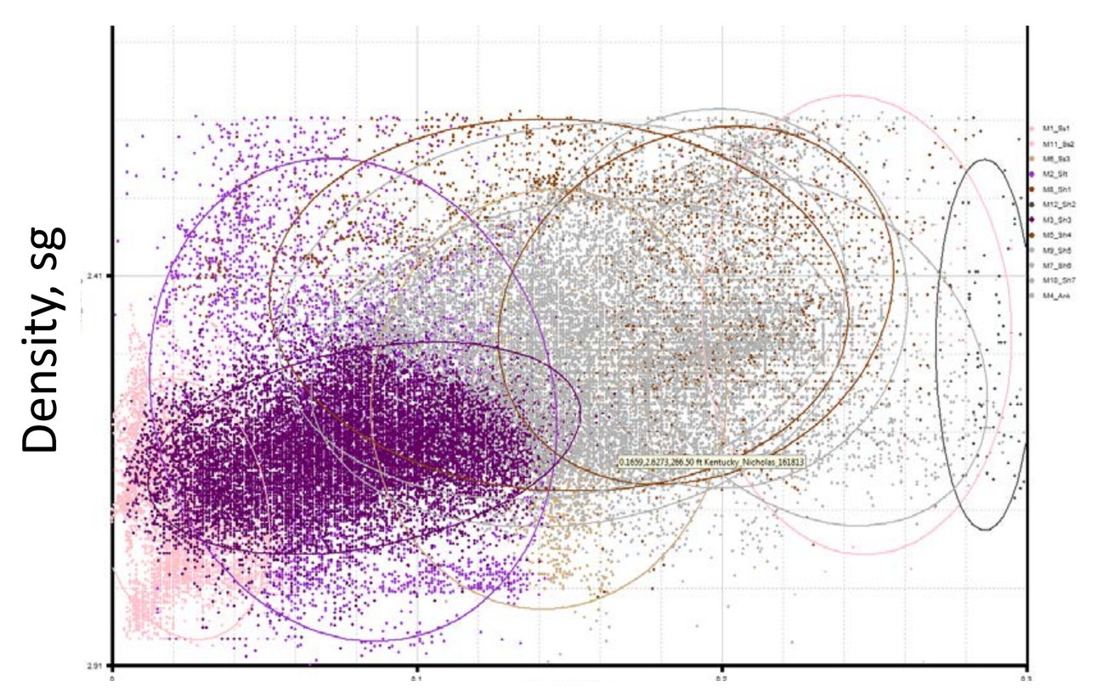


Wells were chosen on the basis of one well/county, in order to minimize distortion of the results due to spatial bias. The well with the most complete log-data set was chosen for each county.

Initial Neutron-Based Bin Assignments



Result of Clustering Run



Comparison of seed mode assignments and final binning indicates that a successful binning operation was completed. Note the separation of many bins and the changes in the neutron-density trends.

