Lithostratigraphy of Middle and Upper Devonian Organic-Rich Shales in W. Virginia

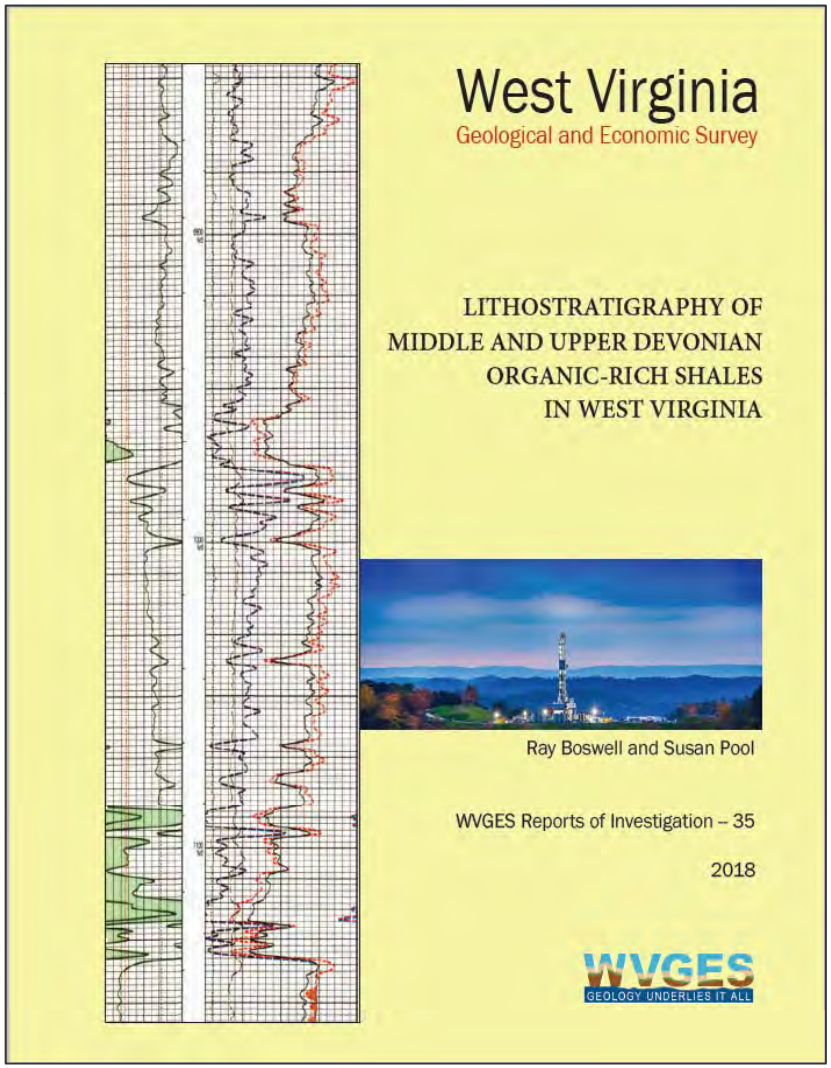
Appalachian Geological Society, September 11, 2018

Ray Boswell (DOE-NETL) and Susan Pool (WVGES)

Marcellus well - Monongalia Co., West Virginia. Courtesy Northeast Natural Energy

WVGES Reports of Investigation 35

Boswell, R.; Pool, S., 2018



- Ongoing resource assessment revealed unsettled formal nomenclature for many Upper and Middle Devonian shale units.
- Well-established stratigraphy exist on the east and on the west, but uncertain how to merge them in the basin center.
- Issues particularly with respect to the Marcellus and the Geneseo/Burket units.
- 3-part release planned:
  - Part 1: Base data and lithostratigraphy (WVGES RI-35)

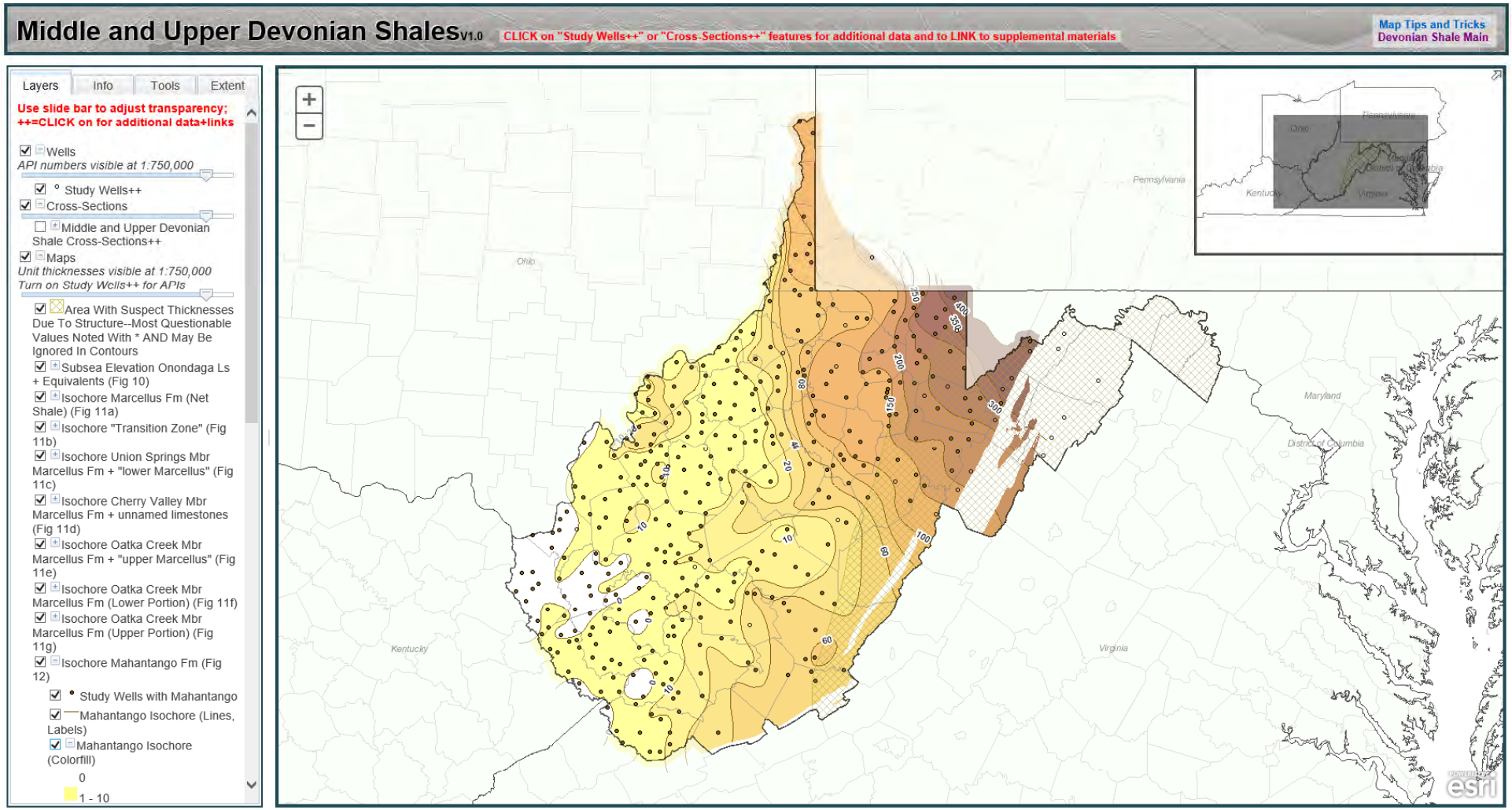
http://www.wvgs.wvnet.edu/www/MUDvnnSh/MUDvnnSh.htm

  - Part 2: Updated GIP for multiple units (TBD)
  - Part 3: Assessment of recoverable resources and recovery efficiency (TBD)
- WVGES RI-35 contains multiple products…

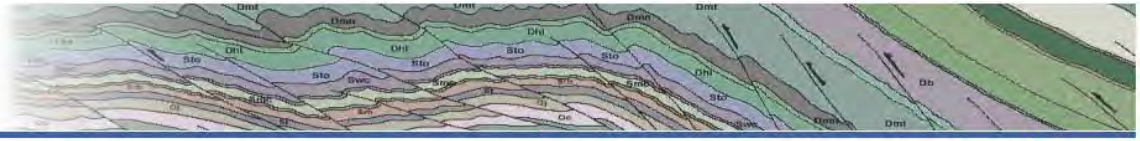
Thanks to our reviewers:
B.J. Carney (NNE); K. Carter & J. Harper (PGS); T. Carr & Doug Patchen (WVU); M. Trippi (USGS); A. Douds (Parsley)

Interactive Mapping Application

http://www.wvgs.wvnet.edu/gis/og/MUDvnnSh/index.html



Downloadable Cross-Sections



West Virginia Geological & Economic Survey

Home >> Middle and Upper Devonian Stacked Shales

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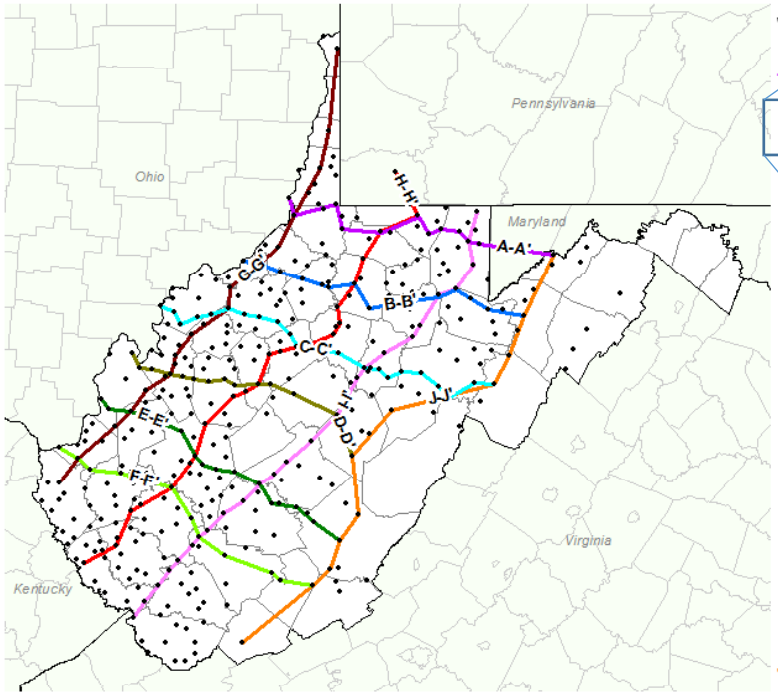
Lithostratigraphy of Middle and Upper Devonian Organic-Rich Shales in West Virginia - Reports of Investigation RI-35

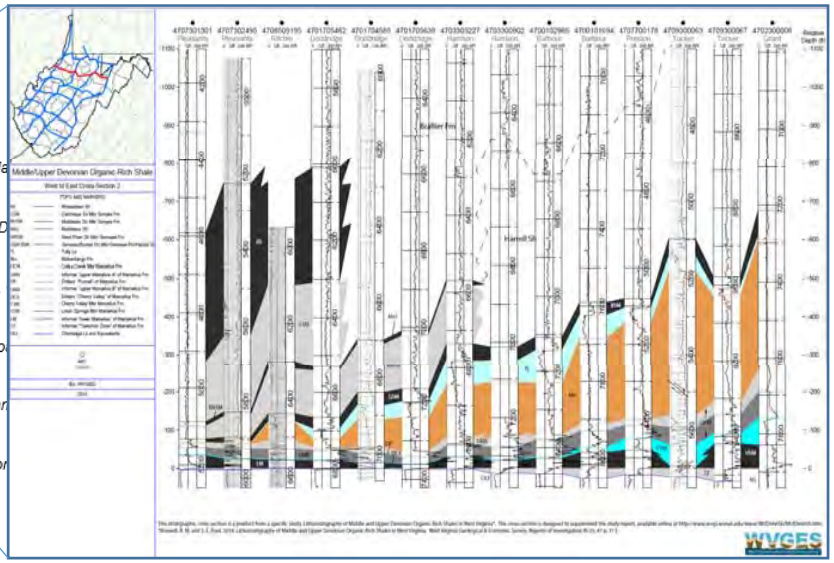
Gamma-ray log stratigraphic cross-sections

Zoom in online to see details; cross-sections designed to fit on 11 x 17 inch (tabloid) paper in landscape mode.



West to East

A-A'	West to East 1 — *Marshall, Wetzel, Ma*
B-B'	West to East 2 — *Pleasants, Ritchie, D*
C-C'	West to East 3 — *Wood, Wirt, Ritchie,*
D-D'	West to East 4 — *Mason, Jackson, Ro*
E-E'	West to East 5 — *Mason, Putnam, Kar*
F-F'	West to East 6 — *Cabell, Lincoln, Boon*



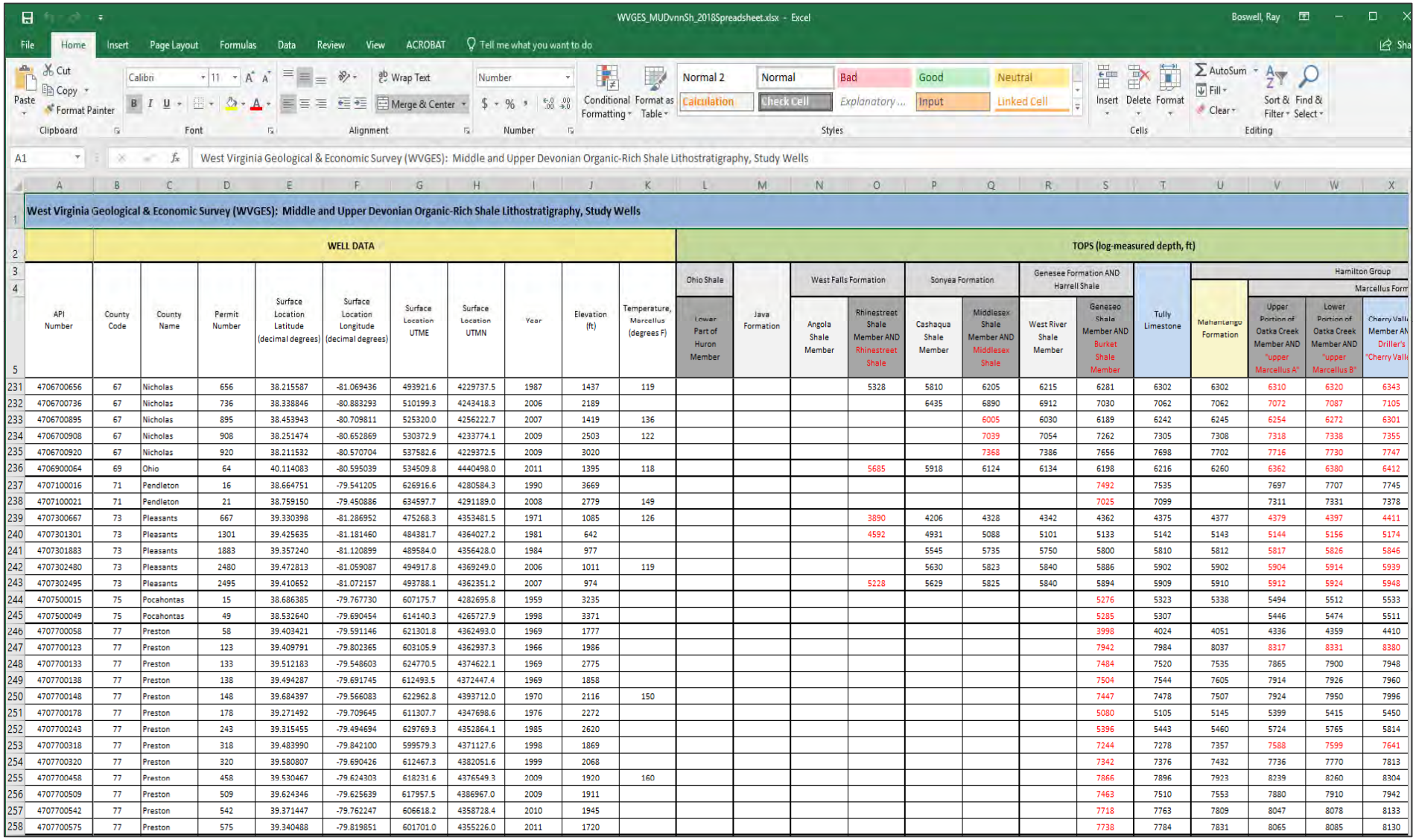
North to South

G-G'	North to South 1 — *Hancock, Ohio, Marshall, Wetzel, Tyler, Pleasants, Wood, Ritchie, Wirt, Jackson, Mason, Putnam, Cabell, and Wayne Counties*
H-H'	North to South 2 — *Greene (PA), Monongalia, Marion, Harrison, Lewis, Gilmer, Calhoun, Roane, Kanawha, Boone, Logan, and Mingo Counties*
I-I'	North to South 3 — *Preston, Barbour, Upshur, Webster, Nicholas, Fayette, Raleigh, Wyoming, Mingo, and McDowell Counties*
J-J'	North to South 4 — *Mineral, Grant, Pendleton, Randolph, Webster, Greenbrier, Summers, and Mercer Counties*

Page last revised May 17, 2018.

Please send web site questions, comments, or suggestions to webmaster.

