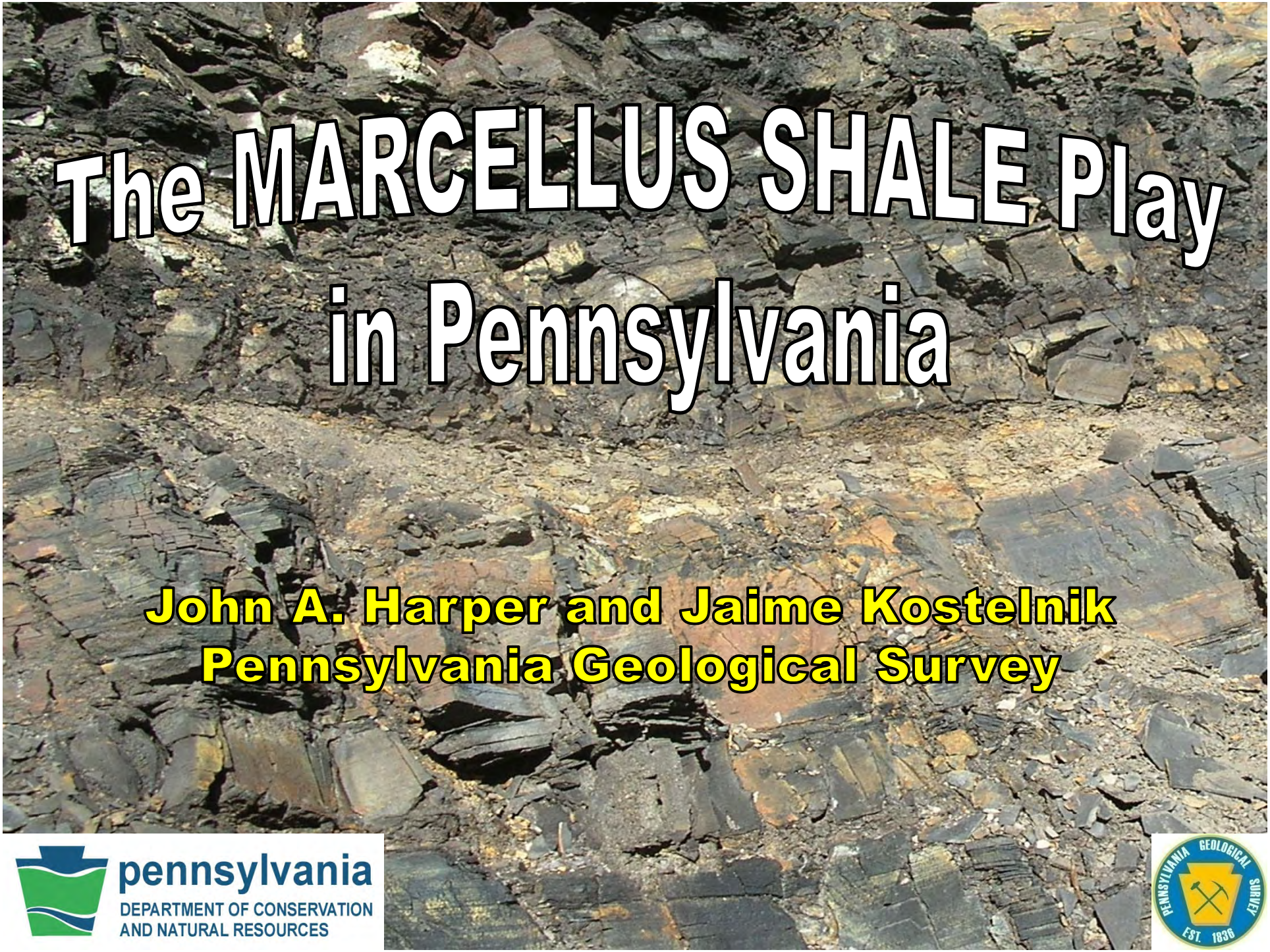


The MARCELLUS SHALE Play in Pennsylvania

John A. Harper and Jaime Kostelnik
Pennsylvania Geological Survey

pennsylvania
DEPARTMENT OF CONSERVATION
AND NATURAL RESOURCES

PENNSYLVANIA GEOLOGICAL SURVEY
EST. 1836

YOU'VE HEARD ABOUT THE INCREDIBLE PRODUCTION RATES FOR THE MARCELLUS SHALE, OR READ THE NEWS REPORTS

- Average initial 24-hr open flow rate of 1 million cubic feet of gas per day (MMcfgpd)
- Initial production rate averaging 4 to 5 MMcfgpd from five vertical wells
- 24-hour initial production rate for 10 wells averaged 7.3 MMcf equivalent of gas per day
- Average initial open flow of 13 vertical wells was 1.3 MMcfgpd
- Average initial potential rate of 4.3 MMcfgpd

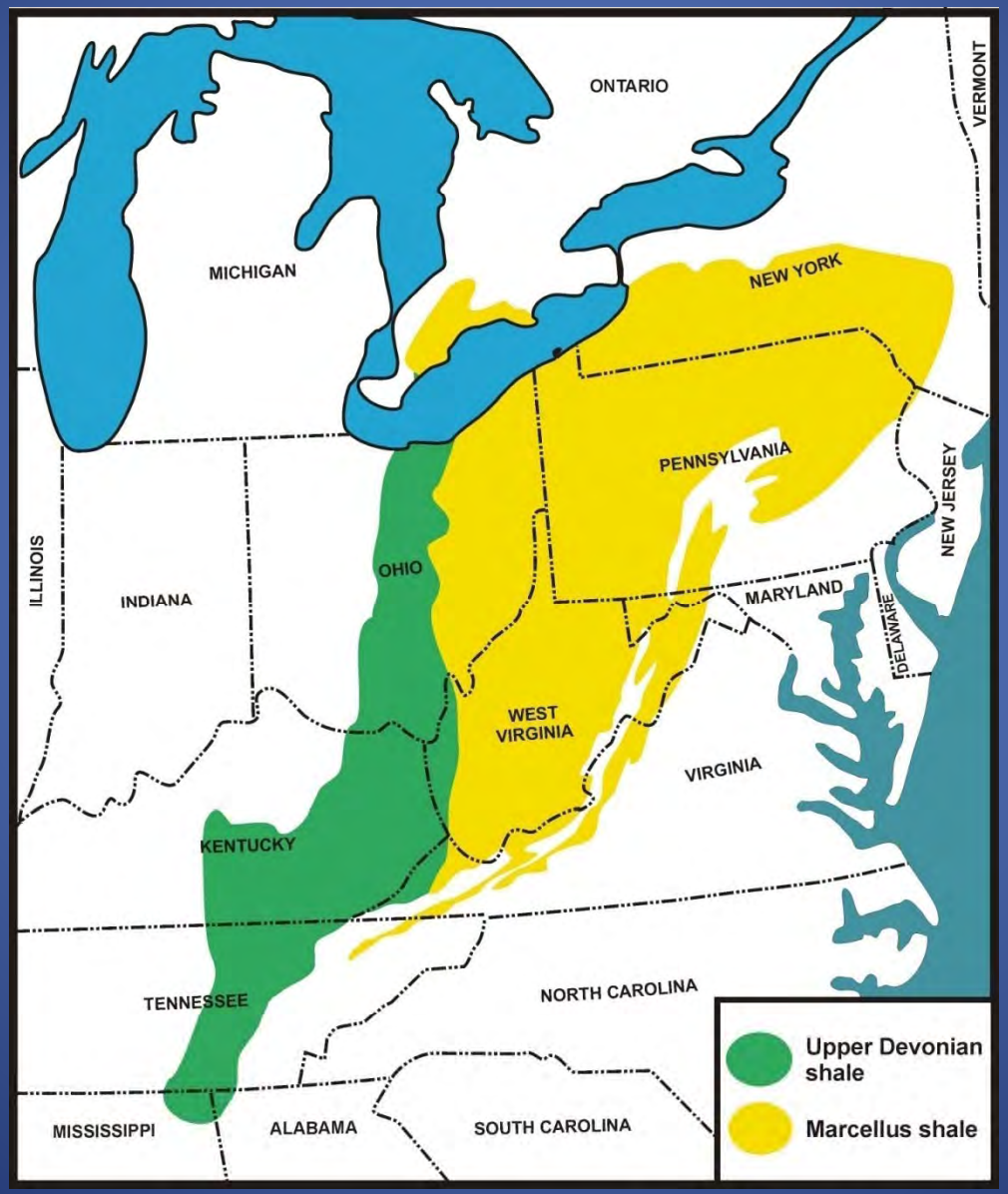
WHAT DO ALL OF THESE HAVE IN COMMON?

- **Average initial 24-hr open flow rate** of 1 million cubic feet of gas per day (MMcfgpd)
- **Initial production rate** averaging 4 to 5 MMcfgpd from five vertical wells
- **24-hour initial production rate** for 10 wells averaged 7.3 MMcf equivalent of gas per day
- **Average initial open flow** of 13 vertical wells was 1.3 MMcfgpd
- **Average initial potential rate** of 4.3 MMcfgpd

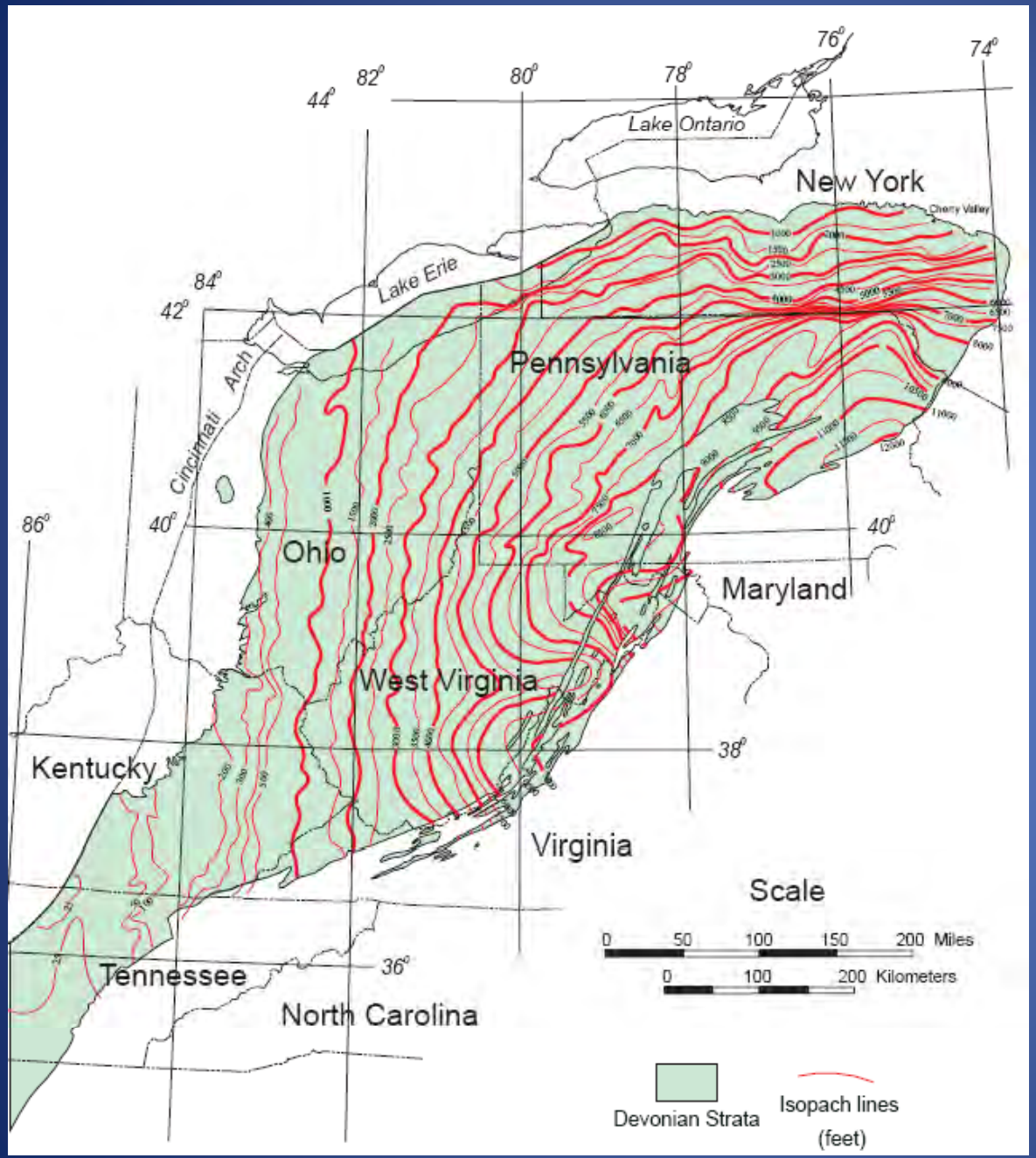
THE MARCELLUS SHALE

Some basic geology . . .

EXTENT OF DEVONIAN SHALES IN THE APPALACHIAN BASIN



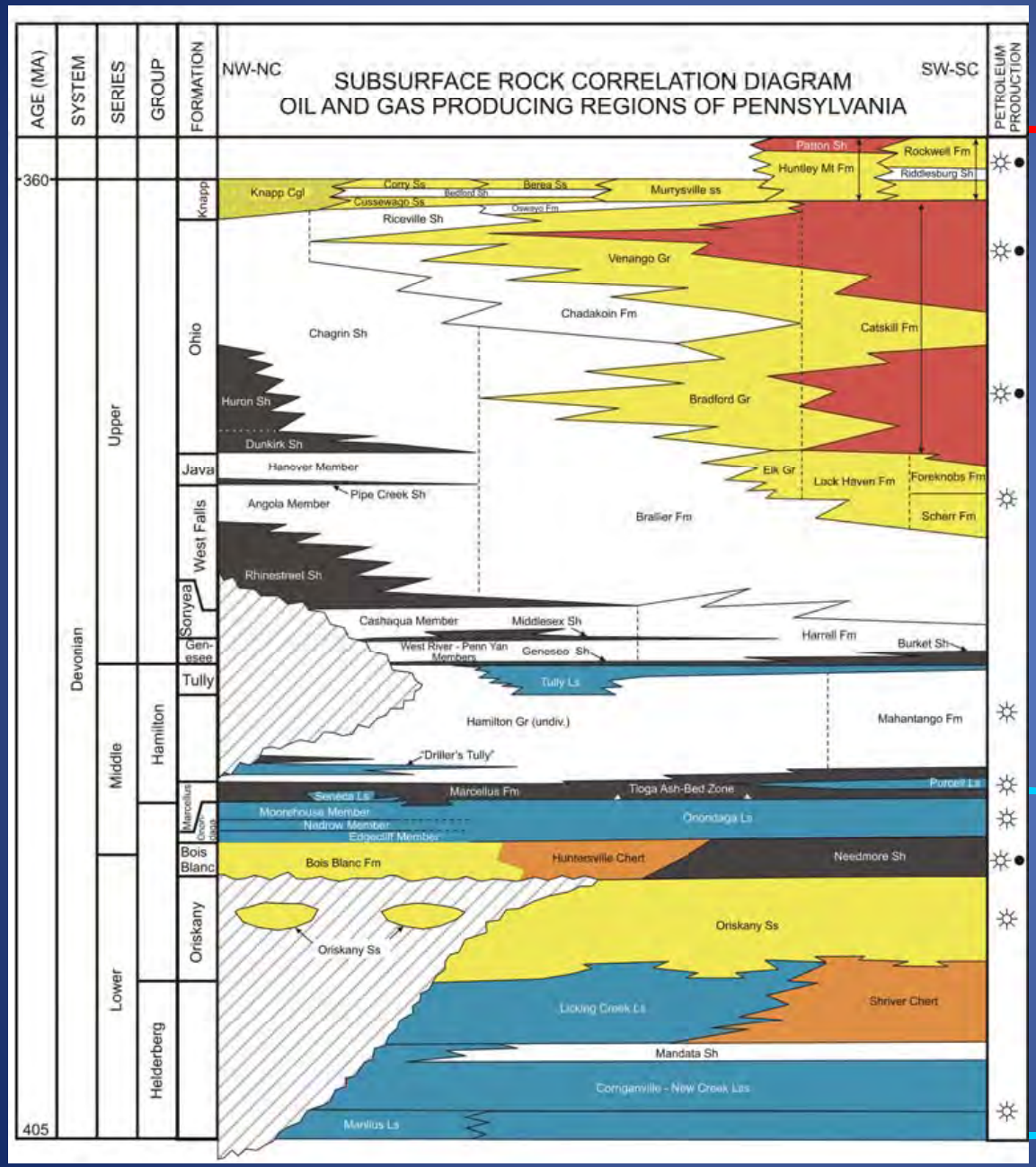
Based on Milici and Sweezey, 2006



THICKNESS AND EXTENT OF THE DEVONIAN SHALE INTERVAL IN THE NORTHERN APPALACHIAN BASIN

Milici and Swezey, 2006

RELATIONSHIP OF DEVONIAN TECTONICS AND SEDIMENTATION



Syn- to post-orogenic deposits

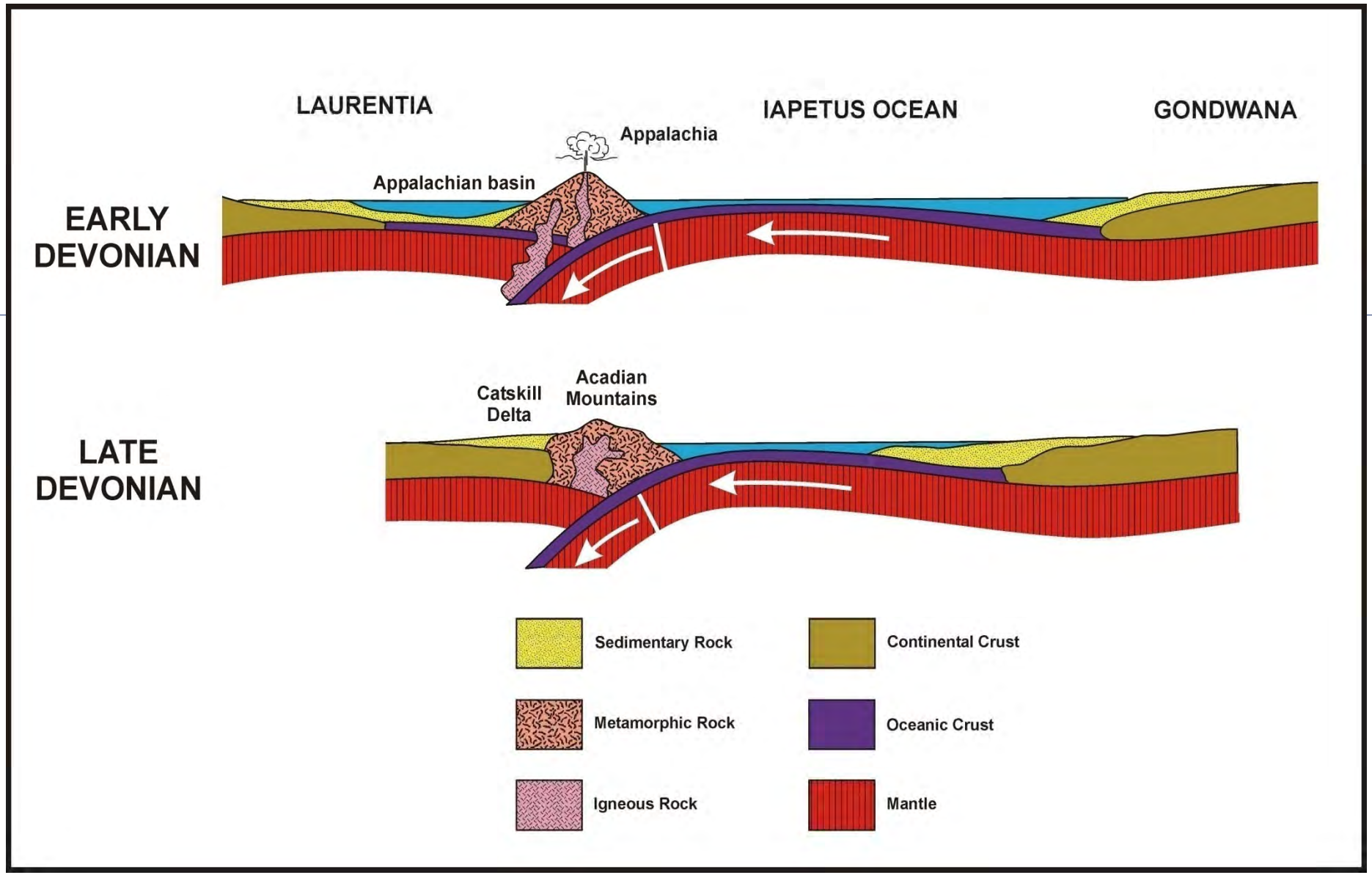
Pre-orogenic stable shelf deposits

Carter, 2007

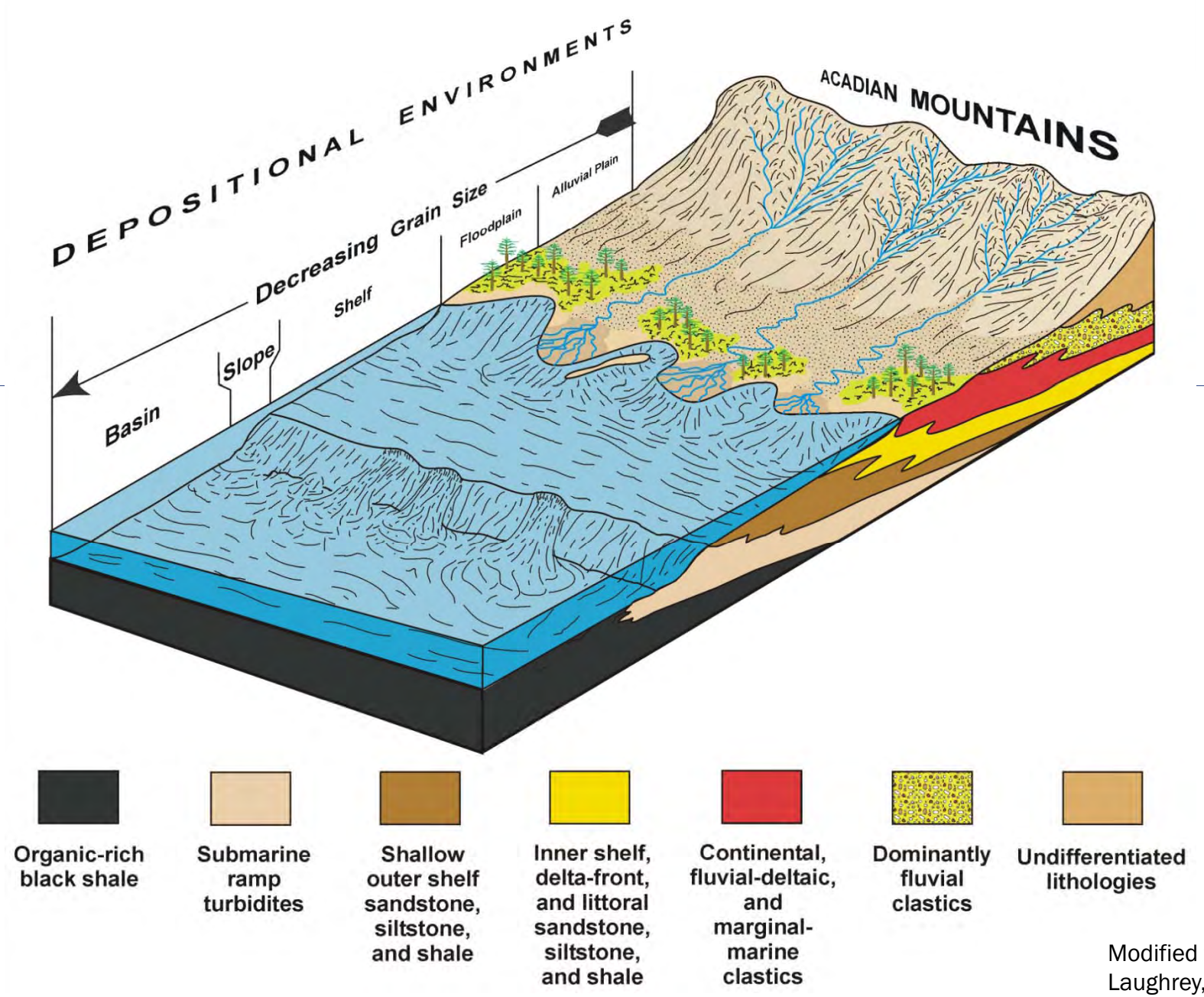
MIDDLE DEVONIAN (385 MA) PALEOGEOGRAPHY OF LAURENTIA

