The Marcellus: An Analogue for the World's Gas Shale Plays?*

Terry Engelder[1]

Search and Discovery Article #80422 (2014)**
Posted November 30, 2014

*Adapted from 2013-2014 AAPG Foundation Distinguished Lecture

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Abstract

Challenges for global gas shale production include infrastructural and geological with the Marcellus providing an analogue for both.

Infrastructural: The production from the Marcellus gas shale presents unique challenges that include issues associated with leasing, geology, landowners, virtually no deep disposal wells, state governments without a severance tax, several river basin commissions, an infrastructure designed for shallow gas production, an emotional group of environmentalists, and one state that has yet to permit horizontal well stimulation. This combination of challenges makes for a very interesting set of lessons that operators will face elsewhere in the world when attempting to play gas shales.

Geological: The Appalachian Basin is characterized by 2nd order depositional sequences (approximately 10's of million years duration) that make up thousands of feet of strata in this basin, 3rd order sequences (1-10 million years) with up to several hundred feet of strata, and parasequences, that comprise tens of feet of strata. Middle Devonian Marcellus Formation encompasses two third order transgressive-regressive (T-R) sequences, MSS1 and MSS2, in ascending order.

Compositional elements of the Marcellus Formation crucial to the successful development of this emerging shale gas play, including quartz, clay, carbonate, pyrite, and organic carbon, vary predictably within the proposed sequence stratigraphic framework. Tops of the parasequences commonly contain a calcareous interval, commonly containing shell debris, overlain by a sharp transition into the high TOC mudrocks of the next overlying parasequence. Thickness trends of Marcellus T-R sequences

and lithostratigraphic units reflect the interplay of Acadian thrust-load-induced subsidence, short-term base-level fluctuations, and recurrent basement structures. Rapid thickening of both T-R sequences, especially MSS2, toward the northeastern region of the basin preserves a record of greater accommodation space and proximity to clastic sources early in the Acadian orogeny. However, local variations in T-R sequence thickness in the western, more distal, area of the basin may reflect the reactivation of inherited Eocambrian basement structures to form a carbonate bank.