Spreadsheet of Project Data



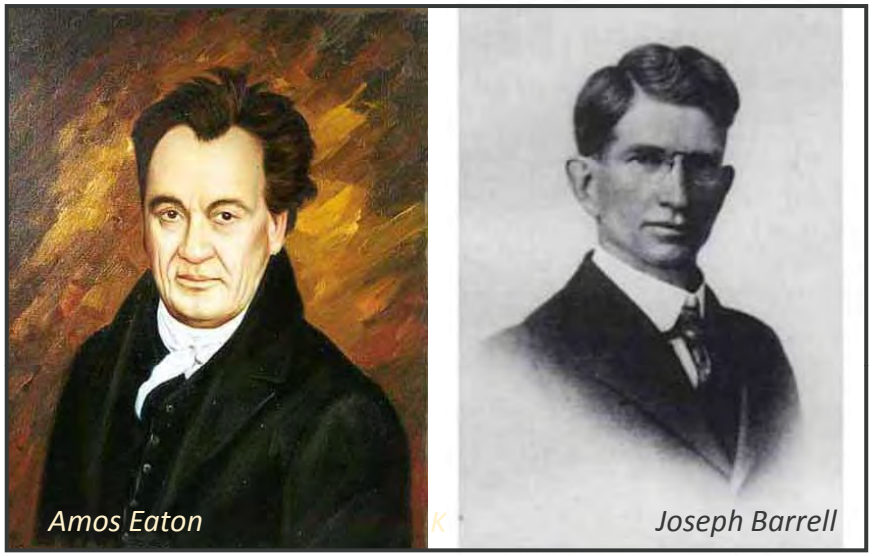
West Virginia Geological & Economic Survey (WVGES): Middle and Upper Devonian Organic-Rich Shale Lithostratigraphy, Study Wells

	WELL DATA											TOPS (log-measured depth, ft)													
												Ohio Shale		West Falls Formation		Sonyea Formation		Genesee Formation AND Harrell Shale			Hamilton Group			
																						Marcellus Form		
	API Number	County Code	County Name	Permit Number	Surface Location Latitude (decimal degrees)	Surface Location Longitude (decimal degrees)	Surface Location UTME	Surface Location UTMN	Year	Elevation (ft)	Temperature, Marcellus (degrees F)	Lower Part of Huron Member	Java Formation	Angola Shale Member	Rhinestreet Shale Member AND Rhinestreet Shale	Cashaqua Shale Member	Middlesex Shale Member AND Middlesex Shale	West River Shale Member	Geneseo Shale Member AND Burket Shale Member	Tully Limestone	Mahantango Formation	Upper Portion of Oatka Creek Member AND "upper Marcellus A"	Lower Portion of Oatka Creek Member AND "upper Marcellus B"	Cherry Valley Member AN Driller's "Cherry Valley
231	4706700656	67	Nicholas	656	38.215587	-81.069436	493921.6	4229737.5	1987	1437	119				5328	5810	6205	6215	6281	6302	6302	6310	6320	6343
232	4706700736	67	Nicholas	736	38.338846	-80.883293	510199.3	4243418.3	2006	2189						6435	6890	6912	7030	7062	7062	7072	7087	7105
233	4706700895	67	Nicholas	895	38.453943	-80.709811	525320.0	4256222.7	2007	1419	136						6005	6030	6189	6242	6245	6254	6272	6301
234	4706700908	67	Nicholas	908	38.251474	-80.652869	530372.9	4233774.1	2009	2503	122						7039	7054	7262	7305	7308	7318	7338	7355
235	4706700920	67	Nicholas	920	38.211532	-80.570704	537582.6	4229372.5	2009	3020							7368	7386	7656	7698	7702	7716	7730	7747
236	4706900064	69	Ohio	64	40.114083	-80.595039	534509.8	4440498.0	2011	1395	118				5685	5918	6124	6134	6198	6216	6260	6362	6380	6412
237	4707100016	71	Pendleton	16	38.664751	-79.541205	626916.6	4280584.3	1990	3669									7492	7535		7697	7707	7745
238	4707100021	71	Pendleton	21	38.759150	-79.450886	634597.7	4291189.0	2008	2779	149								7025	7099		7311	7331	7378
239	4707300667	73	Pleasants	667	39.330398	-81.286952	475268.3	4353481.5	1971	1085	126				3890	4206	4328	4342	4362	4375	4377	4379	4397	4411
240	4707301301	73	Pleasants	1301	39.425635	-81.181460	484381.7	4364027.2	1981	642					4592	4931	5088	5101	5133	5142	5143	5144	5156	5174
241	4707301883	73	Pleasants	1883	39.357240	-81.120899	489584.0	4356428.0	1984	977						5545	5735	5750	5800	5810	5812	5817	5826	5846
242	4707302480	73	Pleasants	2480	39.472813	-81.059087	494917.8	4369249.0	2006	1011	119					5630	5823	5840	5886	5902	5902	5904	5914	5939
243	4707302495	73	Pleasants	2495	39.410652	-81.072157	493788.1	4362351.2	2007	974					5228	5629	5825	5840	5894	5909	5910	5912	5924	5948
244	4707500015	75	Pocahontas	15	38.686385	-79.767730	607175.7	4282695.8	1959	3235									5276	5323	5338	5494	5512	5533
245	4707500049	75	Pocahontas	49	38.532640	-79.690454	614140.3	4265727.9	1998	3371									5285	5307		5446	5474	5511
246	4707700058	77	Preston	58	39.403421	-79.591146	621301.8	4362493.0	1969	1777									3998	4024	4051	4336	4359	4410
247	4707700123	77	Preston	123	39.409791	-79.802365	603105.9	4362937.3	1966	1986									7942	7984	8037	8317	8331	8380
248	4707700133	77	Preston	133	39.512183	-79.548603	624770.5	4374622.1	1969	2775									7484	7520	7535	7865	7900	7948
249	4707700138	77	Preston	138	39.494287	-79.691745	612493.5	4372447.4	1969	1858									7504	7544	7605	7914	7926	7960
250	4707700148	77	Preston	148	39.684397	-79.566083	622962.8	4393712.0	1970	2116	150								7447	7478	7507	7924	7950	7996
251	4707700178	77	Preston	178	39.271492	-79.709645	611307.7	4347698.6	1976	2272									5080	5105	5145	5399	5415	5450
252	4707700243	77	Preston	243	39.315455	-79.494694	629769.3	4352864.1	1985	2620									5396	5443	5460	5724	5765	5814
253	4707700318	77	Preston	318	39.483990	-79.842100	599579.3	4371127.6	1998	1869									7244	7278	7357	7588	7599	7641
254	4707700320	77	Preston	320	39.580807	-79.690426	612467.3	4382051.6	1999	2068									7342	7376	7432	7736	7770	7813
255	4707700458	77	Preston	458	39.530467	-79.624303	618231.6	4376549.3	2009	1920	160								7866	7896	7923	8239	8260	8304
256	4707700509	77	Preston	509	39.624346	-79.625639	617957.5	4386967.0	2009	1911									7463	7510	7553	7880	7910	7942
257	4707700542	77	Preston	542	39.371447	-79.762247	606618.2	4358728.4	2010	1945									7718	7763	7809	8047	8078	8133
258	4707700575	77	Preston	575	39.340488	-79.819851	601701.0	4355226.0	2011	1720									7738	7784	7831	8065	8085	8130

Stratigraphy

In the beginning…

- **Biostratigraphy = Stratigraphy**
  - Rocks cannot change age laterally!
- **1820s: Amos Eaton**
  - The Catskill sure seems to… → Limbo
- **1830s: NY and PA successions developed**
  - J. Hall/H. Rodgers: Onondaga-Marcellus-Hamilton-Tully-Genesee-Portage-Chemung-Catskill-Pocono
- **1900s: Eatons' observations persist**
  - J. Barrell puts the U Devonian into "deltaic" context
  - G. Chadwick; H. Williams… A crisis of stratigraphy
  - The NY stratigraphy is given precedence of that emerging in WV.
- **1930: A new stratigraphy**
  - Lithofacies boundaries are NOT timelines!



BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 46, PP. 343-354, 2 FIGS. FEBRUARY 28, 1935

CHEMUNG IS PORTAGE*

BY GEORGE HALCOTT CHADWICK

INTRODUCTION

A recurring surprise in the progress of the Upper Devonian studies has been the repeated discovery, after a piece of work had resulted in some apparently new stratigraphic correlation, that another worker,

K Caster, 1934

The Stratigraphy and Paleontology of Northwestern Pennsylvania, Part I: Stratigraphy

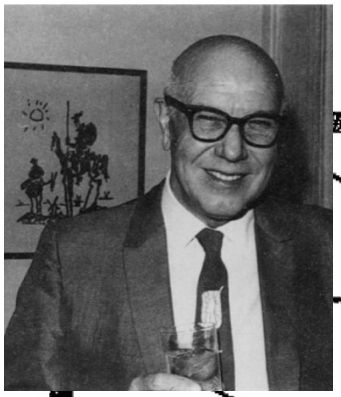
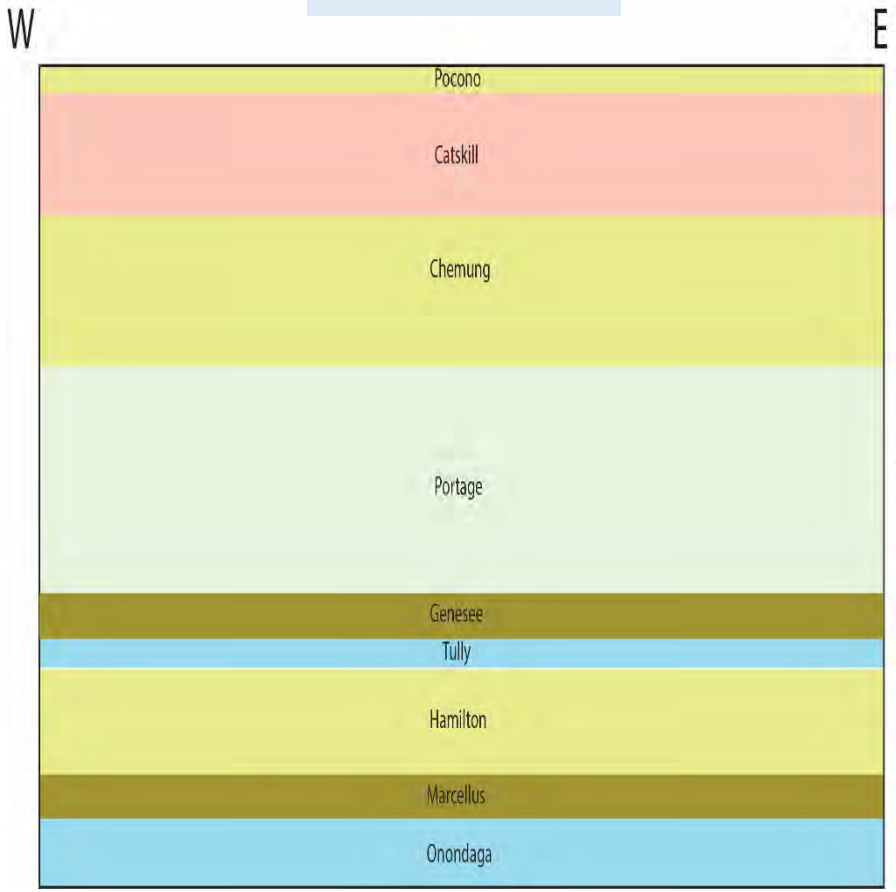


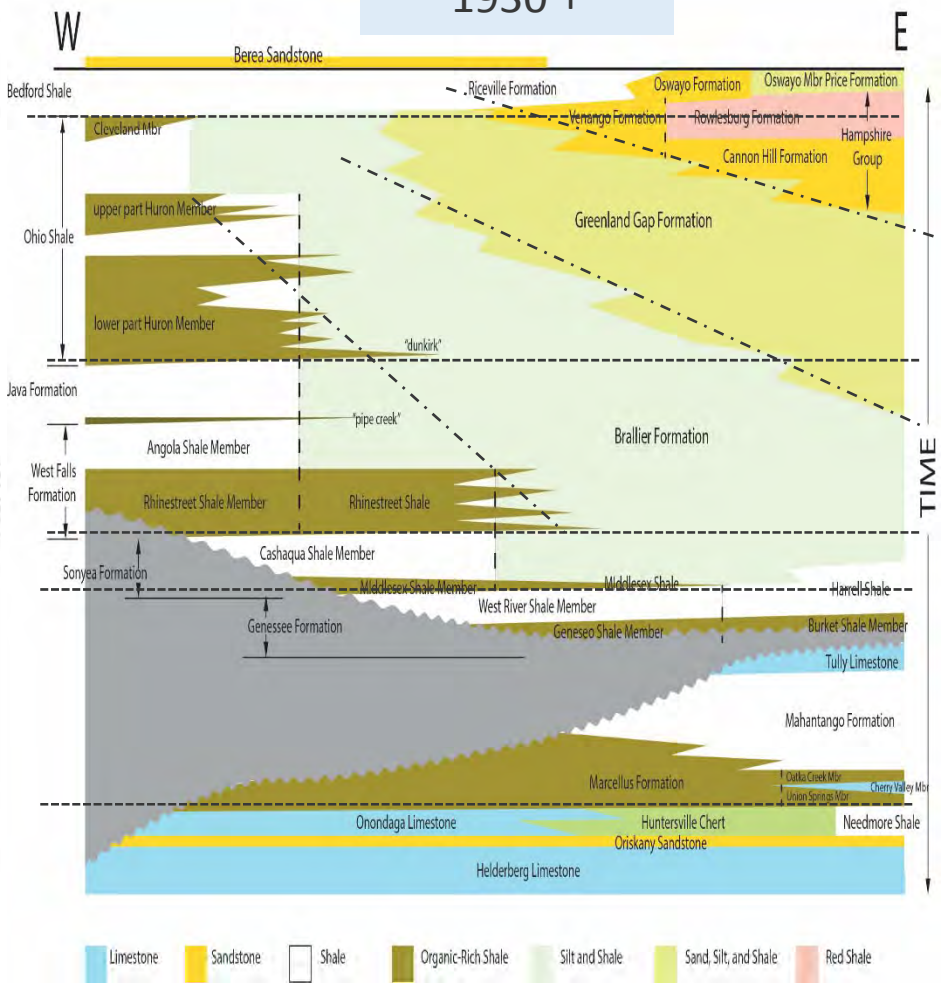
Fig. 2.—Facies components

Evolution of Stratigraphic Nomenclature

1830-1930

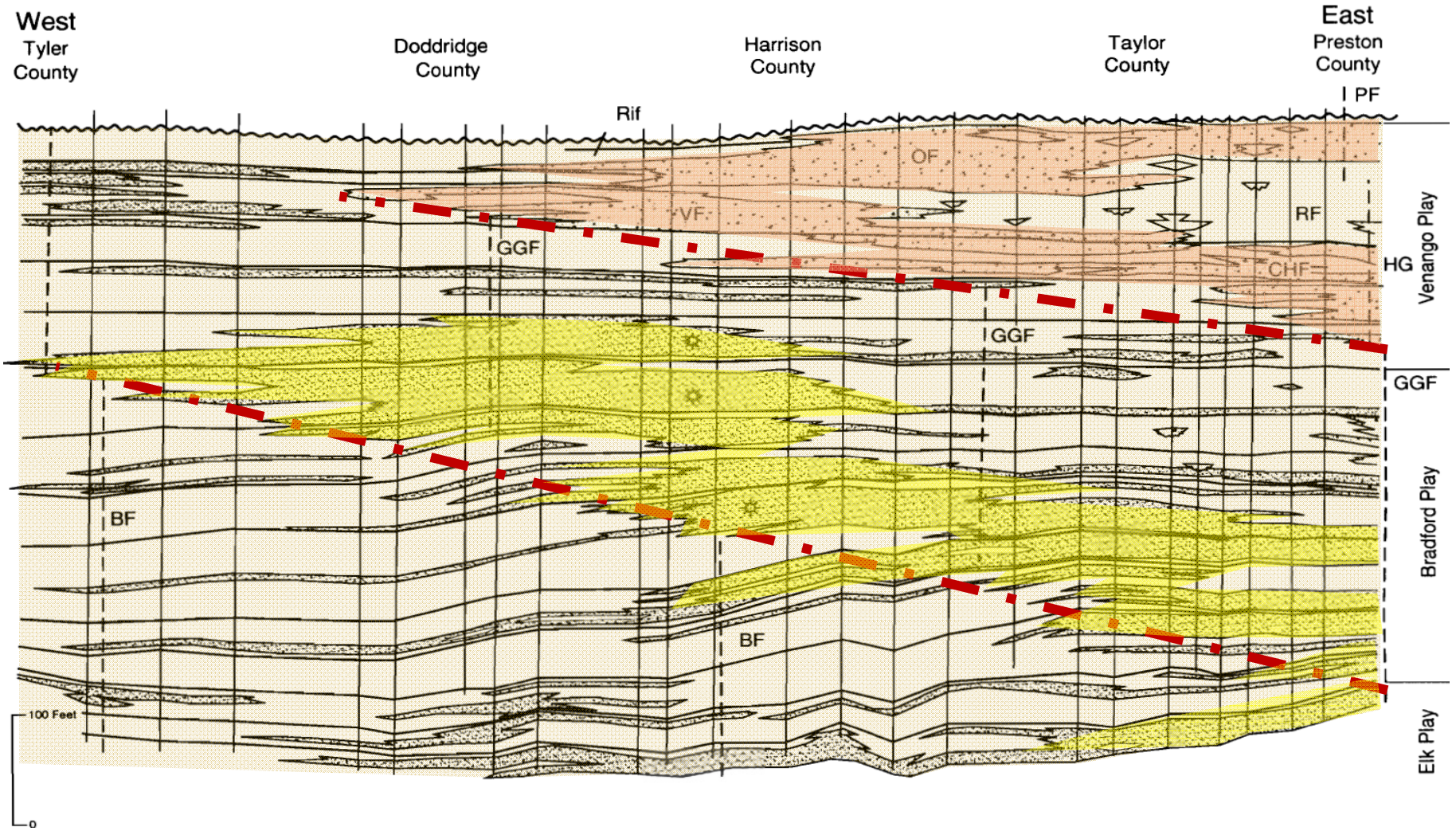


1930 +

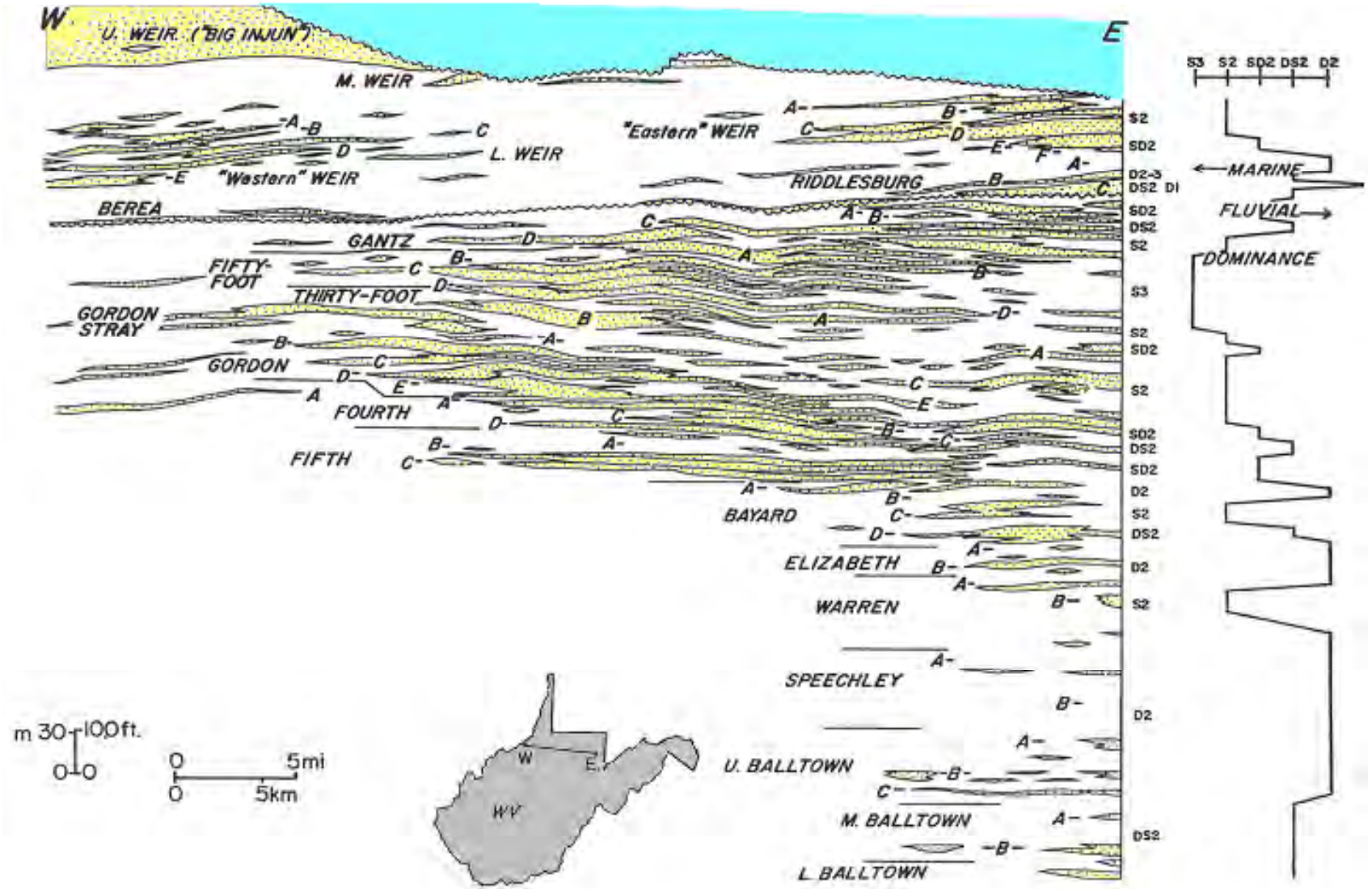


U Devonian; N. West Virginia

Diachronous lithostratigraphic contacts



Driller's Units = Chronostratigraphic Units



1940s - 1990

EGSP, etc…

Old terminology slowly replaced

- Portage → Brallier

(Woodward, 1943)

- Catskill → Hampshire

(Butts, 1945)

- Chemung → Greenland Gap

(Dennison, 1970)