Modified from Blakey, 2009

DEVONIAN PLATE TECTONICS

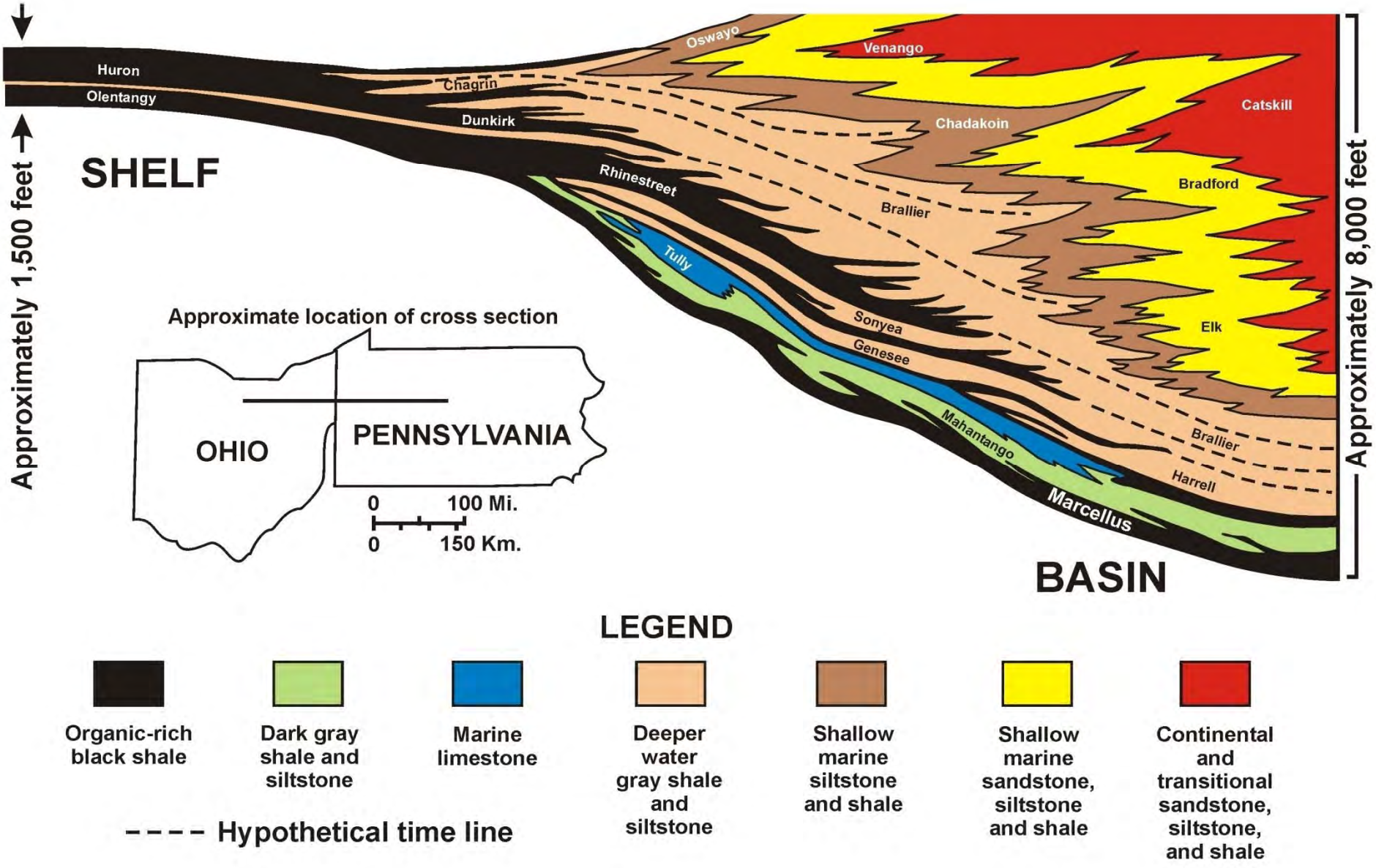


DEVONIAN DEPOSITIONAL ENVIRONMENTS



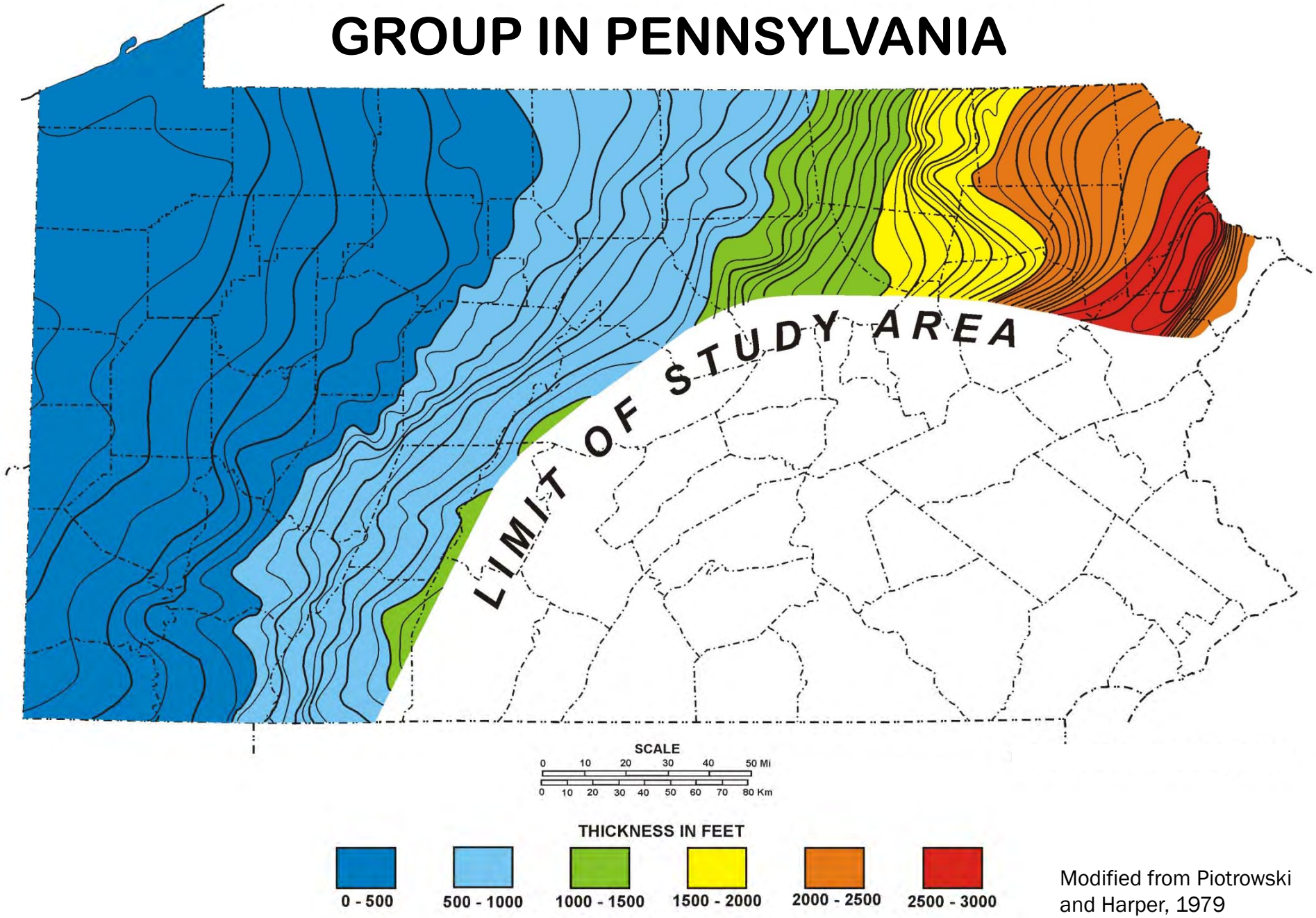
Modified from Laughrey, 2009

THE CATSKILL CLASTIC WEDGE



Modified from Harper, 1999

ISOPACH MAP OF THE HAMILTON GROUP IN PENNSYLVANIA

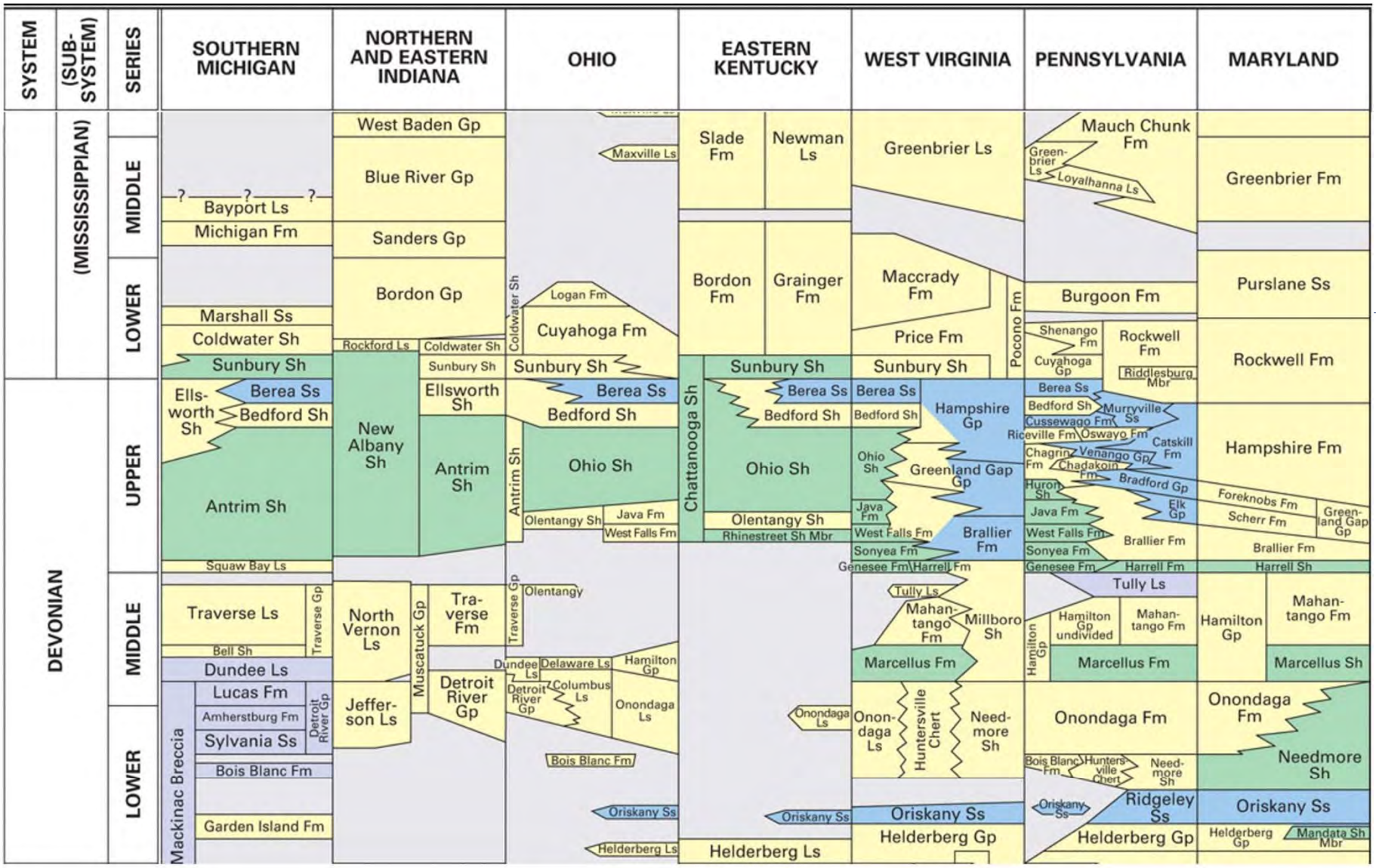


Modified from Piotrowski and Harper, 1979

HAMILTON GROUP STRATIGRAPHY

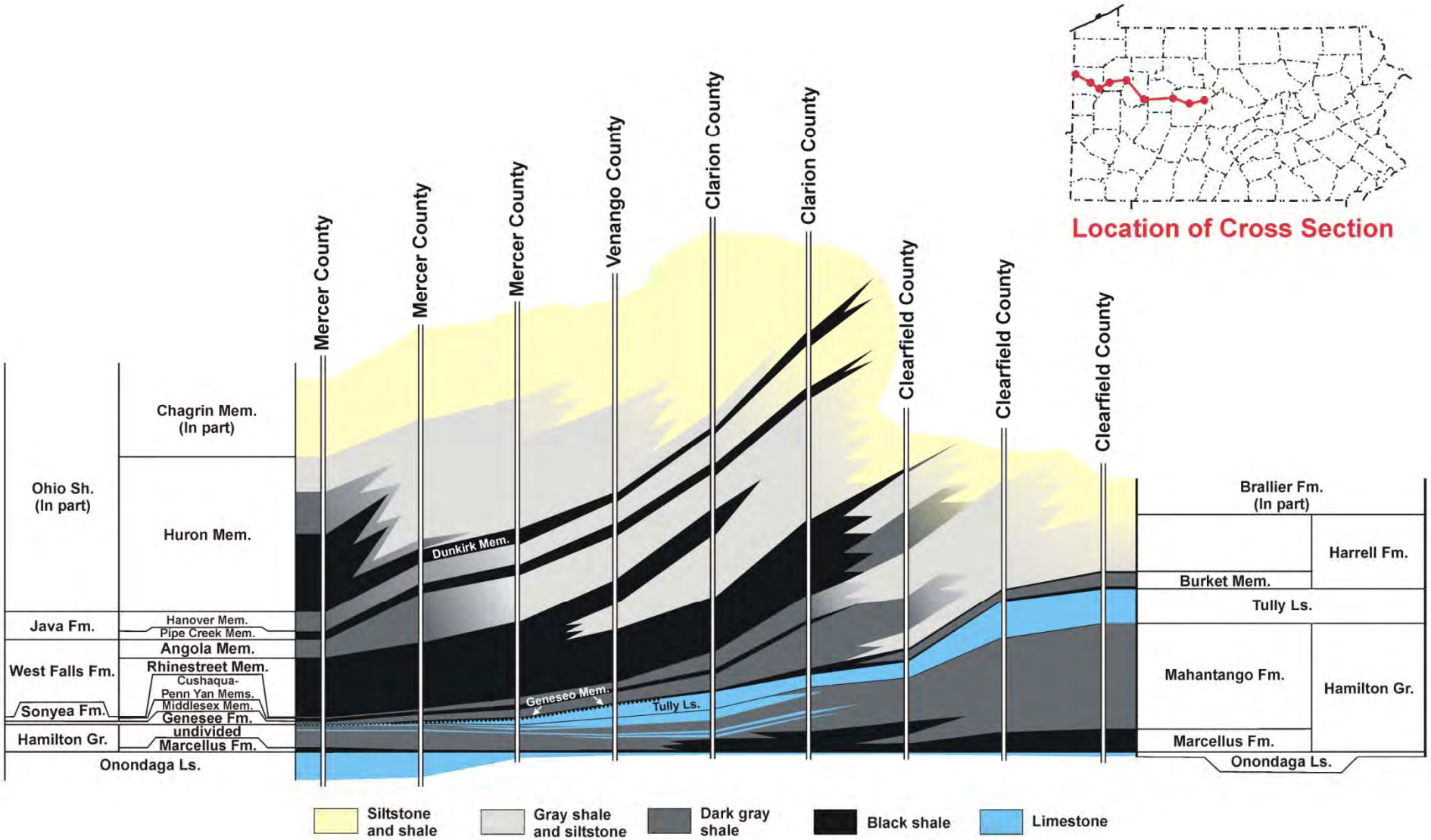
- Marcellus – lower portion of the Hamilton group with higher than normal gamma ray responses
- Mahantango – post Marcellus interval containing significant siltstones and sandstones
- Non-radioactive interval lacking significant siltstones and sandstones as the “Hamilton Group undivided”

MISSISSIPPIAN AND DEVONIAN CORRELATION ACROSS THE APPALACHIAN BASIN

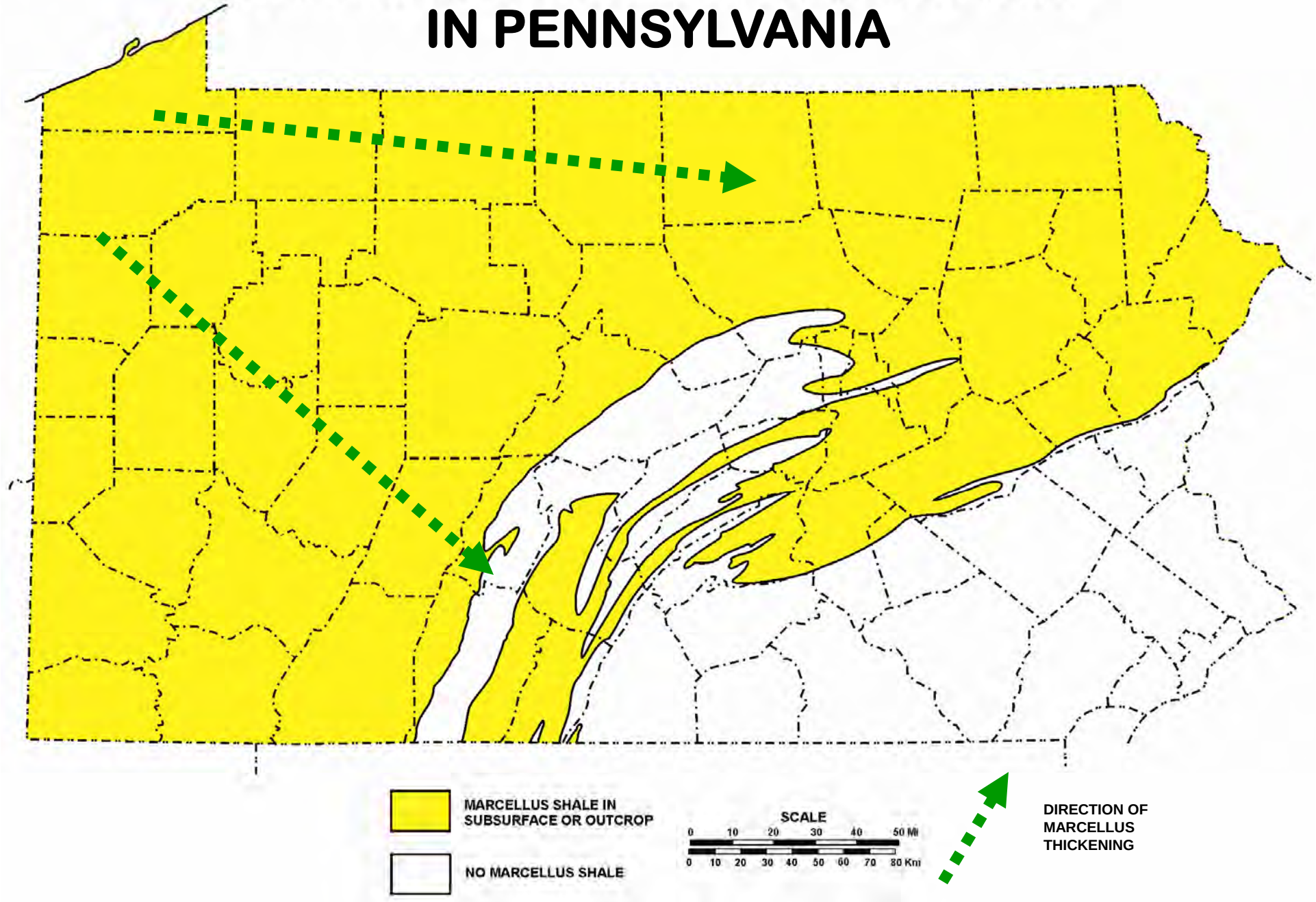


Wickstrom and others, 2005

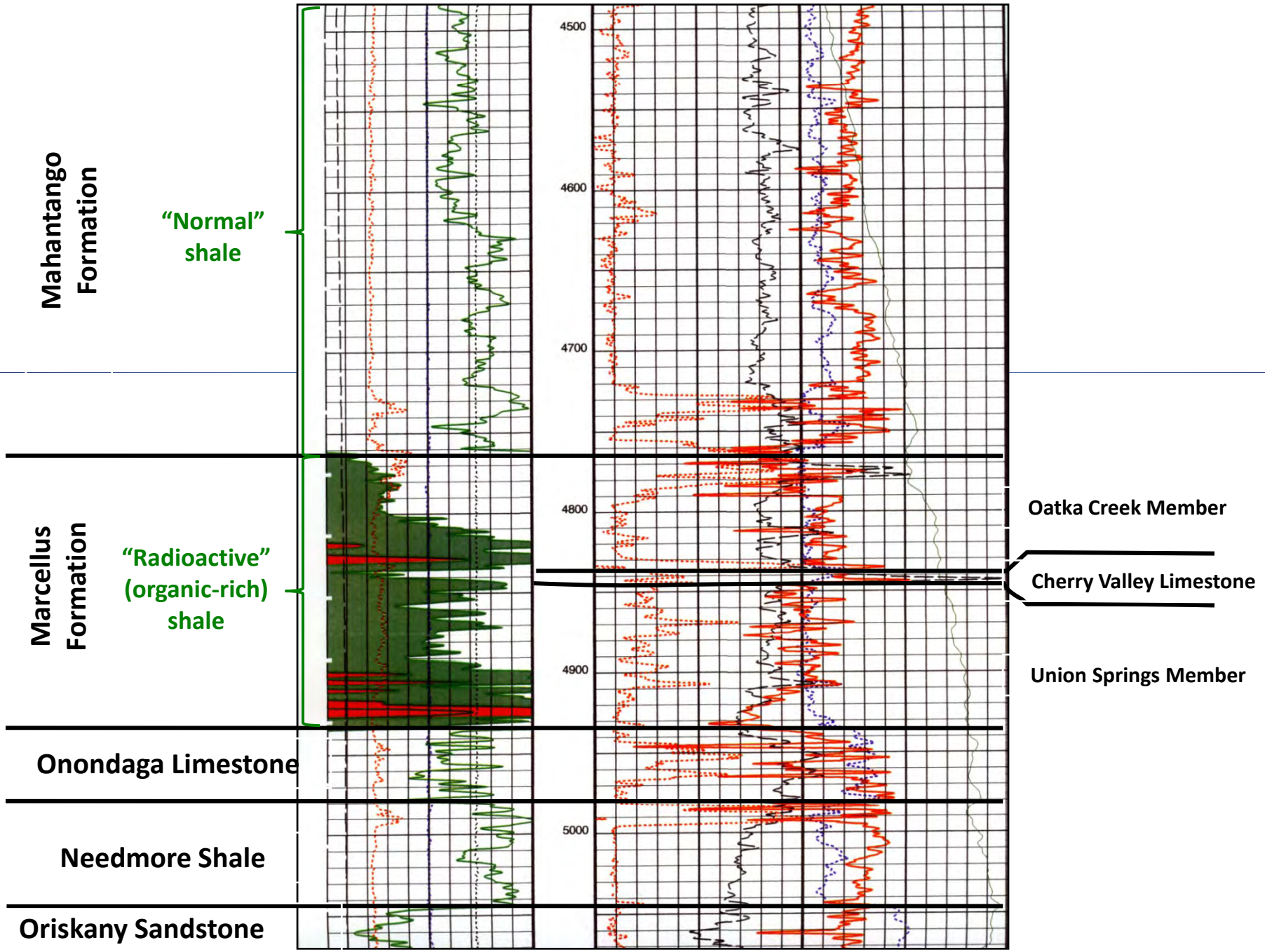
CROSS SECTION OF WESTERN PENNSYLVANIA SHOWING MARCELLUS AND OTHER ORGANIC-RICH SHALES



EXTENT OF MARCELLUS FORMATION IN PENNSYLVANIA



TYPICAL GEOPHYSICAL LOG SIGNATURES




HISTORICAL OVERVIEW

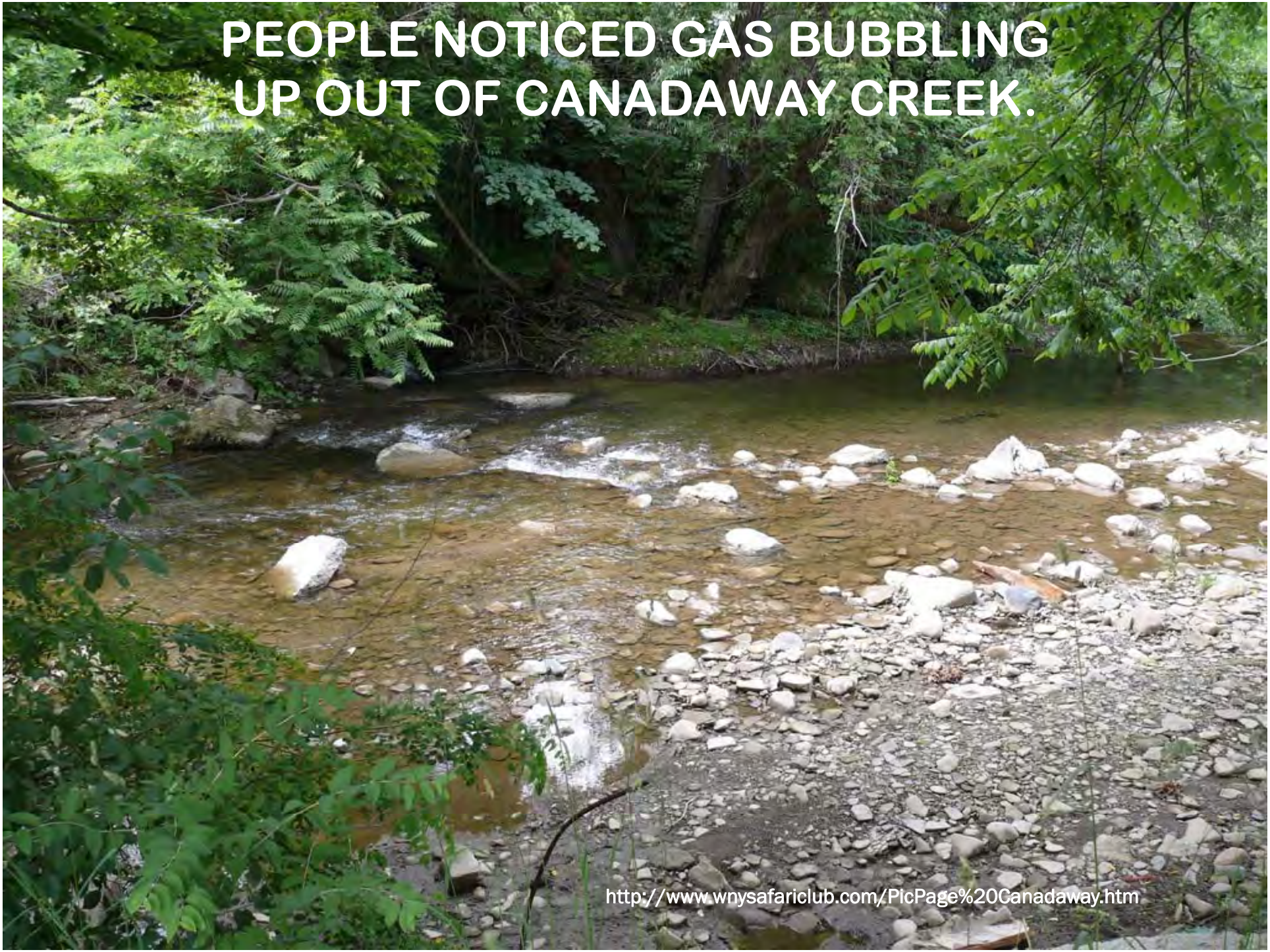
EARLY HISTORY OF APPALACHIAN SHALE GAS

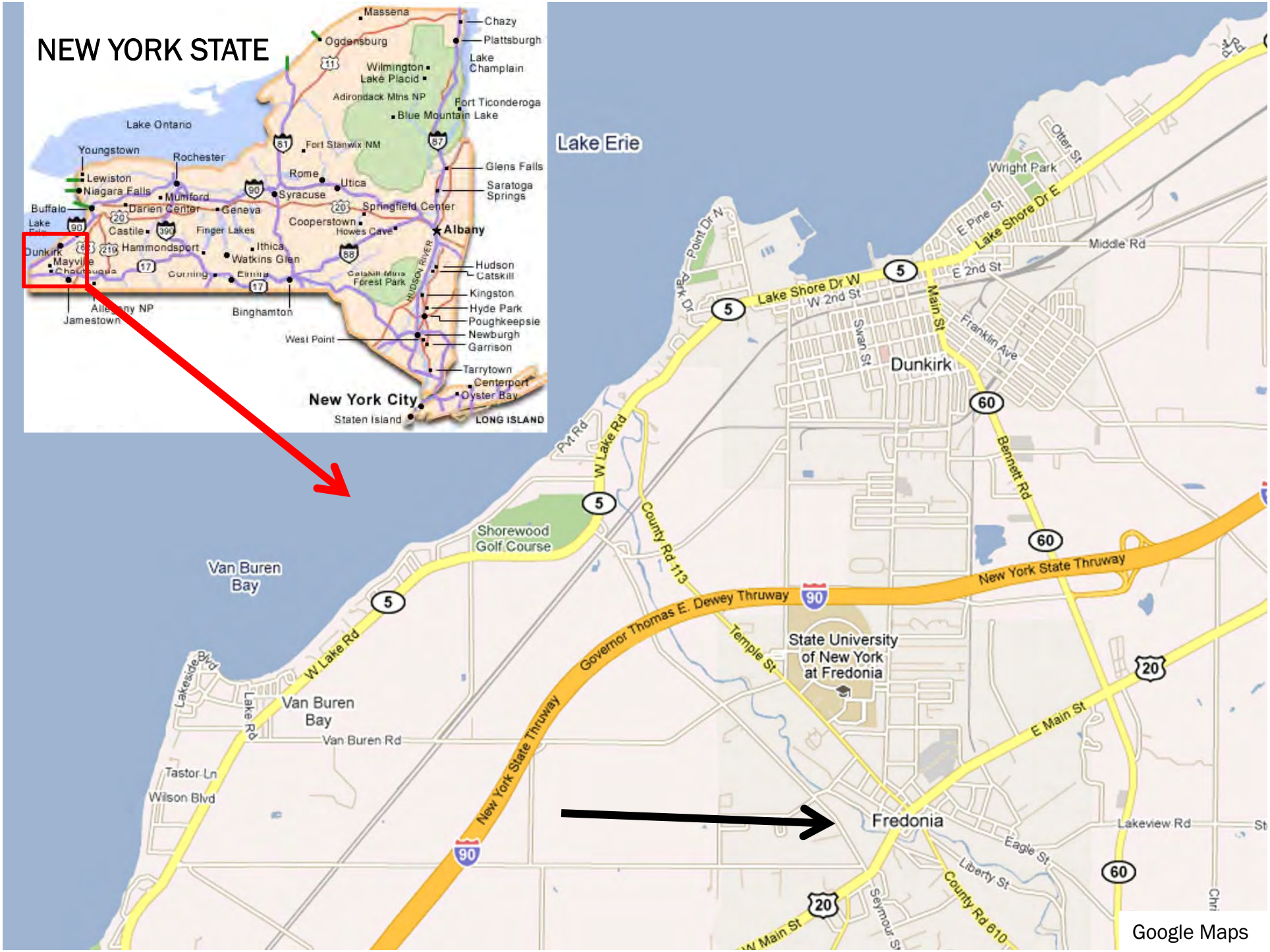
1821-1825

- William Hart dug – with pick and shovel – a 27-foot deep gas well in the village of Fredonia, Chautauqua County, New York