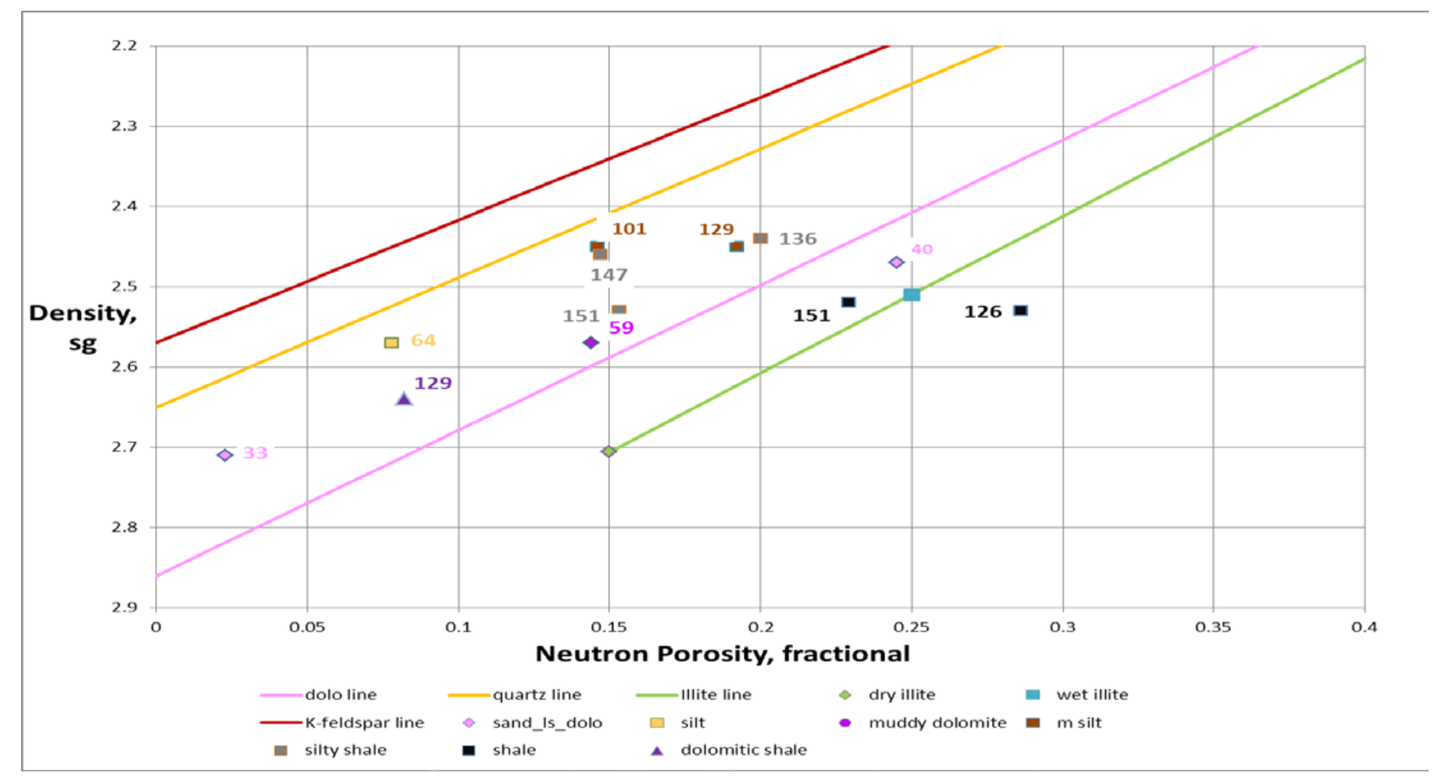
GAMLS Binning Output

Mode	Name	Lith	Plot	Color	%	Hold	Warnings
1	M1_Ss1	Ss	Yes	pink	8.47	☑	
11	M11_Ss2	Ss	Yes	pink	0.19	☑	
6	M6_Ss3	Ss	Yes	dk orchid	3.31	☑	
2	M2_Slt	Slt	Yes	burlywood	8.73	☑	
8	M8_Sh1	Sh	Yes	brown4	7.84	☑	
12	M12_Sh2	Sh	Yes	gray30	0.25	☑	
3	M3_Sh3	Sh	Yes	purple5	31.57	☑	
5	M5_Sh4	Sh	Yes	brown4	5.05	☑	
9	M9_Sh5	Sh	Yes	gray70	6.17	☑	
7	M7_Sh6	Sh	Yes	gray70	0.86	☑	
10	M10_Sh7	Sh	Yes	gray30	1.40	☑	
4	M4_Ank	Ank	Yes	gray70	26.14	☑	

Mode	GD	GR	NEUT	RHO...	ITT_2
1	2.679	33.0	0.023	2.713	49.3
11	2.419	39.2	0.245	2.470	74.1
6	2.592	59.2	0.144	2.574	62.6
2	2.290	64.1	0.078	2.573	58.7
8	2.357	101.2	0.192	2.450	72.3
12	0.675	126.0	0.286	2.530	74.5
3	2.691	129.0	0.082	2.639	61.4
5	2.438	129.3	0.146	2.445	69.6
9	0.000	136.1	0.200	2.437	73.9
7	2.613	136.5	0.147	2.458	77.1
10	2.372	151.0	0.229	2.524	76.1
4	3.143	132.2	0.153	2.531	68.4

The output of the GAMLS binning routine is the division of the log values into twelve petrophysical lithofacies. These were then interpreted and combined into the seven lithofacies.

Cluster Median Neutron-Density Values with Cluster Average Gamma Posted

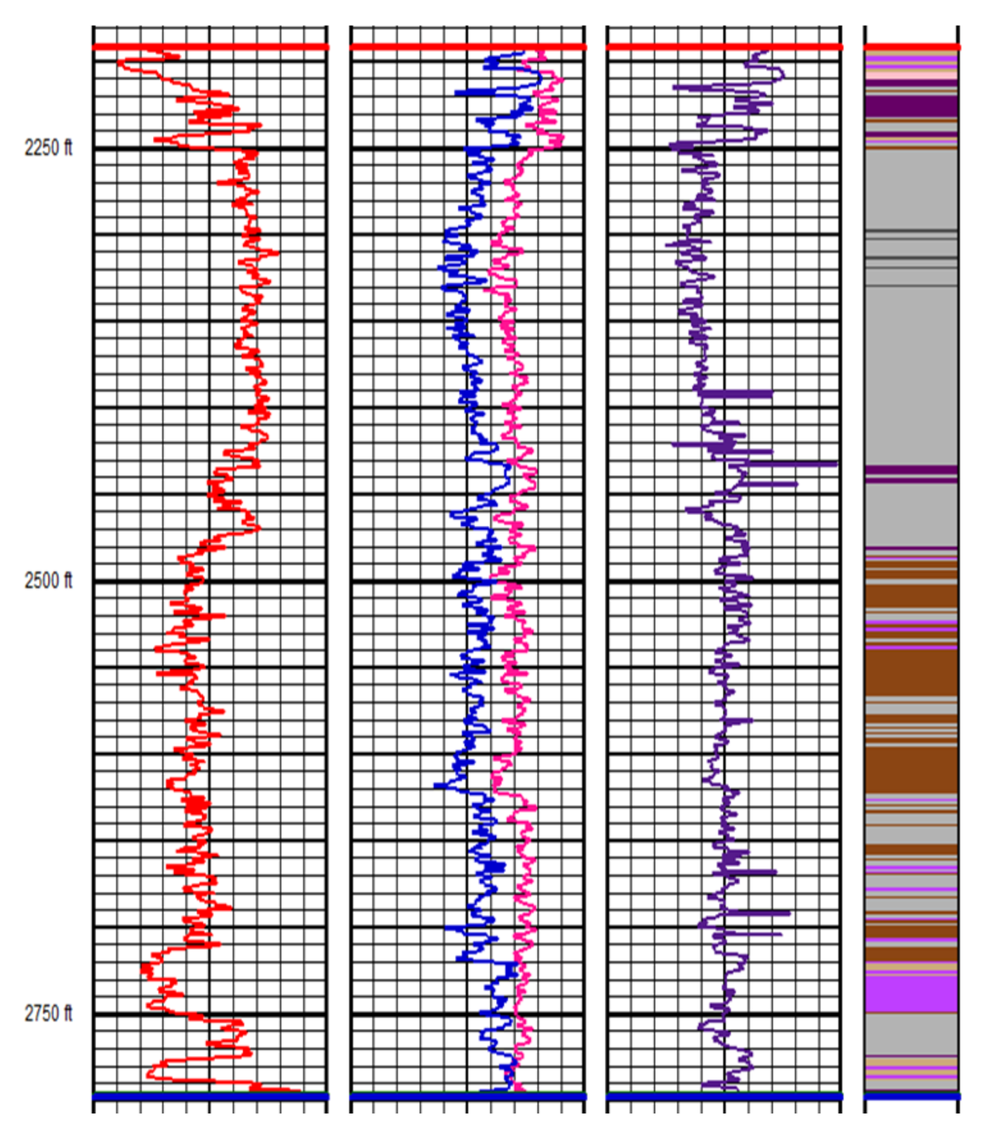


Posting median mode gamma values for each of the seven lithofacies and wet/dry illite on a neutron-density plot shows effect of gamma on binning (Z axis). GAMLS outputs of 12 bins were collected into 7 lithofacies.