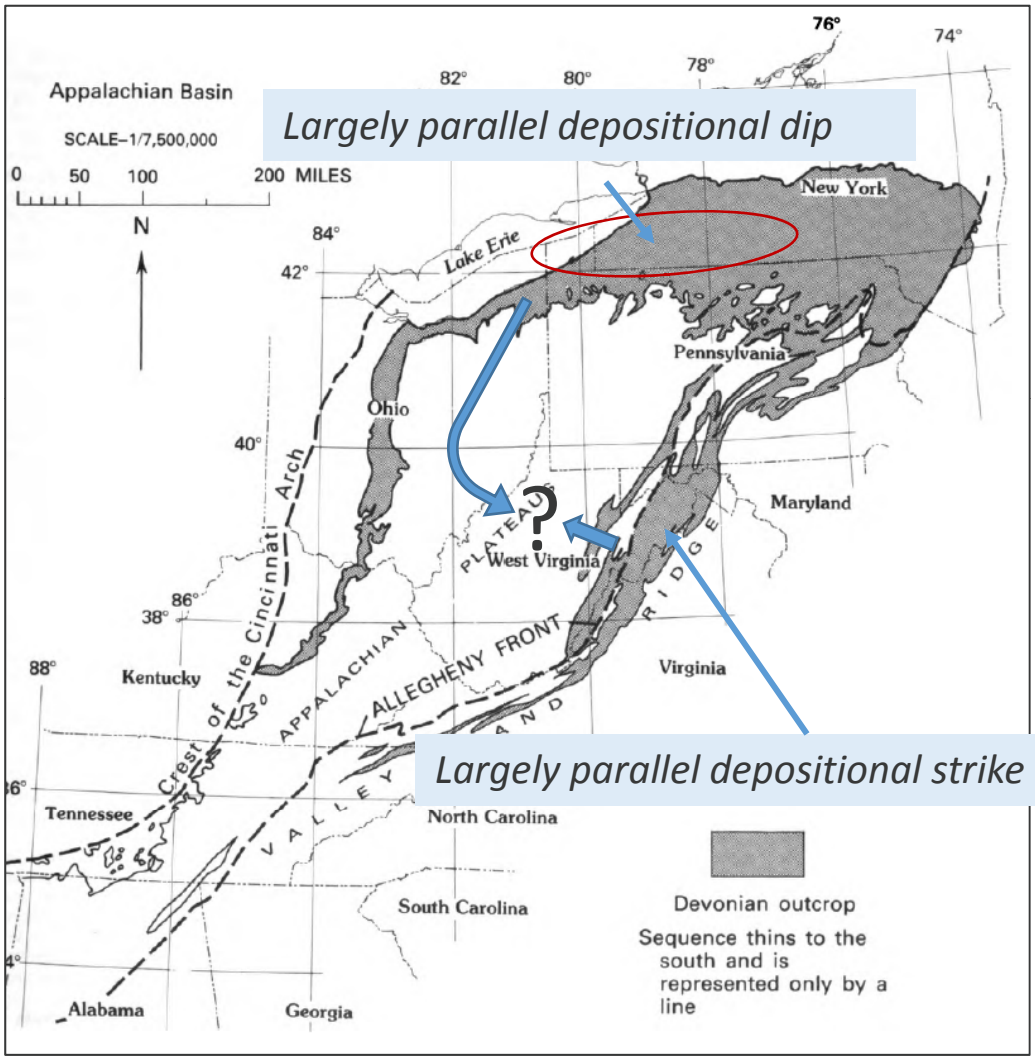
U Devonian Shale section

- "undiff. Devonian", "brown shales"

Eastern Gas Shales Program

- Schweitering, DeWitt et al. track NY stratigraphy south and east into basin center.

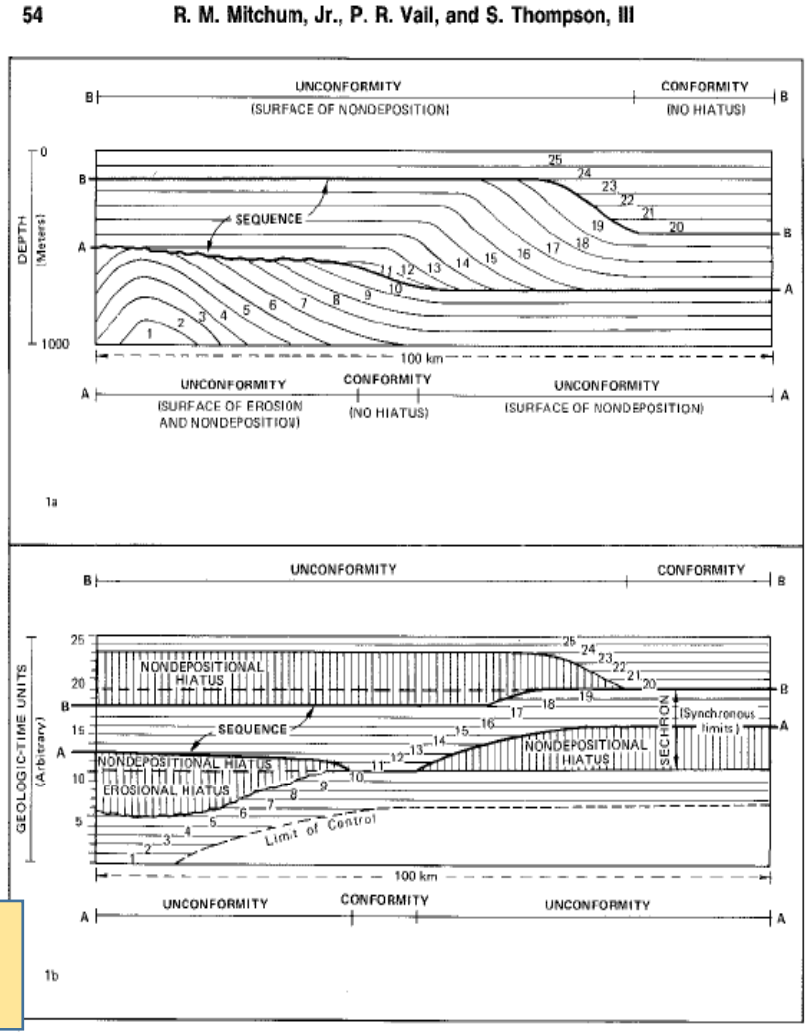
- Systems emerges of Fms with paired members; organic-rich at base.



A Resurgence of Chronostratigraphy

AAPG Memoir 26, 1977

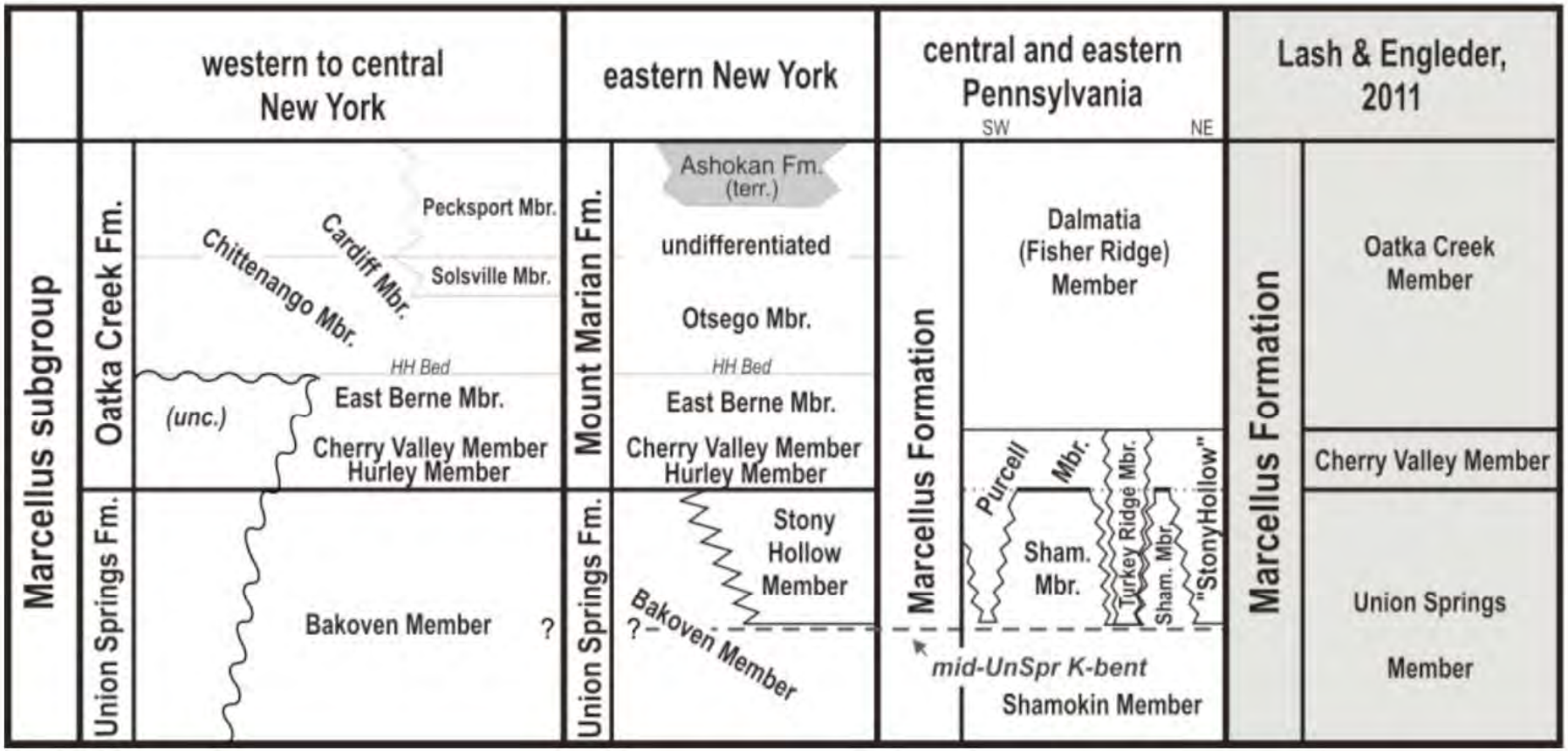
- 1970s: What works in deepwater… w/ seismic?
- Organize not around lithology or age, but around the geometric relationships between associated packages (not as evident in log or outcrop).
- Insight on how the rock got there… a new "genetic (sequence) stratigraphy" linked to a process (sea level change) → chronostratigraphy
- Powerful → predictive, interpretative
- Application spreads back onshore… (complex in outcrops/logs due to lack of continuous data).
- So why lithostratigraphy?



Units with very different properties should not have the same name just because they are the same age – i.e. correlative!

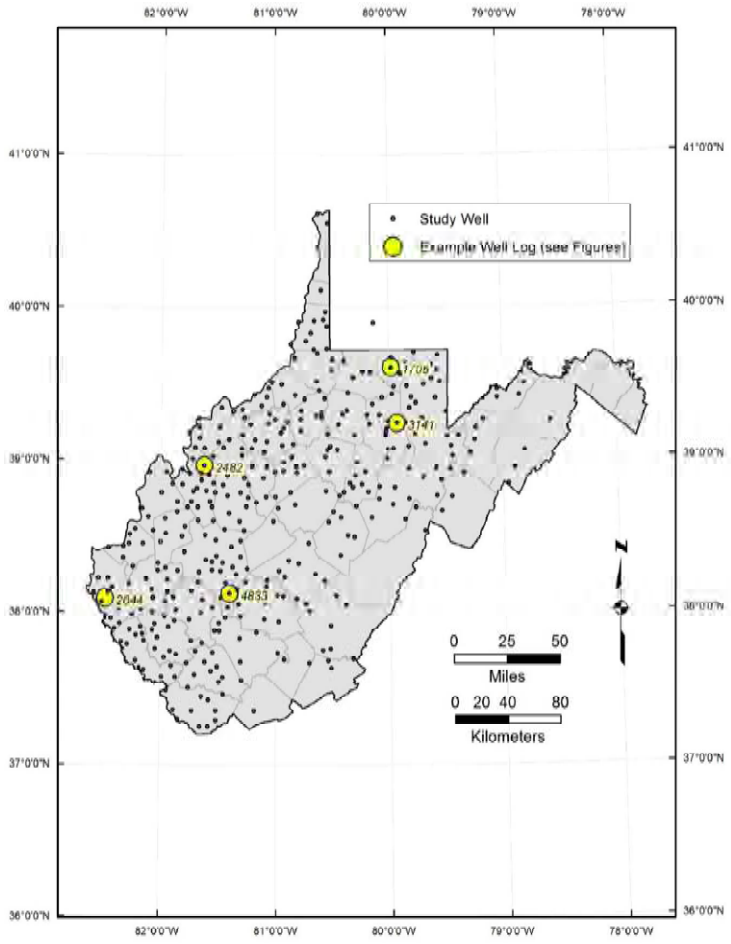
NY Marcellus Stratigraphic Studies

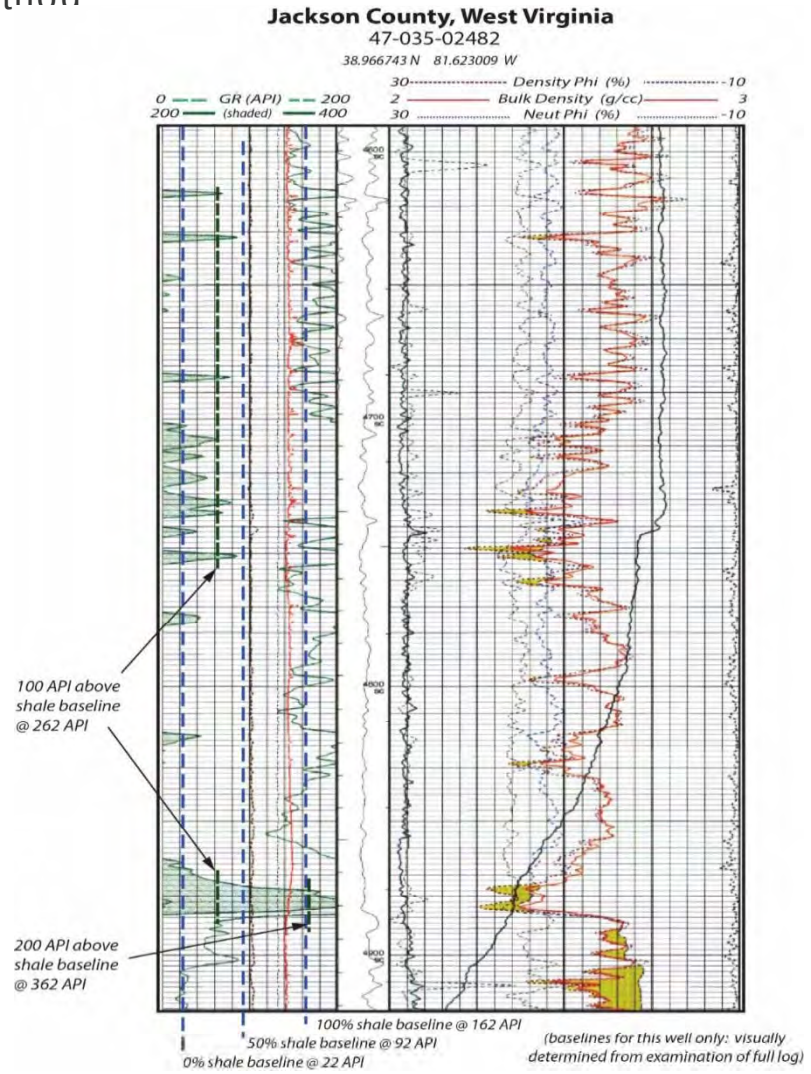
Ver Straeten (2007); extended south using log data by Lash and Engelder (2011)



Data and Methods

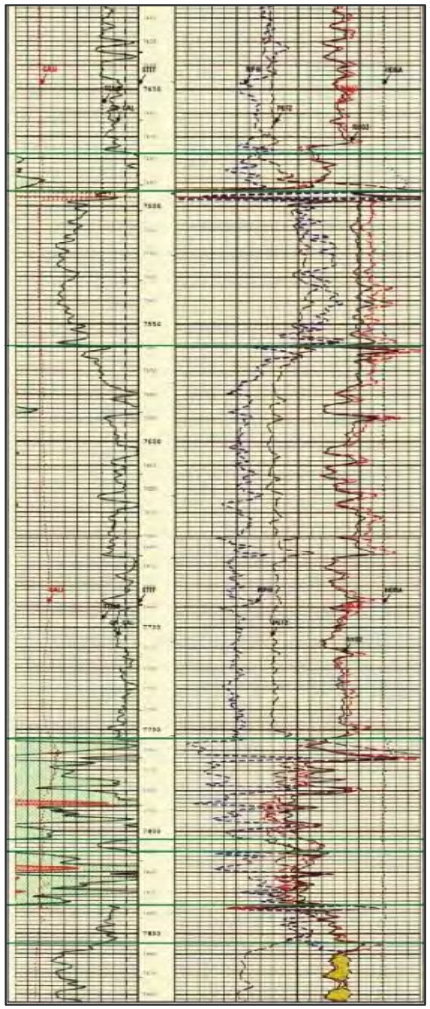
~400 vertical wells; GR-DEN; relative base line method





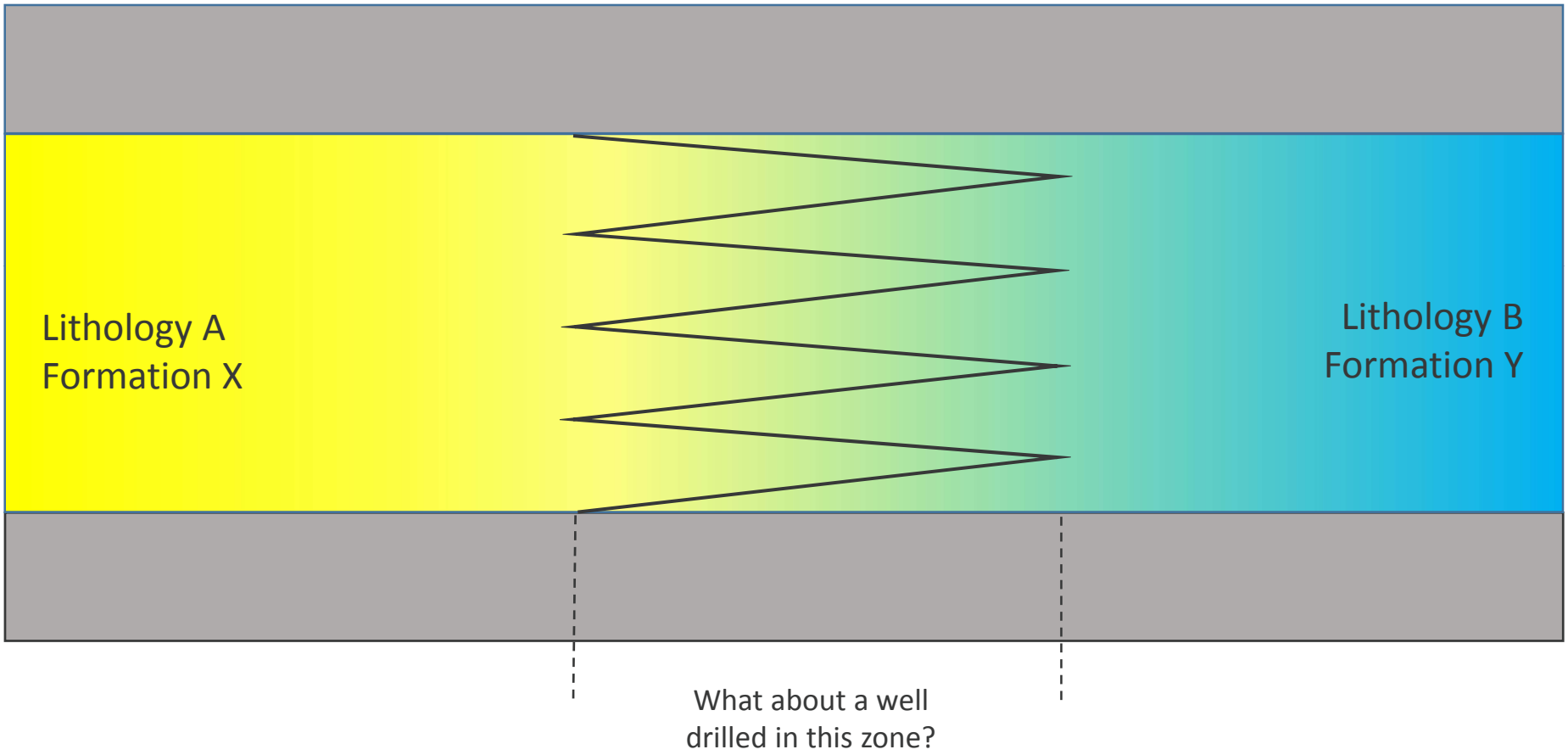
Data and Methods

WVGES RI-35



- **Establish Lithostratigraphy for West Virginia M.& U Devonian Shales**
  - Tailored to subsurface data
  - Avoid new names
  - … Precedence
  - … Utility
  - … Mapability
  - … Lithologic Consistency
- **Recognize the 3-D problem**
  - Formations need not only top and bottom, but edges
  - Clarify lateral transitions, particularly where lithologic units "fade away"
  - …and without using "shazams"