Commemorative plaque on glacial erratic
(http://mary-travel2008.blogspot.com/2008/01/fredonia-new-york-december-2007.html)

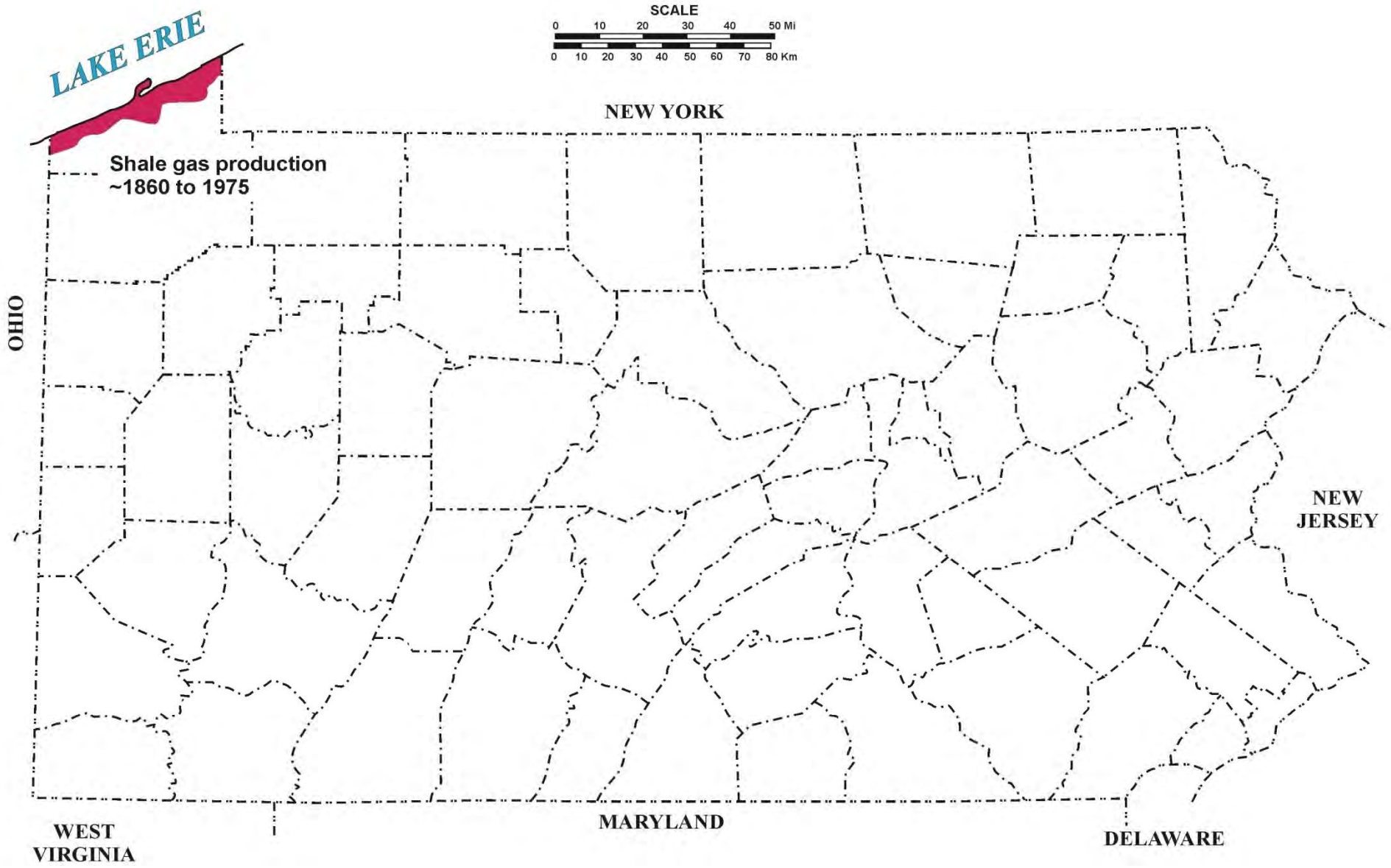
- Gas provided the light of "two good candles"
- By 1825, it supplied enough natural gas for lights in two stores, two shops, and a grist mill
- The pipeline to transport the gas was made from hollowed-out logs connected together with tar and rags


PEOPLE NOTICED GAS BUBBLING
UP OUT OF CANADAWAY CREEK.
http://www.wnysafariclub.com/PicPage%20Canadaway.htm

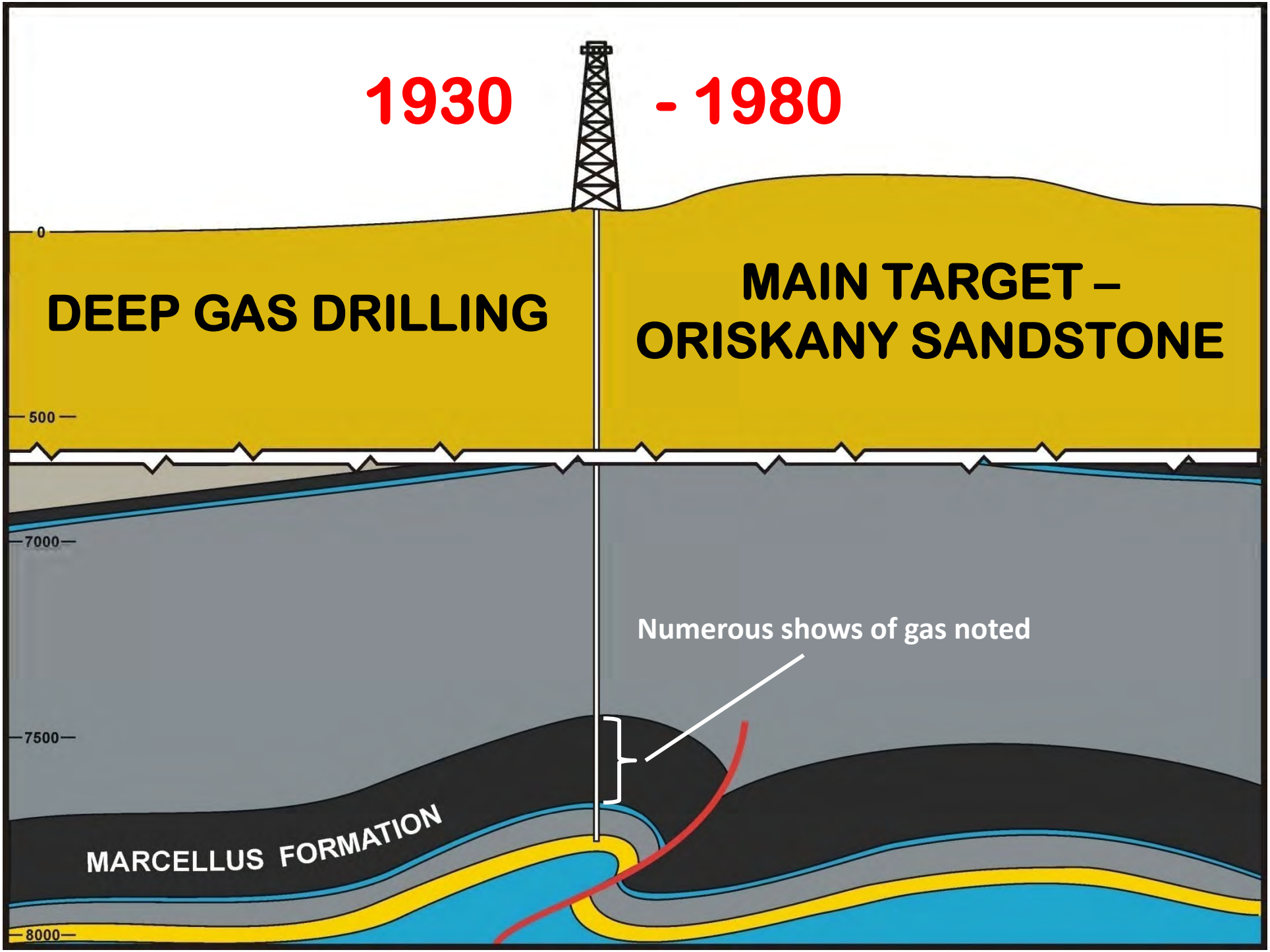

NEW YORK STATE
Massena
Ogdensburg
Chazy
Plattsburgh
Lake Champlain
Wilmington
Lake Placid
Adirondack Mtns NP
Fort Ticonderoga
Blue Mountain Lake
Lake Ontario
Youngstown
Rochester
Fort Stanwix NM
Glens Falls
Saratoga Springs
Lewiston
Niagara Falls
Rome
Utica
Mumford
Syracuse
Buffalo
Darien Center
Geneva
Springfield Center
Lake Erie
Castile
Finger Lakes
Cooperstown
Howes Cave
Albany
Dunkirk
Hammondsport
Ithica
Watkins Glen
Mayville
Corning
Elmira
Hudson
Catskill
Kingston
Hyde Park
Poughkeepsie
Newburgh
Garrison
Jamestown
Binghamton
West Point
Tarrytown
Centerport
Oyster Bay
New York City
Staten Island
LONG ISLAND
Lake Erie
Wright Park
Otter St
Point Dr N
E Pine St
Lake Shore Dr E
Middle Rd
Lake Shore Dr W
W 2nd St
E 2nd St
Main St
Swan St
Franklin Ave
Dunkirk
Pvt Rd
W Lake Rd
Bennett Rd
Shorewood Golf Course
County Rd 113
New York State Thruway
Governor Thomas E. Dewey Thruway
Van Buren Bay
Temple St
State University of New York at Fredonia
Lakeside Blvd
Lake Rd
Van Buren Bay
Van Buren Rd
E Main St
Tastor Ln
Wilson Blvd
Fredonia
Lakeview Rd
Eagle St
Liberty St
County Rd 610
W Main St
Seymour St
Google Maps

EARLY HISTORY OF APPALACHIAN SHALE GAS
1850-1860

- In 1850, the well was deepened to 50 feet and produced enough gas to light 200 burners
- Fredonia Gas Light Company, North America's first gas company, was formed in 1858 – they drilled a second well to more than 200 feet
- Shale gas wells were dug along Lake Erie shoreline from Buffalo, NY to Sandusky, OH. After Drake, wells were drilled.



Wells are 200 to 1000 feet deep and have small flows – measured in ounces of pressure – but they last for scores of years


1930
- 1980
0
DEEP GAS DRILLING
MAIN TARGET –
ORISKANY SANDSTONE
500
7000
Numerous shows of gas noted
7500
MARCELLUS FORMATION
8000

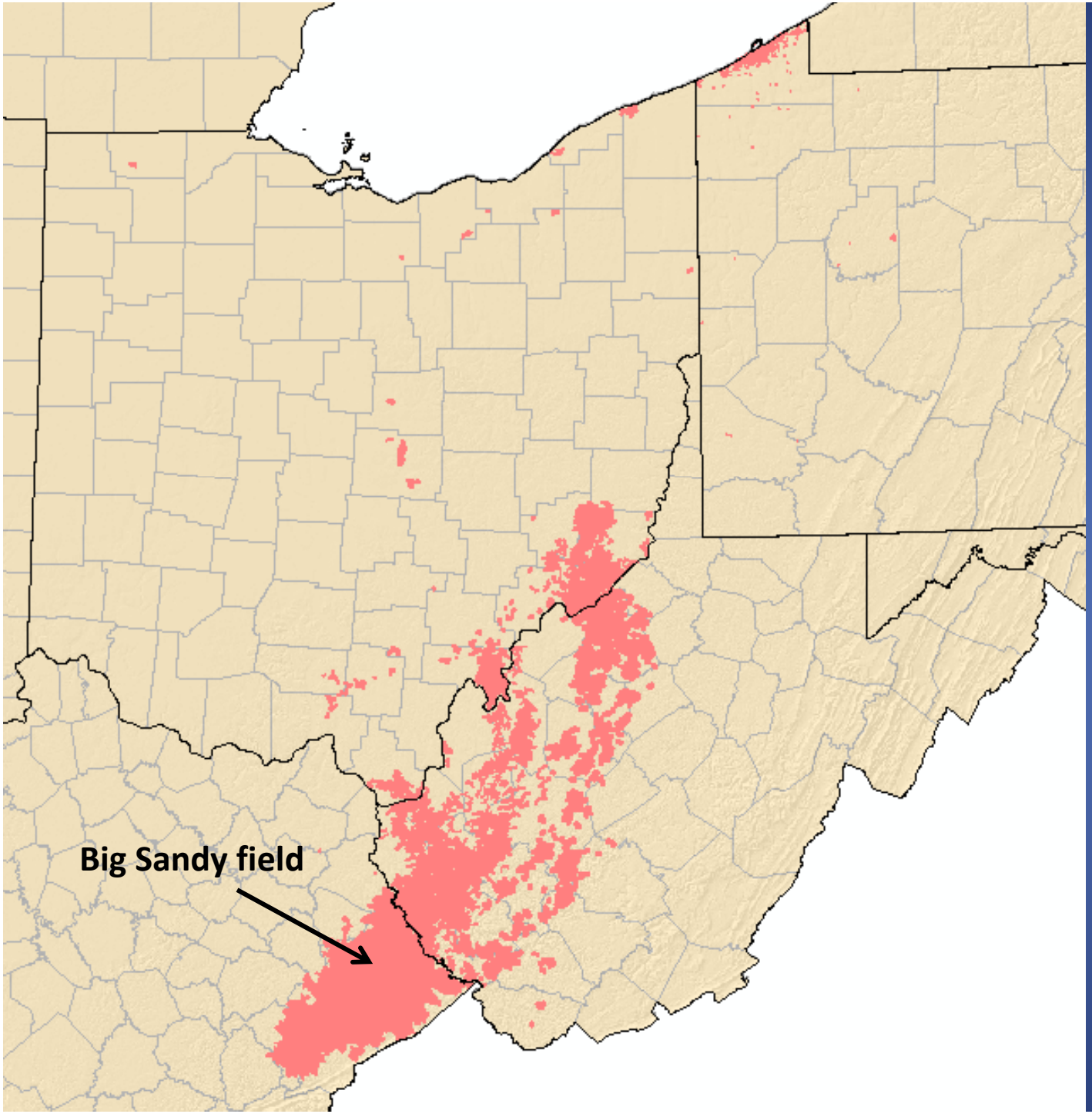
EASTERN GAS SHALES PROJECT (EGSP)

LATE 1970S – EARLY 1980S

A multistate program spanning the Appalachian, Michigan, and Illinois basins

GOALS:

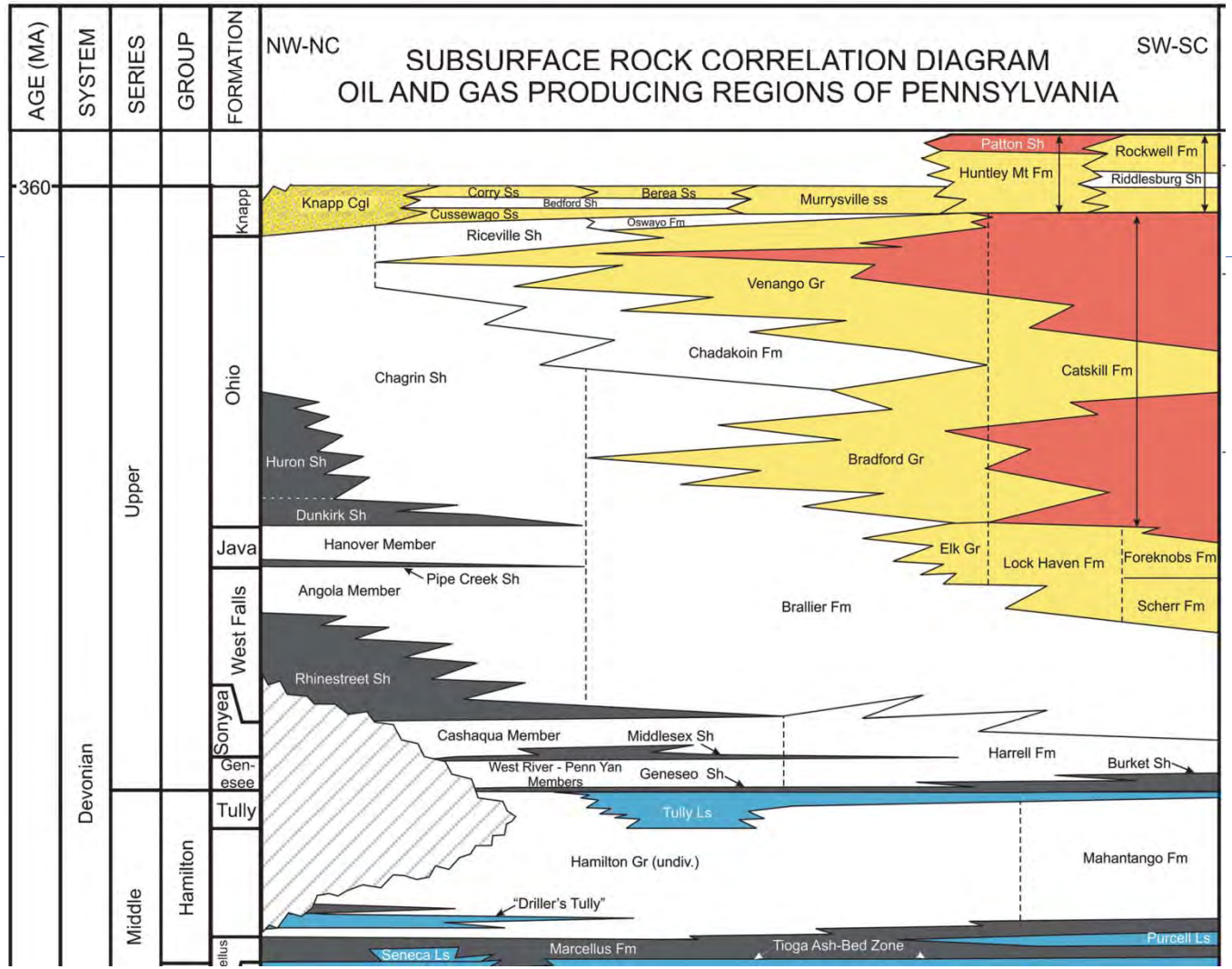
- Determine the extent, thickness, structure and stratigraphy of all Devonian organic-rich shales
- Develop and implement drilling, stimulation and recovery technologies
- Generate numerous cross sections, maps, and technical reports related to the entire Middle and Upper Devonian sequence in western and north-central Pennsylvania