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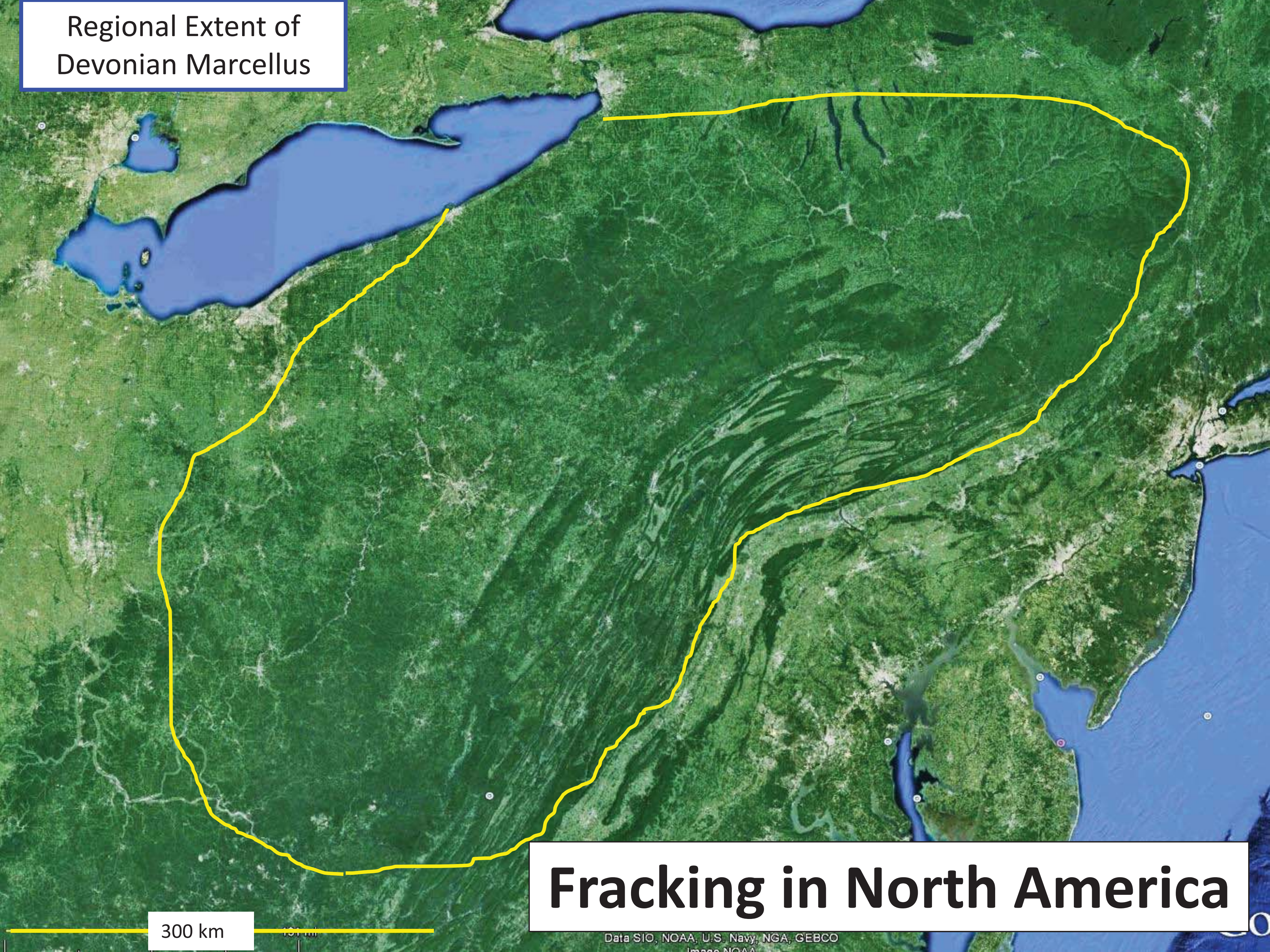
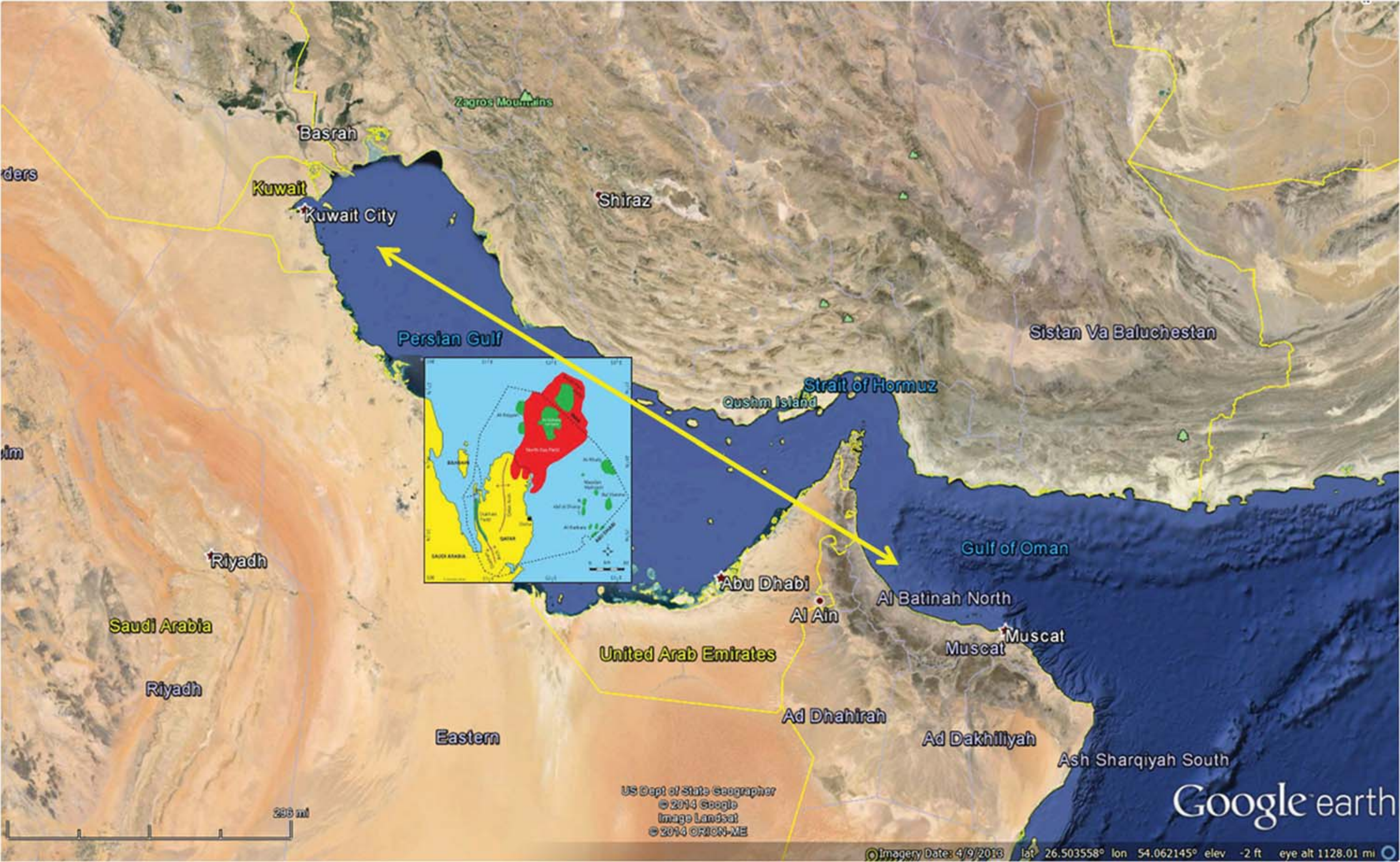
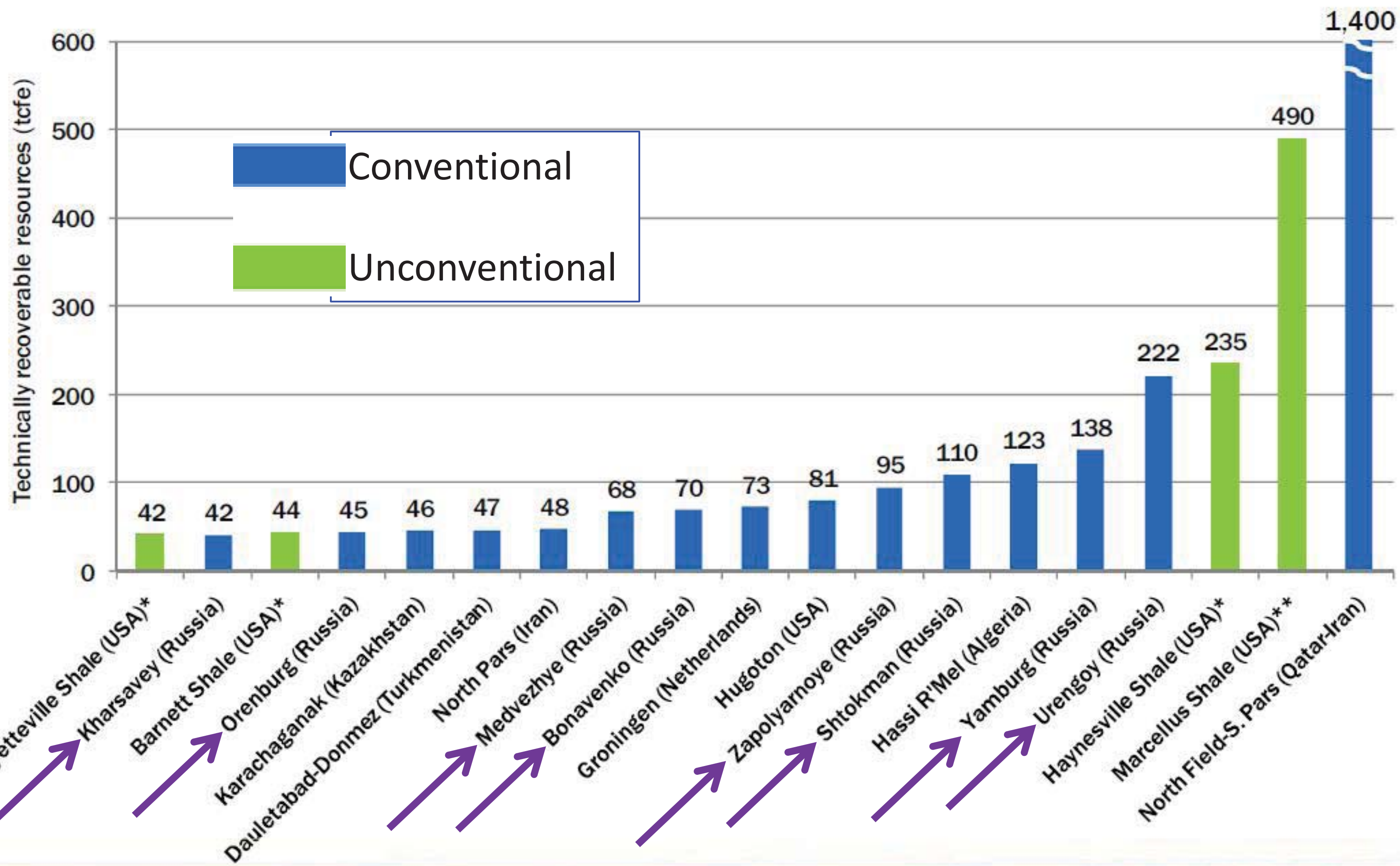
The Marcellus: An analogue for global gas shale plays?