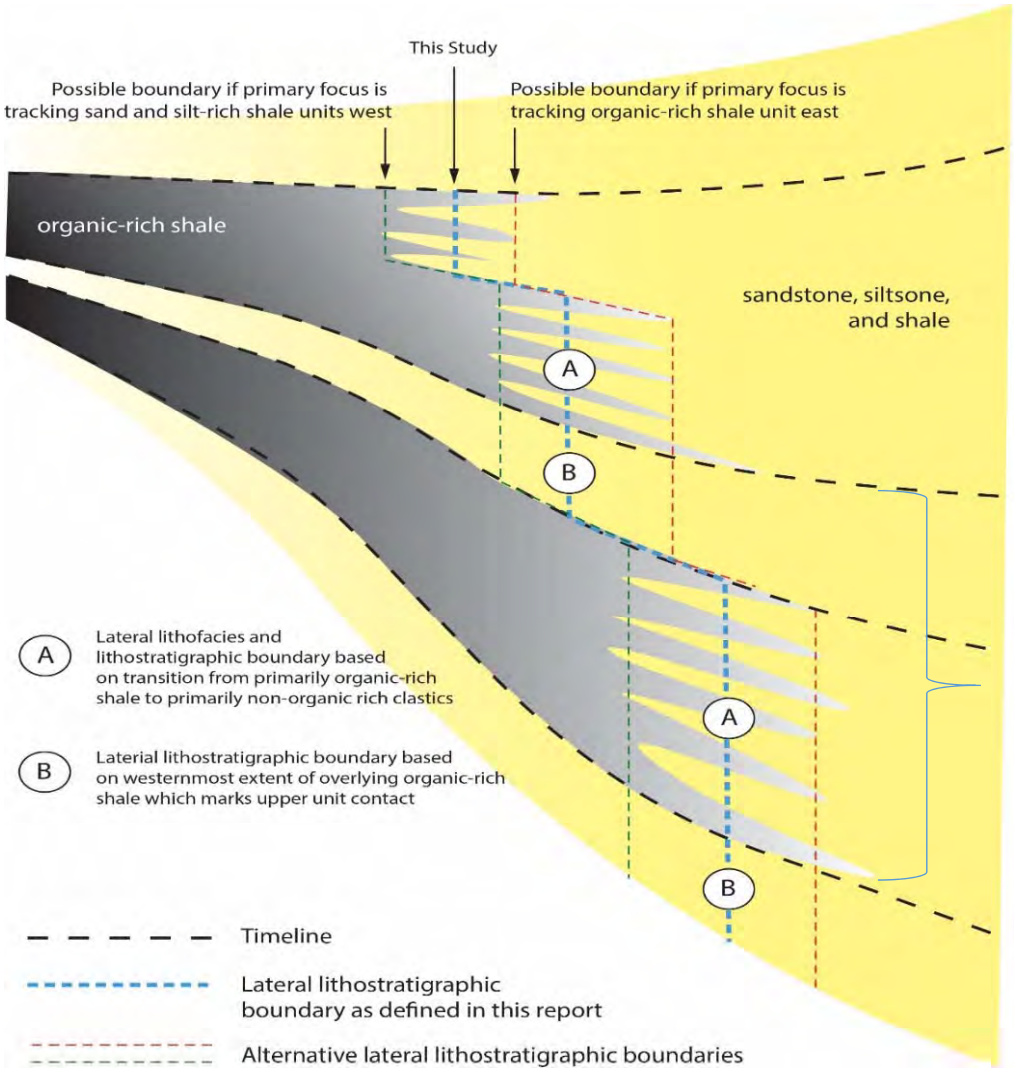
Gradational Lateral Transition



Methods

Lateral lithofacies boundaries

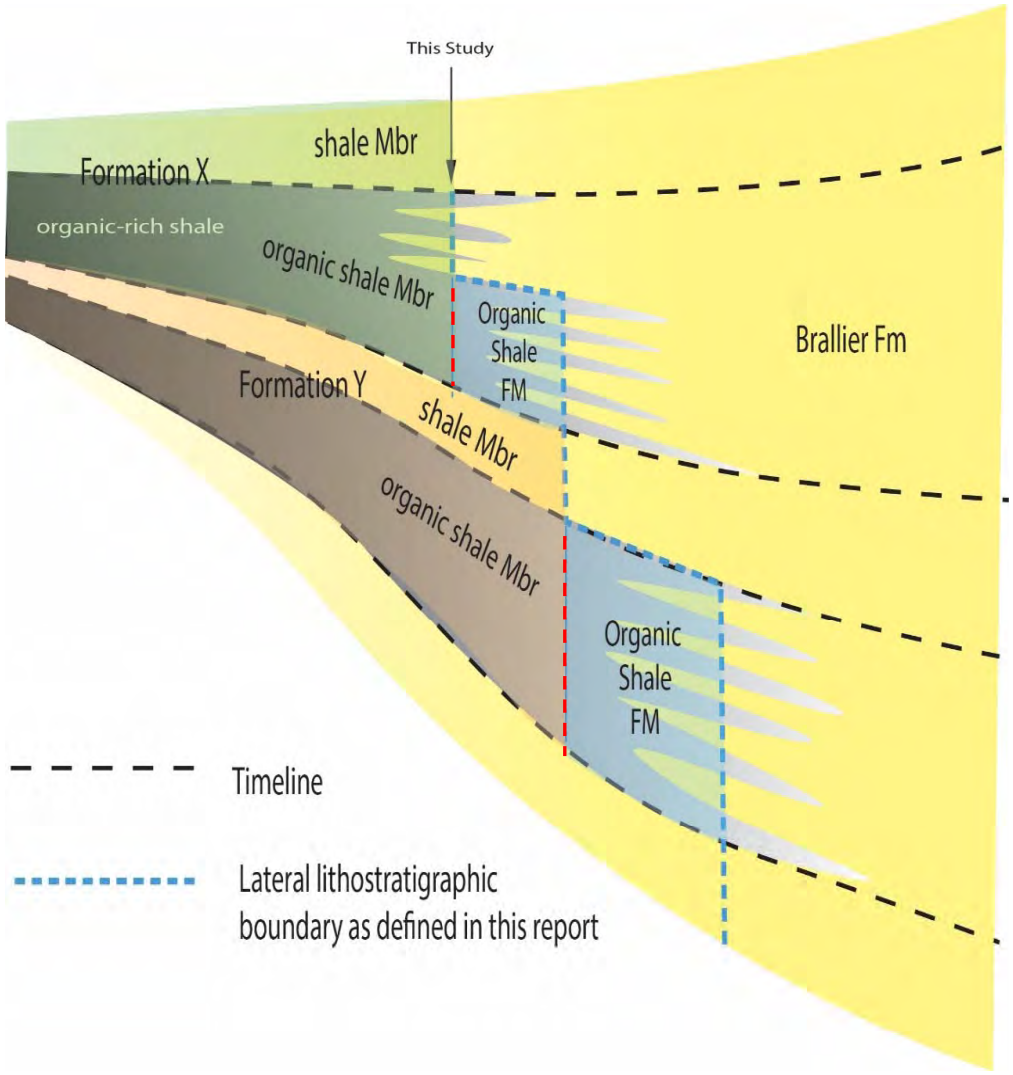
- To the east, the formations to do not pinch out, they fade away.
- The age-correlative interval can still be readily correlated; but that does not mean it is the same lithologic unit!
- Lateral boundary placement fairly arbitrary… If tracing from the west, one would tend to extend the shales further.
- Goal was to place the line near the 50:50 point (non-quantitatively)
- This may look very arbitrary for locations near this line.



Lateral Lithostratigraphic Boundaries

Generic

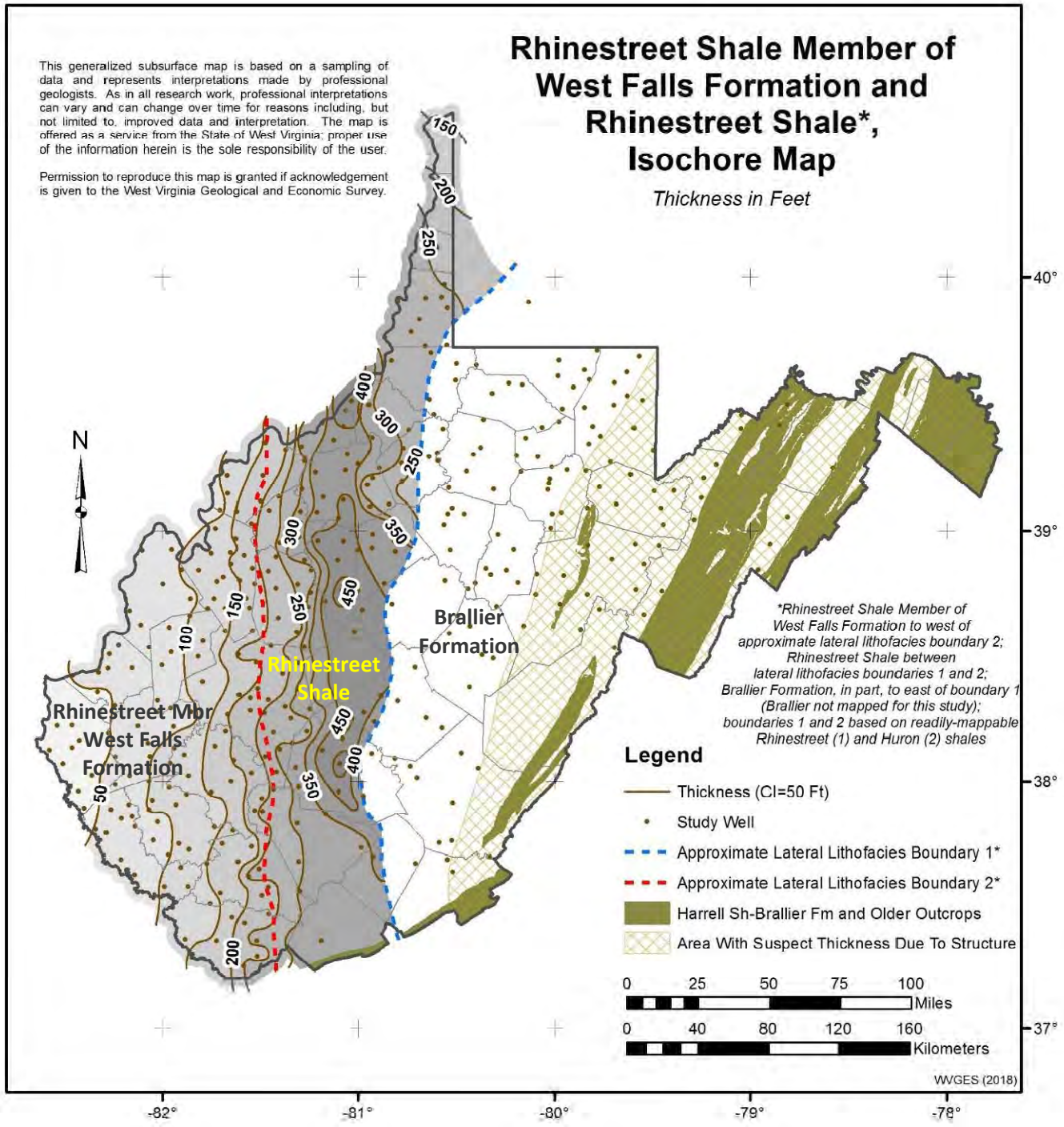
- Retain the structure of organic-rich shale/organic-poor shale couplets comprising two members of a Formation.
- Those formations are tracked as far east as both upper and lower boundaries exist to differentiate it.
- Upper boundary extent generally controls this.
- Where organic-rich member persists beyond point where overlying member is not mappable, it becomes a Formation (PGS).



Example

West Falls Formation

- Correlative interval has graded into age-equivalent organic-poor shales of the Brallier Fm to east of blue line
- Rhinestreet Shale Member of West Falls Fm to west of red line
- Rhinestreet Shale (Fm status) between red and blue lines



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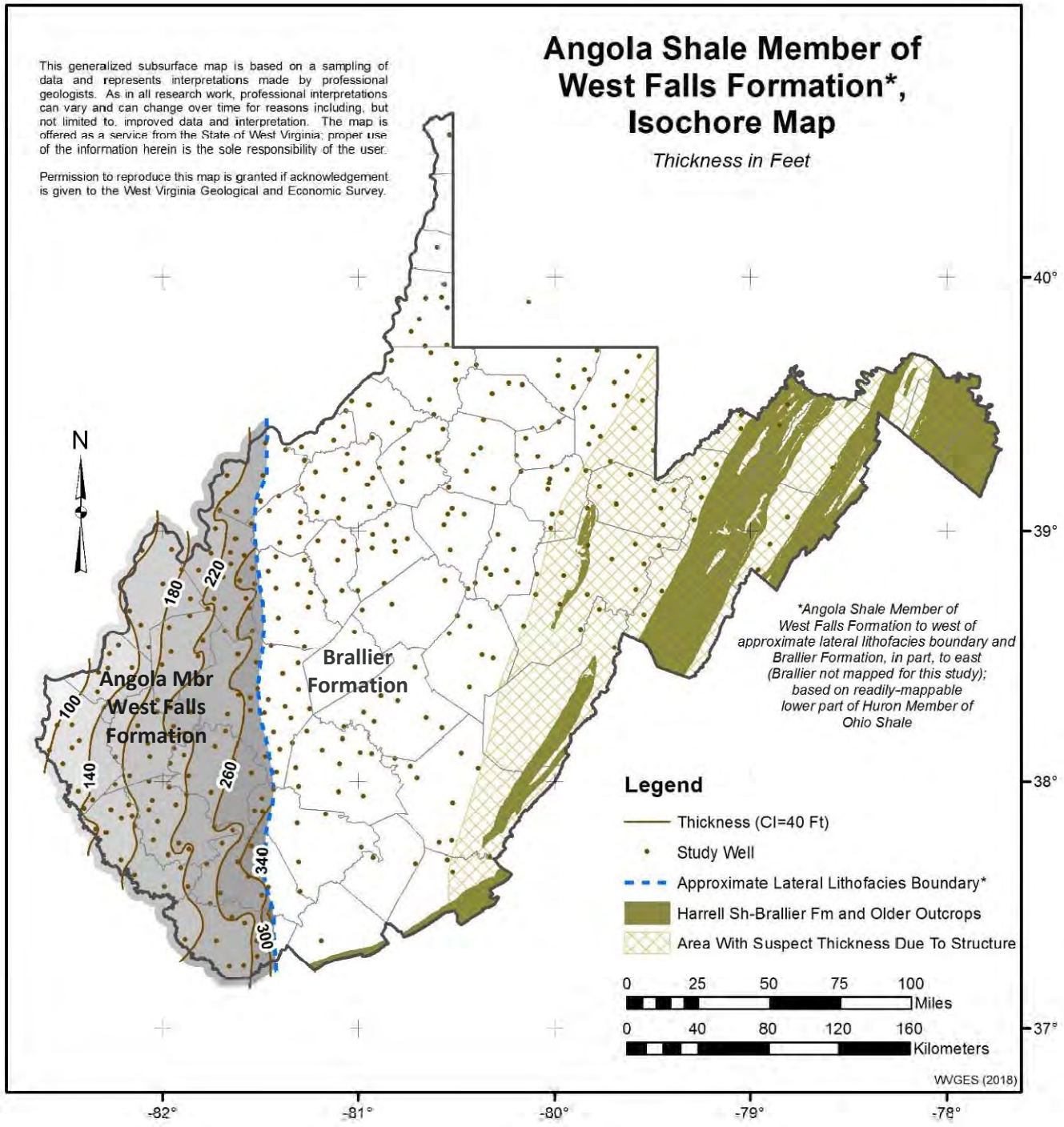
Example

West Falls Formation

- Angola Member (upper) lateral facies transition (blue line)
- That boundary (and eastward limit of the Java Fm above) is determined based on the western extent of the Huron organic-rich shale.



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Results

Middle and Upper Devonian Organic-Rich Shale Lithostratigraphy

Younger Shales

- Pipe Creek not readily mappable: Java Fm without members

Geneseo/Burket

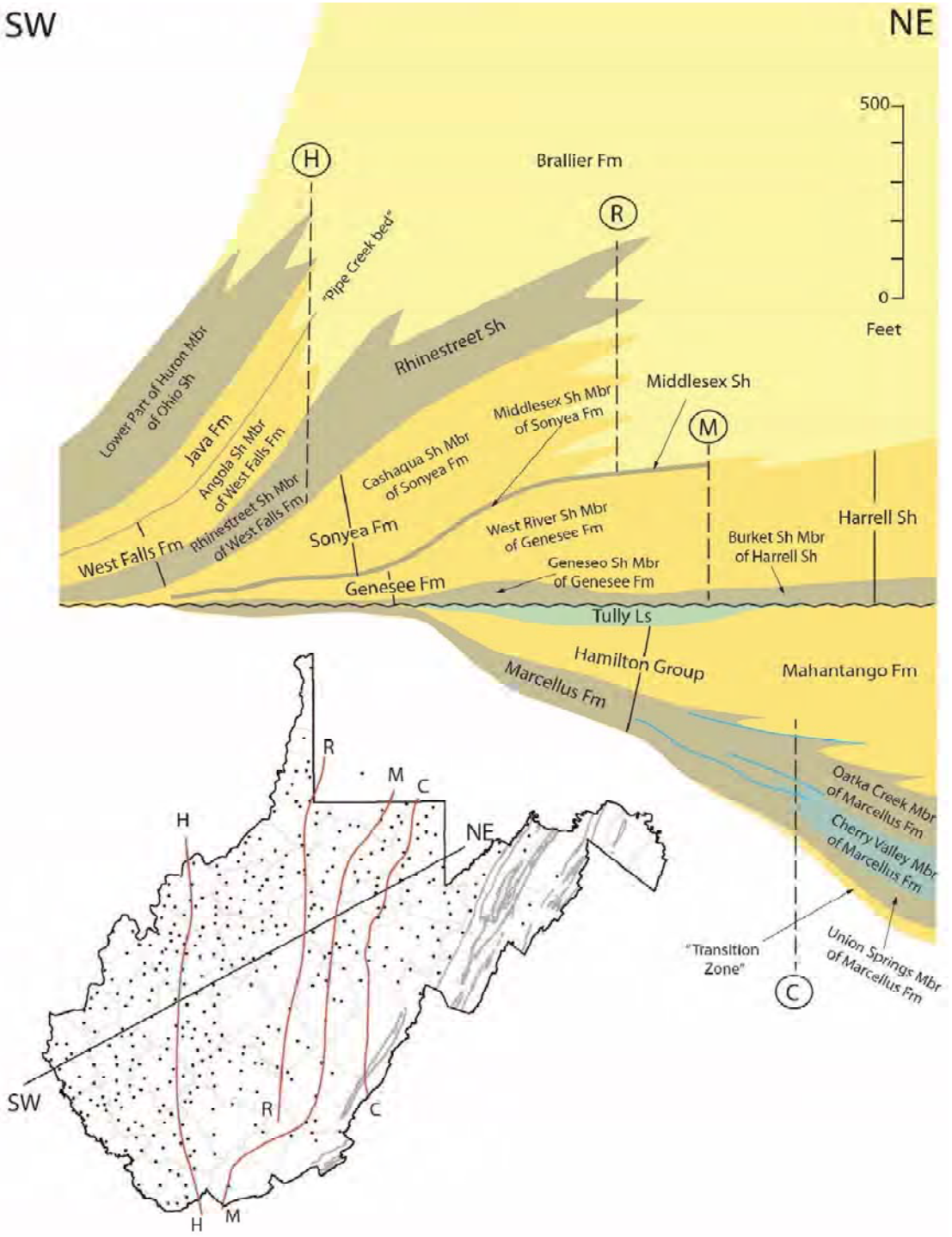
- Geneseo as far east as Genesee Formation is mapped: Harrell Shale to east

Mahantango Formation

- complex to map individual members - separating limestones very thin and losing character to the south.