PRODUCING DEVONIAN SHALE GAS FIELDS PRIOR TO DISCOVERY OF THE MARCELLUS PLAY

Wickstrom and others, 2005

EGSP IDENTIFIED THREE MAJOR AND THREE MINOR BLACK SHALE FACIES IN PENNSYLVANIA

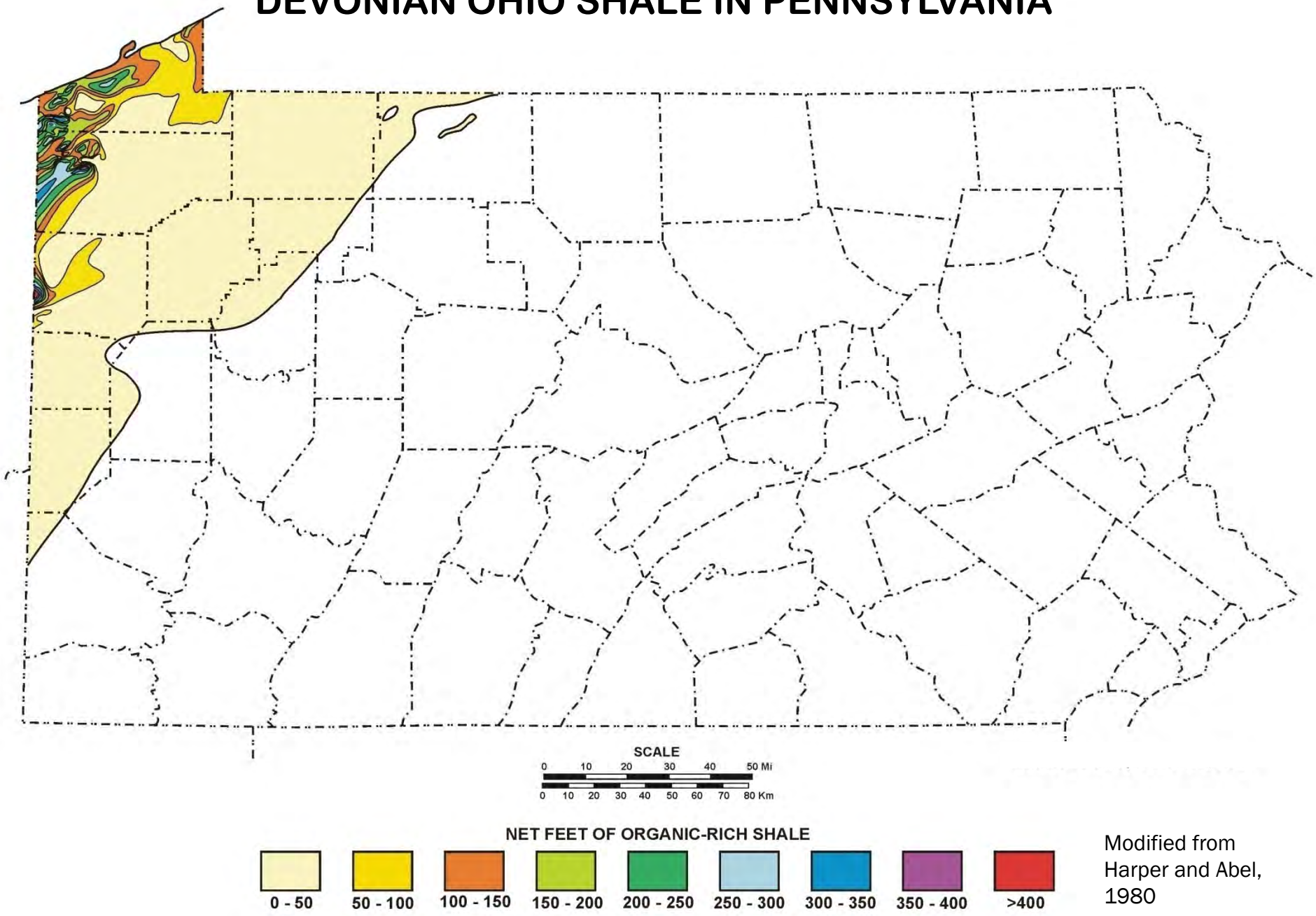


Major: **Huron, Rhinestreet, and Marcellus**

Minor: **Pipe Creek, Middlesex, and Geneseo/Burket**

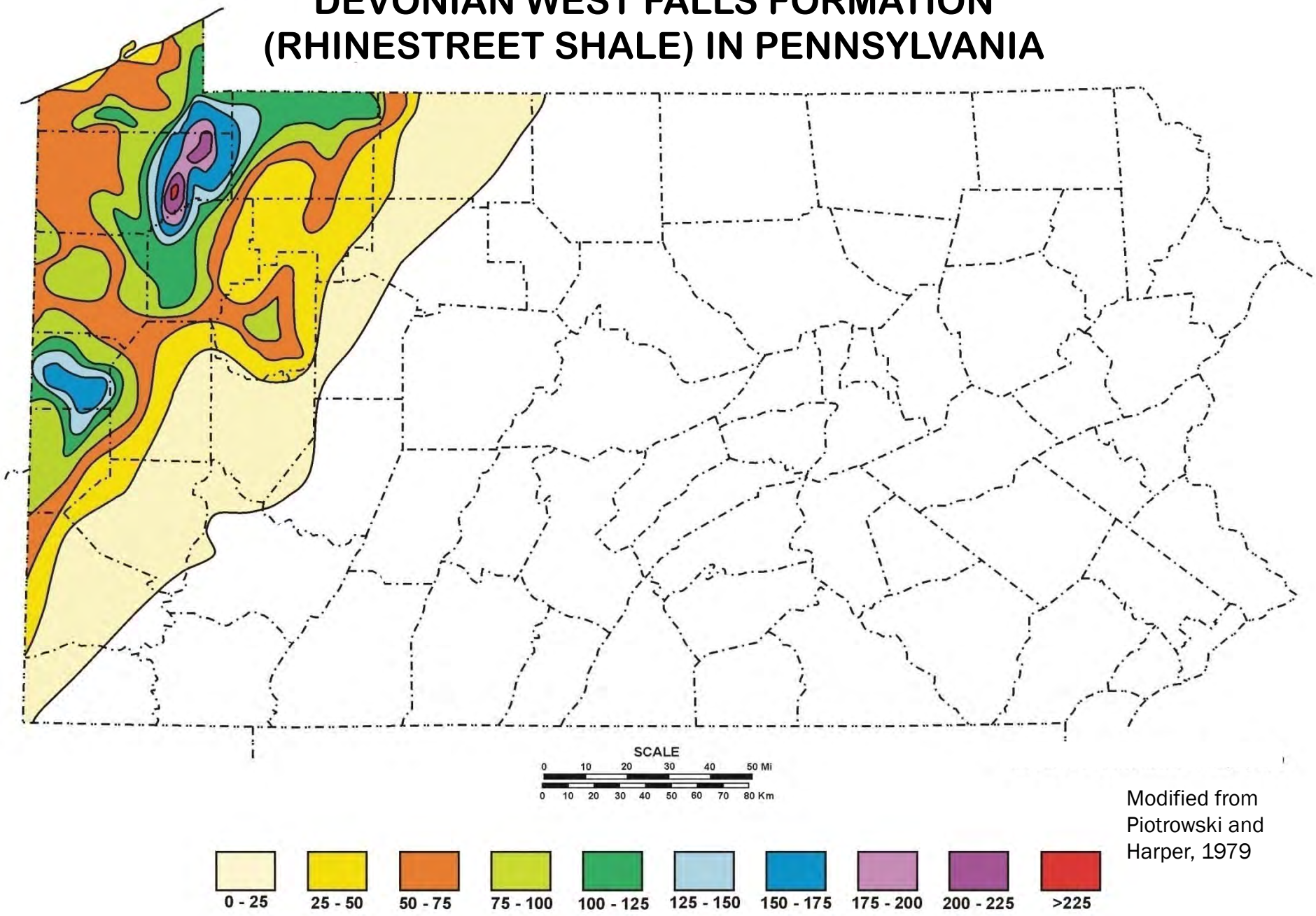
Carter, 2007

NET FEET OF ORGANIC-RICH SHALE IN THE UPPER DEVONIAN OHIO SHALE IN PENNSYLVANIA



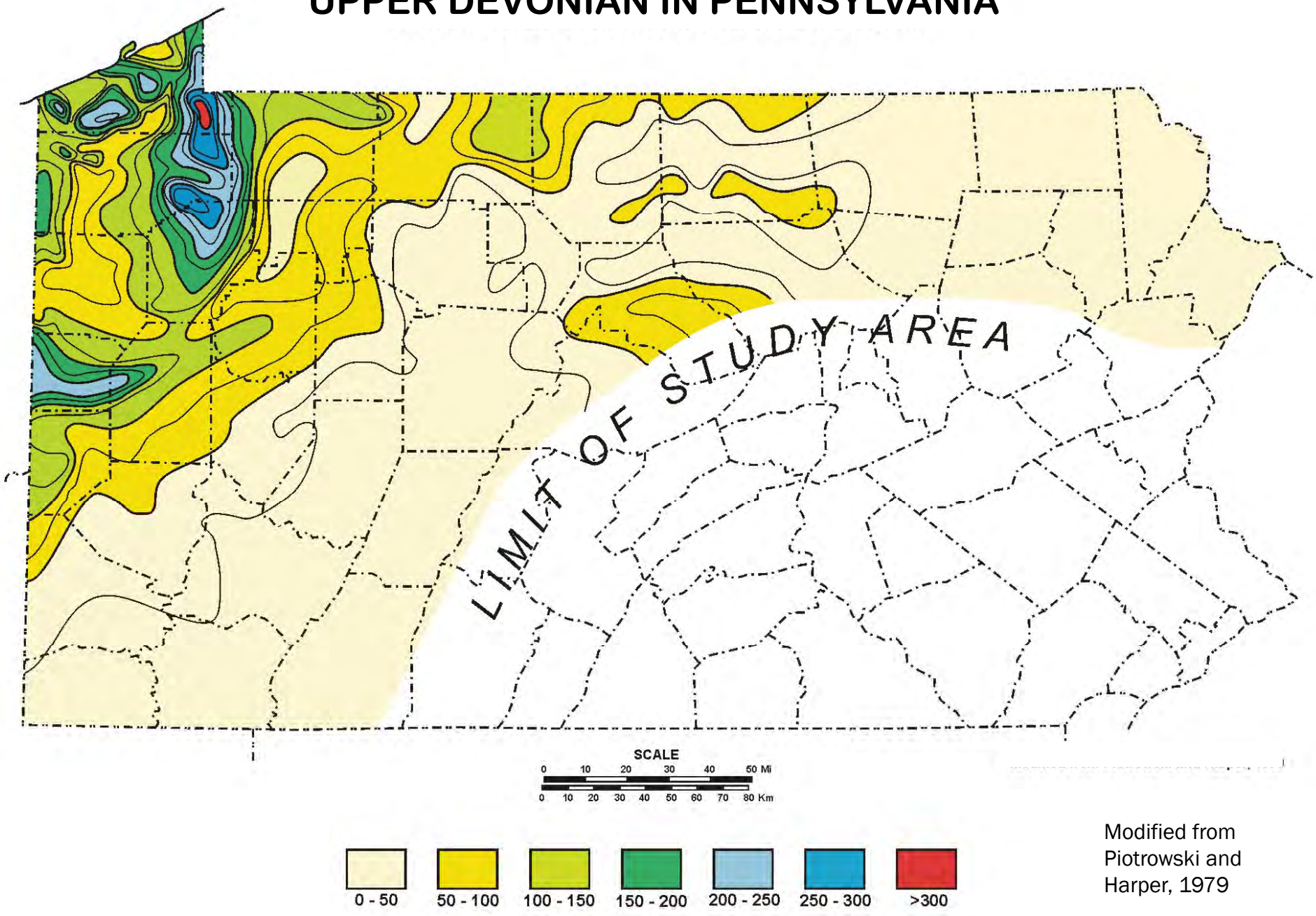
Modified from Harper and Abel, 1980

NET FEET OF ORGANIC-RICH SHALE IN THE UPPER DEVONIAN WEST FALLS FORMATION (RHINESTREET SHALE) IN PENNSYLVANIA



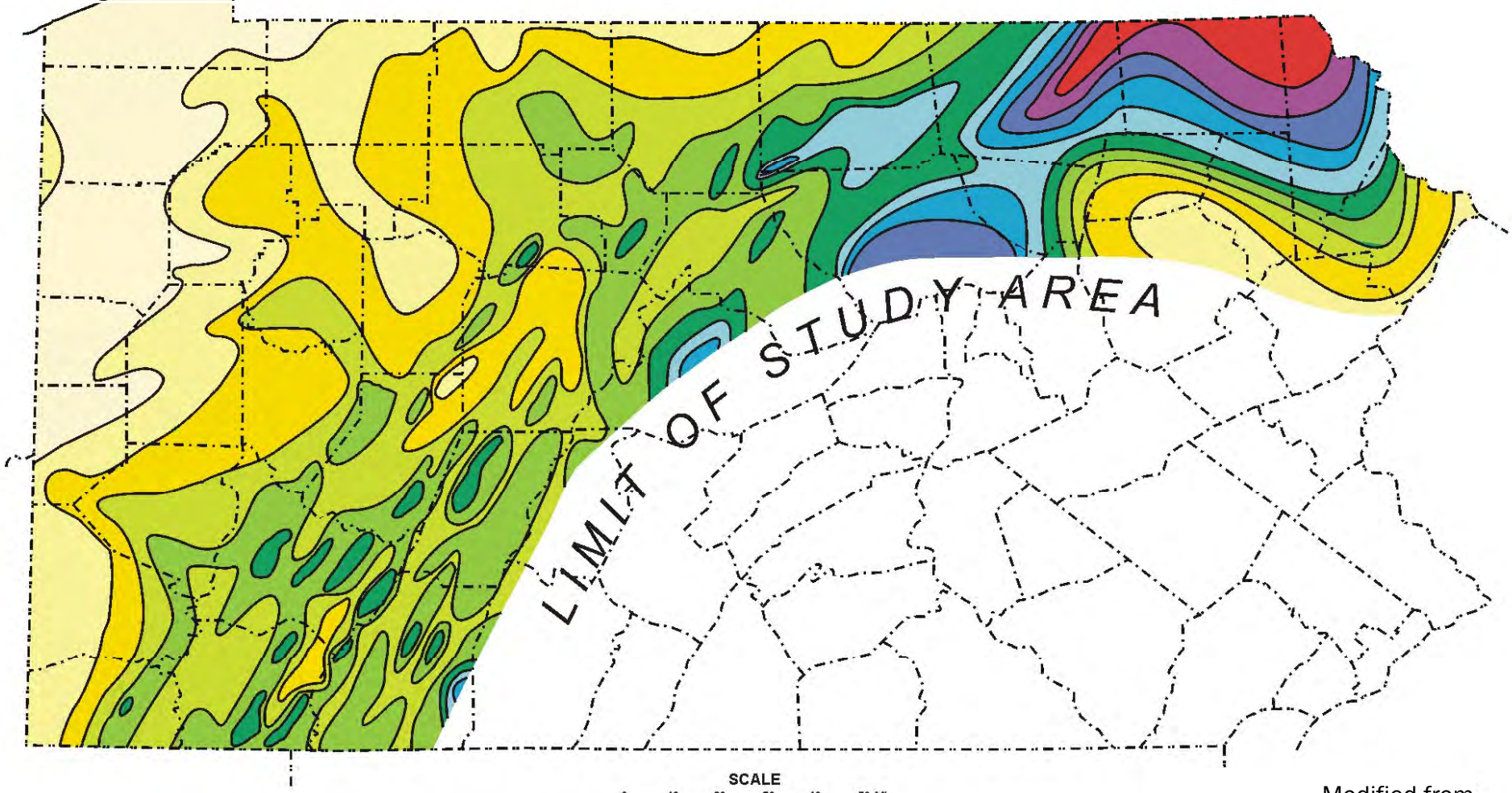
Modified from Piotrowski and Harper, 1979

NET FEET OF ORGANIC-RICH SHALE IN THE UPPER DEVONIAN IN PENNSYLVANIA



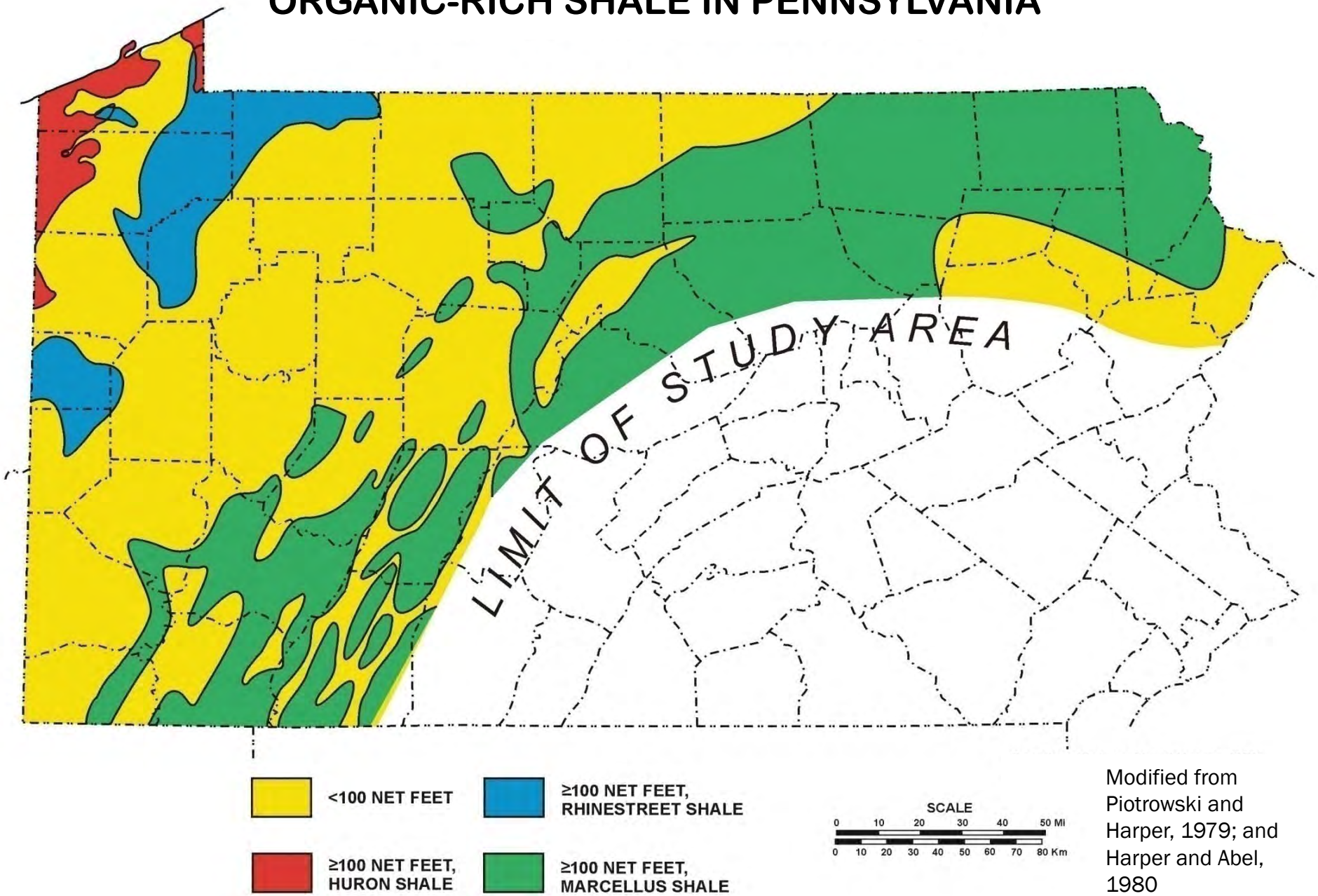
Modified from Piotrowski and Harper, 1979

NET FEET OF ORGANIC-RICH SHALE IN THE MIDDLE DEVONIAN HAMILTON GROUP (MARCELLUS FORMATION) IN PENNSYLVANIA



Modified from Piotrowski and Harper, 1979

“THREE BELT” DISTRIBUTION OF THICK ORGANIC-RICH SHALE IN PENNSYLVANIA



Modified from Piotrowski and Harper, 1979; and Harper and Abel, 1980

RESULTS OF EGSP

1. Devonian organic –rich shales could be important gas reservoirs in northwestern Pennsylvania where they were both thick and close to the surface and have excellent potential to fill the needs of users if better technology for inducing and enhancing fracture systems was developed.

2. The Marcellus Formation was considered to be much less attractive and would remain so until gas prices increased and technology advanced enough to make drilling and completion competitive with more conventional targets.


THE
MODERN
MARCELLUS
SHALE
PLAY

"SO," YOU MIGHT ASK, "WHAT HAS CHANGED?"

1. A **mind shift** from viewing shales as a source rock and seal for oil and gas reservoirs to viewing shales as source, seal AND reservoir
2. **Technological advances** in drilling, especially horizontal drilling
3. Use of **massive amounts of water** in hydraulic fracturing
4. Natural gas demand coupled with **higher energy prices**
5. Wall Street's **acceptance of unconventional plays** such as coal bed methane, tight gas sands, oil shales, and shale gas

SO, HOW DID THE PLAY HAPPEN?

1. The "new" Marcellus shale play began in 2004, after Range Resources drilled a well in 2003 to the Lower Silurian in Washington County, PA. The deep formations (such as the Oriskany Sandstone) did not look favorable, but the Marcellus shale had some promise. Range completed the well late in 2004 as a producing shale well and drilled some additional wells in the area. They experimented with drilling and hydraulic fracturing techniques borrowed and revised from those used on the Barnett Shale gas play in Texas. Range began producing Marcellus gas in 2005. Since then, the company has permitted more than 150 Marcellus wells in Washington County alone.

SO, HOW DID THE PLAY HAPPEN?

2. Other companies took note and started following suit, and the play began heating up. Soon, there was a loud buzz within the oil and gas industry . . .

3. In late 2007, Penn State put out numerous press releases highlighting the research on the Marcellus by Dr. Terry Engelder and SUNY Fredonia collaborator Dr. Gary Lash in which they state the play could produce 50 trillion cubic feet of gas . . .

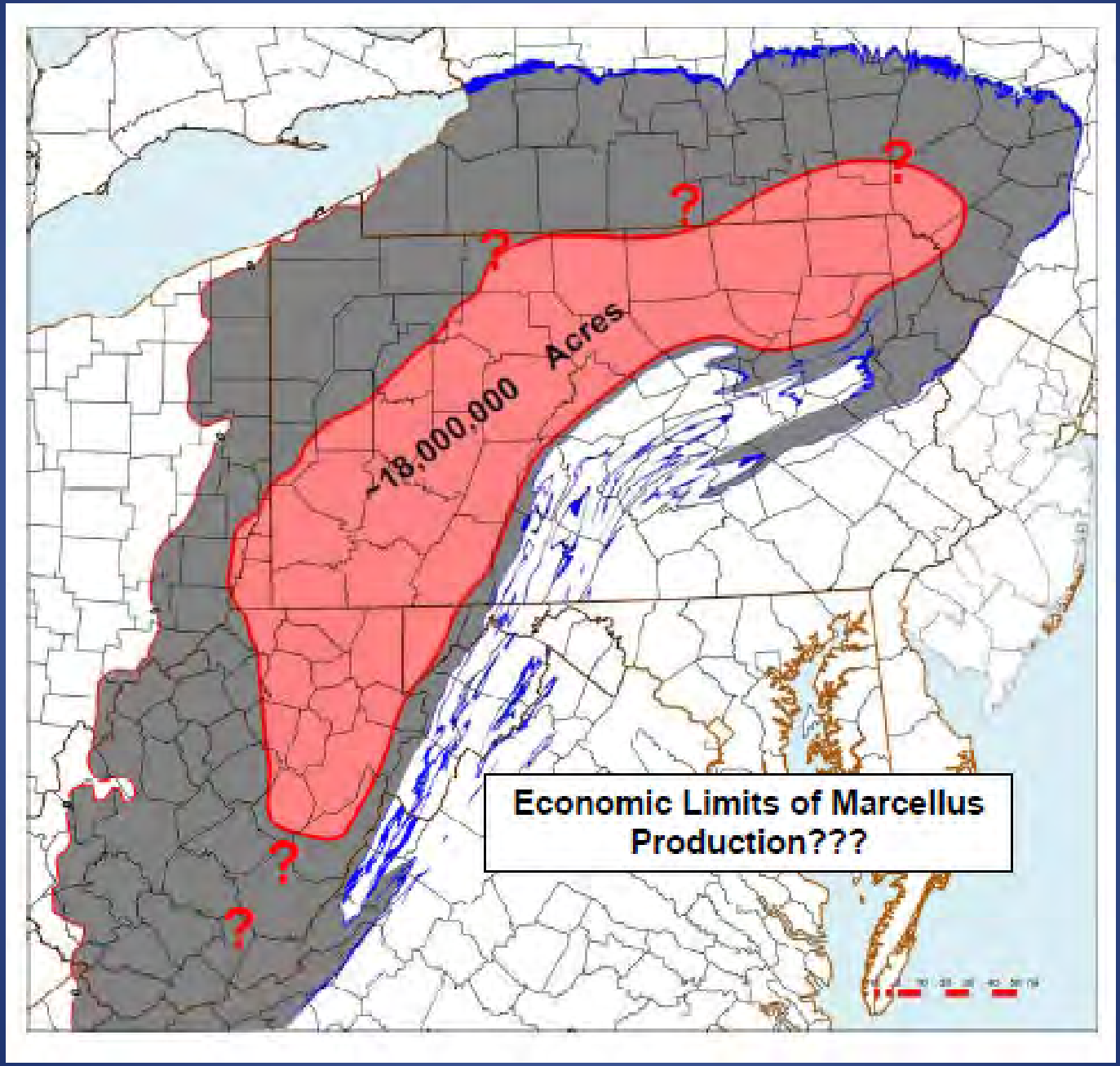
4. This helped bring the mainstream media into the play, increasing the visibility (and hype) tremendously.

SO, HOW DID THE PLAY HAPPEN?

5. Leases, which for years had been a “standard” $25/acre for 5 years with a 12.5% royalty, began climbing, and eventually went “through the roof” – some reaching as high as $6,000/acre and 25% royalty – as companies with deep pockets began taking an interest in the Appalachian basin.

6. Ironically, many of these companies had chosen for decades to ignore the Appalachians as not worth the investment, so they had to scramble to pick up leases, buy out existing operators, and learn the geology and engineering characteristics of the rocks.

THE MARCELLUS PLAY



Courtesy of Gregory Wrightstone

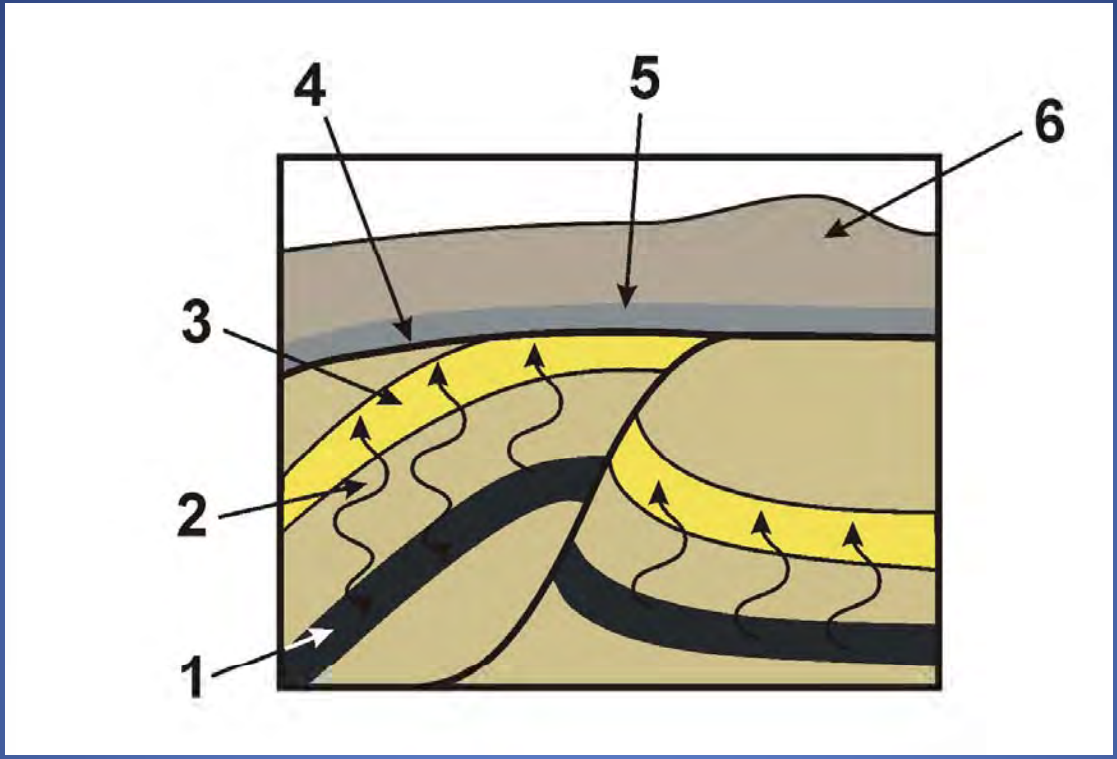
SOME BASIC FACTS ABOUT THE MARCELLUS

- The Marcellus play area extends from New York through Pennsylvania into West Virginia – a slim area of eastern Ohio contains Marcellus at 50 feet or thicker. Marcellus does not appear to extend into Kentucky at all.

- Total vertical depths (TVD) drilled in the play thus far range from ~ 1,500 feet near the Lake Erie shoreline to ~ 9,300 feet in Elk County, PA

- It is most definitely an unconventional reservoir

CONVENTIONAL PETROLEUM SYSTEM



1. Source rock (organic-rich shale) – generation and expulsion
2. Migration – from source to reservoir
3. Reservoir rock (sandstone or limestone) – holds petroleum in internal pore space
4. Trap (e.g. unconformity or fault) – keeps petroleum in reservoir
5. Seal – impervious rock such as shale or non-porous limestone
6. Overburden – buries reservoir under thousands of feet of rock

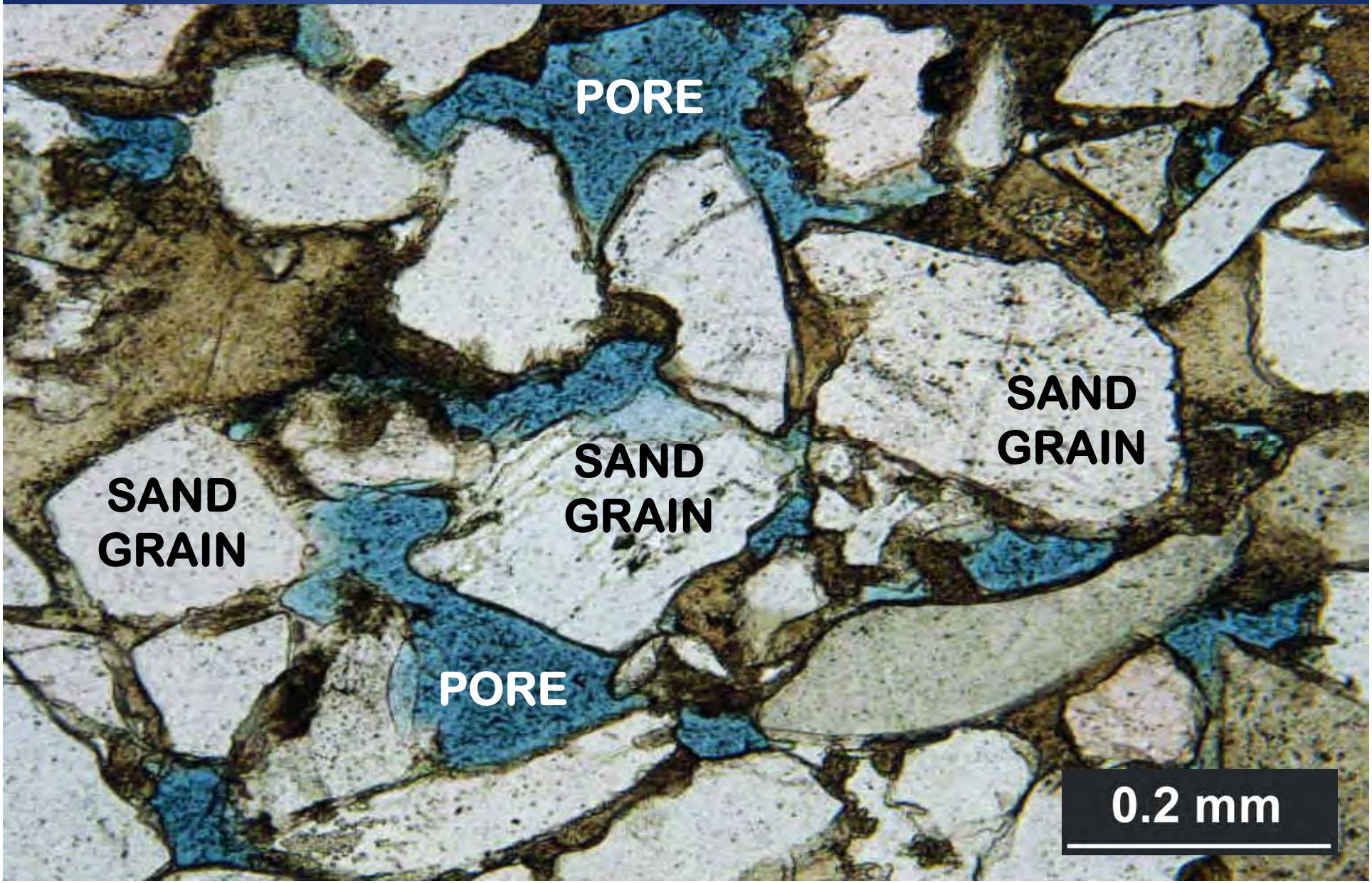
CONVENTIONAL RESERVOIRS

Reservoirs are NOT holes in the ground (e.g. caves and caverns).