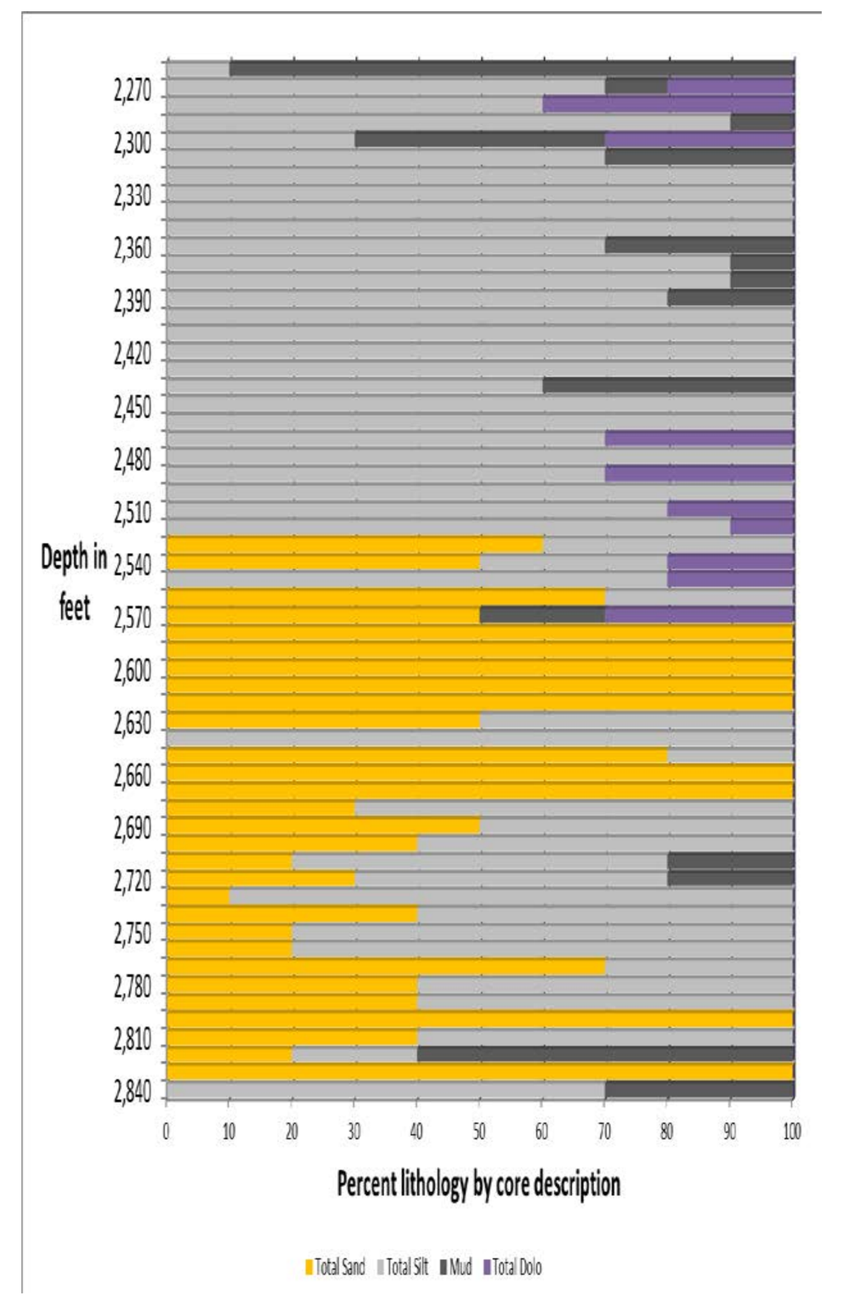
Geological interpretation of GAMLS lithofacies assignments.

	CRISP 1-12	Color
LS/Dolo/SS	1, 11	
Muddy Dolomite	6	
Dolomitic Shale	3	
Clean Silt	2	
Muddy Silt	5, 8	
Clean Shale	10, 12	
Silty Shale	4, 7, 9	

Fulton County, Indiana



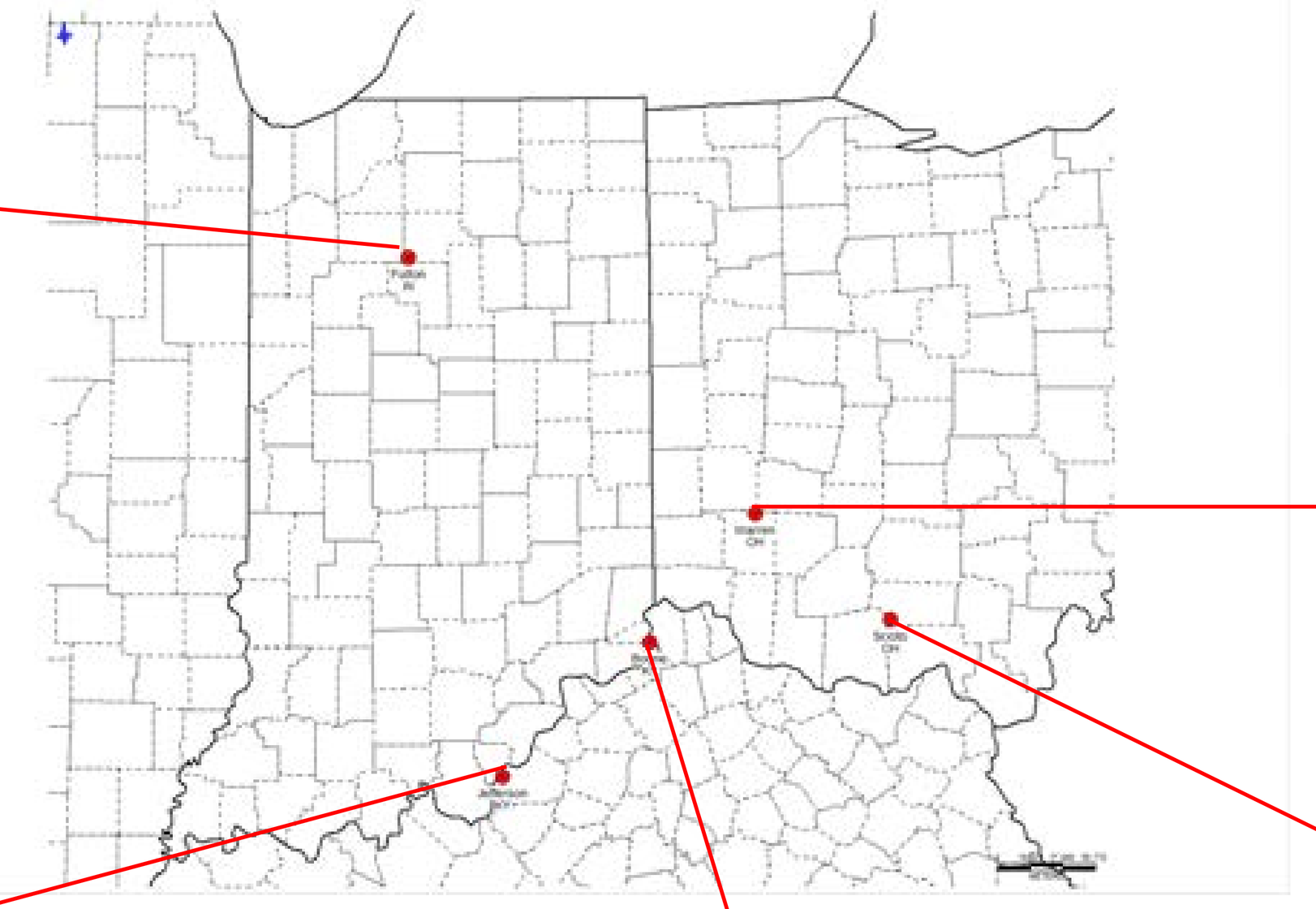
Core Description by T. Lovell
Purdue University