Marcellus Formation

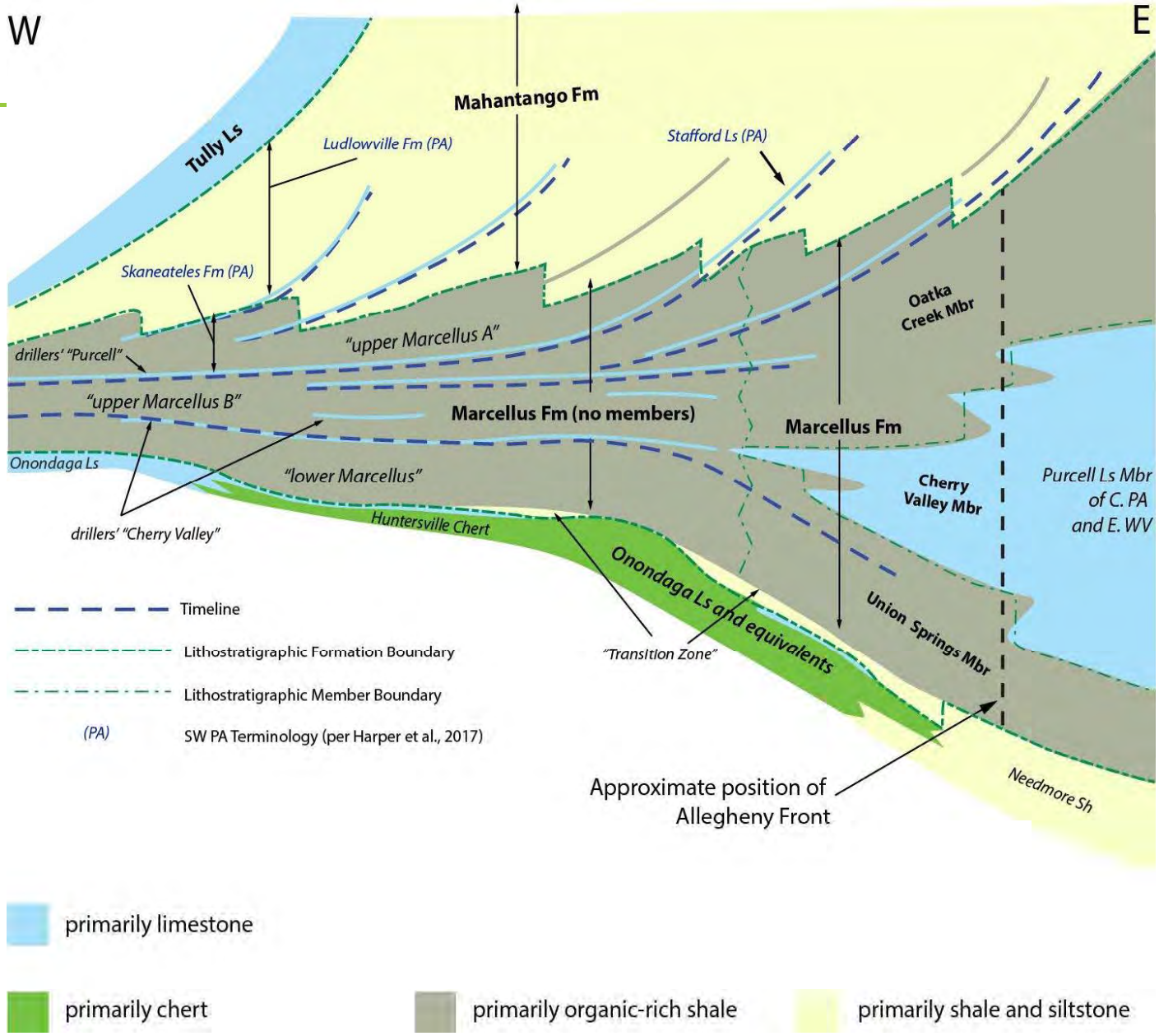
- members only mappable to point medial LS member is mapped (LINE C).
- to west, informal units can be mapped but are lithologically very similar (in GR data).



Results

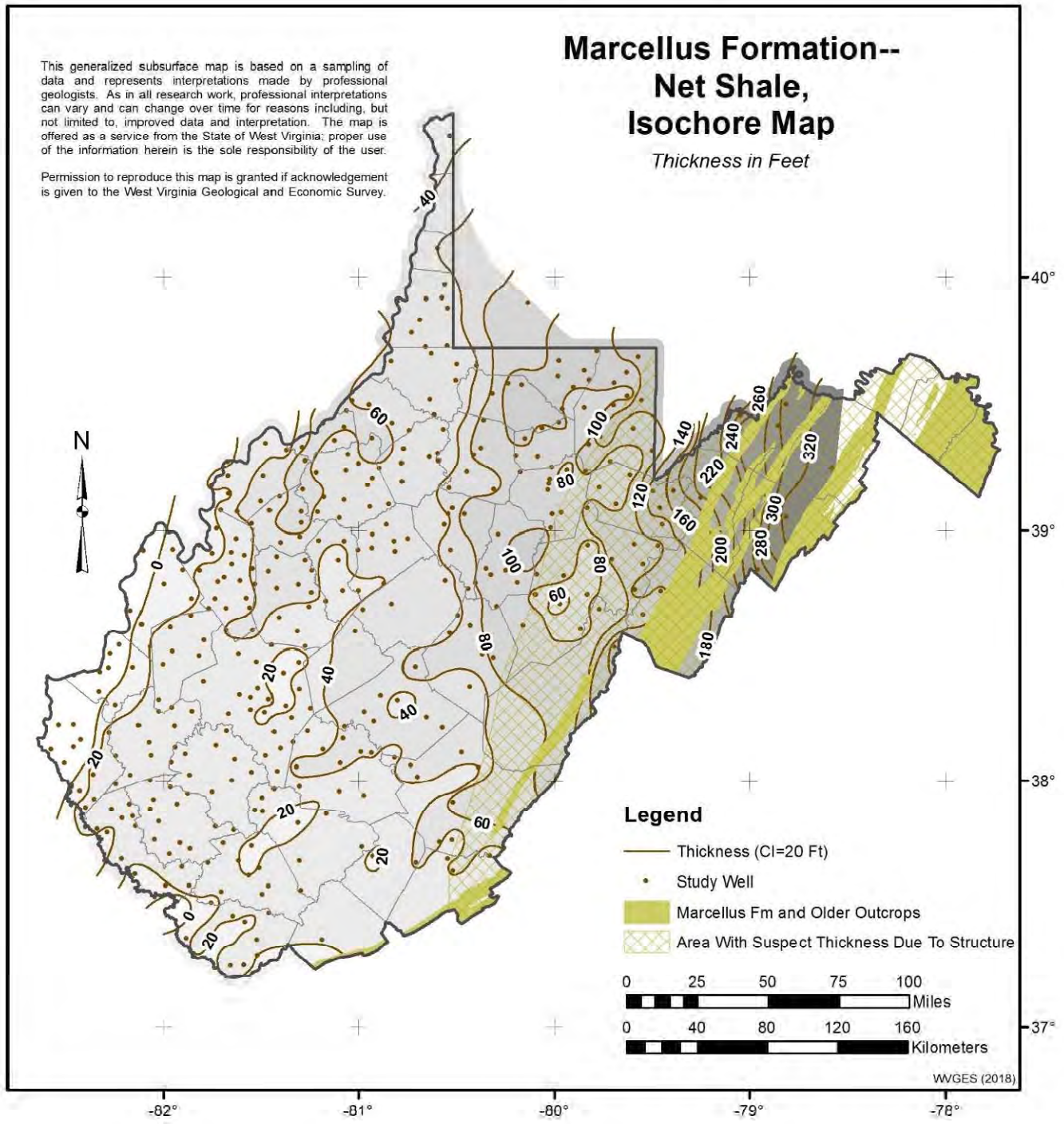
Marcellus lithostratigraphy

- Mbrs only where Cherry Valley can be confidently mapped
- Informal units to the west, delineated by informal and thin "Purcell" and "Cherry Valley" lime-rich driller's units (per deWitt et al., 1993 and some industry practice)
- Unnamed unit at the base: "transition zone"
- Top of Marcellus is progressively younger to the west.



Marcellus Fm

Net Shale Isochore



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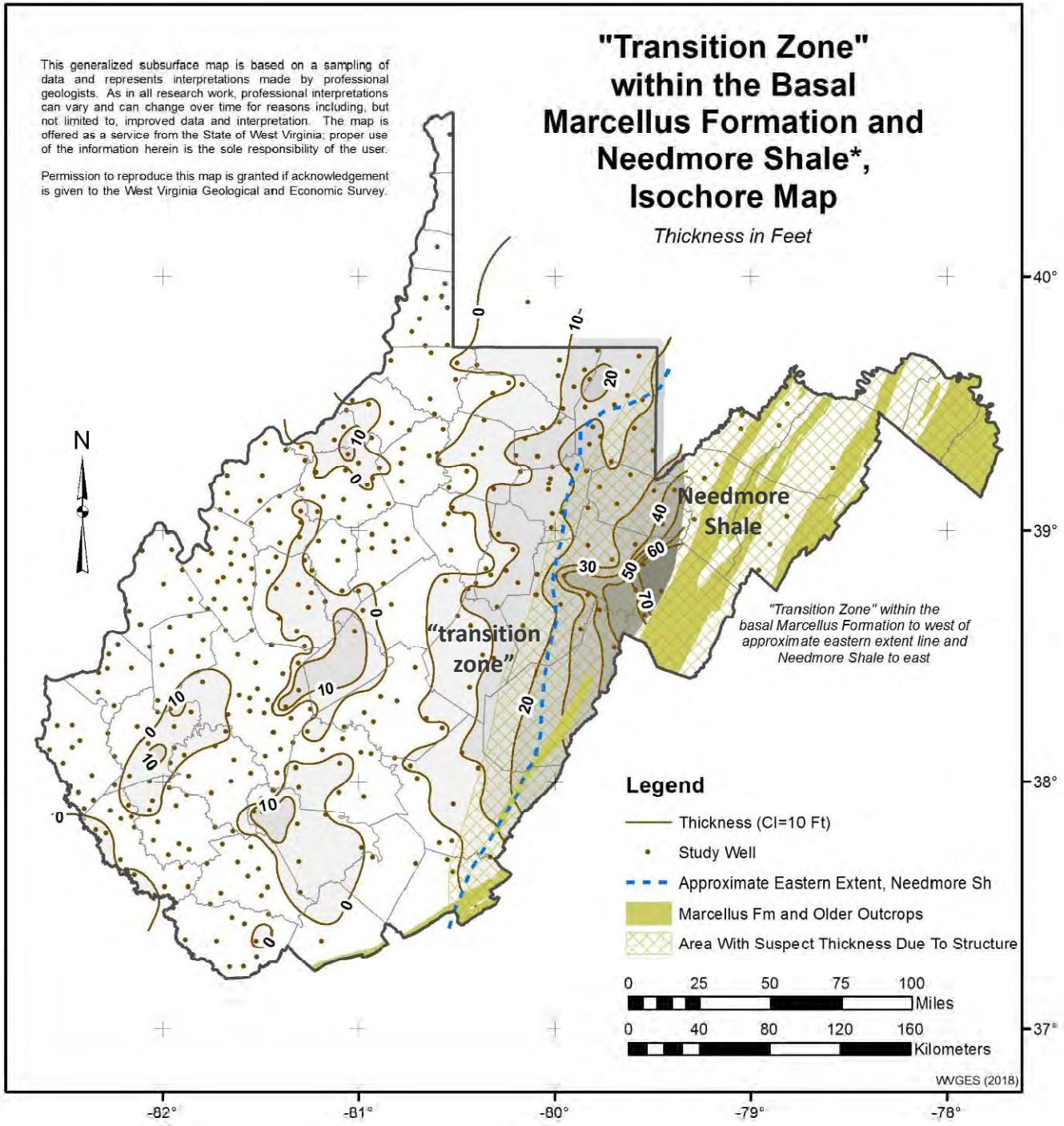
“transition zone”

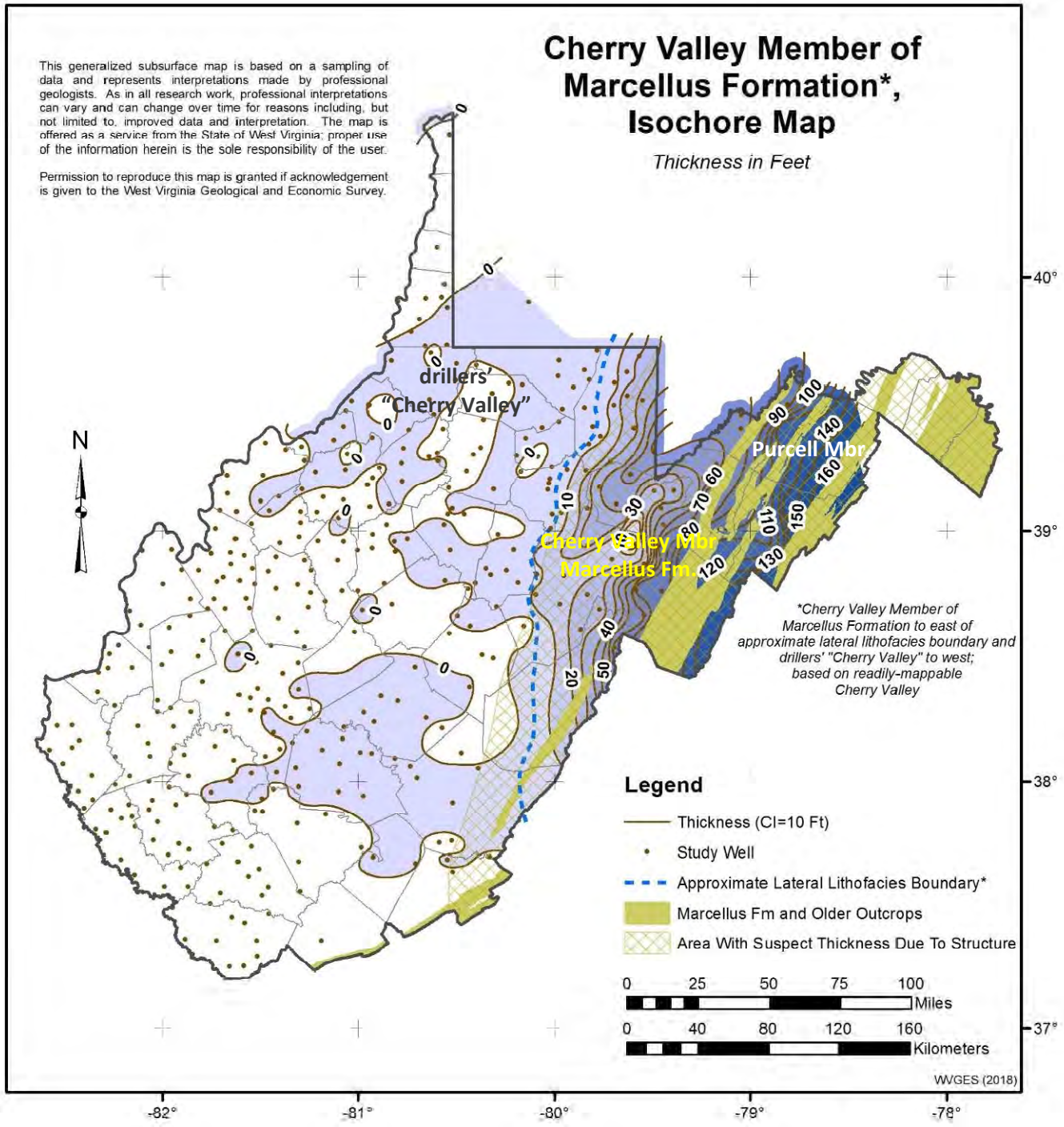
- Grades into upper part of the Needmore Shale to the east of blue line
- Where missing – Marcellus-Onondaga contact may represent an unconformity
- Where present, the contact may be conformable



U.S. DEPARTMENT OF ENERGY

Cherry Valley Mbr

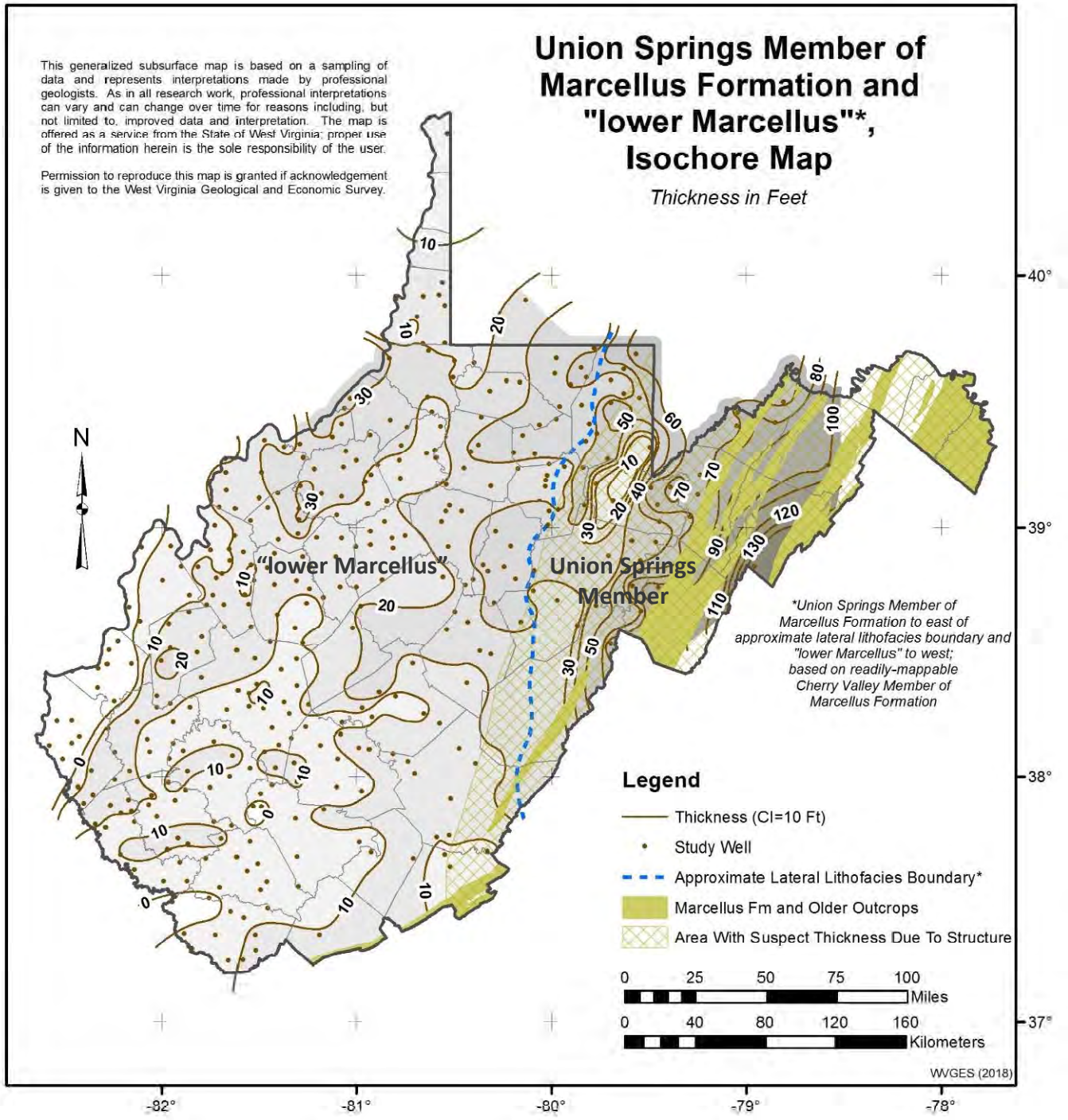
- Correlates to several informal low GR/high DEN spikes to the west
- Correlates to the Purcell Mbr in the eastern panhandle