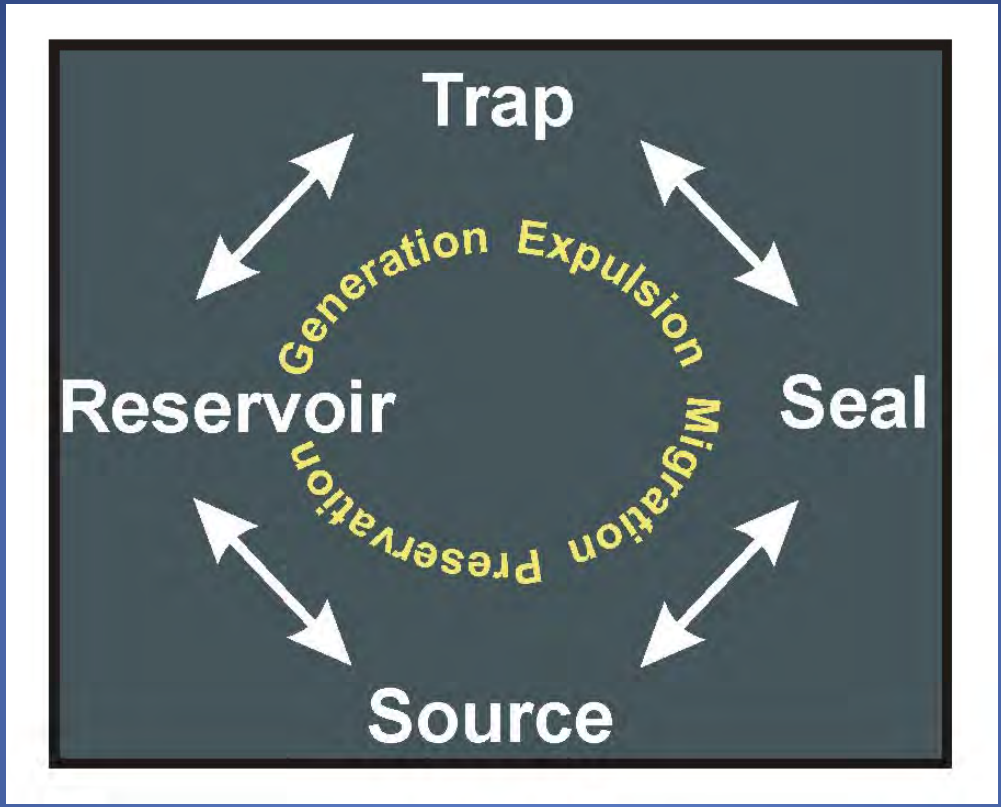
They are solid rock with seemingly insignificant pore spaces


SANDSTONE: A TYPICAL RESERVOIR ROCK

HIGHLY MAGNIFIED THIN SECTION OF A PIECE OF POROUS SANDSTONE EMBEDDED IN BLUE EPOXY TO SHOW THE PORE SPACES



SHALE PETROLEUM SYSTEM



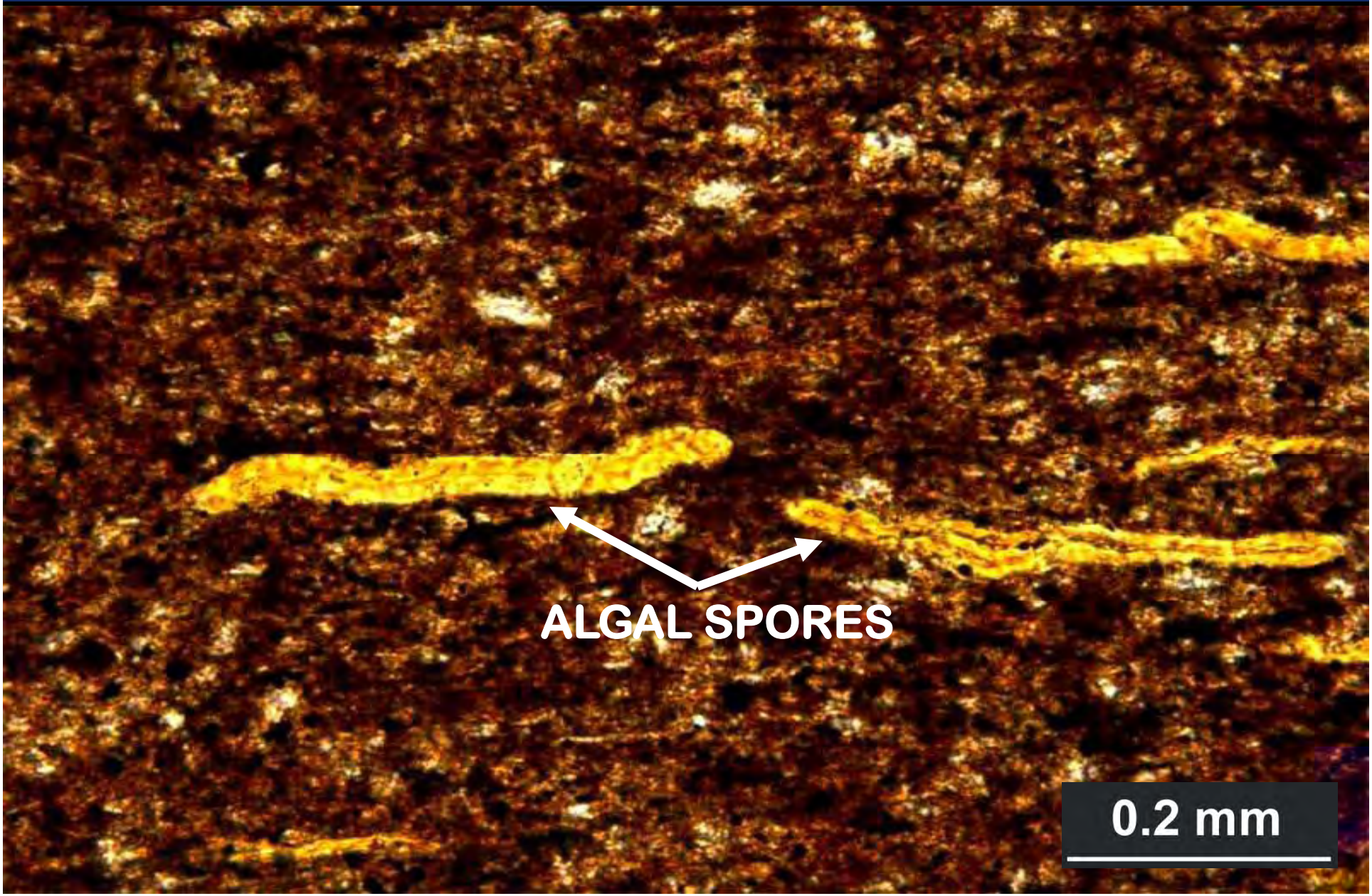
Source rock elements (organic compounds) remain in the shale

Reservoir and seal are vastly different than those in conventional systems

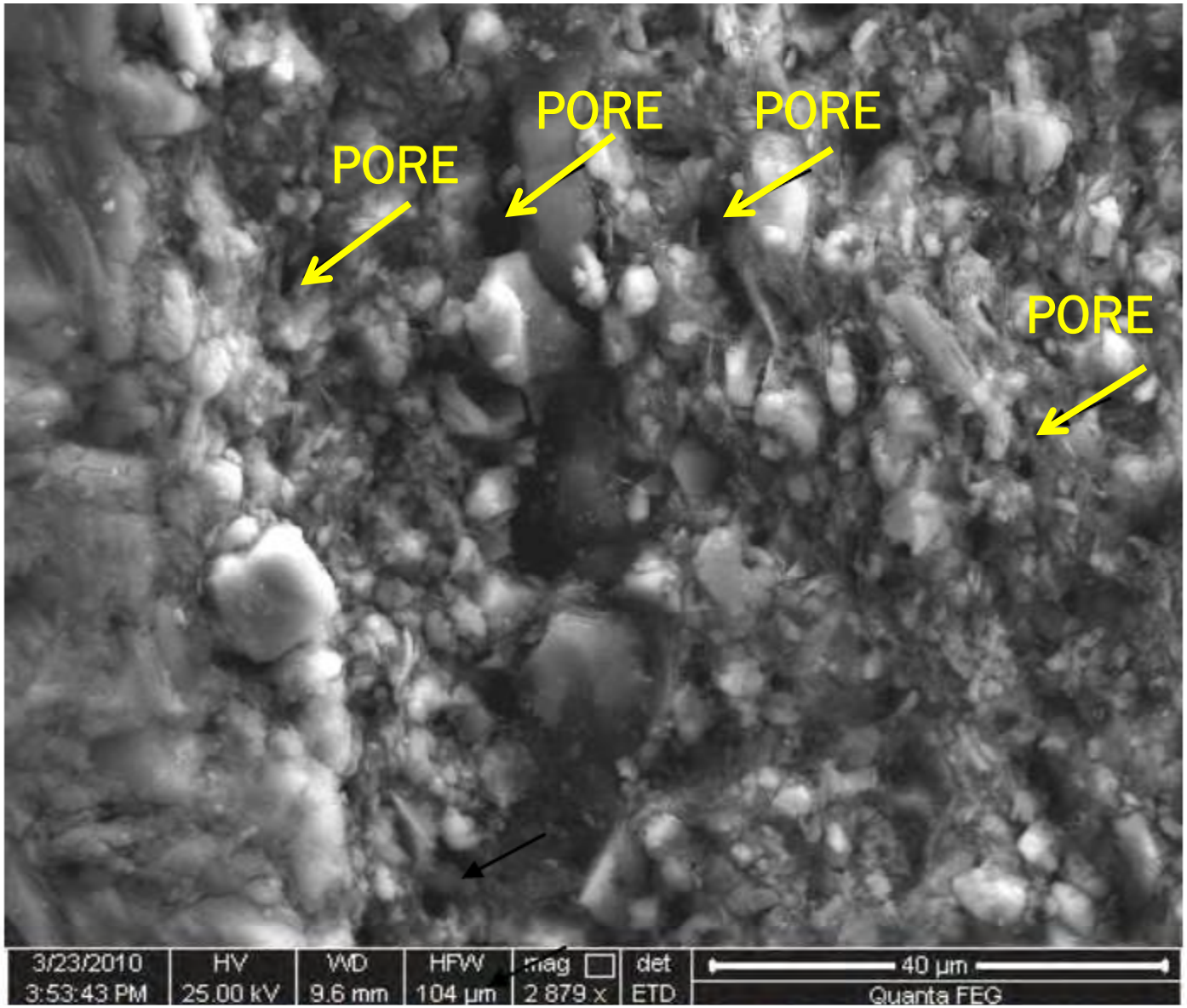
Porosity (total pore space) and permeability (interconnected pore space) are low


TYPICAL ORGANIC-RICH SHALE

HIGHLY MAGNIFIED THIN SECTION OF A PIECE OF ORGANIC-RICH SHALE SHOWING EXTREMELY FINE GRAIN SIZE



SCANNING ELECTRON MICROSCOPE (SEM) PHOTO OF THE MARCELLUS ORGANIC-RICH SHALE



Marcellus shale. – ". . . has produced considerable quantities of gas in western part of Ontario County, New York. Certain wells have had rather large open flows but decline in production is generally rapid although a very small production may be maintained for many years. Seems to be ***most productive where fracturing and brecciation have opened joint-plains in which gas can accumulate."***

Paul D. Torrey, 1935

NATURAL FRACTURES IN SHALE

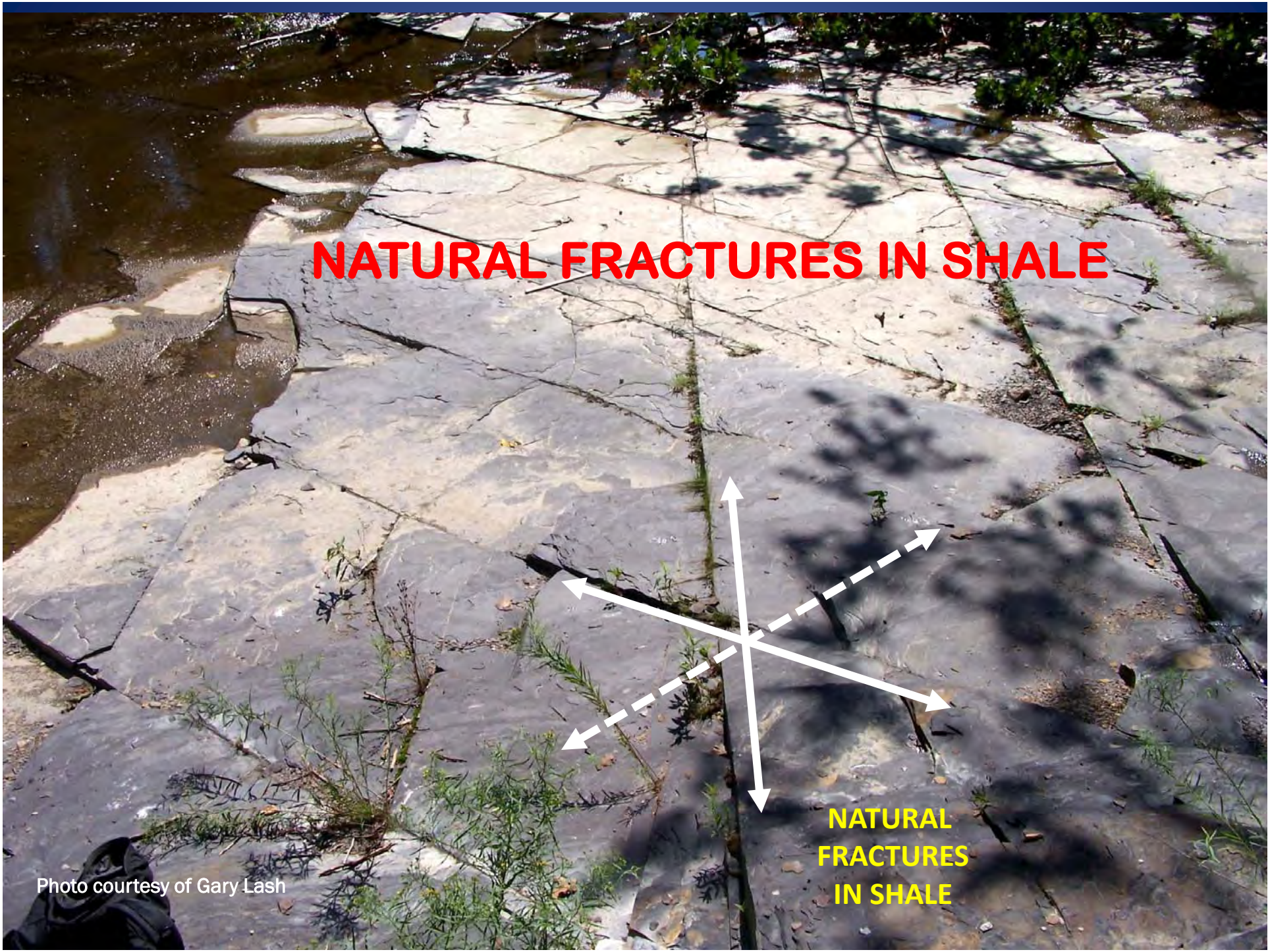
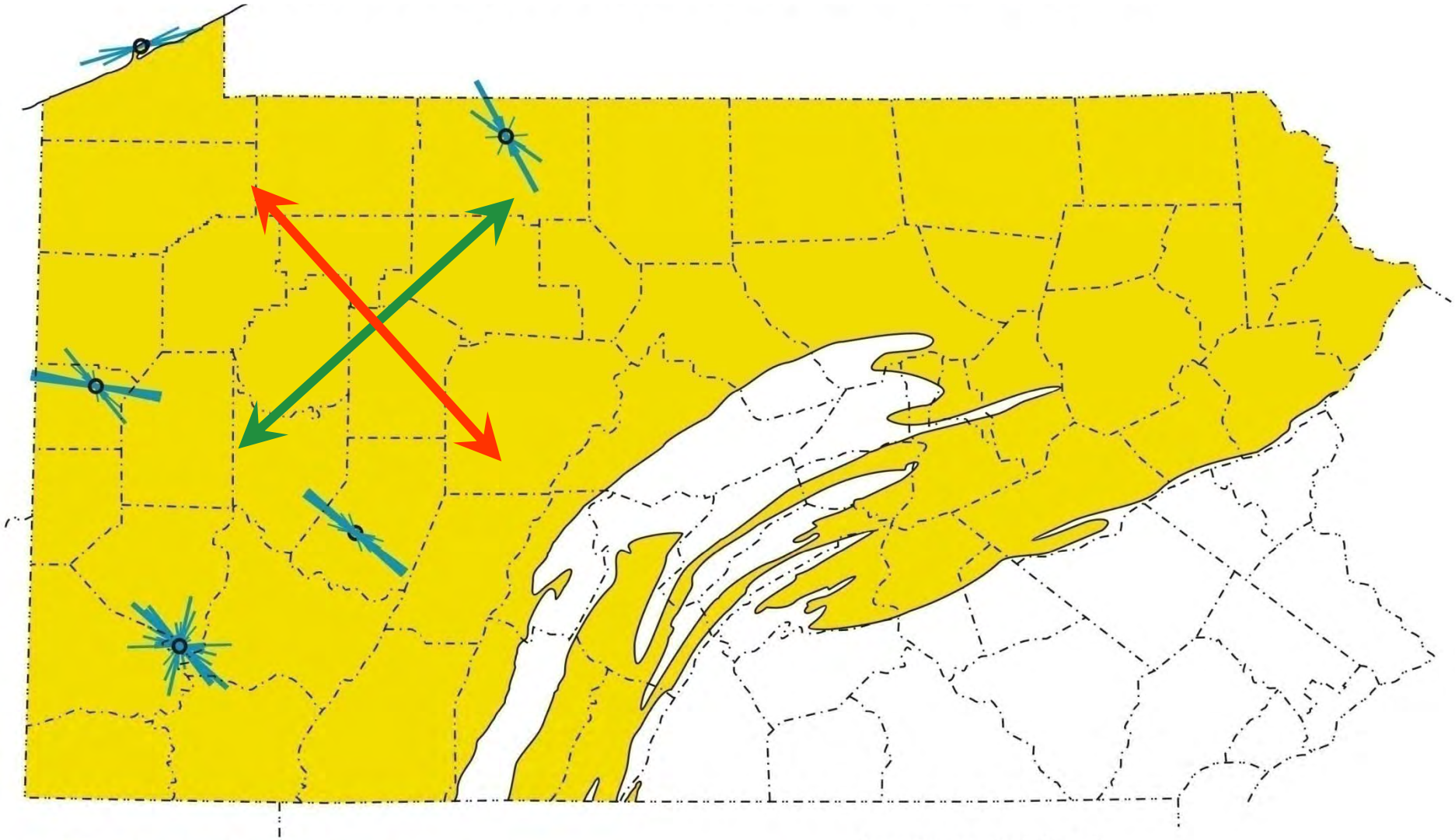


Photo courtesy of Gary Lash


J1
J1
J1
J1
J1
J1
J1
J2
J2
J2
fracture porosity
matrix porosity
Looking WSW
Leroy, New York
Photo courtesy of Gary Lash

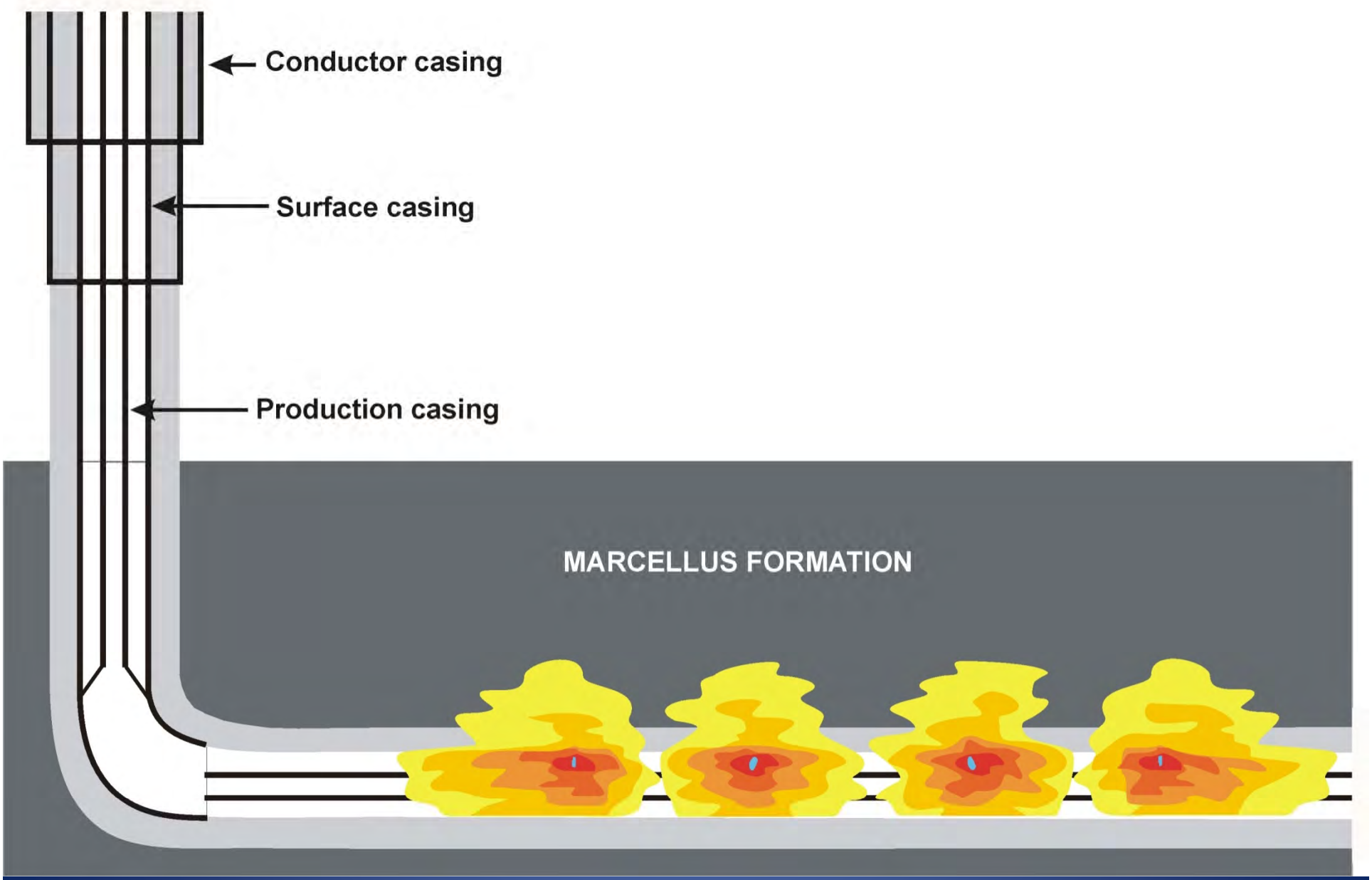
ORIENTATIONS OF FRACTURES IN FIVE EGSP CORES IN PA