Terry Engelder, Distinguished Lecturer
Department of Geosciences
The Pennsylvania State University


Regional Extent of
Devonian Marcellus
Fracking in North America
300 km
Data SIO, NOAA, U.S. Navy, NGA, GEBCO


Zagros Mountains
Basrah
Kuwait
Kuwait City
Shiraz
Persian Gulf
Sistan Va Baluchestan
Strait of Hormuz
Qushm Island
Gulf of Oman
Riyadh
Abu Dhabi
Al Batinah North
Al Ain
Muscat
Muscat
Saudi Arabia
United Arab Emirates
Riyadh
Ad Dhahirah
Eastern
Ad Dakhiliyah
Ash Sharqiyah South
US Dept of State Geographer
© 2014 Google
Image Landsat
© 2014 ORION-ME
Google earth
296 mi
Imagery Date: 4/9/2013 lat 26.503558° lon 54.062145° elev -2 ft eye alt 1128.01 mi

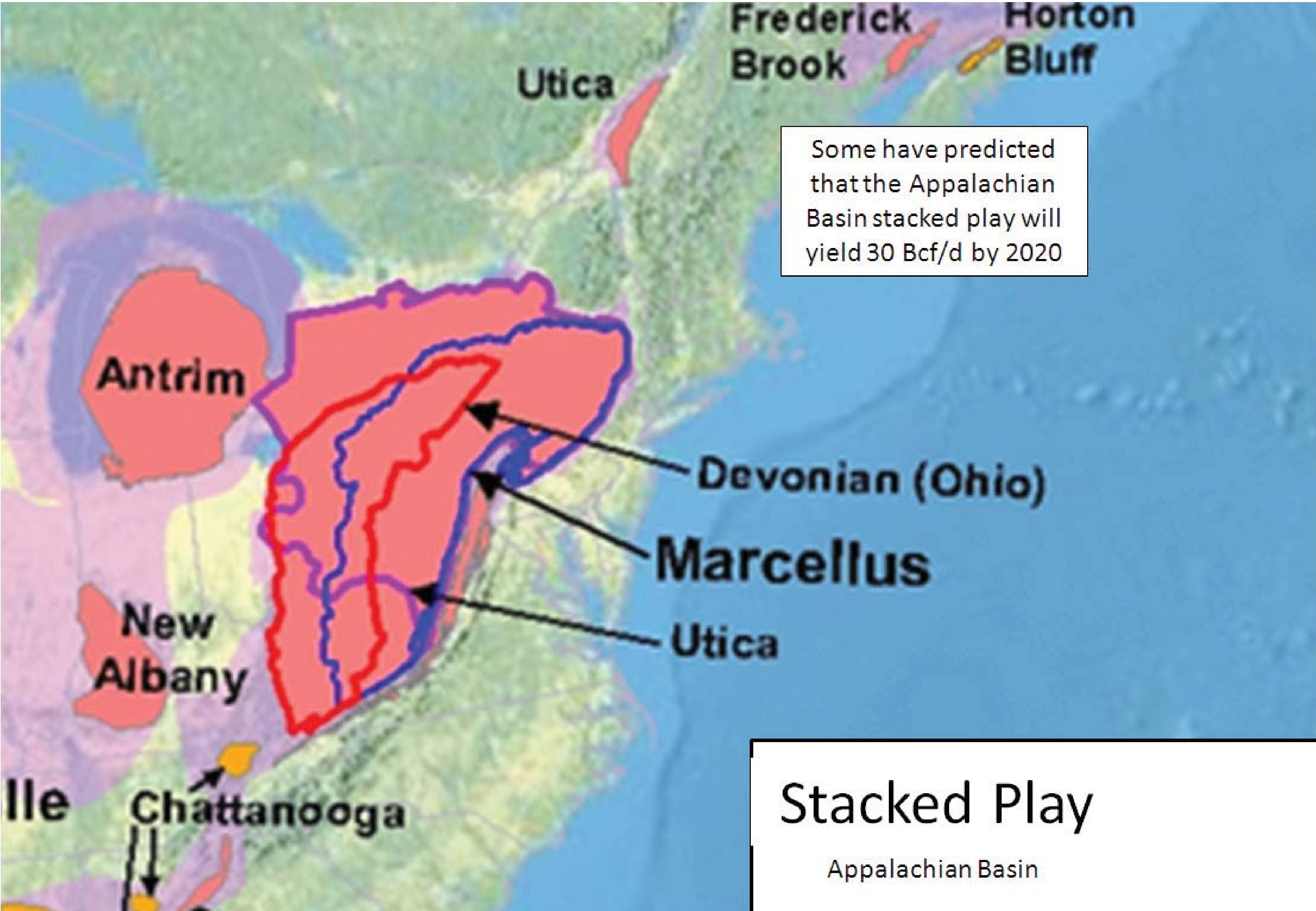
U.S. Natural Gas Shale Plays are World-Class Resources