U.S. DEPARTMENT OF ENERGY

Union Springs Mbr

"lower Marcellus"

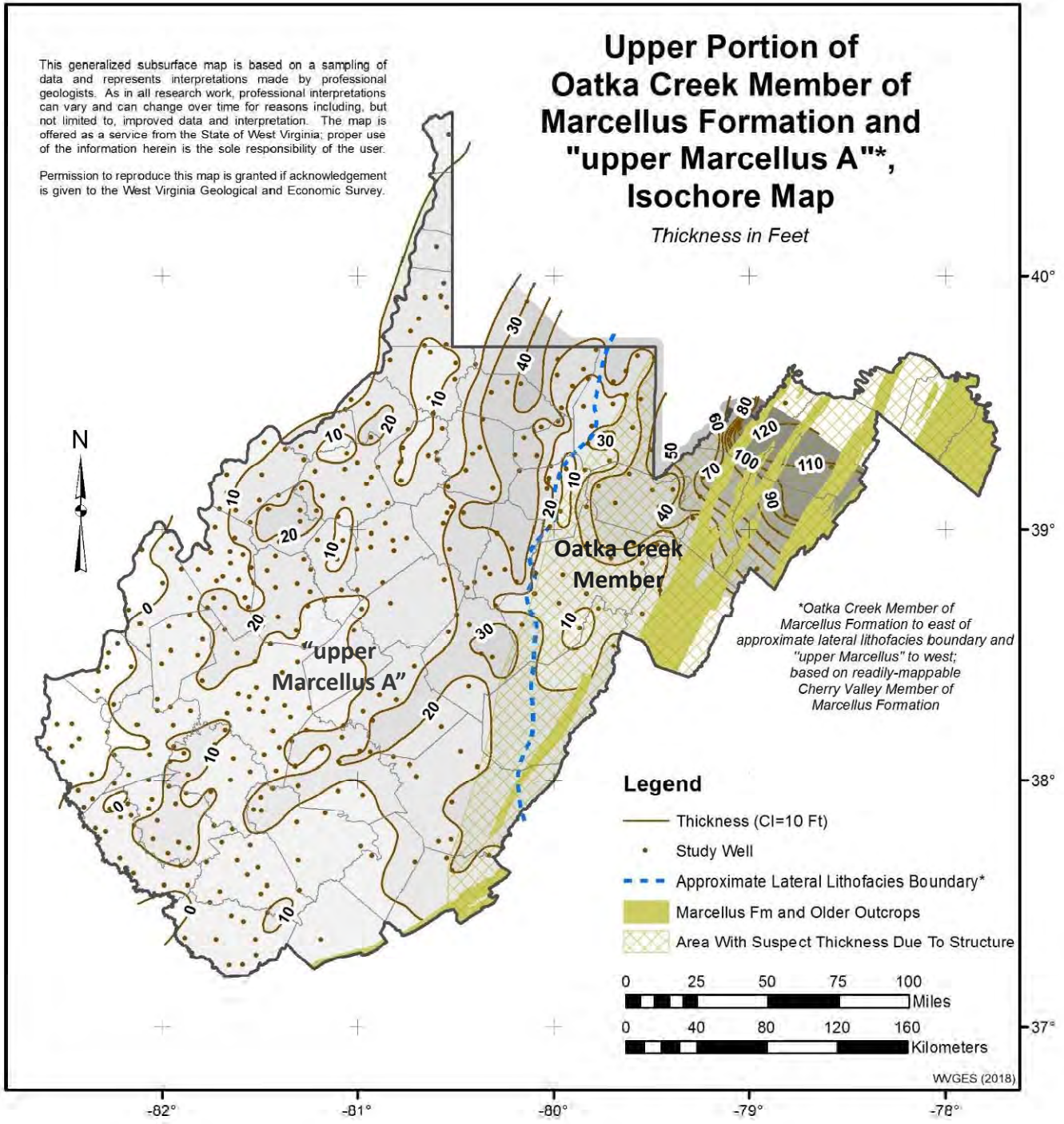


U.S. DEPARTMENT OF ENERGY

Oatka Creek Mbr

"upper Marcellus A"

- Upper portion
- Base is "drillers' Purcell"
- Correlative to Skaneateles Fm of Pennsylvania

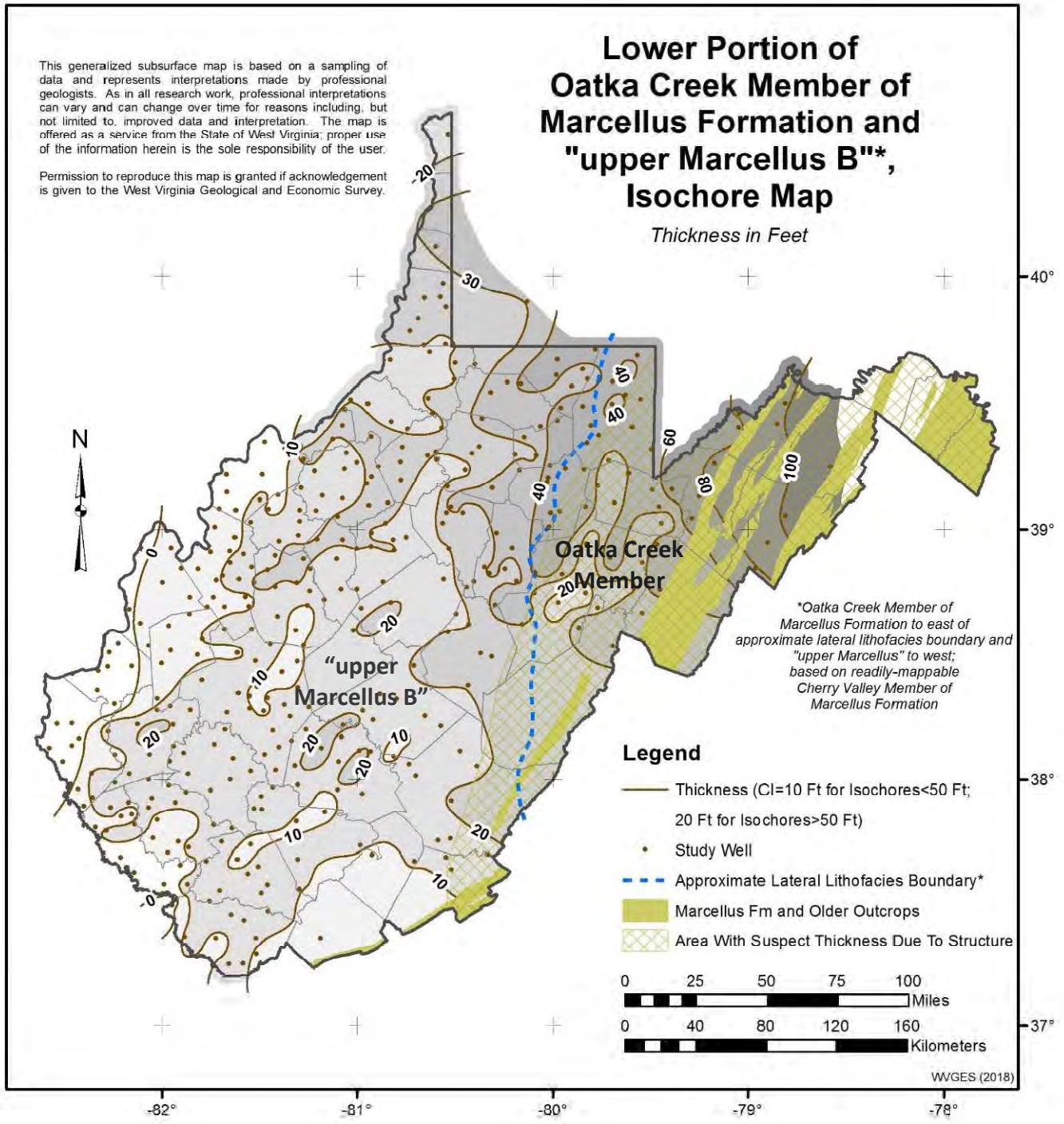


U.S. DEPARTMENT OF ENERGY

Oatka Creek Mbr

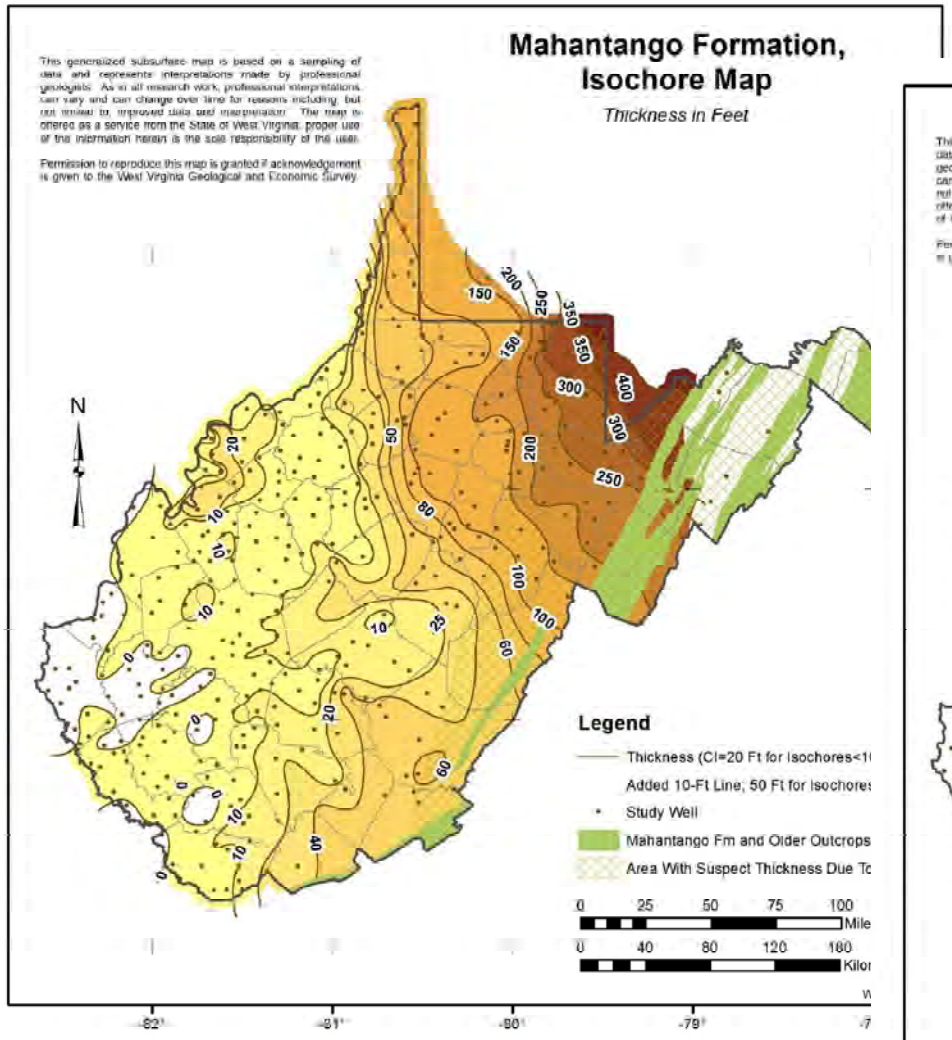
"upper Marcellus B"

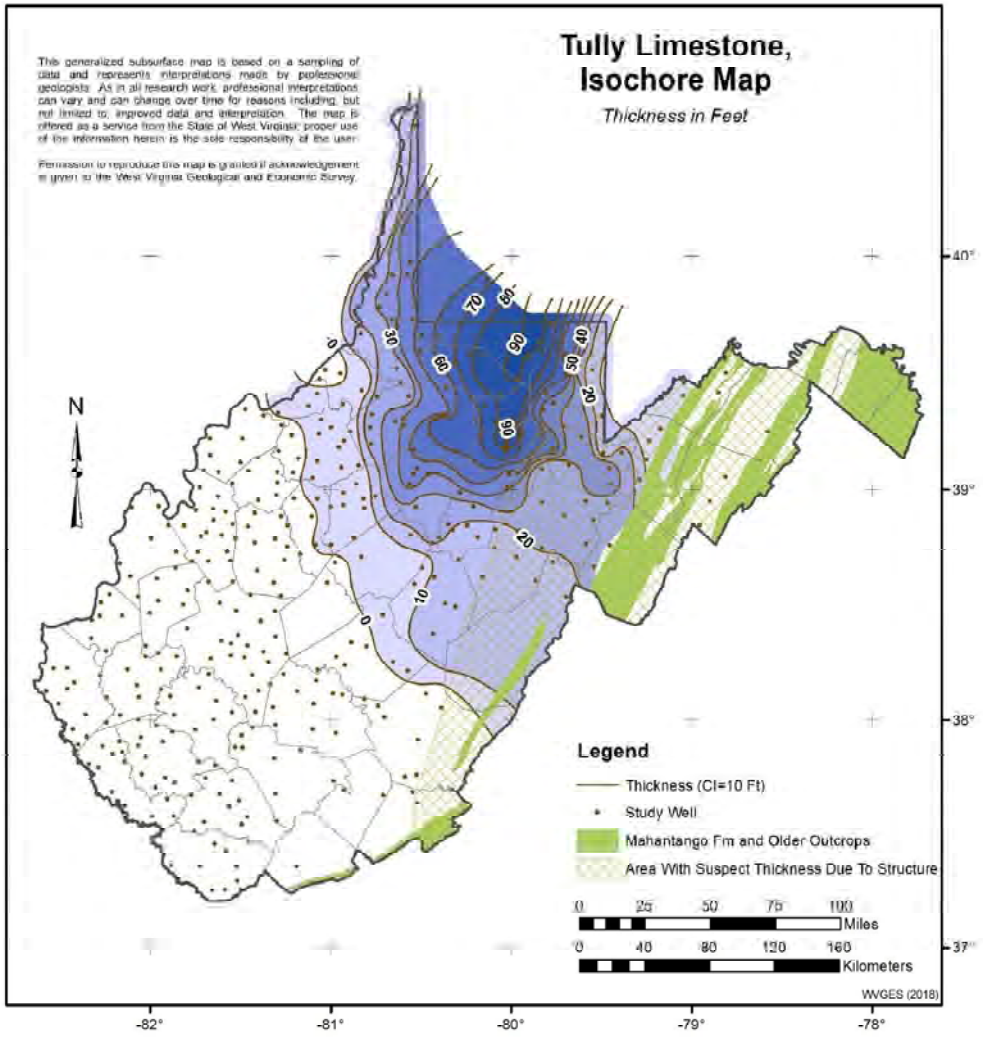
- Top is drillers' "Purcell" and eq.
- Base is driller's Cherry Valley or Cherry Valley