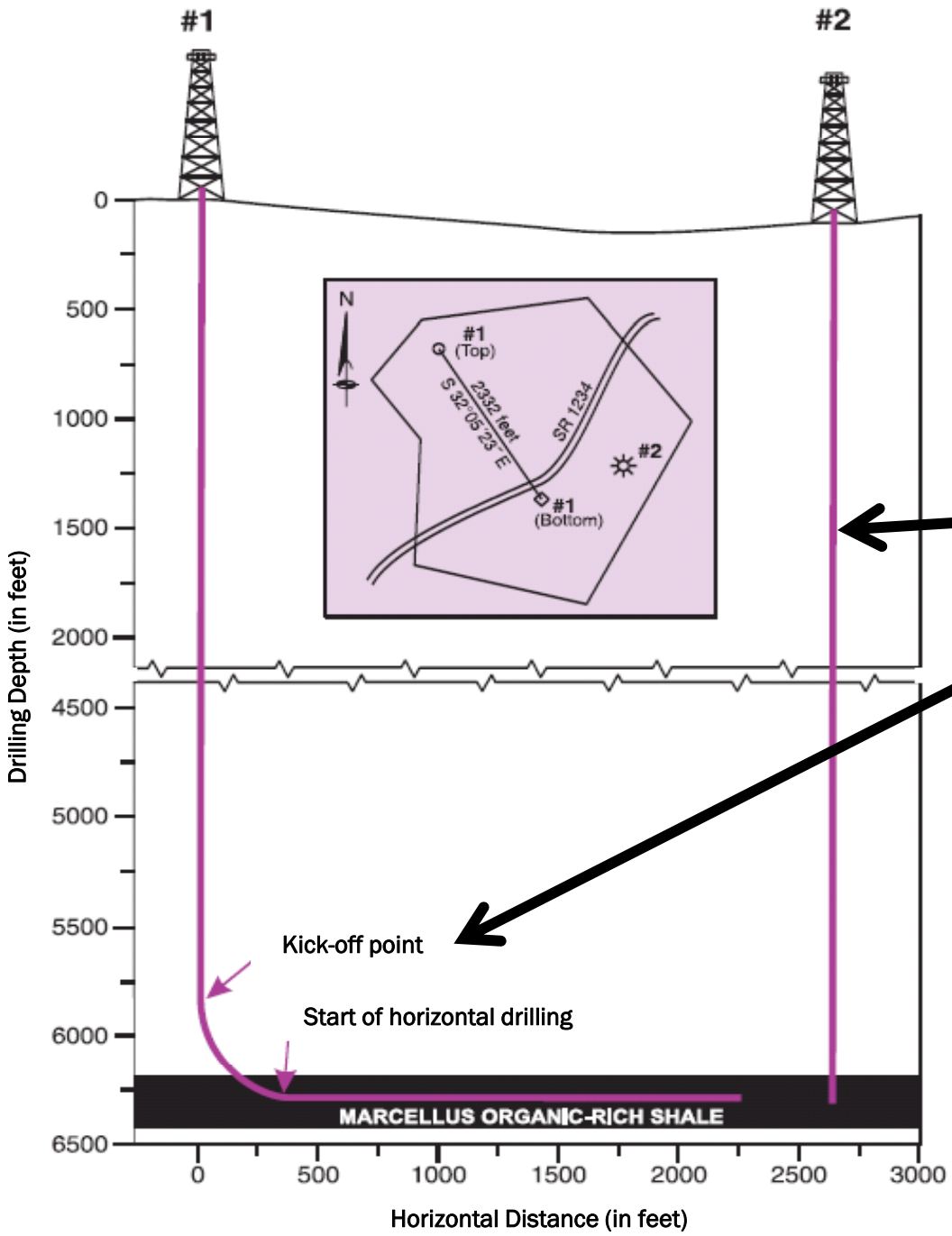
Modified from Harper, 2008


TYPICAL MARCELLUS DRILLING SITE
http://www.chiefog.com/drilling_process.htm

MARCELLUS SHALE DRILLING AND COMPLETION



Modified from Wiley and others, 2004

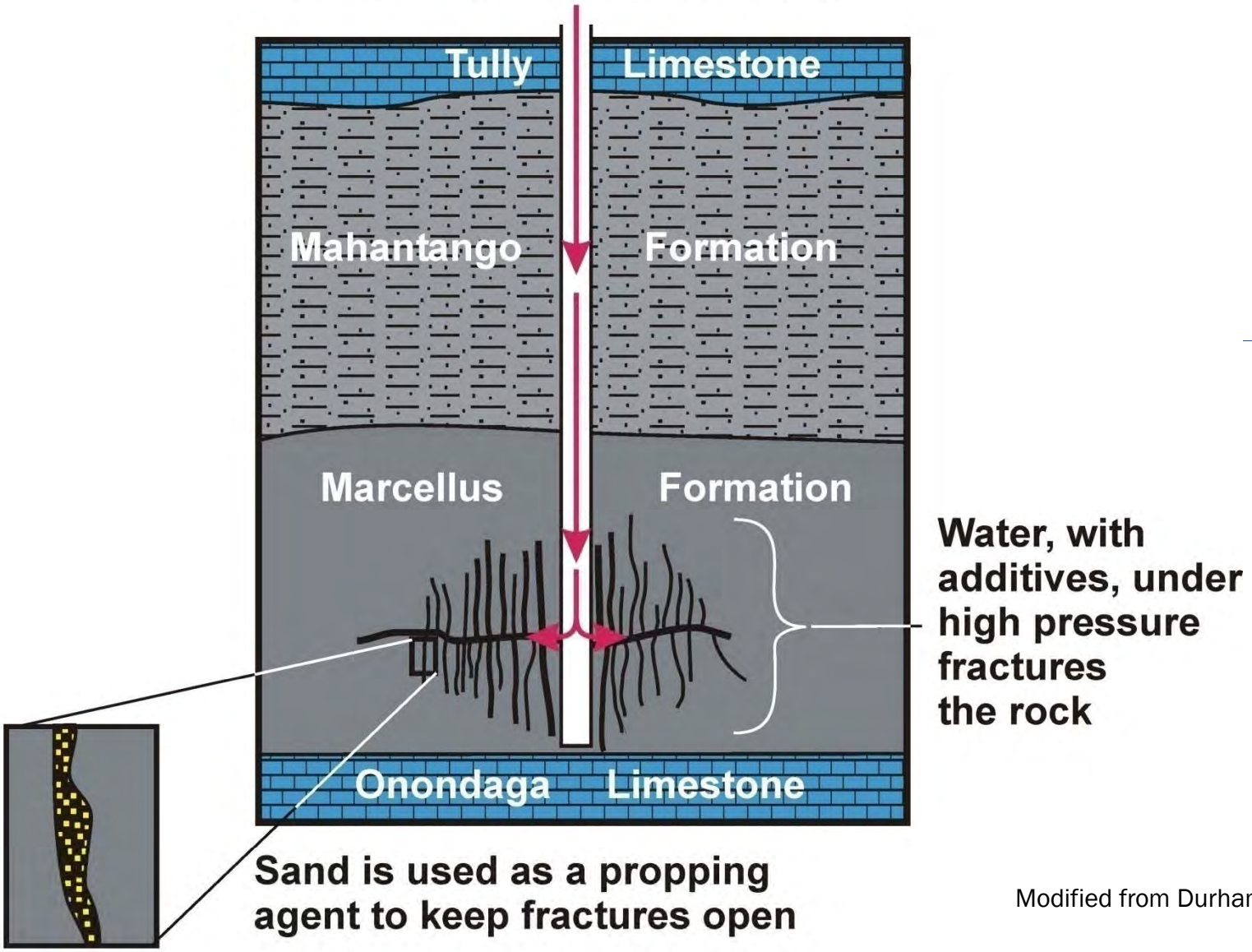


VERTICAL VS. HORIZONTAL DRILLING

Modified from Harper, 2008

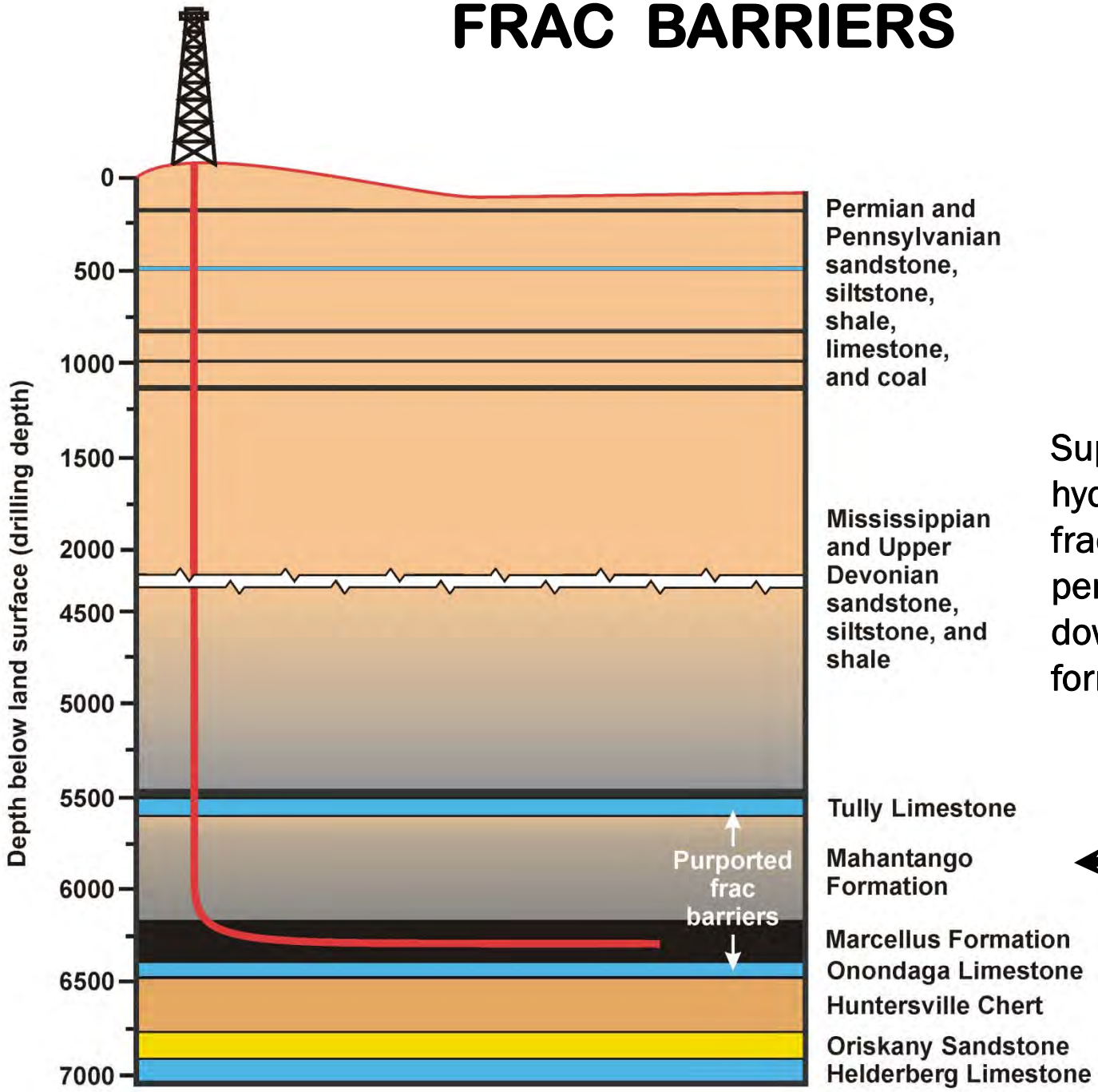
A TYPICAL MARCELLUS FRAC JOB

WATER AND SAND INJECTED INTO WELL UNDER HIGH PRESSURE



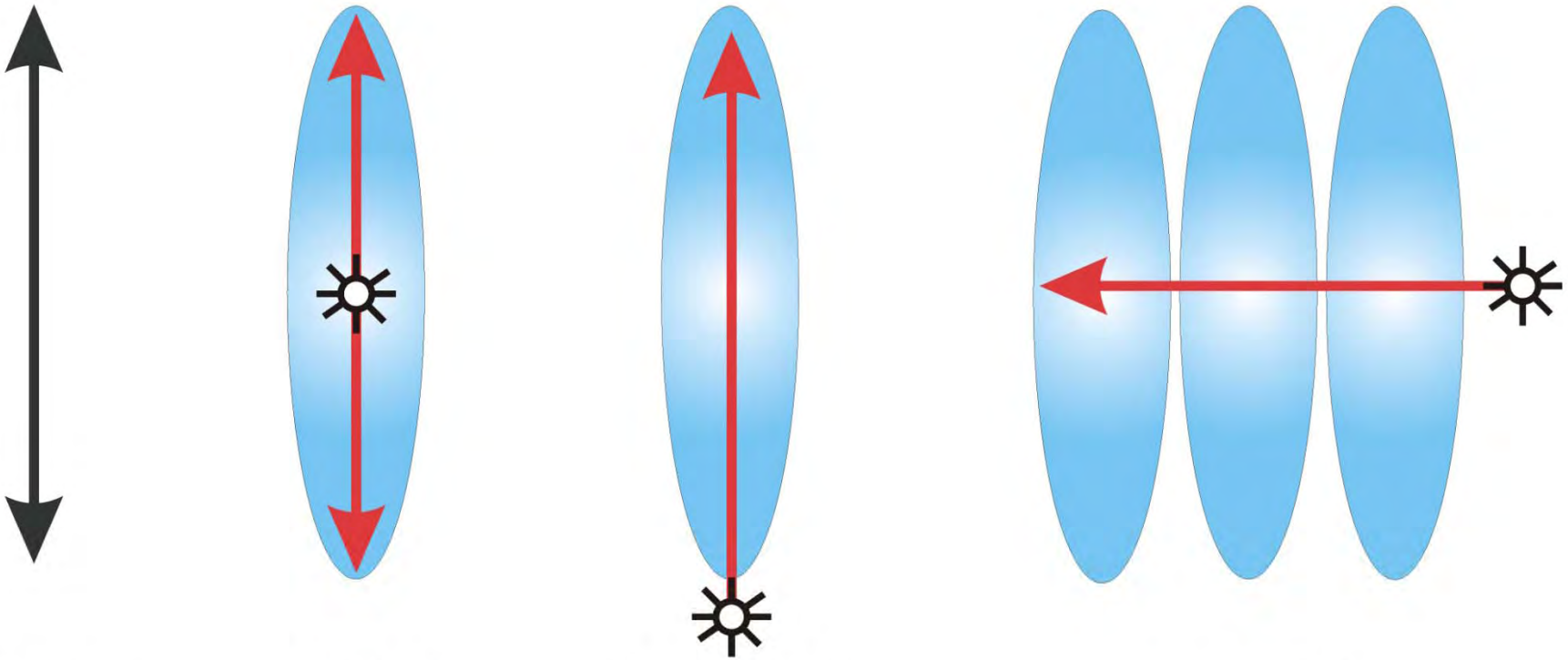
Modified from Durham, 2007

FRAC BARRIERS



Supposedly keeps hydraulically generated fractures from penetrating upward and downward into adjacent formations

WAYS TO STIMULATE A MARCELLUS WELL



Primary Direction of Natural Fracturing

Vertical Well Stimulation

Horizontal Well With Longitudinal Stimulation

Horizontal Well With Transverse Stimulation

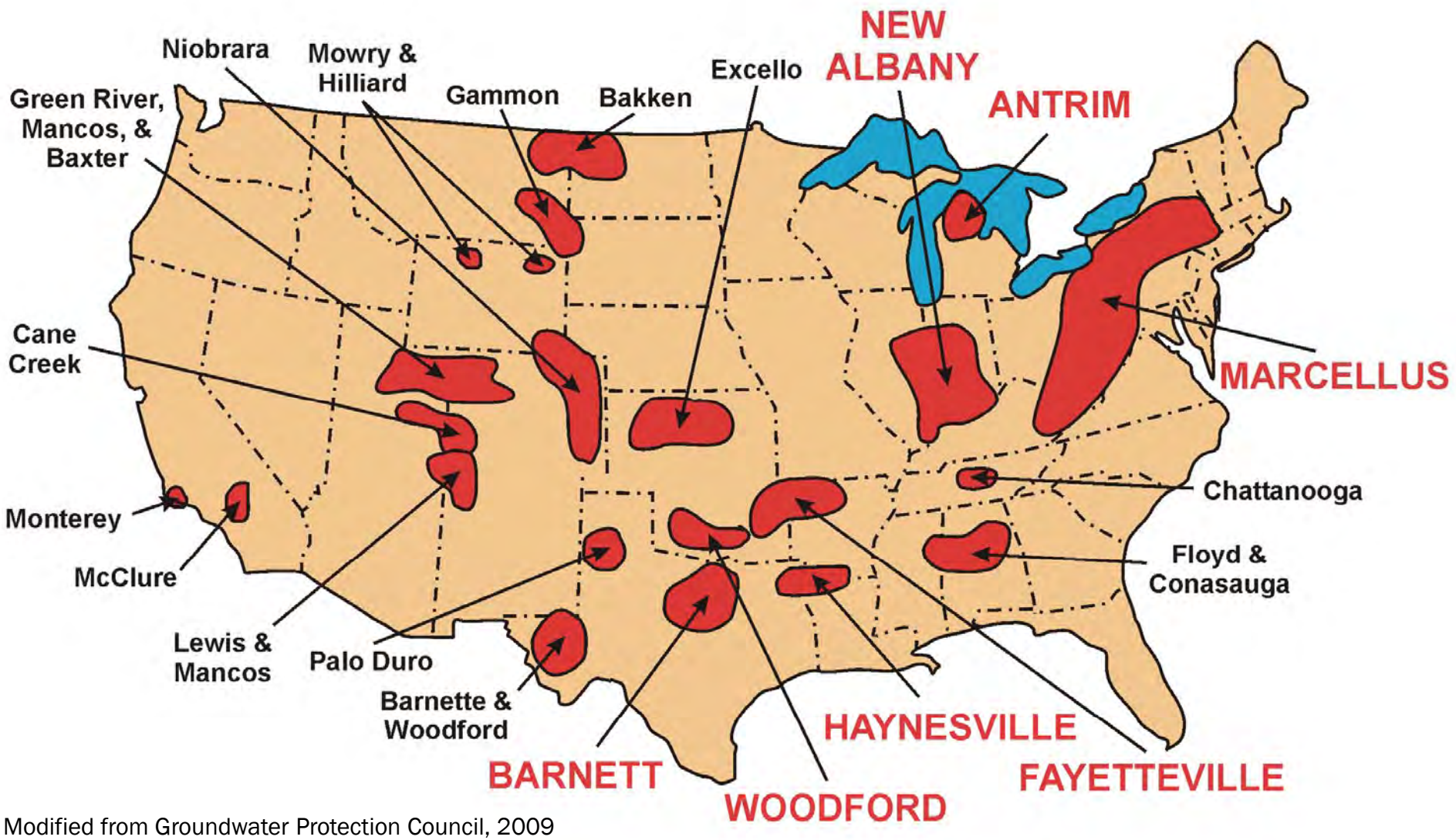

A TYPICAL MARCELLUS FRAC JOB USES APPROXIMATELY 3.5 MILLION GALLONS OF WATER
Billman, 2009

COMPARISONS OF MARCELLUS WITH OTHER SHALE PLAYS

http://geology.com/articles/marcellus-shale.shtml

HOW DOES THE MARCELLUS STACK UP AGAINST OTHER GAS SHALES IN THE U.S.?

U.S. SHALE BASINS



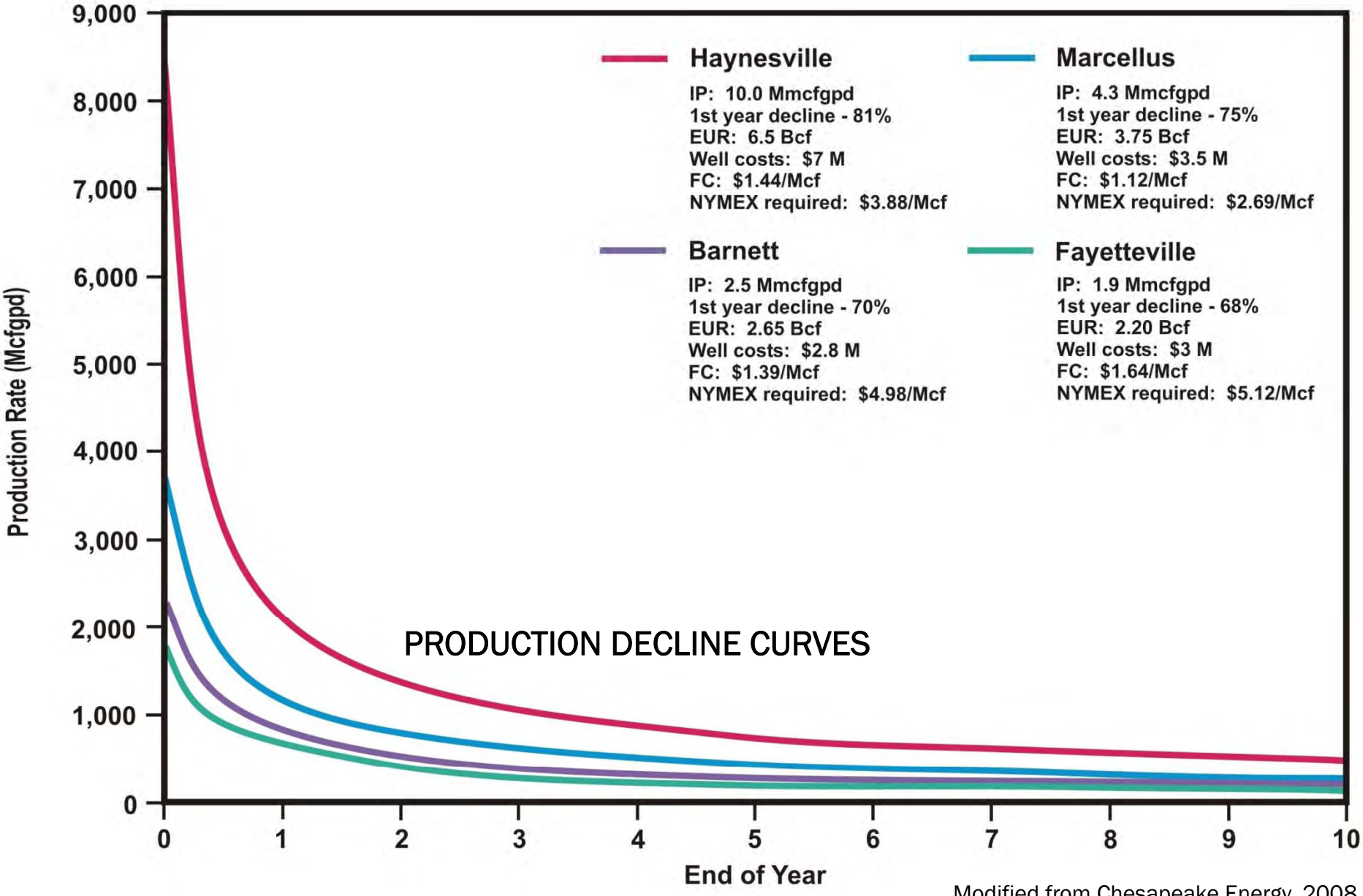
Modified from Groundwater Protection Council, 2009

COMPARISONS OF DATA FOR THE MAJOR U.S. SHALE PLAYS

EXHIBIT 3. COMPARISON OF DATA FOR THE GAS SHALES IN THE UNITED STATES							
	Barnett	Fayetteville	Haynesville	Marcellus	Woodford	Antrim	New Albany
Estimated Basin Area, square miles	5,000	9,000	9,000	95,000	11,000	12,000	43,500
Depth, ft	6, 500 - 8,500	1,000 - 7,000	10,500 -13,500	4,000 - 8,500	6,000 – 11,000	600 – 2,200	500 – 2,000
Net Thickness, ft	100-600	20-200	200[11]- 300	50-200	120-220	70-12	50-100
Depth to Base of Treatable Water, ft	~1200	~500	~400	~850	~400	~300	~400
Rock Column between Pay and Base of Treatable Water	5,300– 7,300	500 – 6,500	10,100 – 13,100	2,125 – 7,650	5,600 – 10,600	300 – 1,900	100 – 1,600
Total Organic Carbon, %	4.5	4.0-9.8	0.5 – 4.0	3-12	1-14	1-20	1-25
Total Porosity, %	4 5	2 8	8 9	10	3 9	9	10 14
Gas Content, scf/ton	300-350	60-220	100-330	60-100	200-300	40-100	40-80
Water Production, Barrels water/day	0	0	0	0		5-500	5-500
Well spacing, Acres	60-160	80-160	40-560	40-160	640	40-160	80
Original Gas-In-Place, Tcf	327	52	717	1,500	52	76	160
Reserves, Tcf	44	41.6	251	280	11.4	20	19.2
Est. Gas Production, mcf/day/well	338	530	625-1,800	3,100	415	125-200	

Modified from Groundwater Protection Council, 2009

COMPARISONS OF FOUR MAJOR SHALE PLAYS



Modified from Chesapeake Energy, 2008

WHAT DOES IT TAKE TO DRILL AND COMPLETE A MARCELLUS WELL?

- → Drilling and completion costs - **$1.5 TO 3.5 million per well**
- → Drillbit finding and developing cost – **$1.12 per Mcf**
- → Vertical depth – **5,000 to 8,000 feet**
- → Horizontal length – **4,000 feet average**
- → Well stimulation – **4-stage fracture**
- → Time to drill – **30 days**
- → Assumed risk factor – **75%**

PRODUCTION AND ECONOMICS OF MARCELLUS WELLS

Gas in place in the shale:

- Approximately 70 to 150 billion cubic feet per square mile (Bcf/mi^2)

Vertical wells:

- Expected production – from 150,000 cubic feet per day (150 Mcf/d) to 5 million cubic feet per day (5,000 Mcf/d)
- Recovery Factor: 8 – 15%

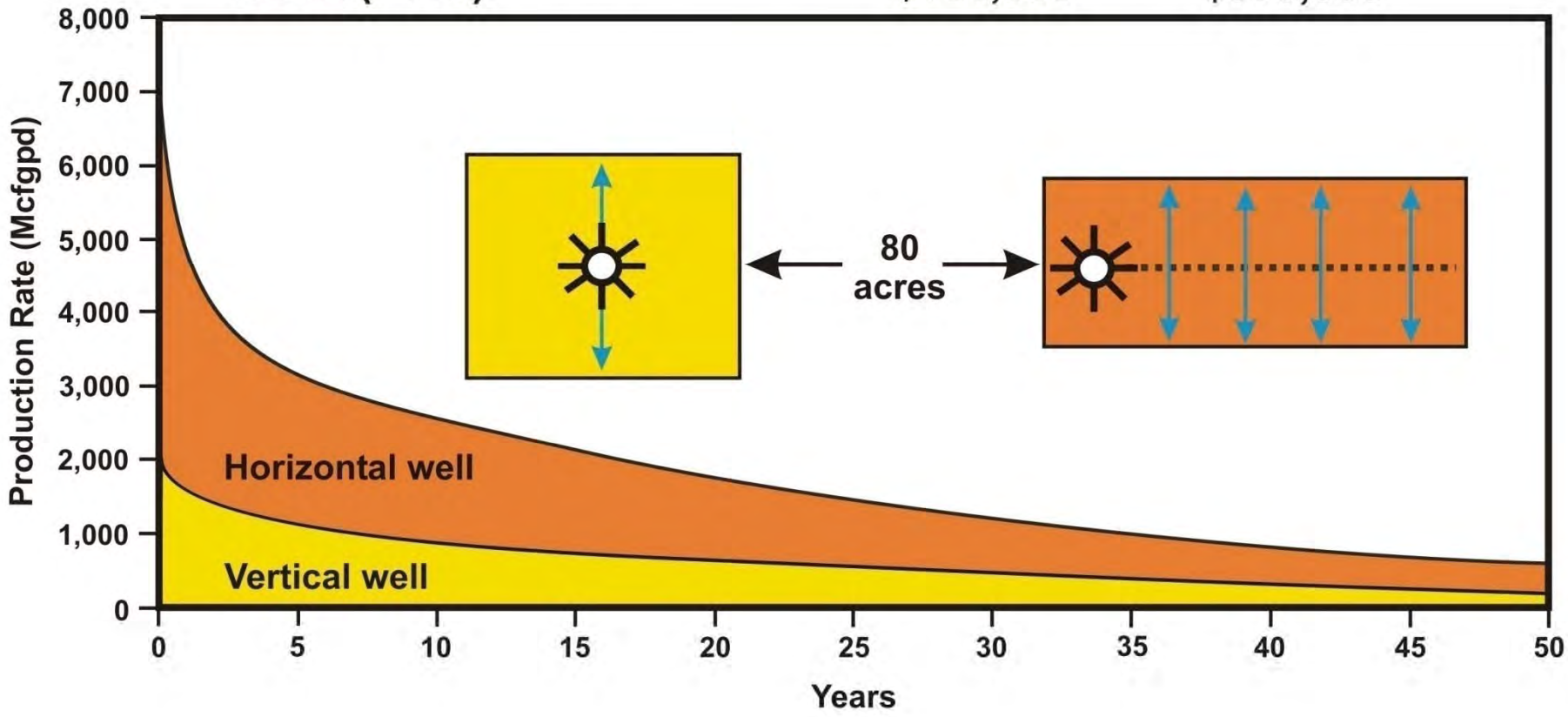
Horizontal wells:

- Expected production – from less than 400 Mcf/d to 24,500 Mcf/d
- Recovery Factor: 20 – 40%

Data from Laughrey, 2009

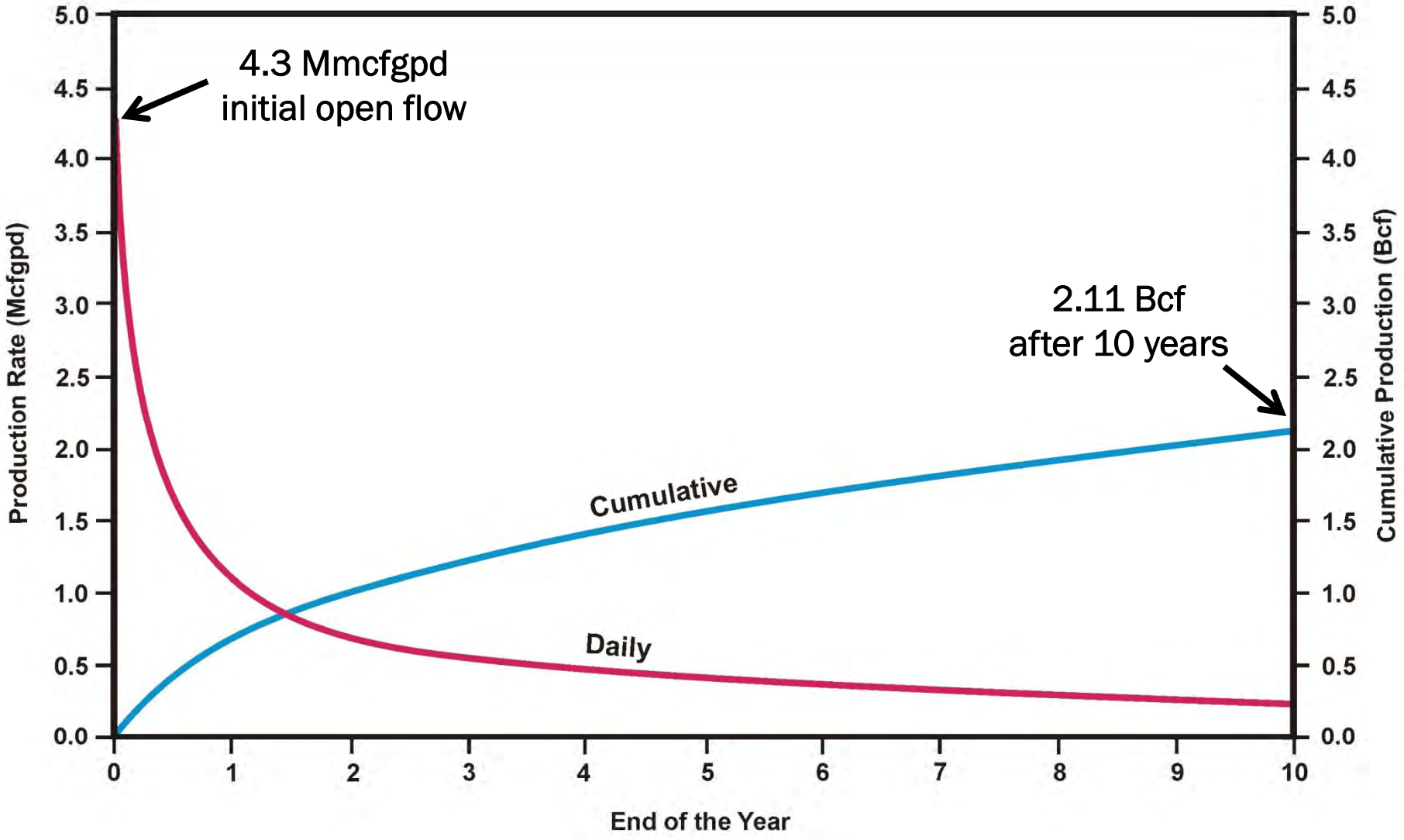
VERTICAL VS. HORIZONTAL WELL PRODUCTION

	VERTICAL	HORIZONTAL
Reserves:	0.3 - 0.5 Bcf	0.75 - 1.0 Bcf
Avg 1st month IP:	75 Mcfgpd	400 Mcfgpd
Cost:	$0.4M	$1.2M
Reserves/Production ratio:	20/1	13/1
ATAX (Pv10):	$106,000	$370,000