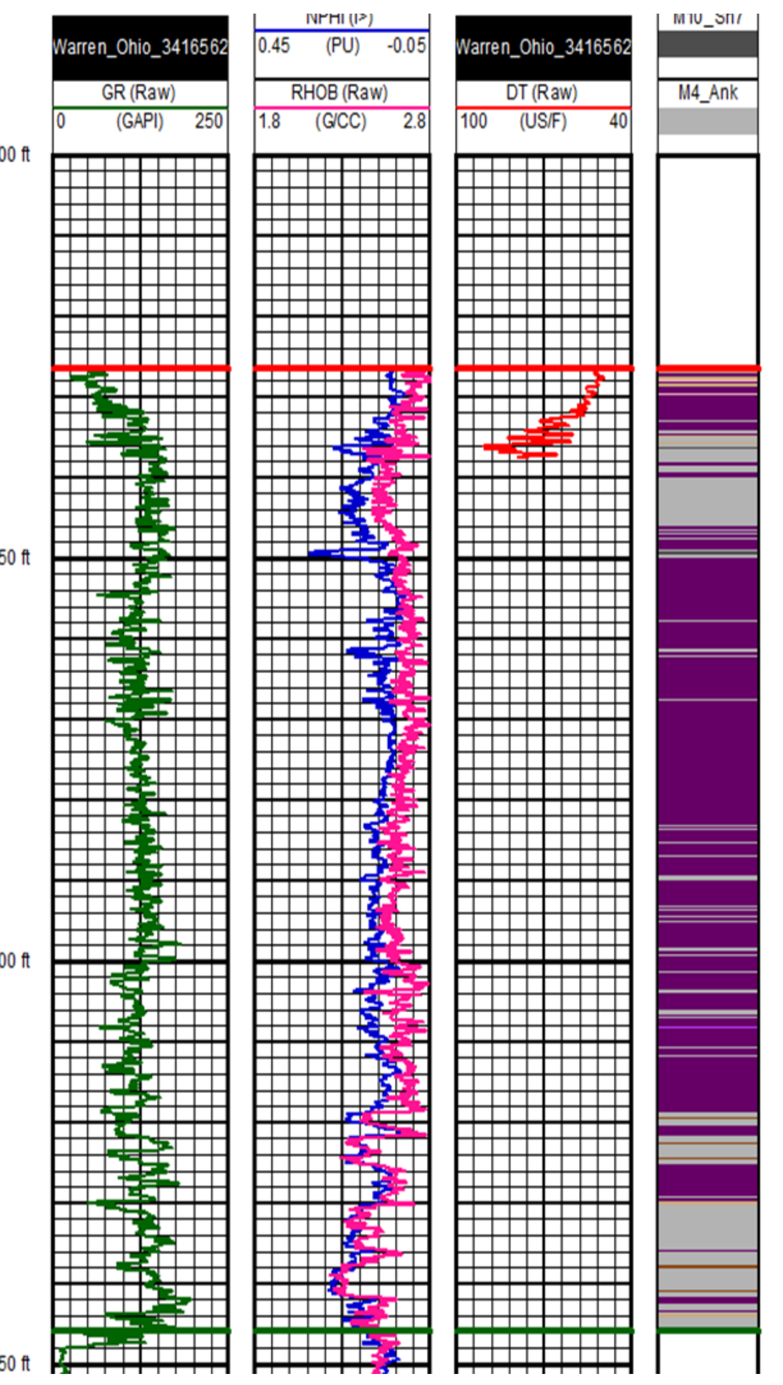
Lower Eau Claire interpreted as sand and silt by core description and muddy silt/silty shale by GAMLS. Upper Eau Claire interpreted as silty shale and shale by core description and by GAMLS.