U.S. DEPARTMENT OF ENERGY

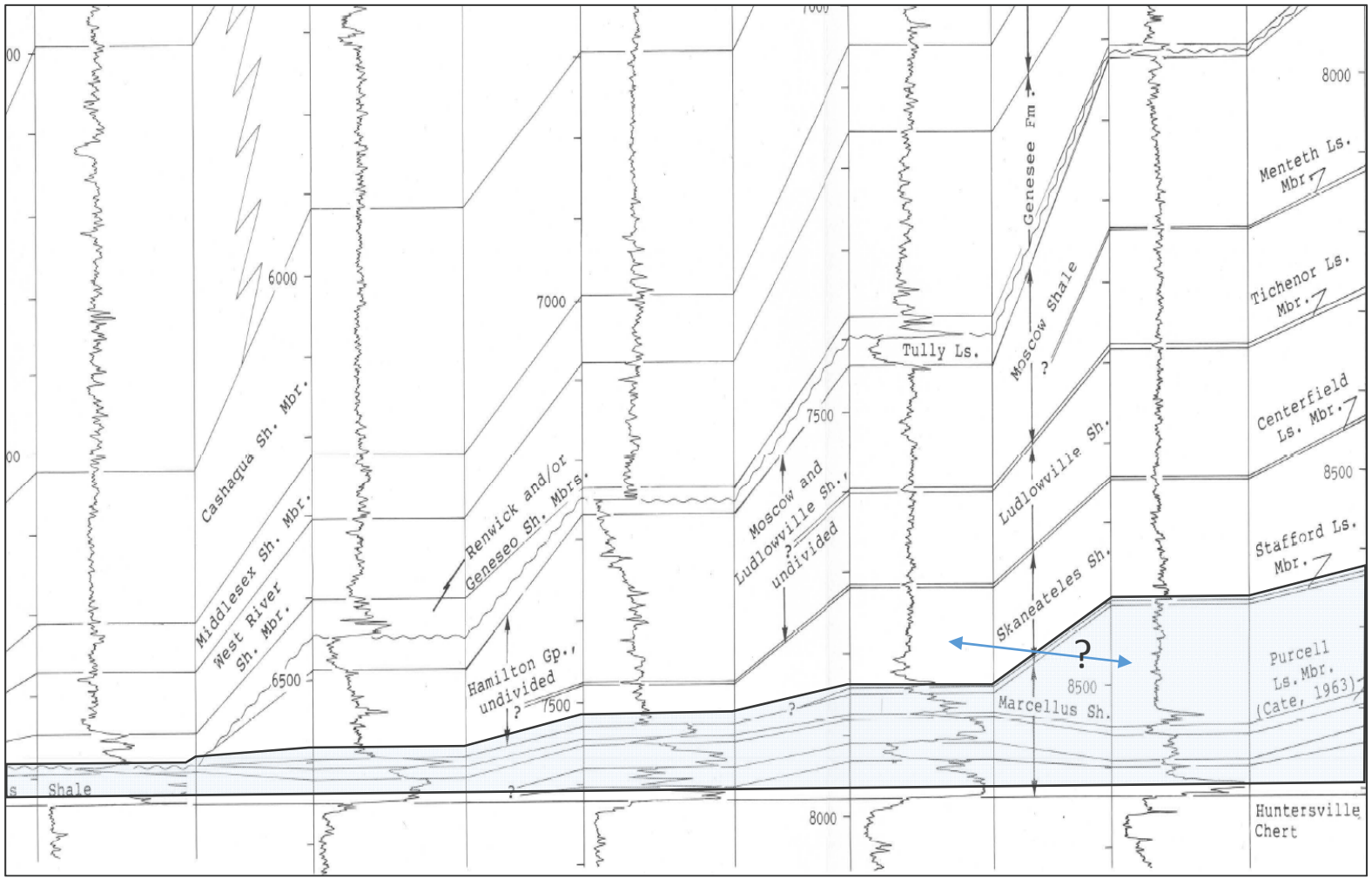
Mahantango Fm and Tully Ls





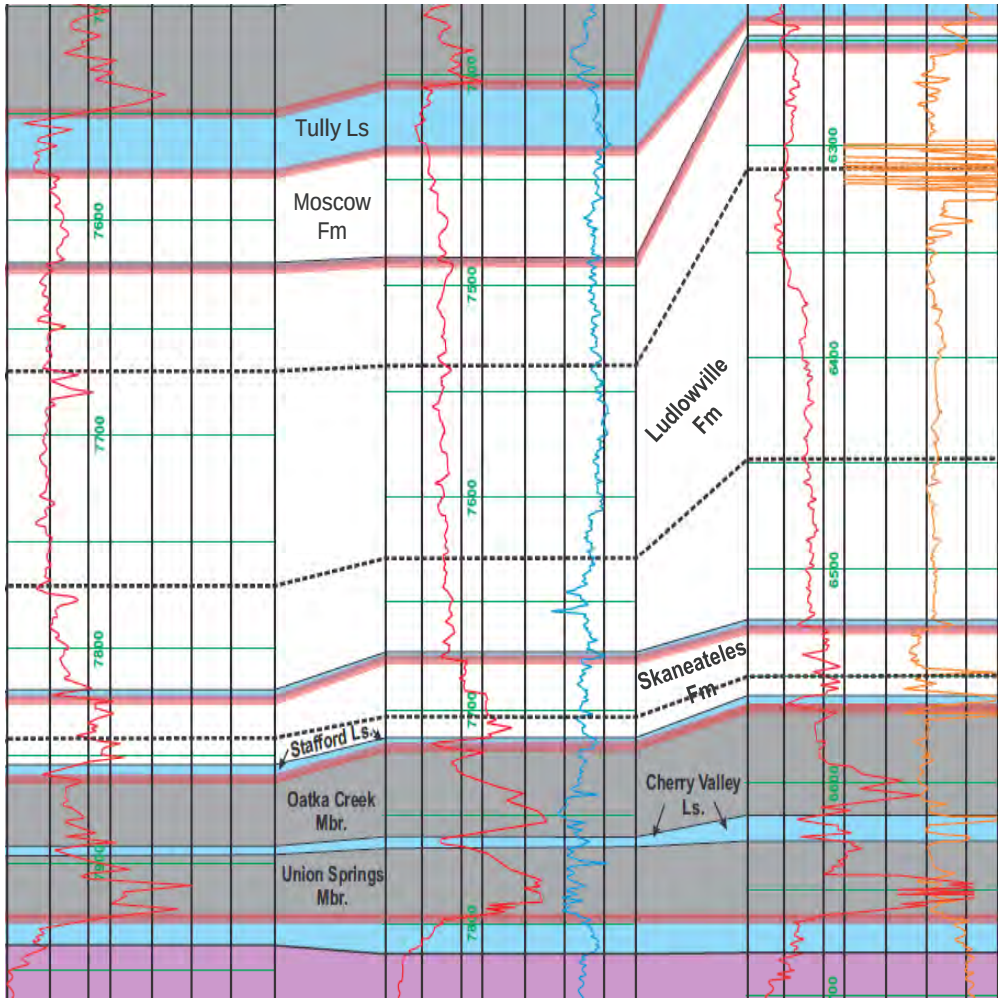
USGS Bulletin 1909

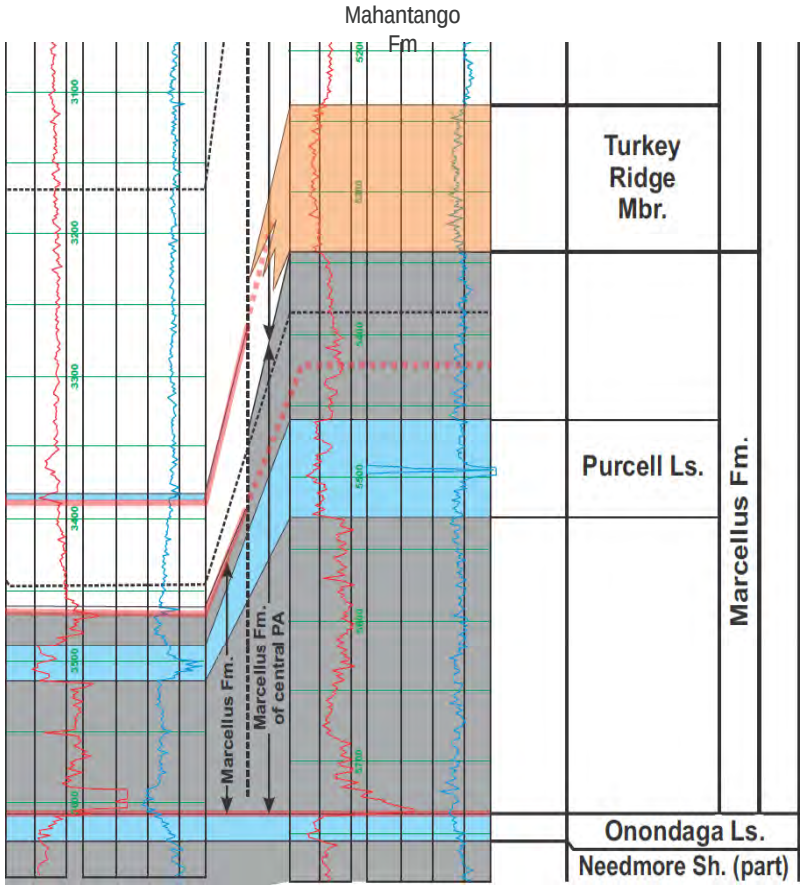
DeWitt et al., 1993



PA Stratigraphy

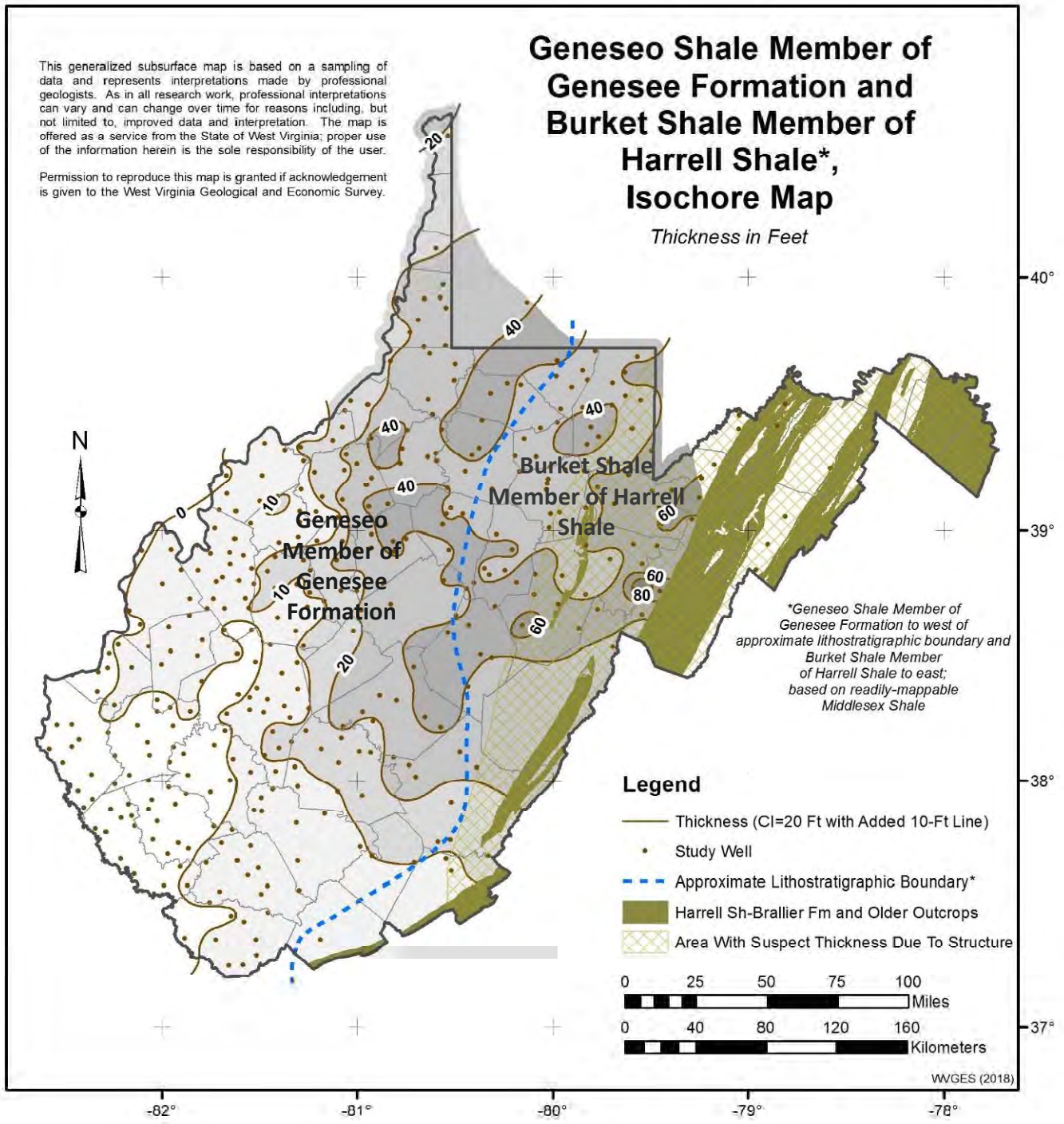
Harper et al., 2017





Geneseo-Burket

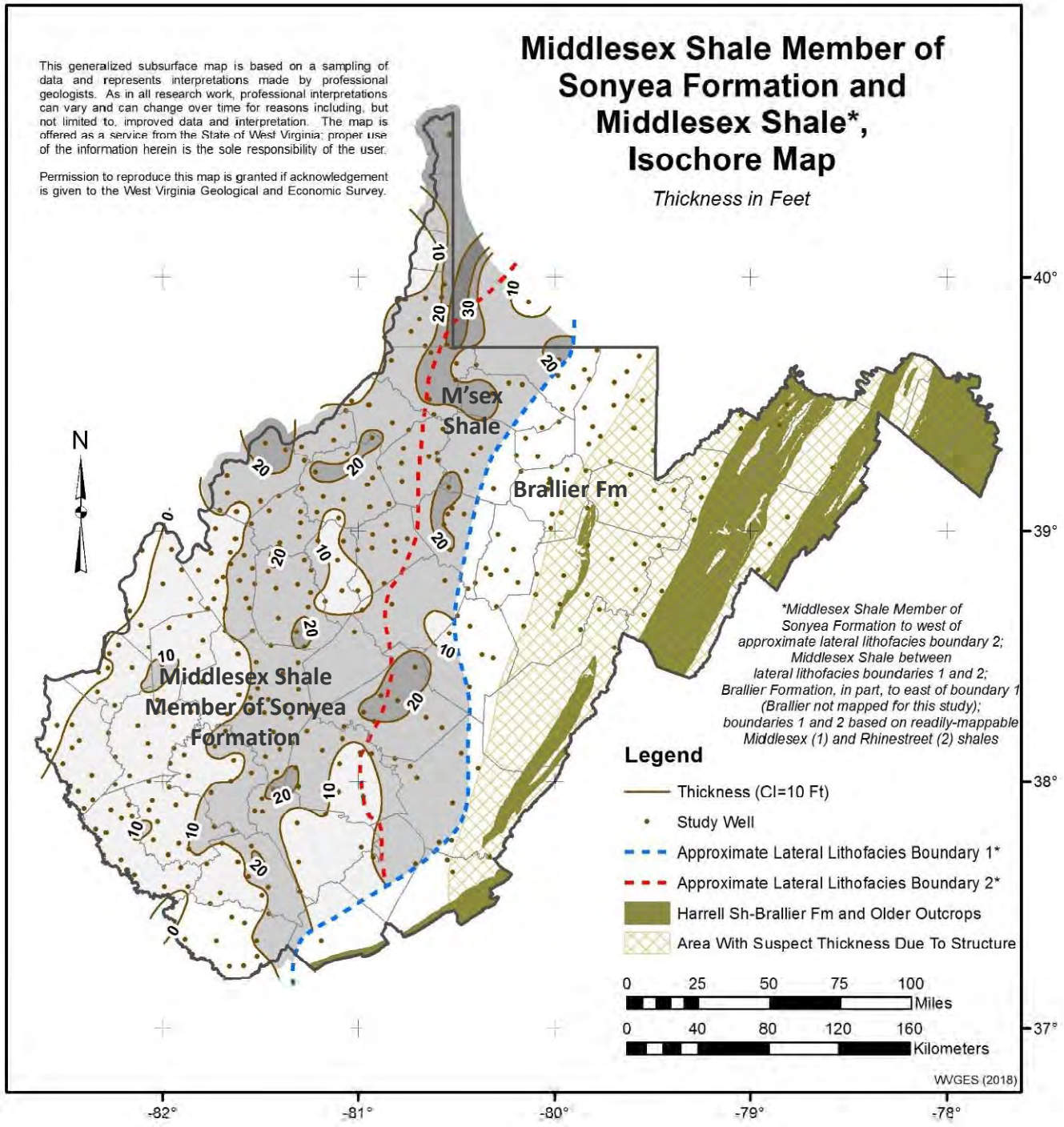
- Geneseo Shale Mbr of Genesee Fm to the west.
- Geneseo Mbr overlain by West River Mbr of Genesee Fm
- Burket Shale Mbr of the Harrell Shale to the east.



U.S. DEPARTMENT OF ENERGY

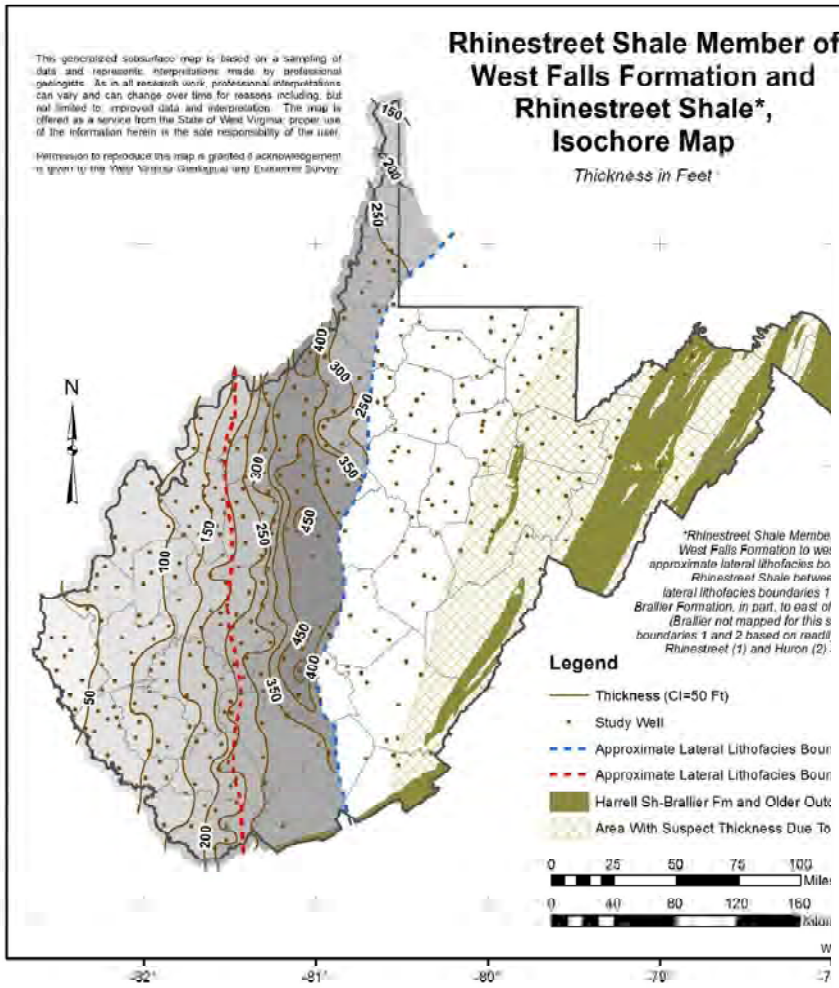
Middlesex Shale

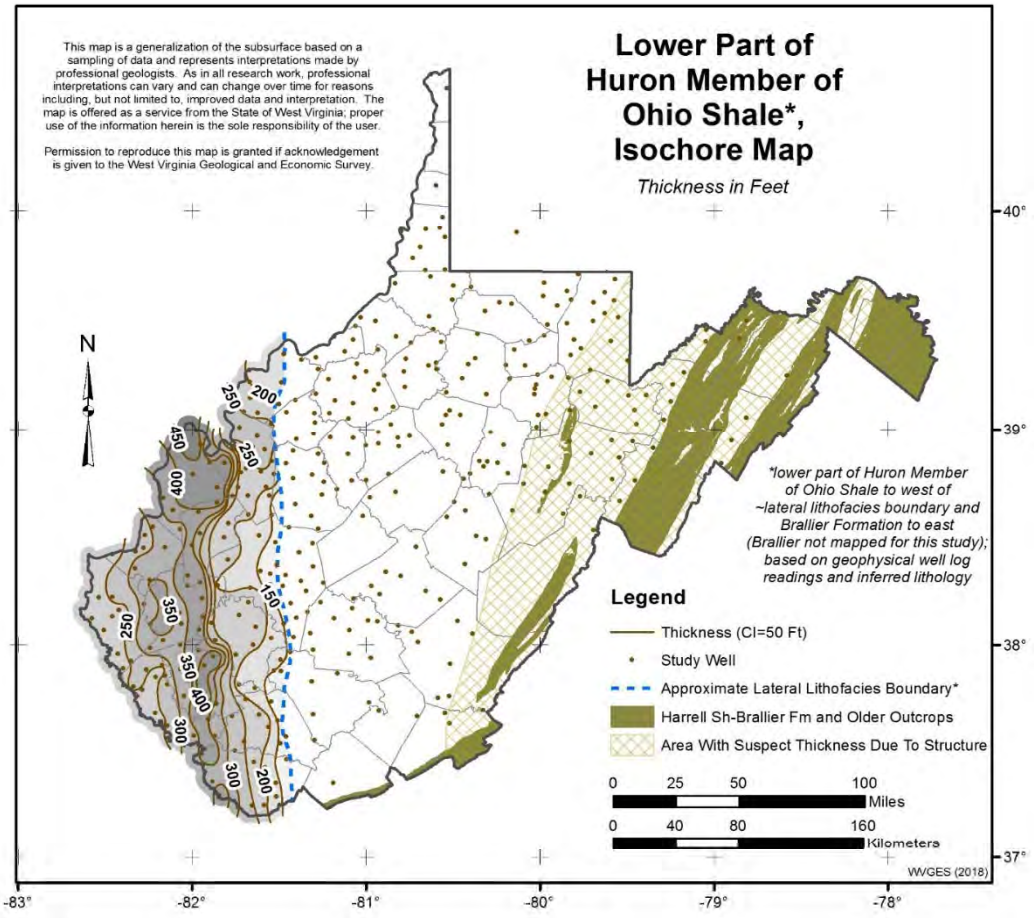
- Middlesex Shale Mbr of Sonyea Fm west of red line
- Middlesex Shale between red and blue lines
- Correlative interval has graded into Brallier Fm organic-poor shale east of blue line
- Middlesex Sh Mbr overlain by Cashaqua Sh Mbr of Sonyea Fm



U.S. DEPARTMENT OF ENERGY

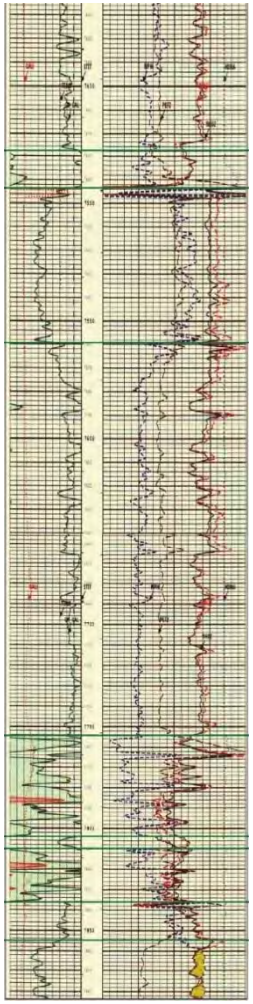
Rhinestreet and Huron Shales





Results

No new names proposed…. some are new to the state (formally)



Marcellus "Formation"

- (non-shale; non-shale members; Fm in PA/NY)
- three Members limited to small area in NE West Virginia; Undifferentiated elsewhere
- use Oatka Creek, Cherry Valley, Union Springs as applied in Greene, Fayette, etc. PA
- restrict Purcell as informal name in subsurface.
- as in central PA, Purcell retains its current status as member until further work is done.
- retain PA "Skaneateles" as Marcellus (lithologic consistency)

Mahantango Formation

- in lieu of other names used in PA (Ludlowville, Moscow, Stafford, etc.)