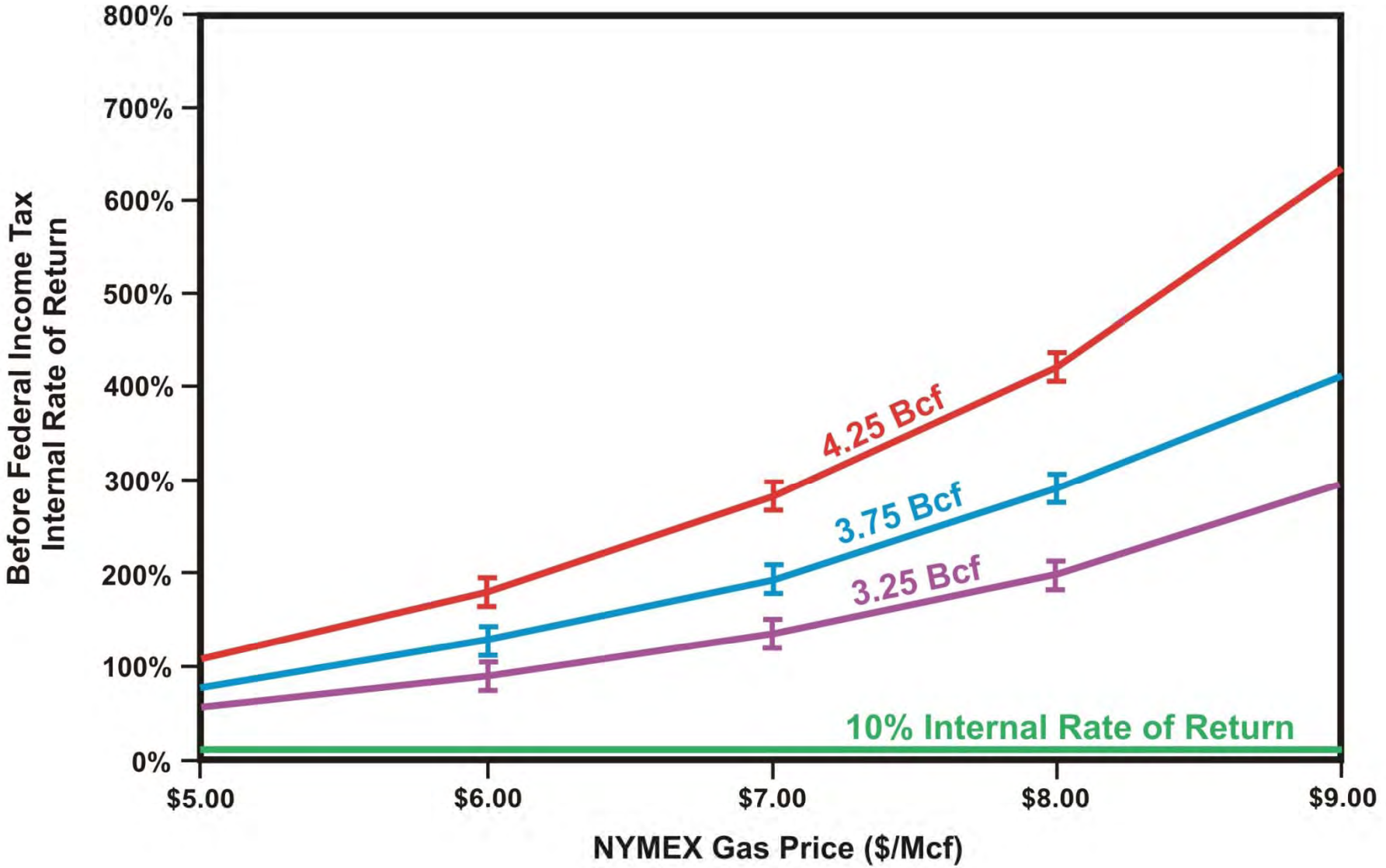
Modified from Billman, 2009

PROJECTED MARCELLUS DECLINE AND CUMULATIVE CURVES



Modified from DeWitt, 2008

MARCELLUS SHALE GAS RATE OF RETURN



Modified from DeWitt, 2008

THE MARCELLUS PLAY IN PENNSYLVANIA

MARCELLUS PLAY DISCOVERY WELL

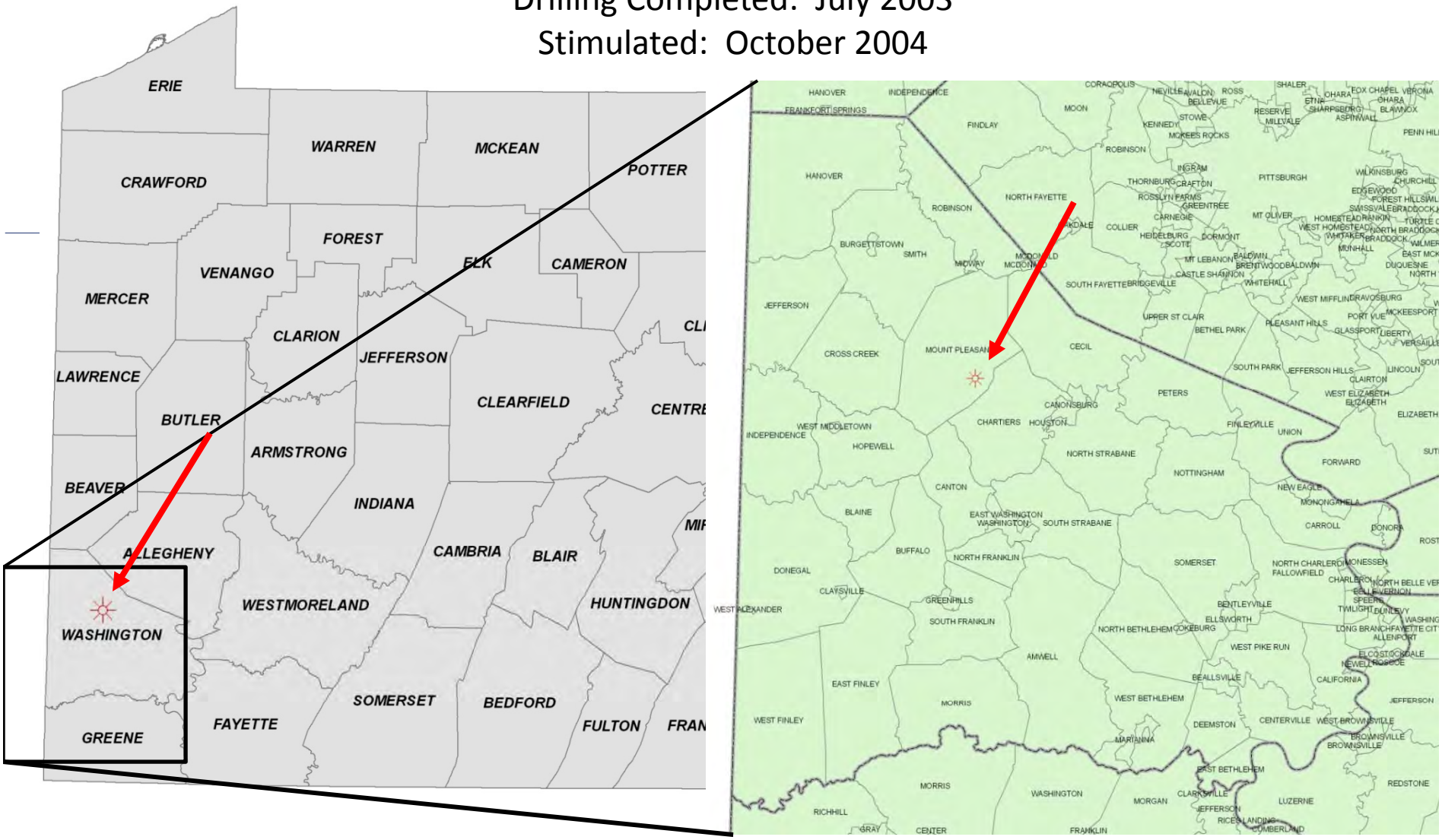
Range Resources

Renz Well

Original Target: Silurian, Lockport Dolomite

Drilling Completed: July 2003

Stimulated: October 2004



WELL RECORD OF THE MARCELLUS PLAY DISCOVERY WELL

5500-FM-OG0004 Rev 5/98

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
Oil & Gas Management Program

DEP USE ONLY

REVISED

WELL RECORD AND COMPLETION REPORT

Well Operator: Great Lakes Energy Partners, L.L.C.	DEP ID#: 141142	Well API # (Permit / Reg): 37-125-22074	Project Number	Acres: 75.32
Address: P O Box 235, Route 85 and Northern Avenue		Well Farm Name: Renz	Well #: 1	Serial #
City: Yatesboro	State: PA	Zip Code: 16263	County: Washington	Municipality: Mount Pleasant
Phone: 724-783-7144	Fax: 724-783-7655		USGS 7.5 min. quadrangle map: Midway	

WELL RECORD
Also complete Log of Formations on back (page 2).

Well Type: ☒ Gas ☐ Oil ☐ Combination Oil & Gas ☐ Injection ☐ Storage ☐ Disposal

Drilling Method: ☒ Rotary - Air ☐ Rotary - Mud ☐ Cable Tool

Date Drilling Started	Date Drilling Completed	Surface Elevation	Total Depth - Driller	Total Depth - Logger
5/31/03	7/5/03	1130'	8473'	8470'

Casing and Tubing

Cement returned on surface casing? ☒ Yes ☐ No
Cement returned on coal protective casing? ☒ Yes ☐ No ☐ N/A

Hole Size	Pipe Size	Wt.	Thread / Weld	Amount in Well (ft)	Material Behind Pipe Type and Amount	Packer / Hardware / Centralizers Type	Size	Depth	Date Run
22"	20"	94	Thread	39'	Driven	-----	-----	-----	5/31/03
19"	16"	53	Thread	132'	Class A Cement, 160 sks	Guide Shoe	16"	132'	6/1/03
15"	11-3/4"	42	Thread	344'	Class A Cement, 260 sks	Guide Shoe	11-3/4"	344'	6/1/03
11"	8-5/8"	24	Thread	2541'	Class A Cement, 500 sks	Guide Shoe	8-5/8"	2541'	6/11/03
7-7/8"	5-1/2"	17	Thread	8441'	UFL Cement, 750 sks	Float Shoe	5-1/2"	8441'	7/3/03
						Float Collar	"	8396'	"

COMPLETION REPORT

Perforation Record

Date	Interval Perforated From	To
8/1/03	7326'	7372'
12/9/03	7568'	7630'
12/17/03	6562'	6584'
10/20/04	6174'	6284'

Stimulation Record

Date	Interval Treated	Fluid Type	Fluid Amount	Propping Agent Type	Propping Agent Amount	Average Injection Rate
8/1/03	Lockport	Acid	5600 gal	20-40 sand	None	10 bpm
12/10/03	Salina	Acid	300 gal	20/40 sand	None	4.2 bpm
12/19/03	Oriskany	Gelled Acid	13000 gal	20/40 sand	None	23 bpm
10/23/04	Marcellus	Slick water	942970 gal	20/40 sand 30/50 sand	35000 # 335000 #	65 bpm

PENDING APPROVAL

Natural Open Flow	Natural Rock Pressure	Hours	Days
NA	NA		
After Treatment Open Flow: 110 Mcfpd	After Treatment Rock Pressure: 2300 psi	Hours: 72	Days

Well Service Companies -- Provide the name, address, and phone number of all well service companies involved.

Whipstock Natural Gas Serv., Inc., 150 Franklin Street, Route 286, Clymer, PA 15728 724-254-0600

Superior Well Services, P. O. Box 458, Blairsville, PA 15716 724-248-1001

Universal Well Services, P.O. Box 295, Punxsutawney, PA 15767 814-938-2051

Key Energy Services Inc. 2021 S. Route Indiana, PA 15701 724-349-7930
Phoenix Drilling, Inc. P.O. Box 2269, Buckhannon, WV 26201 304-473-1600

Allegheny Wireline Services, P.O. Box 506 Weston, WV 26452 304-269-2500

DEC 14 2004

COMPLETION REPORT

Perforation Record

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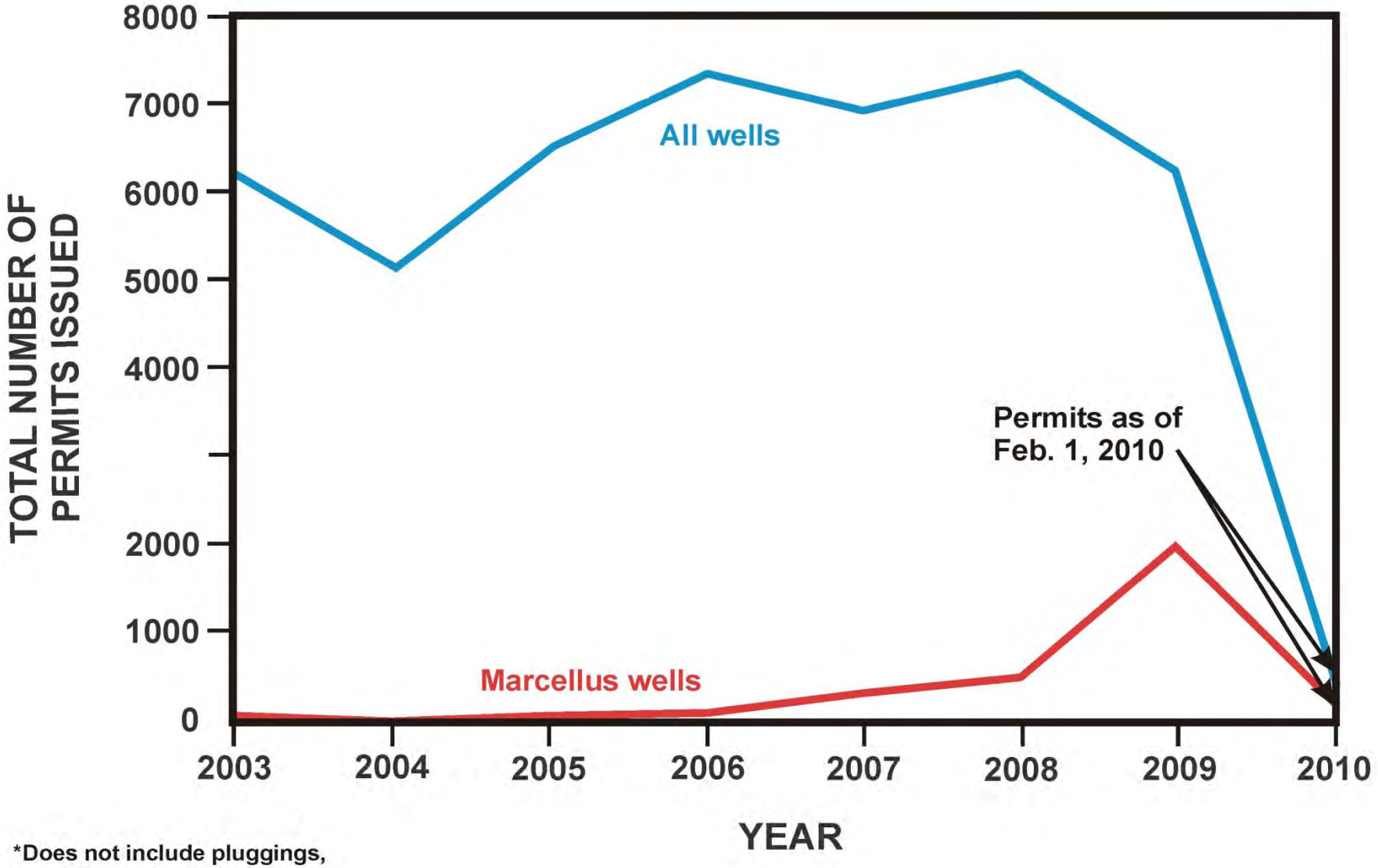
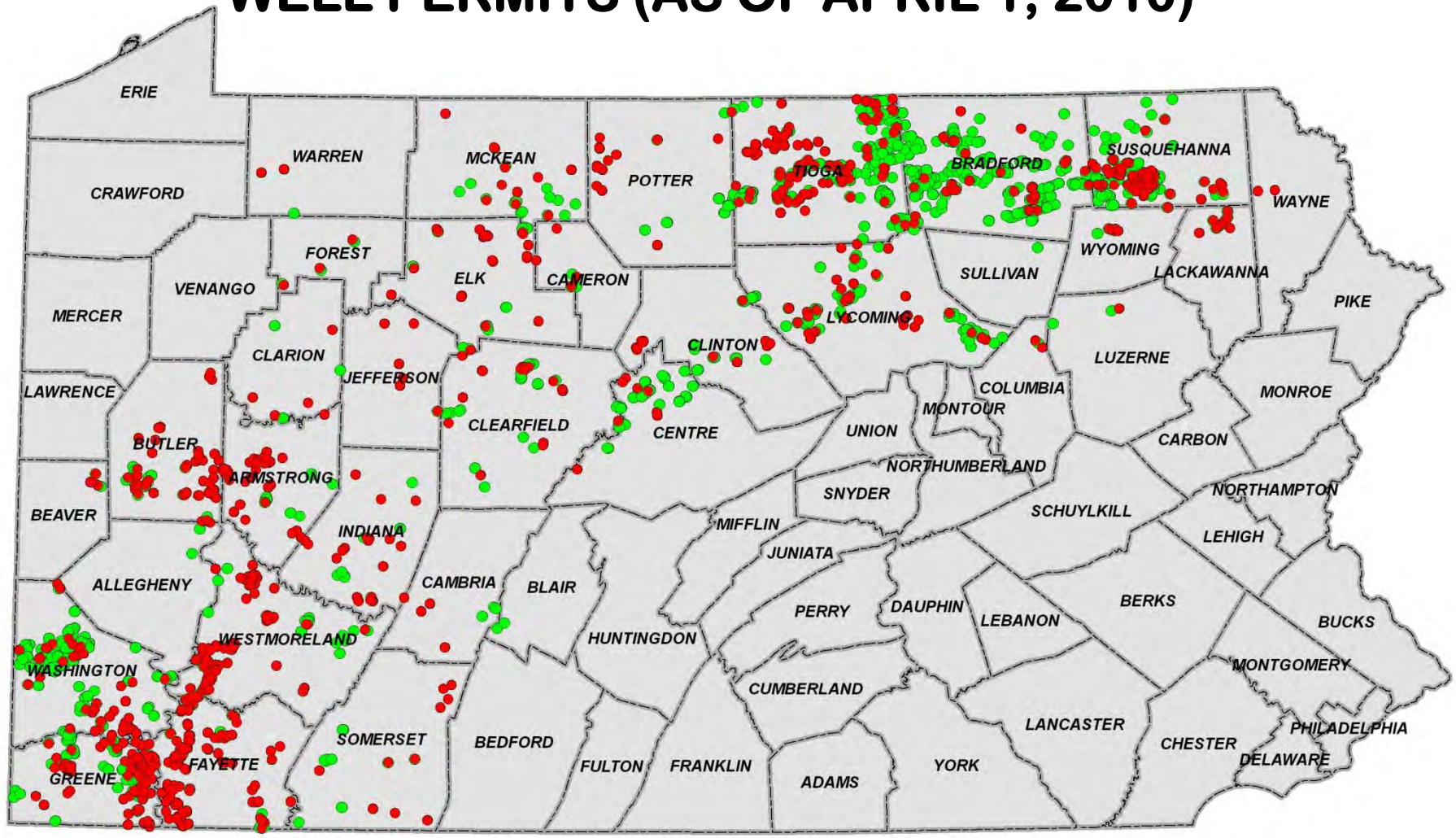
10/23/04	Marcellus	Slick water	942970 gal	20/40 sand 30/50 sand	35000 # 335000 #	65 bpm

MARCELLUS VS. ALL PERMITS ISSUED*



*Does not include pluggings, canceled, or expired permits

HORIZONTAL VS. VERTICAL MARCELLUS WELL PERMITS (AS OF APRIL 1, 2010)



- Vertical Well
- Horizontal Well

WHAT ABOUT REPORTED PA PRODUCTION???

The Marcellus play is relatively new, so there is very little data other than company stock projections

Fortunately, Pennsylvania has the first four years' worth of production data from Marcellus wells – 2005 to 2008

Unfortunately, Pennsylvania collects only annual production totals, and by state law has to keep by-well data confidential for 5 years

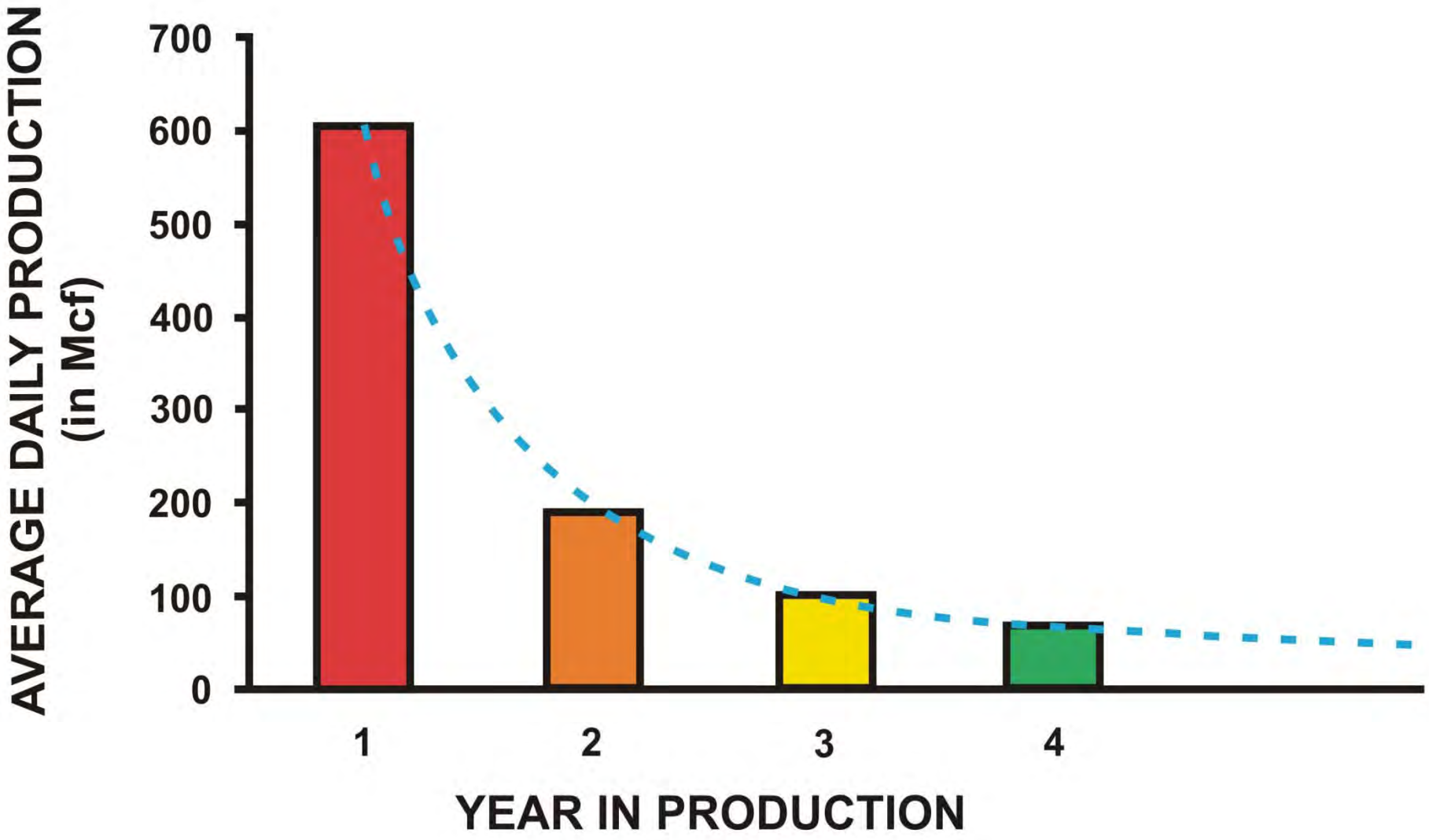
Fortunately, we can report aggregate numbers, which allows us to perform rough statistical analyses

But, only if it doesn't give away too much information!!!

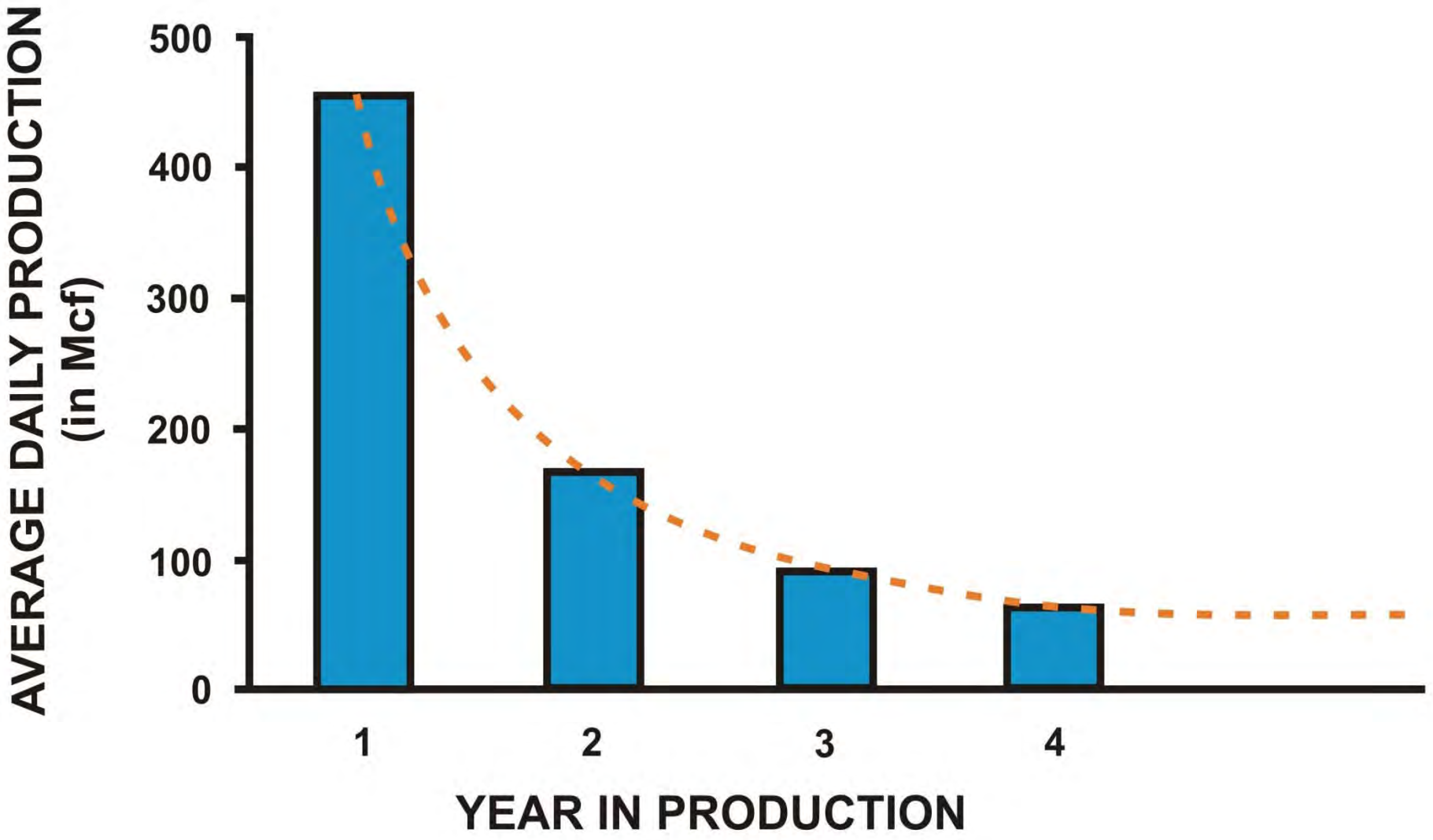
WHAT ABOUT REPORTED PA PRODUCTION???