Cores/GAMLS interpretations

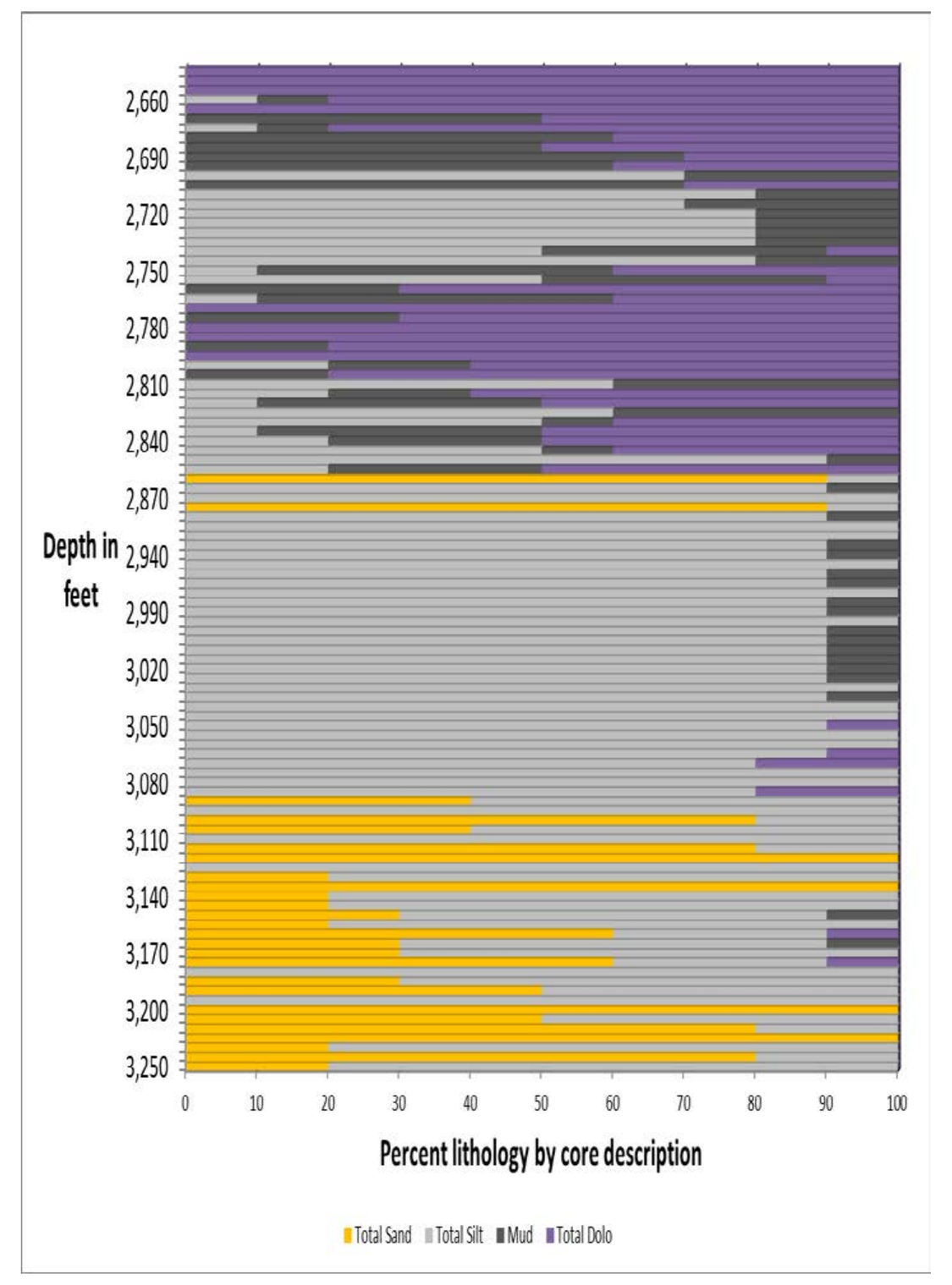
Locations of cores described in order to tie GAMLS lithologies to observed/interpreted lithologies.



Warren County , Ohio

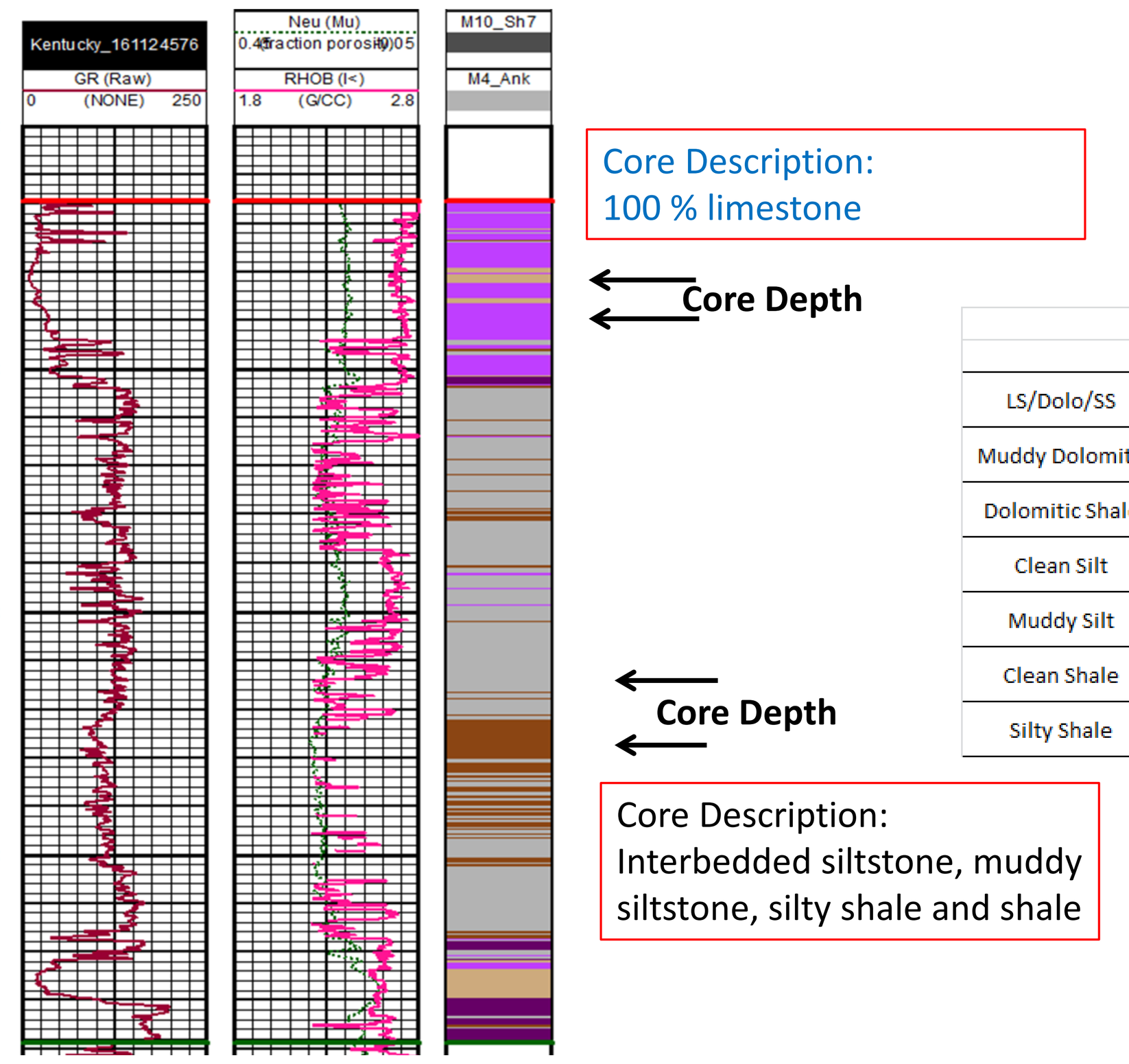


Core Description by Ralph Bandy, U. of Kentucky



Western Ohio cores and GAMLS show increasing carbonate content relative to Kentucky and Indiana and broad correlation of GAMLS and core-based lithologies.