Geneseo/Burket

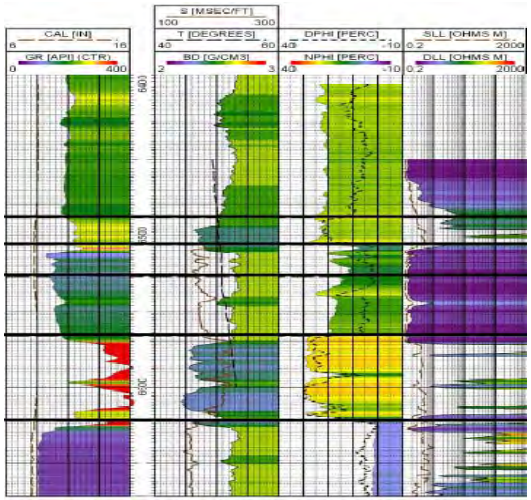
- demarcate lateral transition and basis

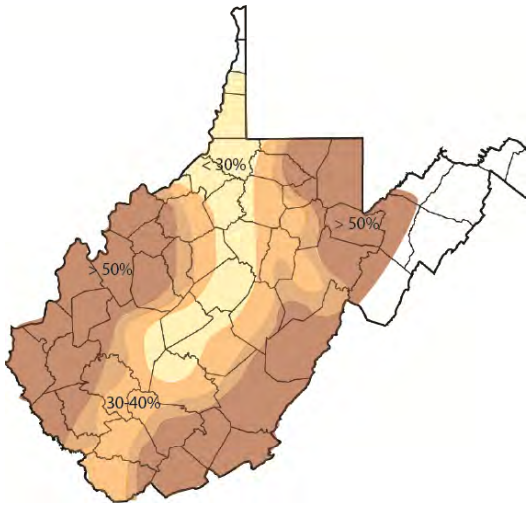
Remaining Organic-rich Shale

- follow PA convention: transition from Mbr to Fm beyond eastward extent of host Fm
- recognize "Pipe Creek" and "Dunkirk" as informal beds in WV.
- do not recognize "Perrysburg Fm."

WVGES-NETL Resource Assessment

122 tcf GIP in Marcellus in WV: Pool et al., 2013.





Pressure: WVGES Oil and Gas (as reported by operator)

- new data: re-evaluation: is pressure a f(TOC)??

Porosity: From Logs: bulk density/density porosity: V_{ker} correction. Ambrose correction.

- new opportunities for core calibration?

Saturation: From Logs: Simandoux (A = 1.0; M= 1.7; N = 1.7); V_{ker} correction.

- recent work (Douds et al., AAPG) → logs and cores overstate S_w; Set at consistent low value?

Formation Volume Factor: Standard equation

- gas density correction – need pore size distribution information

Adsorbed Gas: TOC from DlogR (Passey); LOM; check with literature (WVU)…TOC converted to GC; calibration to EGSP data

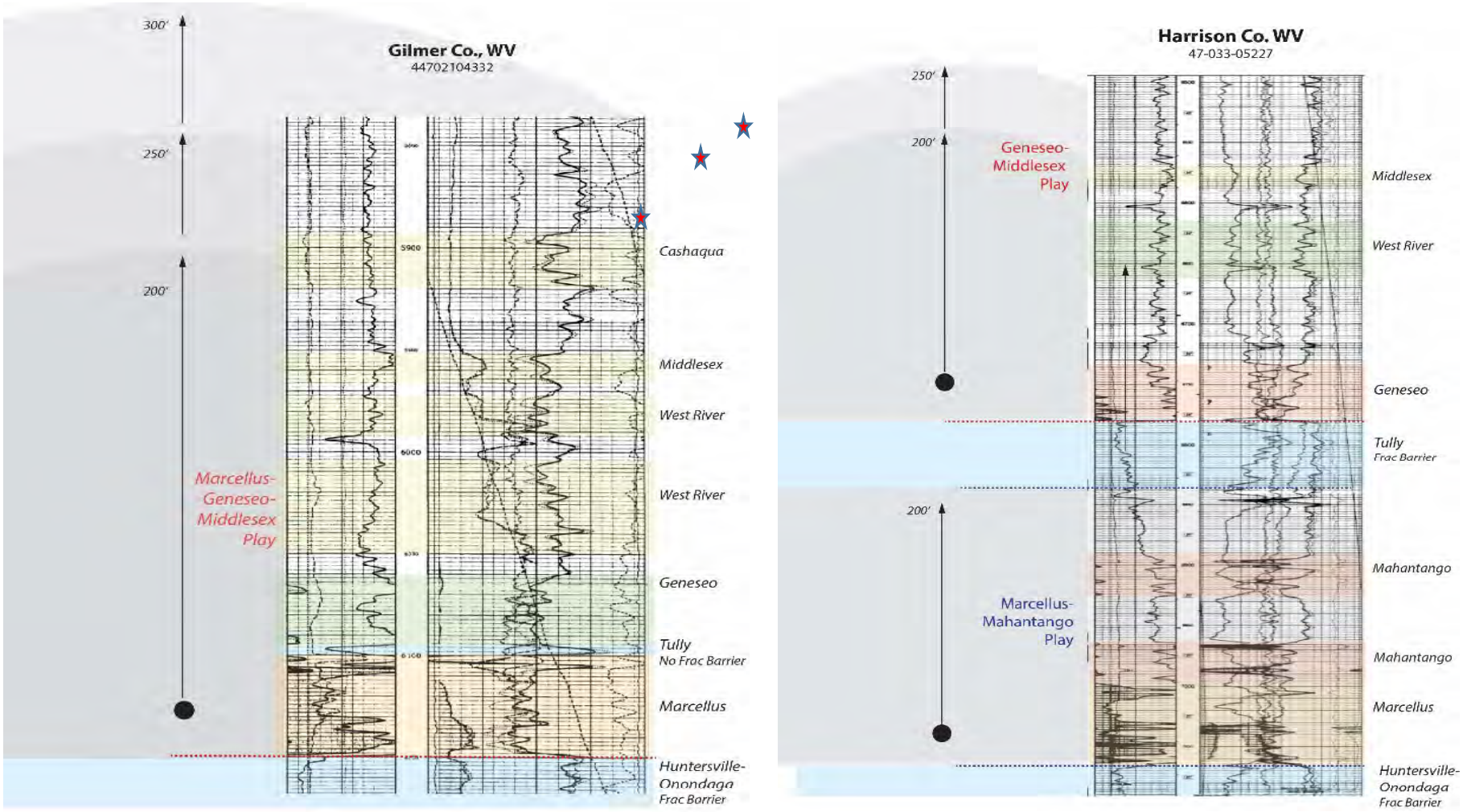
- TOC from GR (Marcellus)… new opportunities for core calibration?

"Pay" Thickness: From log correlation

- new approach to unit definition: from lithologic unit to "flow unit"

WV Shale "Plays"

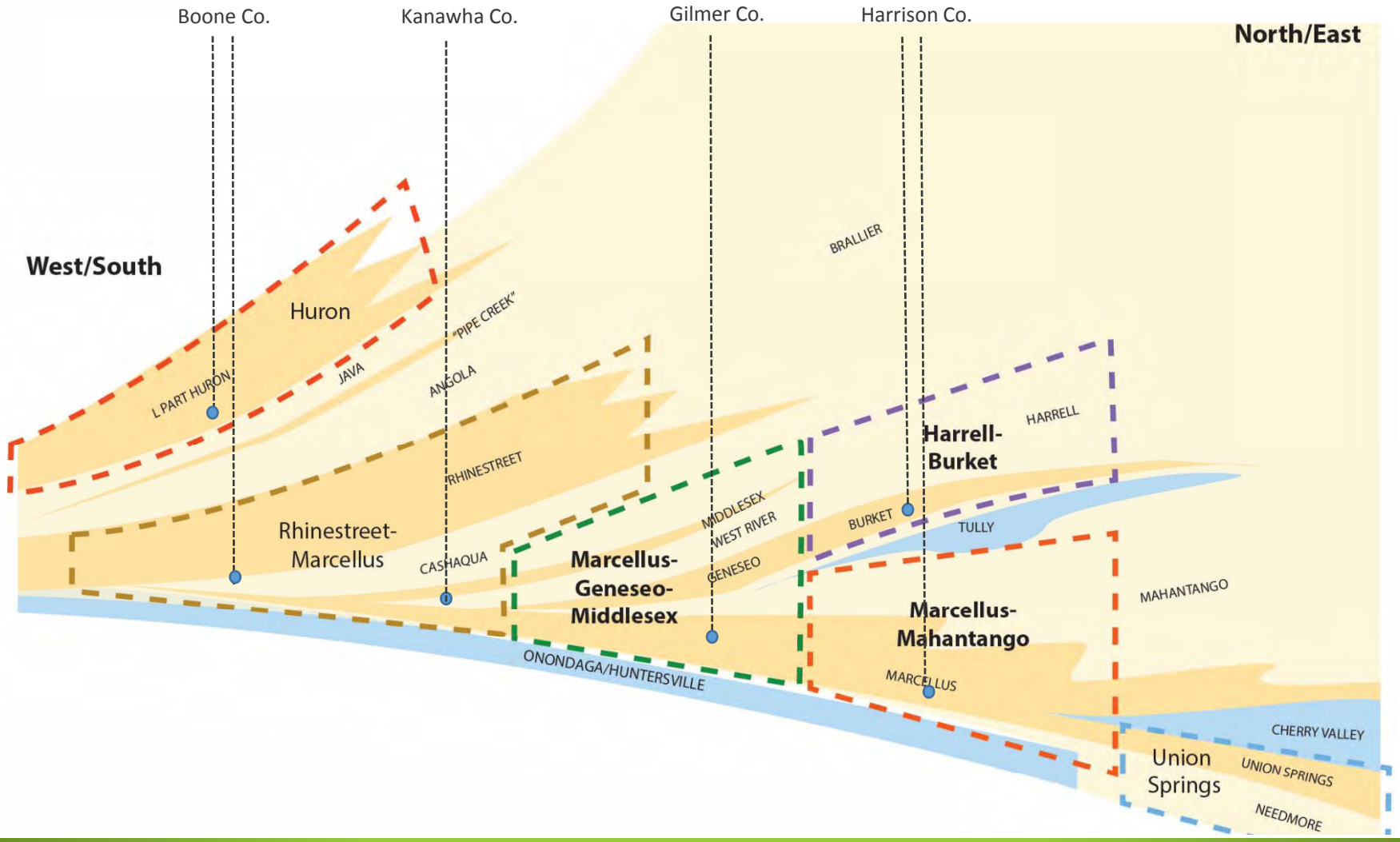
GIP in units within the Contributing Rock Volume: CRV function of occurrence of frac barriers....



- GIP encompasses all units within the potential CRV
- CRV is constrained by frac reach and frac barriers….

Marcellus Shale Plays in WV

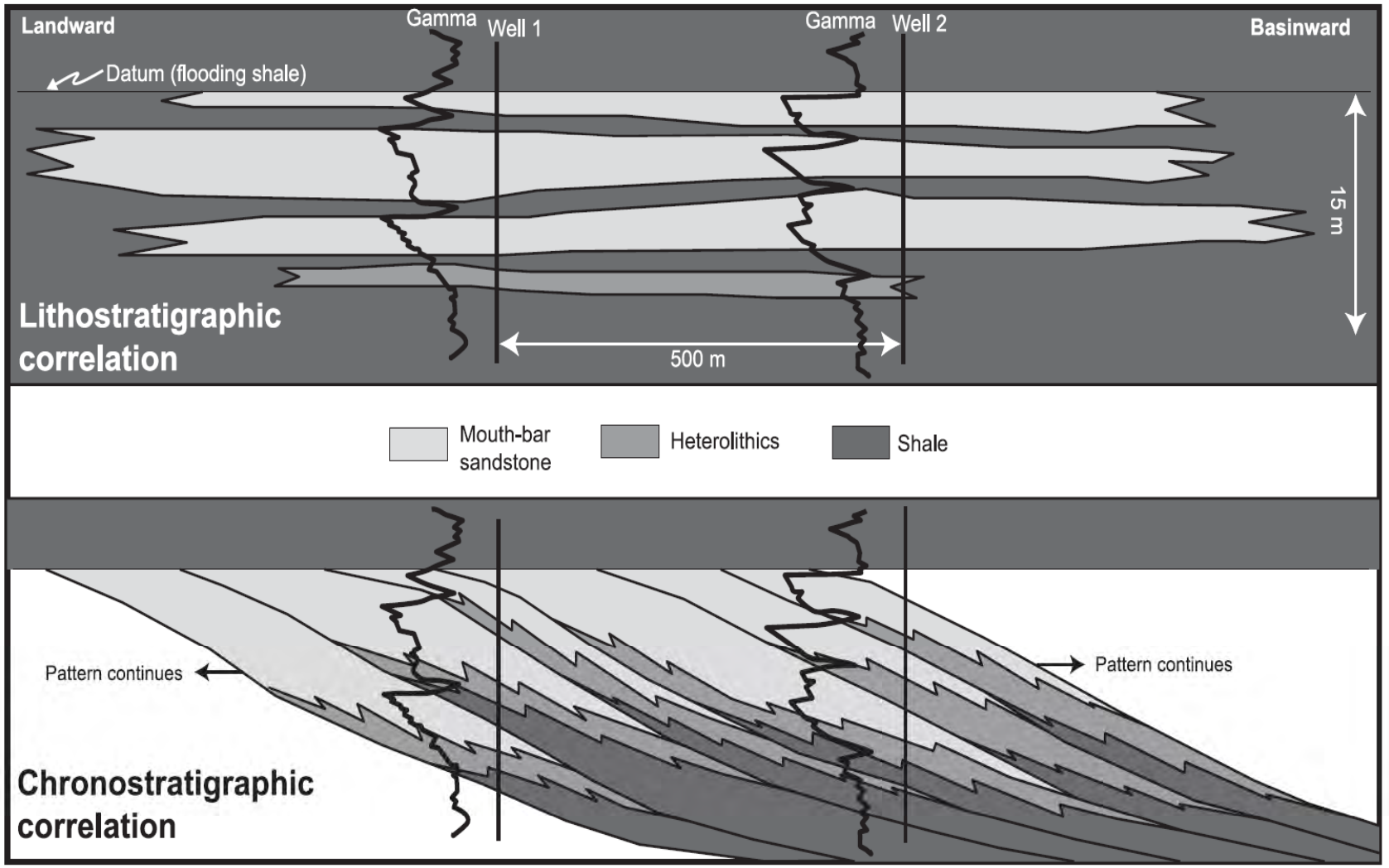
From geologic units to "flow units"



Thank You

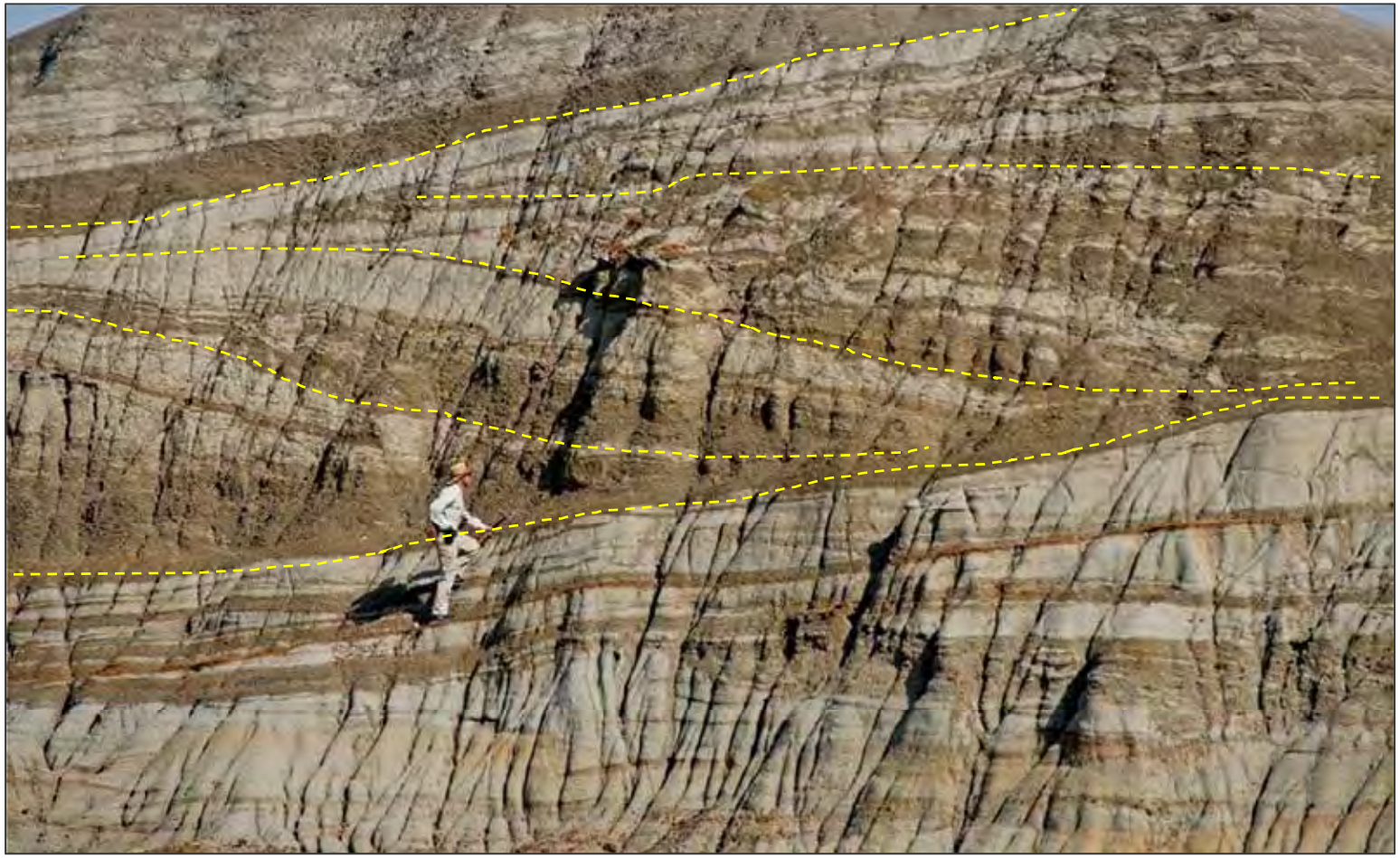
Correlation at Reservoir Scale

Gani and Bhattacharya, 2005



Local Scale Timelines

Point Bar Deposits: Dinosaur Park, Alberta



PA Stratigraphy

Harper et al., 2017