- The following charts show the average daily production of Marcellus wells in PA
- They were determined by dividing the total annual production of each well by the number of days it was in production during the year, then taking the average of those calculations.
- The "year in production" is the numerical year, rather than the calendar year. Wells that produced for the first time in 2008 are included with wells that produced for the first time in 2005, 2006, and 2007. Year 1 is represented by many wells, whereas there are relatively few wells that have a fourth year of production.
- Although the dashed lines connecting the midpoints at the tops of each rectangle mimic true decline curves, they are completely artificial, an artifact of the distribution of data across the four years.

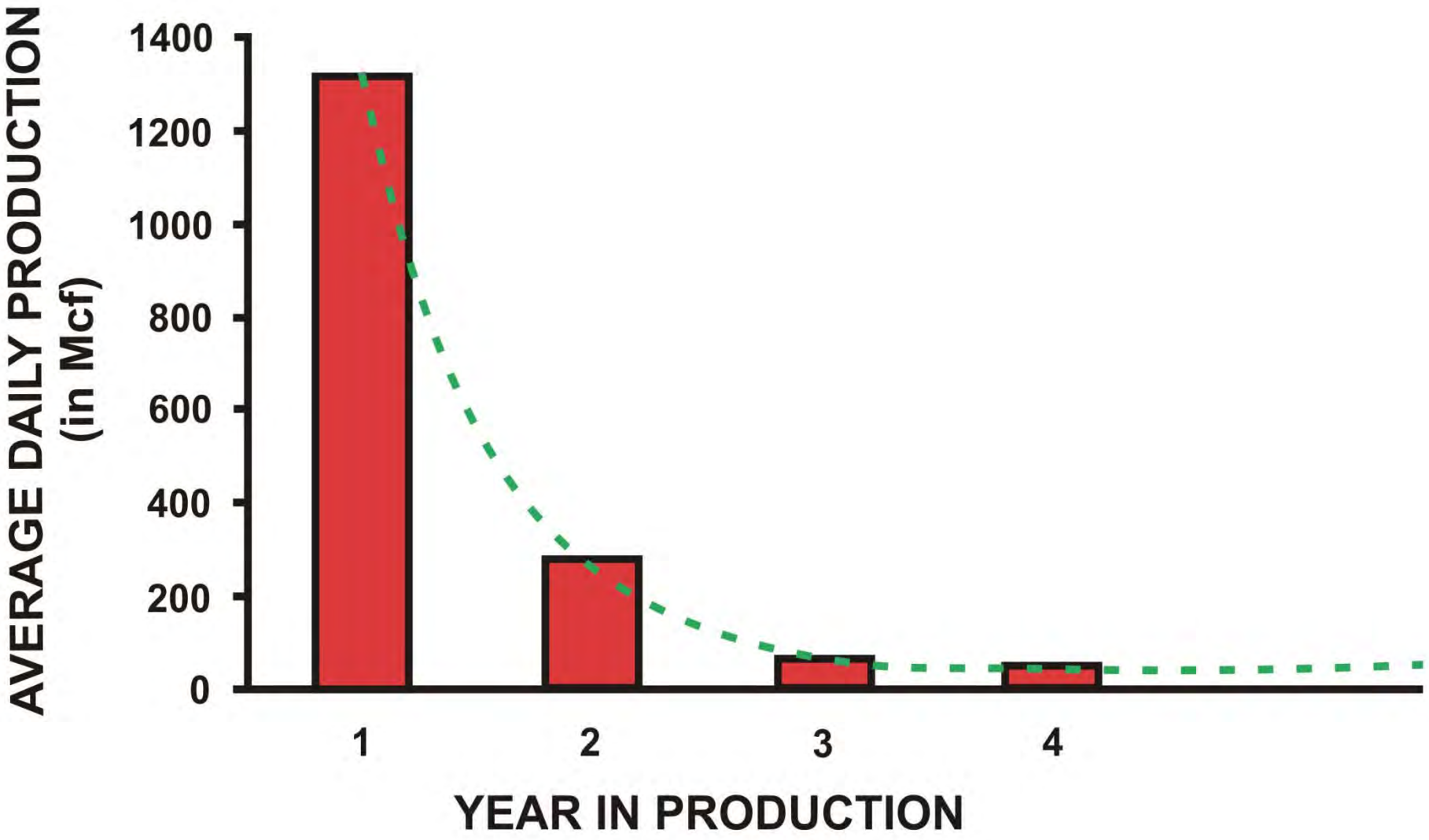
MARCELLUS PRODUCTION
AVERAGE OF ALL WELLS



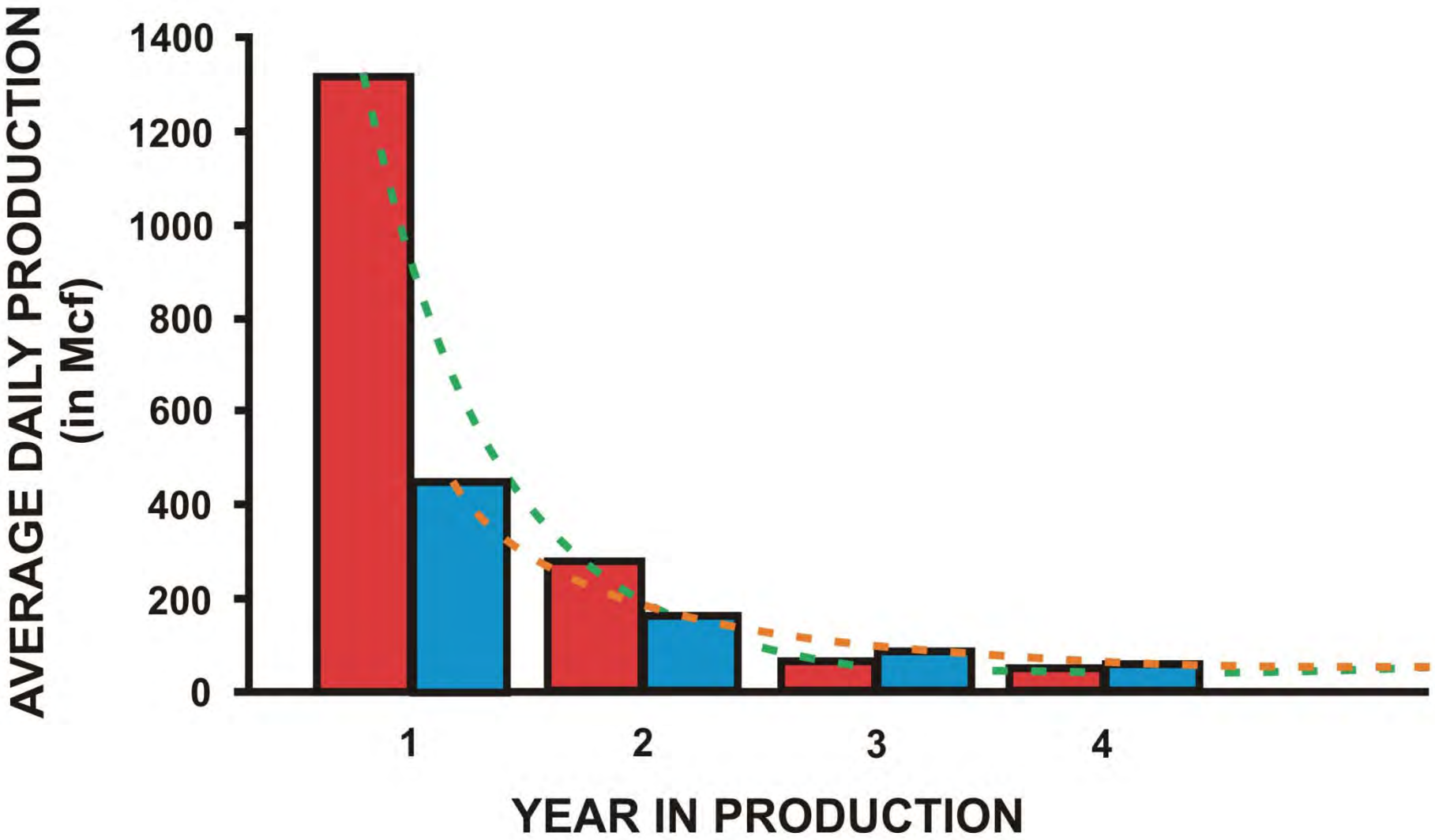
MARCELLUS PRODUCTION
AVERAGE OF ALL VERTICAL WELLS



MARCELLUS PRODUCTION
AVERAGE OF ALL HORIZONTAL WELLS

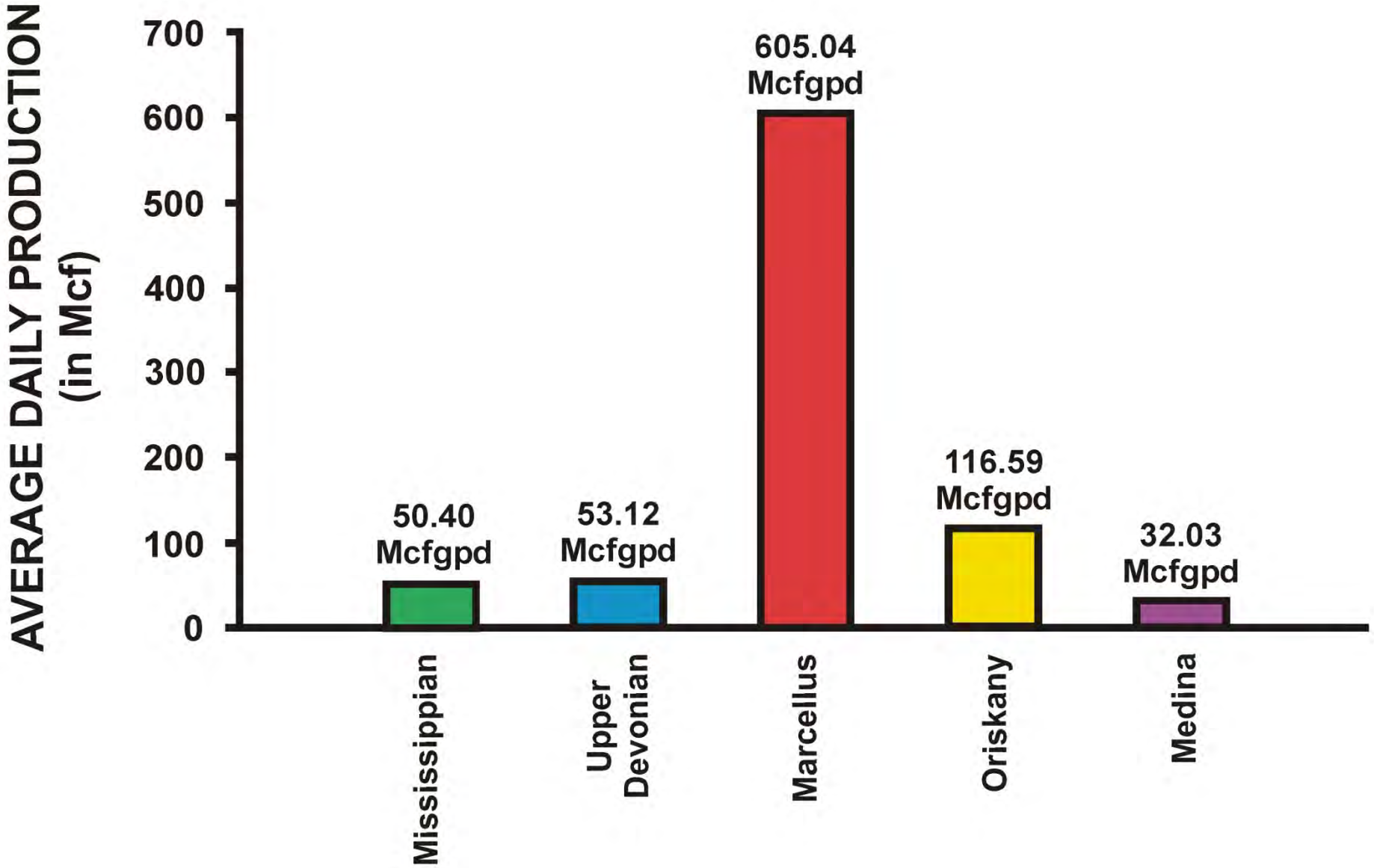


MARCELLUS PRODUCTION
COMPARISON OF VERTICAL AND HORIZONTAL WELLS

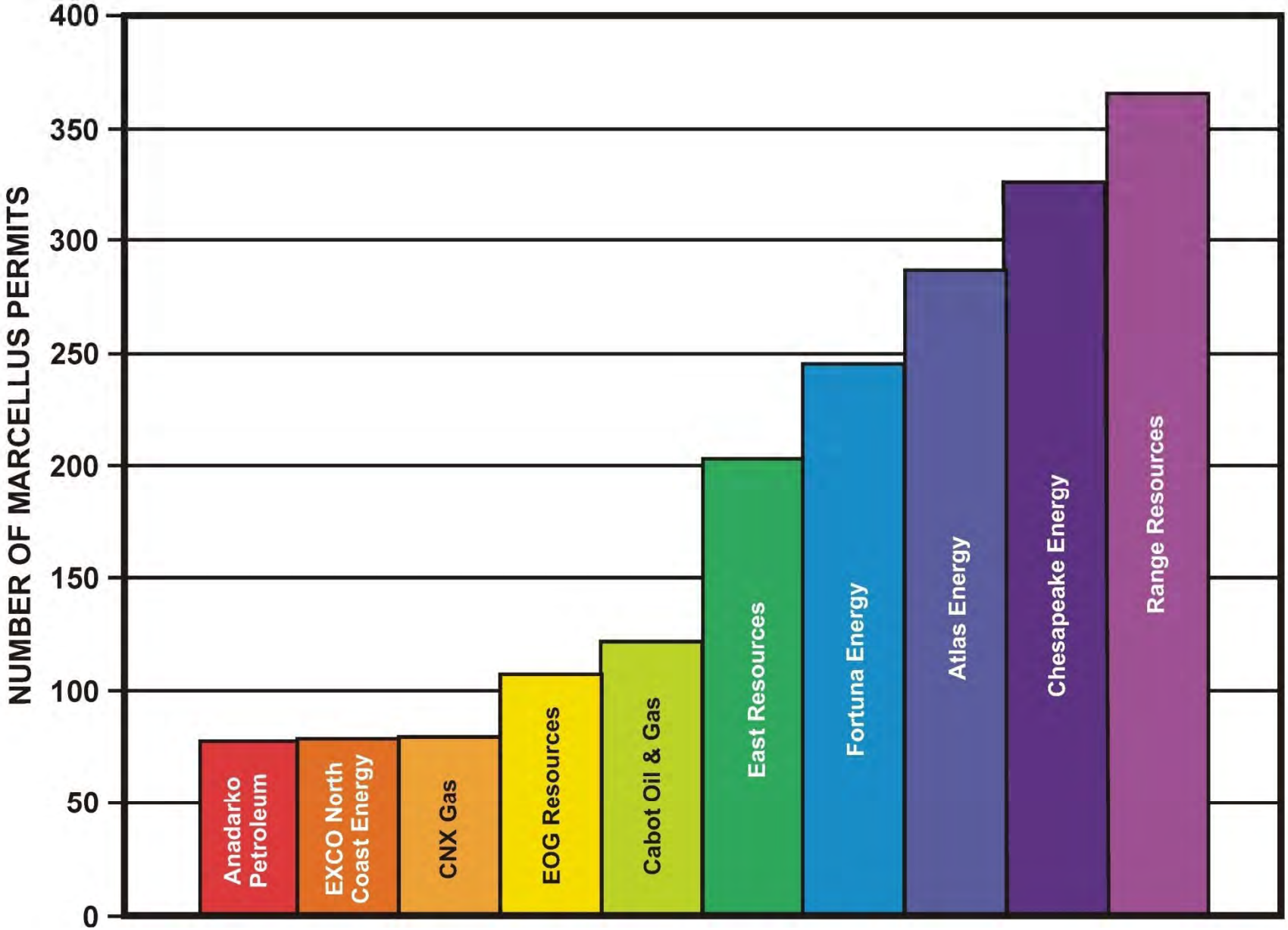


COMPARISONS OF AVERAGE DAILY PRODUCTIONS

(variable numbers of wells)



THE MAJOR PLAYERS IN PENNSYLVANIA



RESOURCE ESTIMATES

US Geological Survey (Milici and Swezey, 2006) –

- 259 Tcf gas-in-place (GIP)
- 1,925 Bcf recoverable

Industry and academe –

- 500 to 5,000 Tcf in place
- 50 to 500 Tcf recoverable!

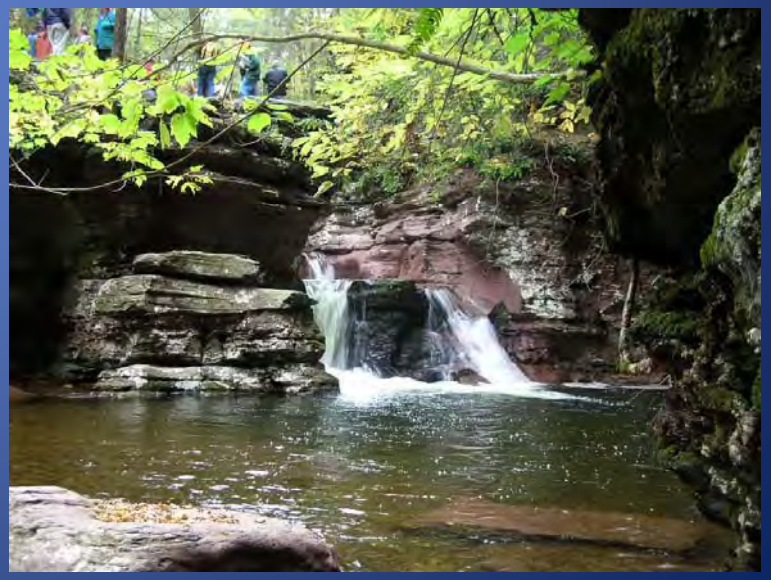
Rational optimism (Kuushkraa and Stevens, 2009) –

- 1,600 Tcf in place
- 100 – 200 Tcf recoverable

In the long run, it will depend on the price of gas at the well-head

RISKS AND CHALLENGES TO PENNSYLVANIA'S MARCELLUS PRODUCERS

- ✓ Topography – Pennsylvania's steep slopes
- ✓ Population centers
- ✓ Effectiveness of completions
- ✓ Pipeline capacity, transportation bottlenecks, and aging infrastructure
- ✓ Well permitting and other oil and gas regulatory issues
- ✓ Water use and disposal issues
- ✓ Fragmented mineral rights ownership
- ✓ Gas leakage, groundwater contamination, and geohazards



WATER NEEDS FOR DRILLING AND FRACING

Shale Gas Play	Volume of Drilling Water per Well (gal)	Volume of Fracturing Water per Well (gal)	Total Volume of Water per Well (gal)
Barnett Shale	400,000	2,300,000	2,700,000
Fayetteville Shale	60,000	2,900,000	3,060,000
Haynesville Shale	1,000,000	2,700,000	3,700,000
Marcellus Shale	80,000*	3,800,000	3,880,000

*** Drilling performed with an air "mist" and/or water-based or oil-based muds for deep horizontal well completions.**

Note: These volumes are approximate and my vary substantially between wells.

Data from Groundwater Protection Council, 2009

NEED TO ADDRESS HYDRAULIC FRACTURING, WATER USE, AND FLOWBACK WATER MANAGEMENT

HYDRAULIC FRACTURING

EPA will revisit hydraulic fracturing technology (2004 study found no problems)

WATER USE:

The average Marcellus well uses about 3.5 million gallons of water

FLOWBACK WATER MANAGEMENT:

Industry/academe working on research to provide treatment technologies – about 30-40% of original water returned during flowback

- Polymer gel treatment
- Wetland management – environmentally friendly
- Recycling – water/salt separation processes ("demineralization") – solid waste and brine trucked to disposal sites
  - ✓ Lower transportation costs
  - ✓ Reduced environmental conflicts
  - ✓ Reduce risk of interruption to development schedule

WATER RESOURCE CONCERNS

- Water supply
  - Water management plans – permit application
  - Water withdrawal approval – Susquehanna River Basin Commission, Delaware River Basin Commission
- Waste water disposal
  - Identify where water will be stored, treated and disposed of prior to drilling
  - determining the proper methods for the safe disposal of the large quantities of potentially contaminated fluids recovered from the wells

WATER USE AND DISPOSAL ISSUES

3 to 5 million gallons of water per hydro-fracturing job + a variety of chemicals

Flowback is 1/2 to 1/3 of this volume in a short time!

Flowback fluids will include a variety of natural rock ingredients as well as water and additives

- *Brine* – ancient sea water containing concentrated salts
- *Metals* – toxic and non-toxic
- *Hydrocarbons* – natural gas and liquids
- *"Radioactive" material* – naturally occurring uranium and thorium ions locked in the organic matrix

These require off-site treatment

TYPES OF MATERIALS USED IN TYPICAL MARCELLUS HYDRAULIC FRACTURING JOBS

Water – forced into the rock under very high pressure

Quartz sand – props open the fractures

Hydrochloric or muriatic acid – dissolves carbonate material in the rock

Ammonium bisulfate – oxygen scavenger

Glutaraldehyde - biocide

Sodium chloride (salt) - breaker

N,n-dimethyl formamide – corrosion inhibitor

Petroleum distillate or diesel – reduces friction

Guar gum or hydroxyethyl cellulose - gel

2-hydroxy-1,2,3-propanetricaboxylic acid – iron control

Ethylene glycol or 2-Butoxyethanol – scale inhibitor

Fluorocarbons, napthalene, butanol, and formaldehyde have also been used

SUMMARY OF FRACING SOLUTIONS

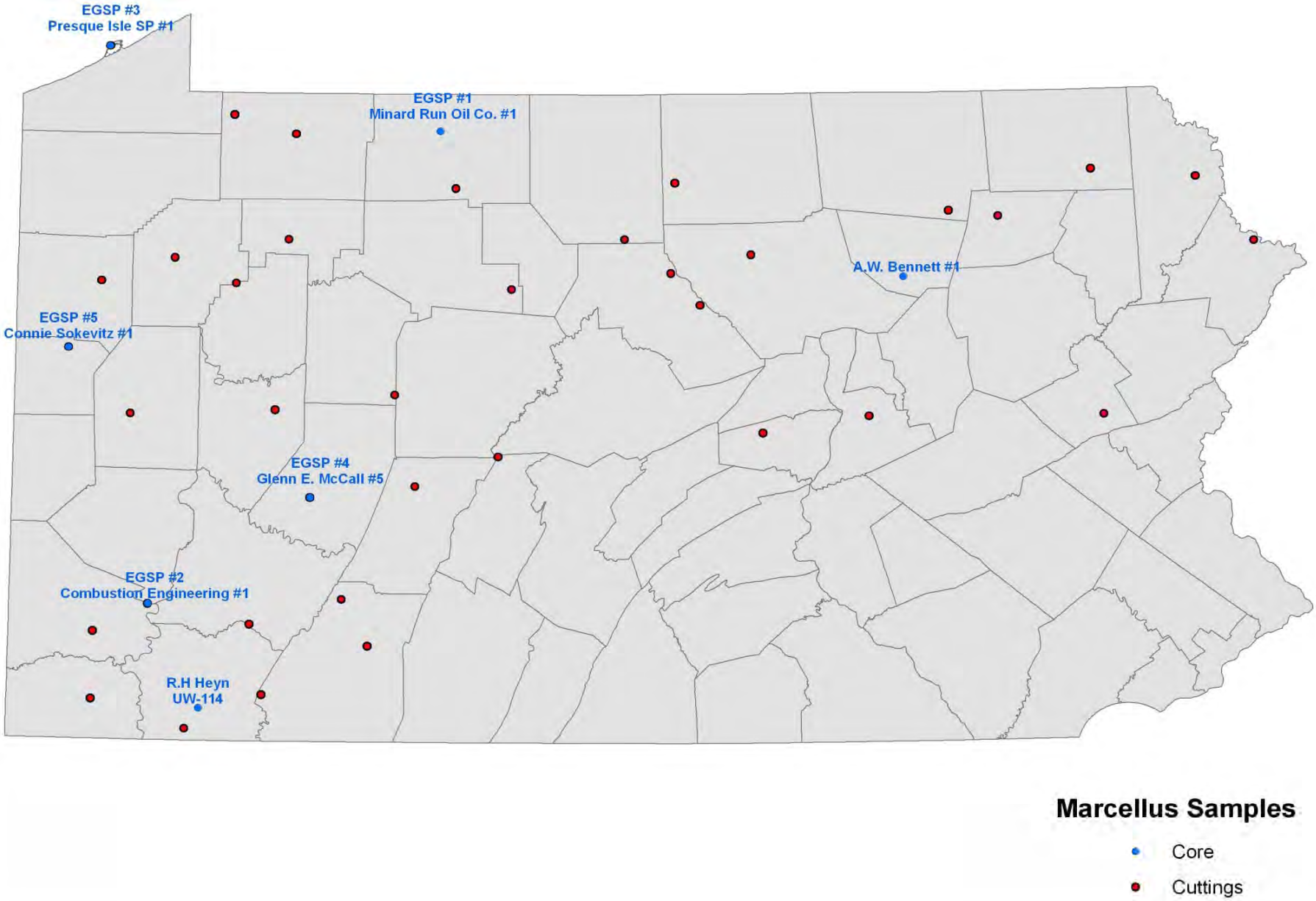
Product Vendor	Application Sequence	Product Name	Hazardous Components (From MSDS)	Hazardous Ingredient Weight %	Pounds of hazardous ingredient / pound water	Gallons of Frac solution per stage	Concentration in Frac Solution (ppm)	EPA Risk Based Concentration - Residential Tapwater (ppm)
BJS	1	HCl	Hydrochloric Acid	8%	0.015834	2000	83.68	
		CI-14	Propargyl Alcohol	5%	0.00004327	2000	0.23	0.073
			Methanol	68%	0.000588472	2000	3.11	18
		Ferrotrol 300L	Citric Acid	70%	0.0035	2000	18.50	
	2	XLW-32	Methanol	90%	0.001593	42000	176.79	18
			Boric Oxide	20%	0.000354	42000	39.29	
		GW-3LDF	Petroleum Distallate Blend	60%	0.00321	42000	356.24	
			Polysaccharide	60%	0.00321	42000	356.24	
		GBW-20C	no hazardous ingredients	0%	0	42000	0.00	
		BF-7L	Potassium Carbonate	100%	0.0005725	42000	63.53	
		GBW-15L	Sodium Chloride	14%	0.000154	42000	17.09	
	3	FRW-14	Hydrotreated light distillate	40%	0.000424	334000	374.20	
			Ethoxylated Alcohol	5%	0.000053	334000	46.77	
		Alpha 125	Glutaraldehyde	30%	0.0000798	334000	70.43	
Fractech	1	HCL	Hydrochloric Acid	8%	0.0168896	2000	89.26	
		40 HTL	Methanol	10%	0.0002	2000	1.06	18
		NE100	Methanol	5%	0.0000485	2000	0.26	18
		FE100L	no hazardous ingredients	0%	0	2000	0.00	
	2	HVG-04	no hazardous ingredients	0%	0	42000	0.00	
		B9	Potassium Hydroxide	20%	0.000206	42000	22.86	
		BXL-2	Potassium Hydroxide	10%	0.000117	42000	12.98	

DEP, 2010

PA Geological Survey

- Stewards of well data
  - ✓ Wells Information System (WIS)
  - ✓ Pennsylvania Internet Record Imaging System (PA*IRIS)
- Geochemical database
  - ✓ Source rock data
  - ✓ Thermal maturity, quality and quantity of organic matter
  - ✓ Available online at http://www.dcnr.state.pa.us/topogeo/oilandgas/source.index.aspx
  - ✓ New data

LOCATIONS OF AVAILABLE DATA



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