Jefferson County, Kentucky



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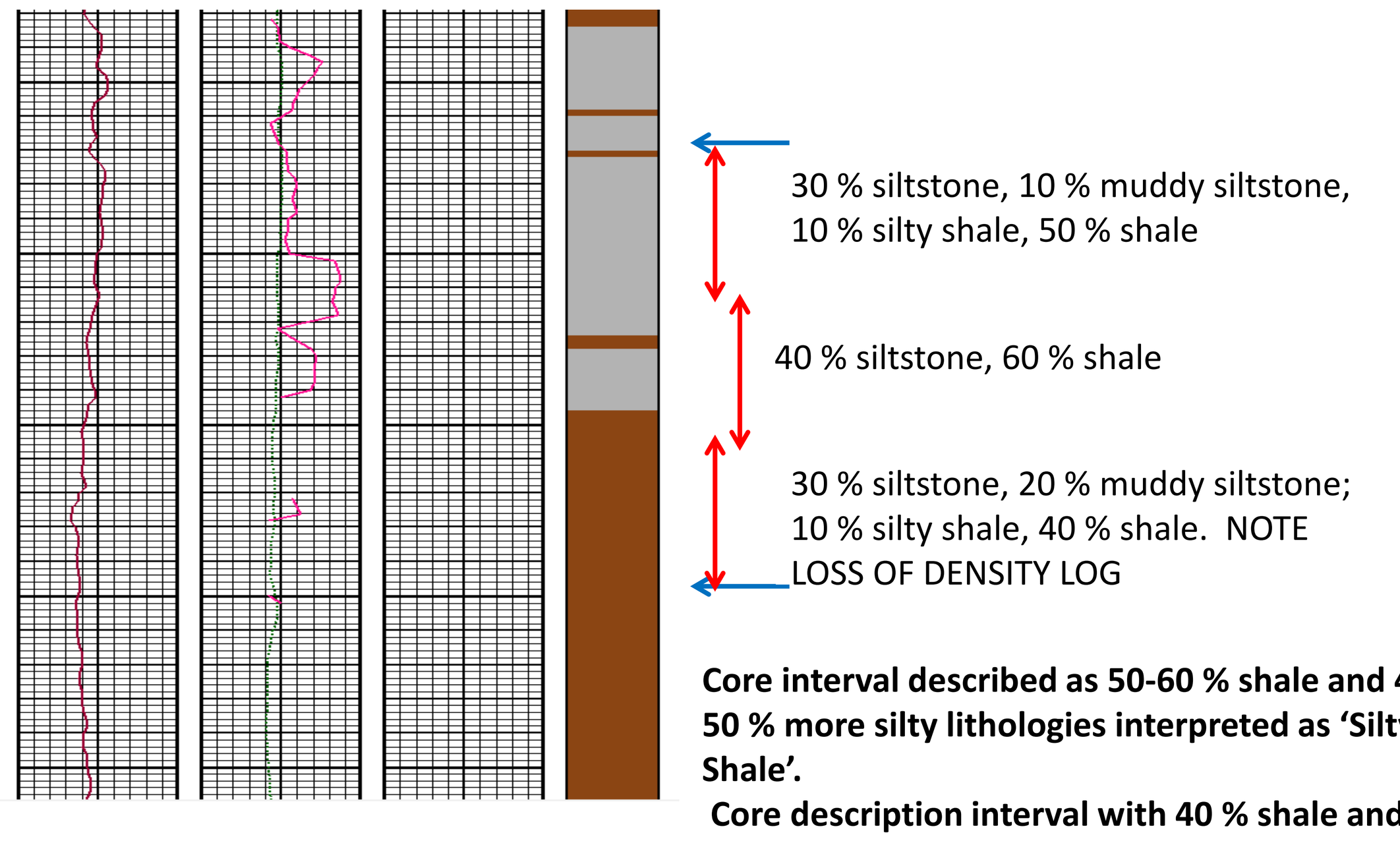
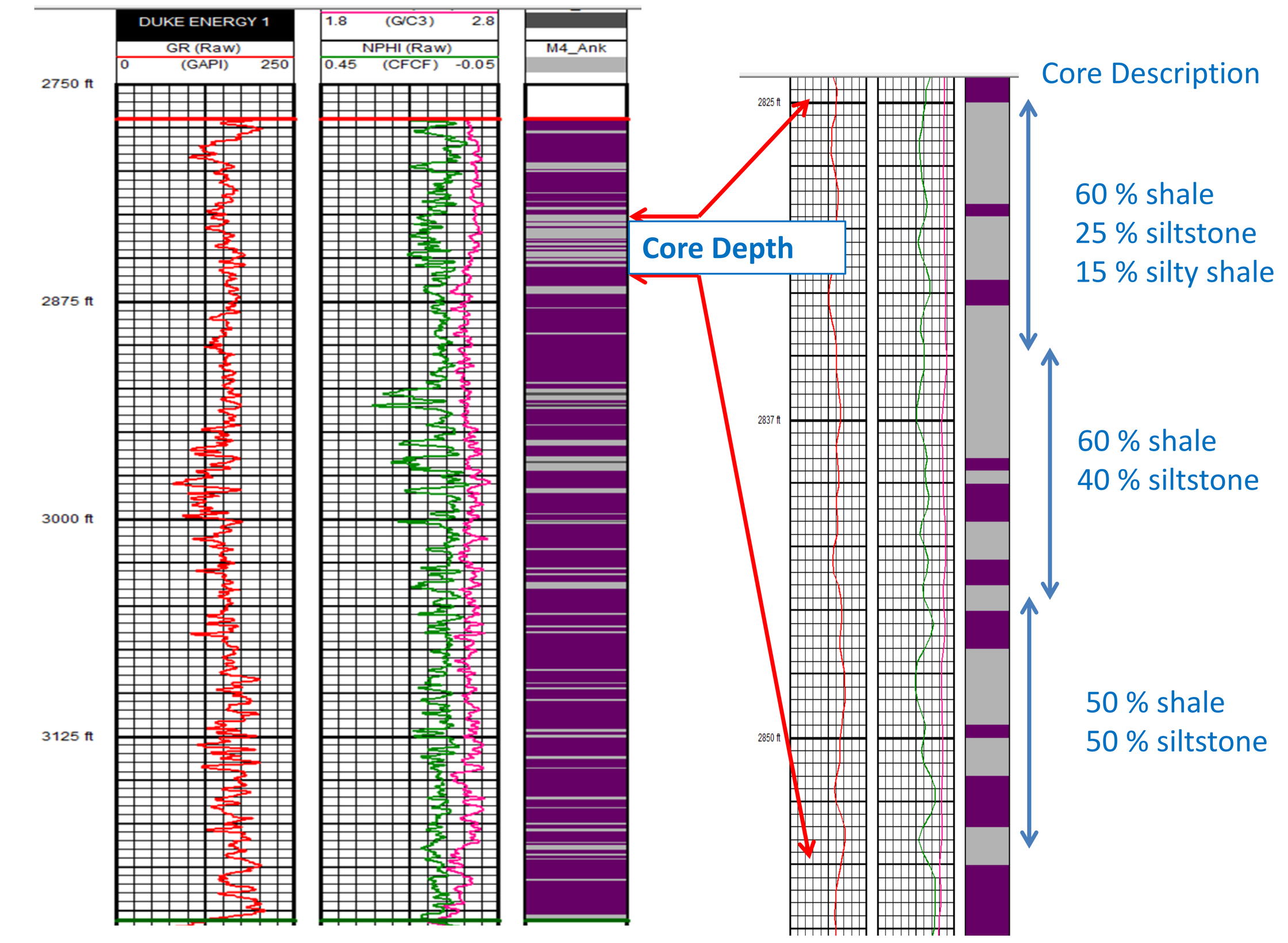