*U.S. Department of Energy (April 2009): Modern Shale Gas Development in the United States: A Primer, p. 17
**Dr. Terry Engelder, Penn State University

Stacked Play

Appalachian Basin



Some have predicted that the Appalachian Basin stacked play will yield 30 Bcf/d by 2020

Christopher Joyce

Correspondent: Science Desk
National Public Radio (NPR)

- I have been in science journalism for more than 30 years and I have never seen more **scientific disinformation*** on any topic as **fracking**. I am amazed at the level of both inadvertent and purposeful disinformation.
- There is such an agenda on everyone's mind.

http://www.youtube.com/watch?v=giCRpul-YBA

Fracking in North America

There are some people who really want it (i.e., production of oil and gas) to fail!

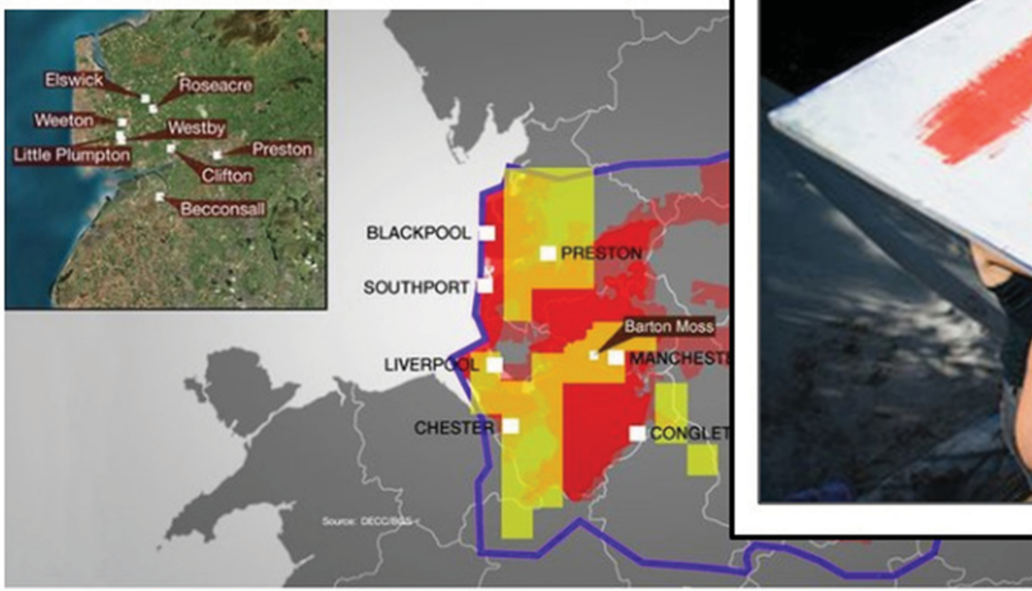
Scott Perry,
Undersecretary for Oil and Gas
Pennsylvania Department of
Environmental Protection

5 March 2014 Last updated at 01:38 GMT

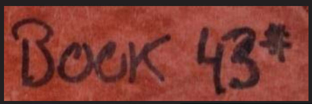
Share

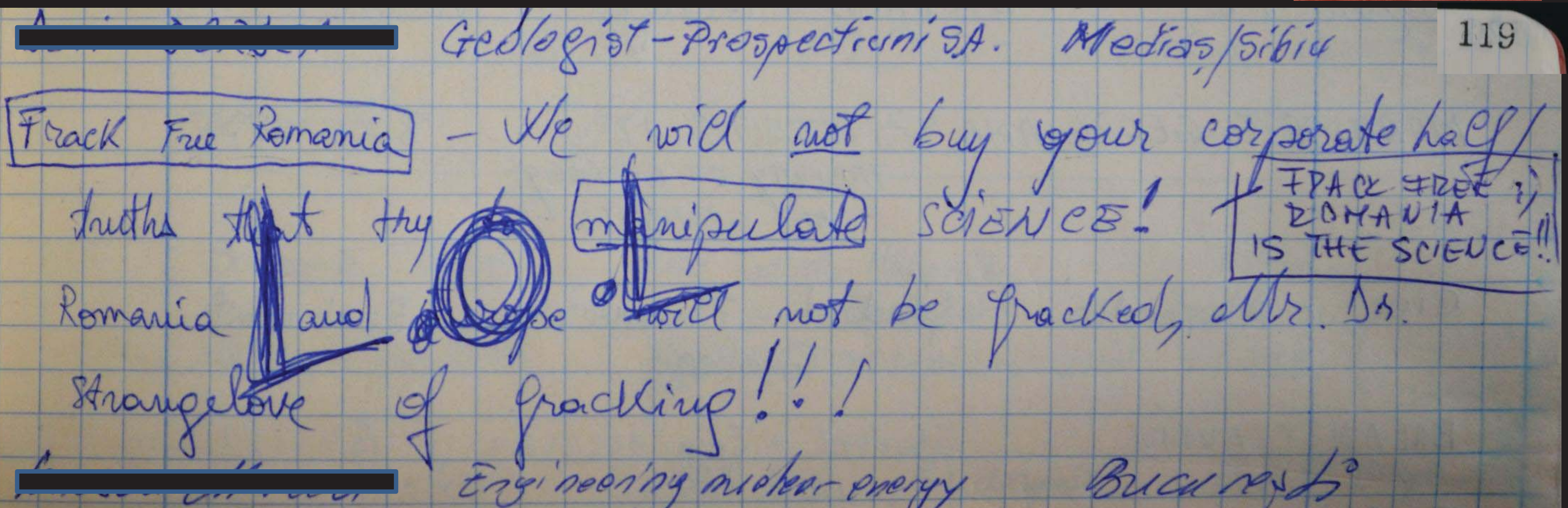
Shale gas estimate in North West 'bigger' than previously thought

By Matt McGrath
Environment correspondent, BBC News



- “Members of AAPG try to manipulate science!”
  - Engelder notebook #43, page 119.





Frack Free Romania - We will not buy your corporate half truths that try to manipulate science! Romania and Europe will not be fracked Mr. Dr. Strangelove of fracking !!!

Frack Free Romania is the science

The Global Context: Politics

Fracking Fact!

"Some Europeans fear the propaganda in the movie, ***Gasland***, more than the hand of Vladimir Putin on the valve that supplies natural gas to Central Europe."

Reporter: Matous Laznovsky iDENS.cz

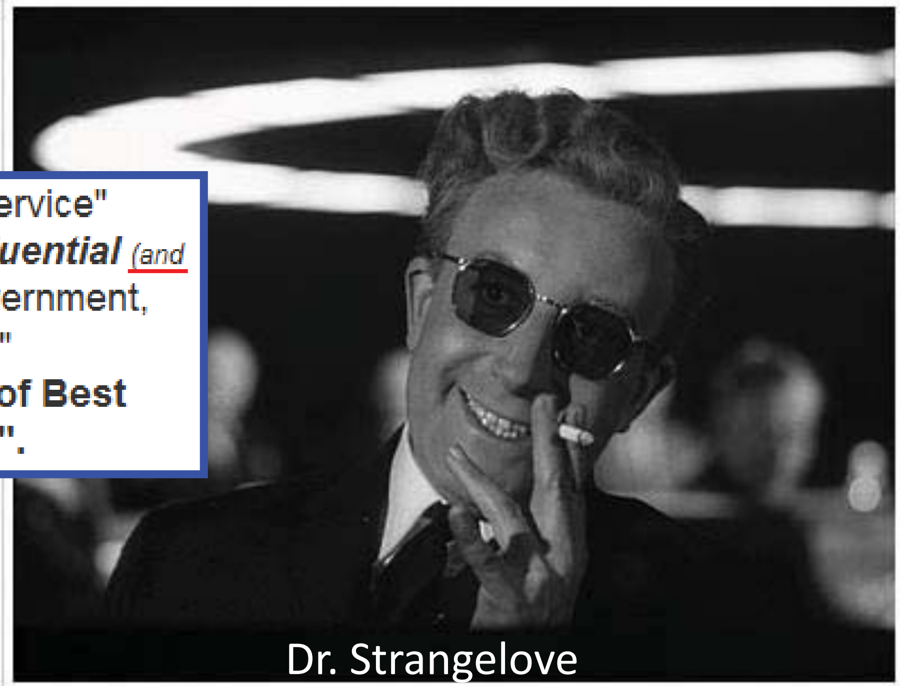
Terry Engelder,
Malostranski Namesti,
Prague
May 17, 2012

MLADÁ FRONTA DNES

- “Anyone who speaks in favor of fracking must be highly paid by industry (i.e., a shill)!”
    - Evidence for this found on many websites like ‘Fracked’.

MONDAY, MAY 31, 2010

"DR" TERRY ENGELDER



In consideration of his longstanding "service" as Penn State Professor and ***very influential*** *(and highly paid?)* ***consultant*** to leaders in government, business, and education, the good "Dr" has assumed the position of **"Arbitor of Best Interests and Necessary Sacrifices".**

Disclaimer: NO business (i.e., Shell) and no government (i.e., EU) will pay me a single Euro for giving this talk!