Core Description by Ralph Bandy, U. of Kentucky

Core interval described as 50-60 % shale and 40-50 % more silty lithologies interpreted as 'Silty Shale'.
Core description interval with 40 % shale and 60 % more silty lithologies interpreted as muddy siltstone.

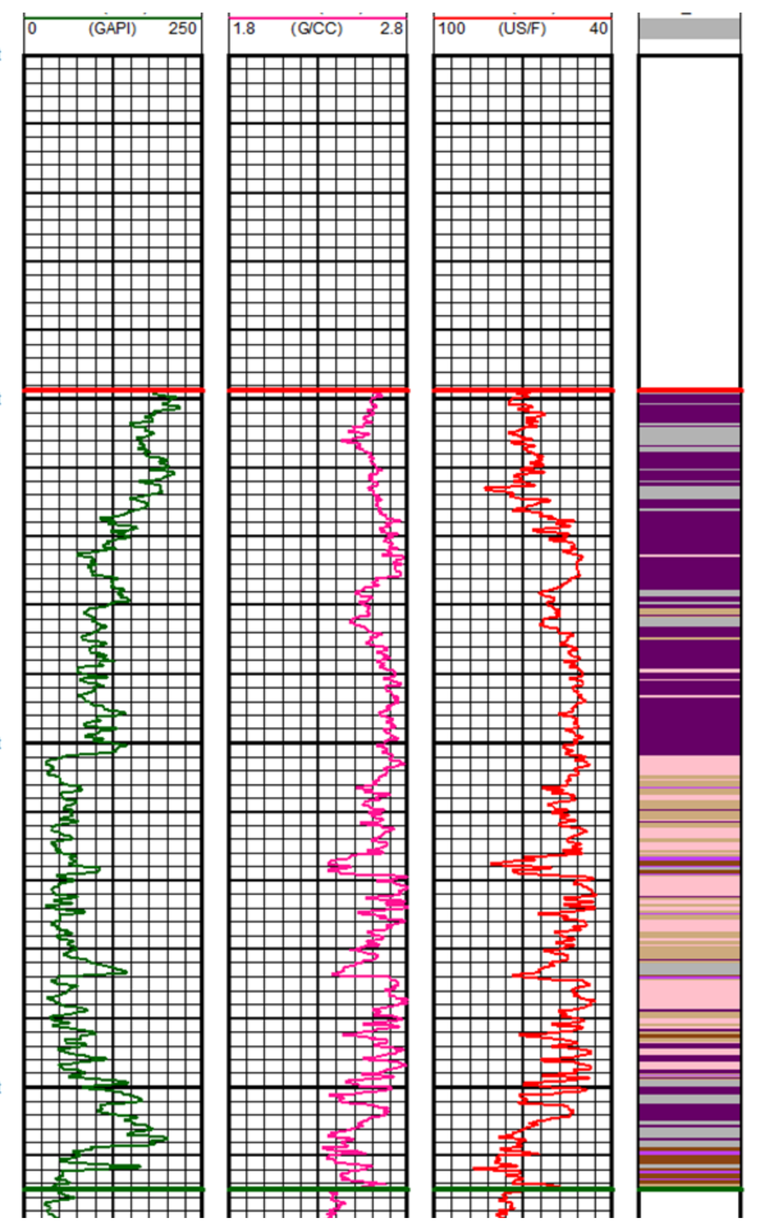
Boone County, Kentucky

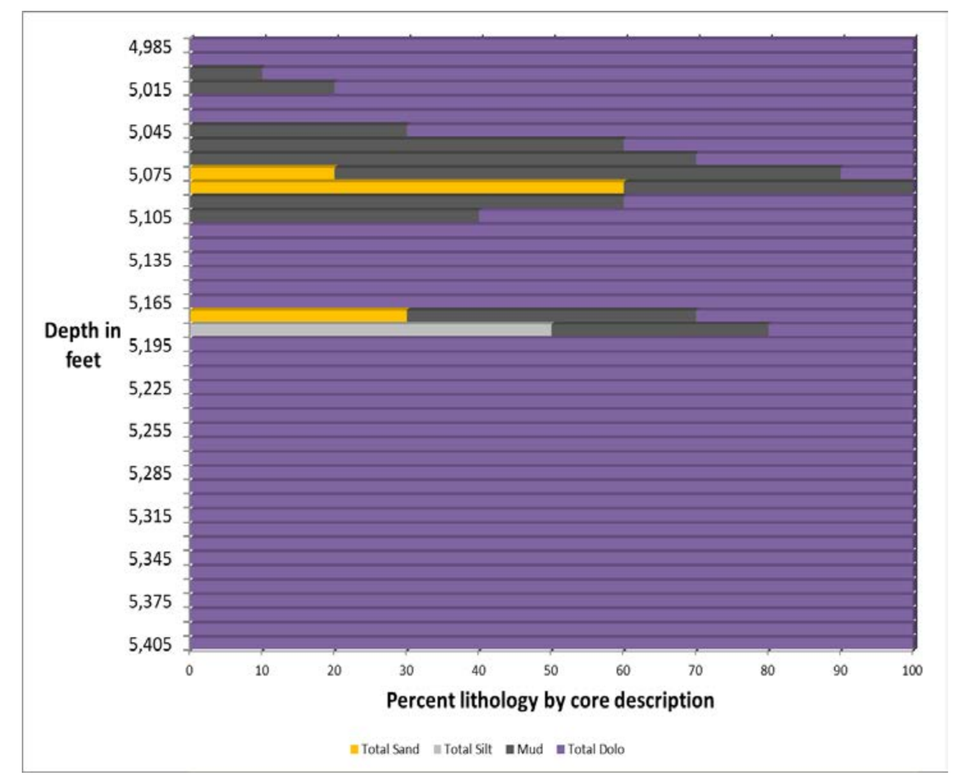


Depth	% quartz	% feldspar	% clay	% carbonate	Lithology?	Core Description
2828	1	31	16	50	Cemented Sha	Shale
2840	14	47	18	17	Muddy Siltstor	Siltstone
2841	6	18	68	7	Shale	Shale
2853	33	34	10	20	Muddy Siltstor	Siltstone
2854	19.4	25.4	36.3	16.5	Silty Shale	Siltstone
2855	0	14.1	72.1	2.5	Shale	Siltstone/Shale interbed