Google: Engelder the fracking debate

http://www.youtube.com/watch?v=BBSVLGf7zPI

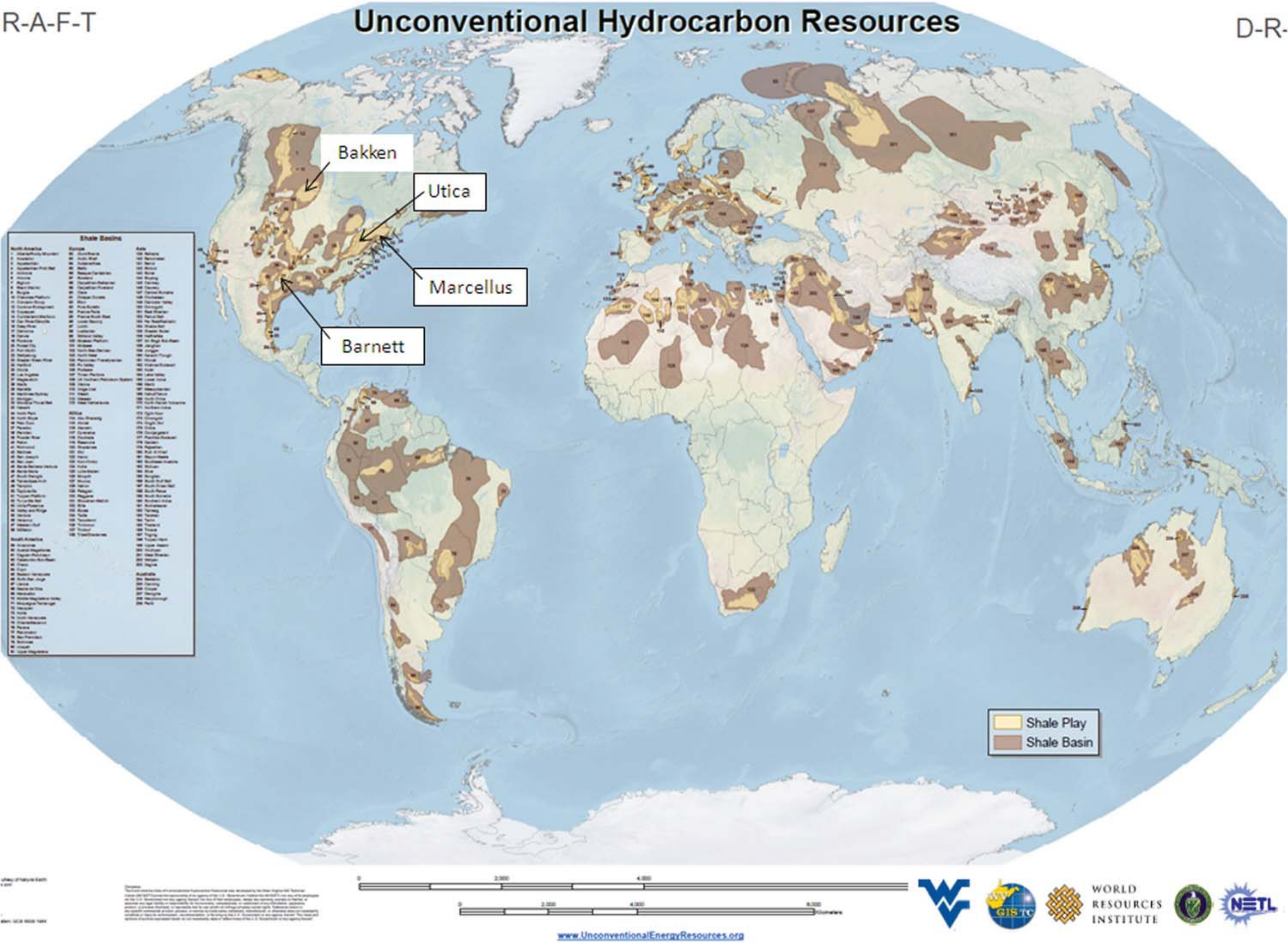
Objective of Talk:
To understand the general infrastructural and geological characteristics of a successful black shale play

Qualities of a prospective gas shale

1. Public Domain Data Base
2. Free Market (Floating-Price) Commodity
3. Total Organic Carbon Content
4. Kerogen Type
5. Thickness
6. Depth
7. Thermal Maturity
8. Porosity
9. Pore Pressure
10. Low Clay Content
11. Total Technically Recoverable
12. Slight Structural Complexity
    i. Natural Hydraulic Fractures
    ii. No Thief Faulting

Public Domain Data Base

- **<u>Small operators plus capital markets</u>** can compete with majors (Exxon Mobil, Shell, Chevron, Total, BP, Statoil)
  - Mitchell Energy
  - Range Resources
  - Devon
  - Chesapeake
  - East Resources


Unconventional Hydrocarbon Resources
Bakken
Utica
Marcellus
Barnett
Shale Basins
Shale Play
Shale Basin
WORLD RESOURCES INSTITUTE
NETL
www.UnconventionalEnergyResources.org