Core Description by Ralph Bandy, U. of Kentucky

Scioto County, Ohio





Core Description by Ralph Bandy, U. of Kentucky

GAMLS interprets silty shale and dolomitic shale; core description indicates shale, siltstone and silty shale. XRD/geochemical data indicate variable but locally abundant (2-50 %) dolomite, confirming dolomitic shale lithotype.

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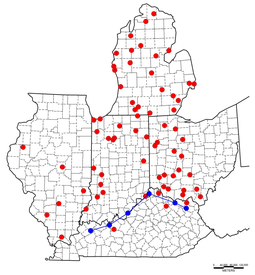
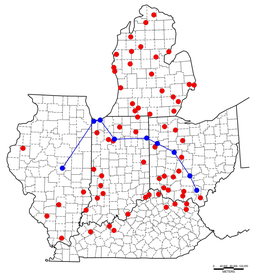
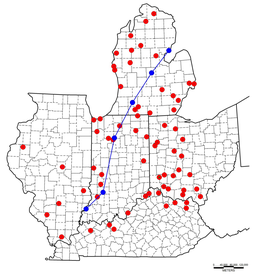


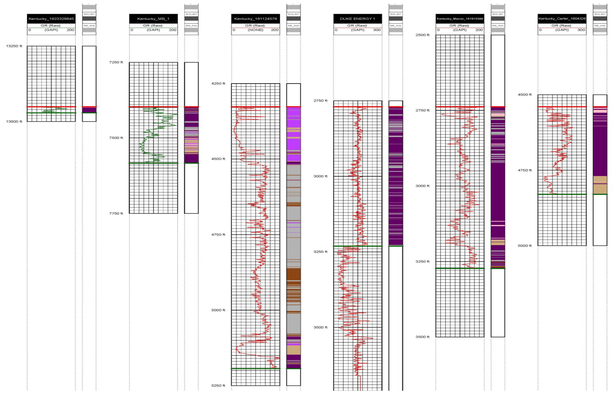
Section Line 1 , Western Kentucky to Eastern Kentucky. Note increase in carbonate content from west to east.

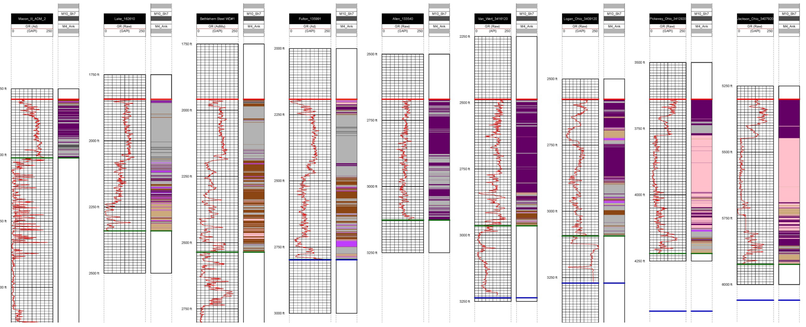


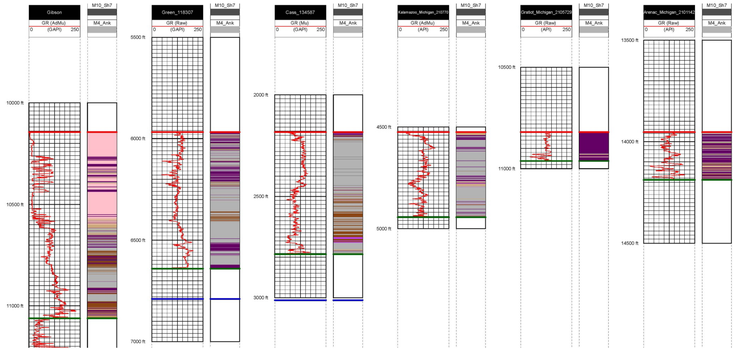
Section Line 2 , Central Illinois to Southern Ohio. Note increase silt content from Illinois to Northwest Indiana and increase in clay and carbonate content from Northern Indiana to Southern Ohio.



Section Line 3, Southern Indiana to Eastern Michigan. Note increase in silt content in northwest Indiana and increase in shale and carbonate to northeast and south.







Interpreted Lithofacies

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CONCLUSIONS

- Application of the GAMLS Software using gamma ray and porosity logs to interpret the lithofacies of the Eau Claire Formation allows distinction of regional variations in the various lithologies that comprise the interval.
- A perfect match between core description lithofacies interpretations and GAMLS characterization is not possible. Most of the differences in interpretation may be attributed to differences in resolution scale from a mm +/- in core description to 10's of centimeters for logs. Acceptable overall correlations of lithology between GAMLS and core description were achieved.
- The Eau Claire Formation displays substantial regional variation in thickness and lithofacies. Key variations are the abundance of silty lithofacies in northern Indiana and the increased importance of carbonate lithofacies in northern Michigan, central/southern Ohio and eastern Kentucky.
- The abundance of silty/sandy lithofacies in northwest Indiana, especially in the lower part of the Eau Claire, could result in greater matrix permeability relative to areas that are more shale/silt dominated, such as southeast Indiana. The increased abundance of carbonate facies within this sealing interval in eastern Kentucky and Ohio could result in buffering of the acidity associated with CO_2 storage in the underlying unit.
- The increase thickness of shale and dolomitic shale lithofacies within the seal in eastern and northeastern Indiana should provide effective confinement because of the presence of significant intervals with low permeability and the high buffering capacity of the carbonate intervals.

ACKNOWLEDGEMENTS

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