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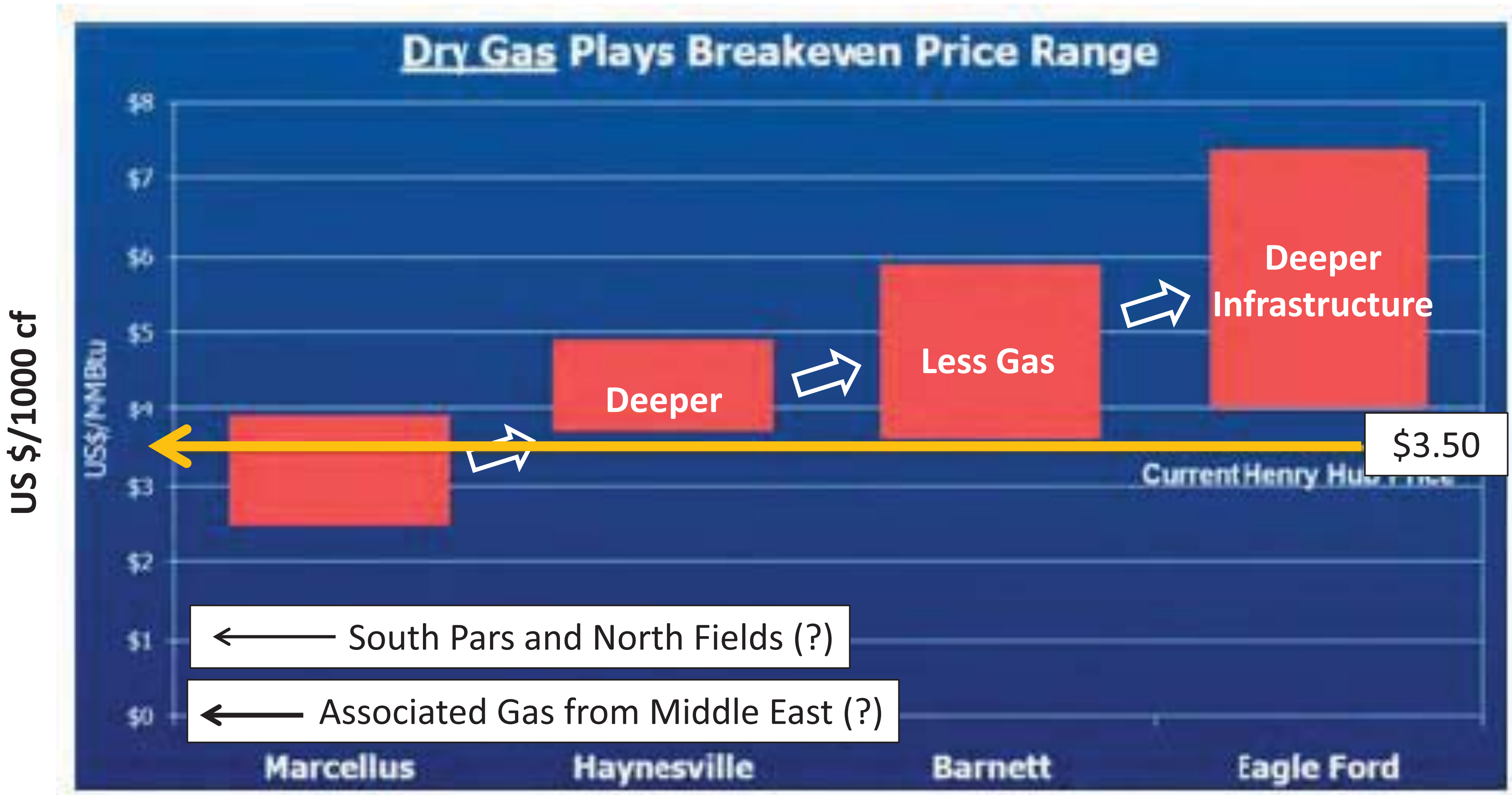
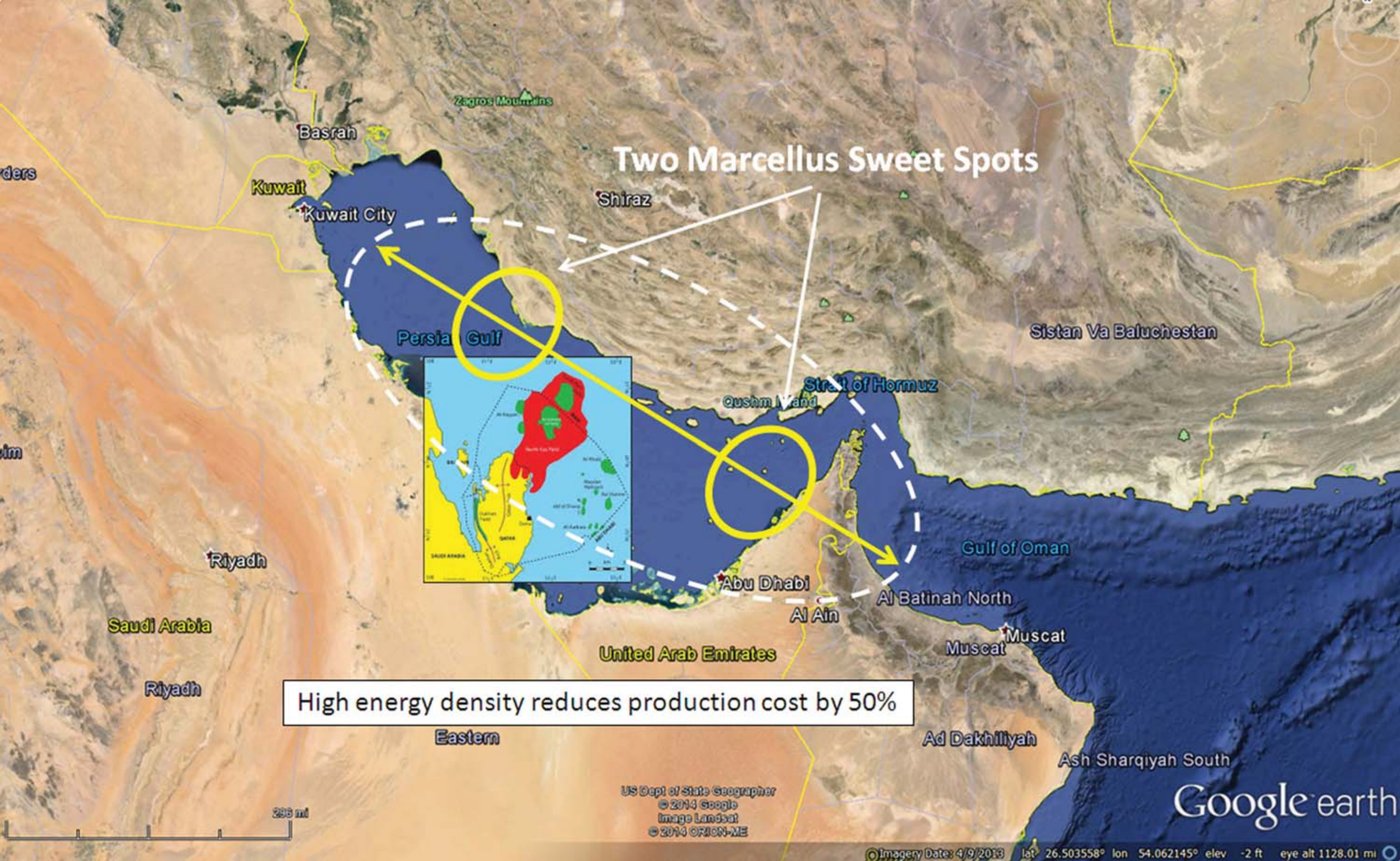
2. Free Market (Floating-Price) Commodity

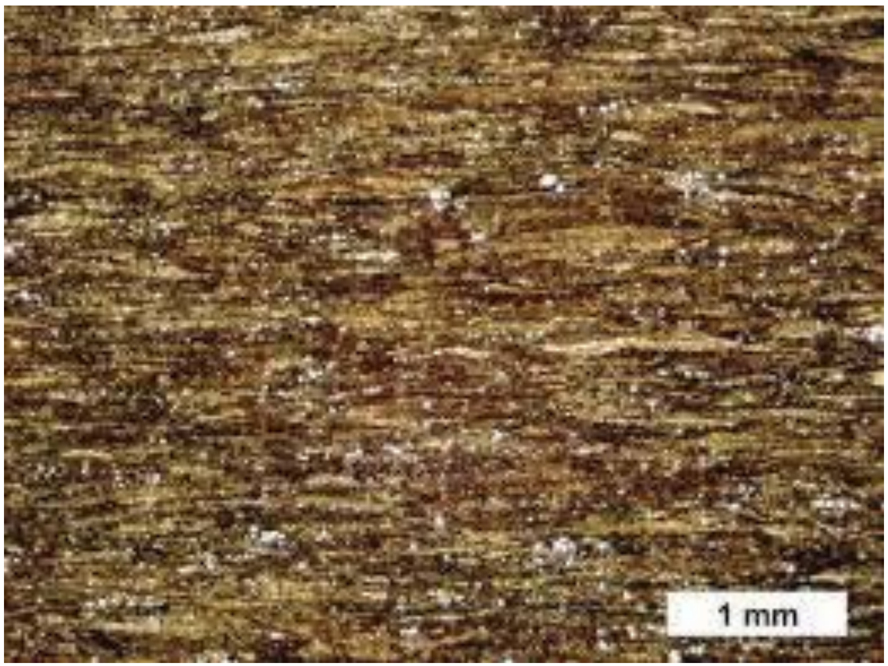


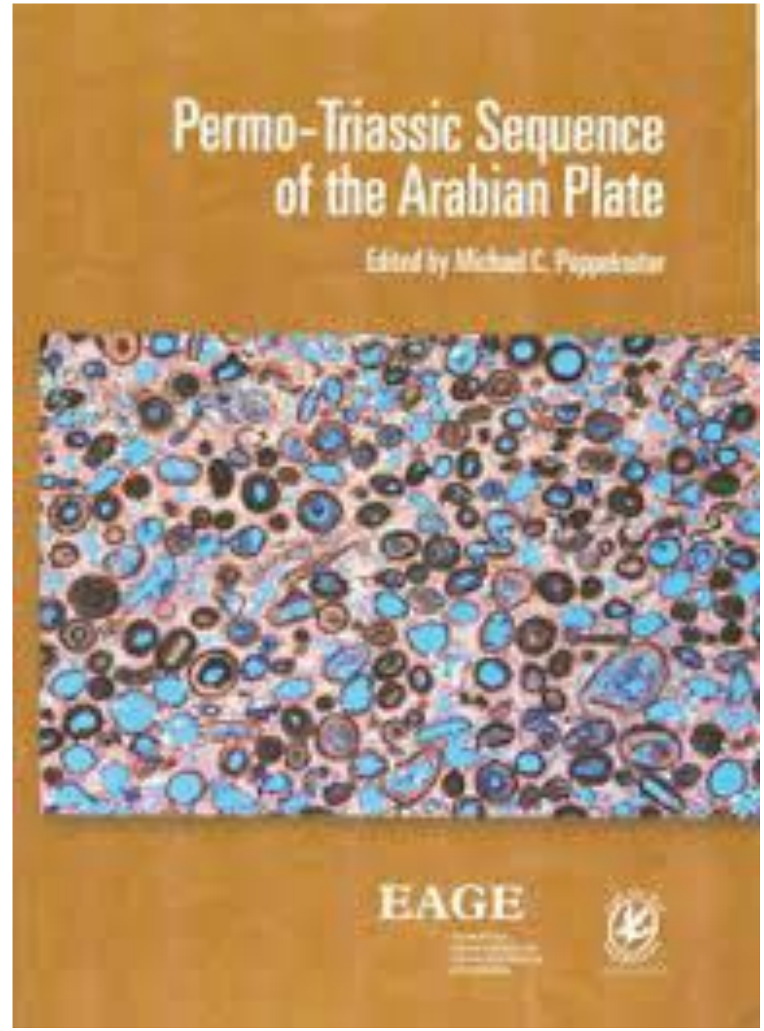
Modified after Richardson, 2013, North American Shale Revolution and Potential and Prospects of Shale/Tight Oil and Shale Gas Production in Alberta. Data from Rousset (2013) plus Tudor Pickering (2012) & Barclays (2012)


Two Marcellus Sweet Spots
High energy density reduces production cost by 50%
Zagros Mountains
Basrah
Kuwait
Kuwait City
Shiraz
Persian Gulf
Strait of Hormuz
Qushm Island
Sistan Va Baluchestan
Gulf of Oman
Abu Dhabi
Al Ain
Al Batinah North
Muscat
Muscat
Riyadh
Saudi Arabia
United Arab Emirates
Riyadh
Eastern
Ad Dakhiliyah
Ash Sharqiyah South
US Dept of State Geographer
© 2014 Google
Image Landsat
© 2014 ORION-ME
296 mi
Google earth
Imagery Date: 4/9/2013 lat 26.503558° lon 54.062145° elev -2 ft eye alt 1128.01 mi

High permeability reduces production cost by 50%

Marcellus





k < 500 nd

k > 100 md

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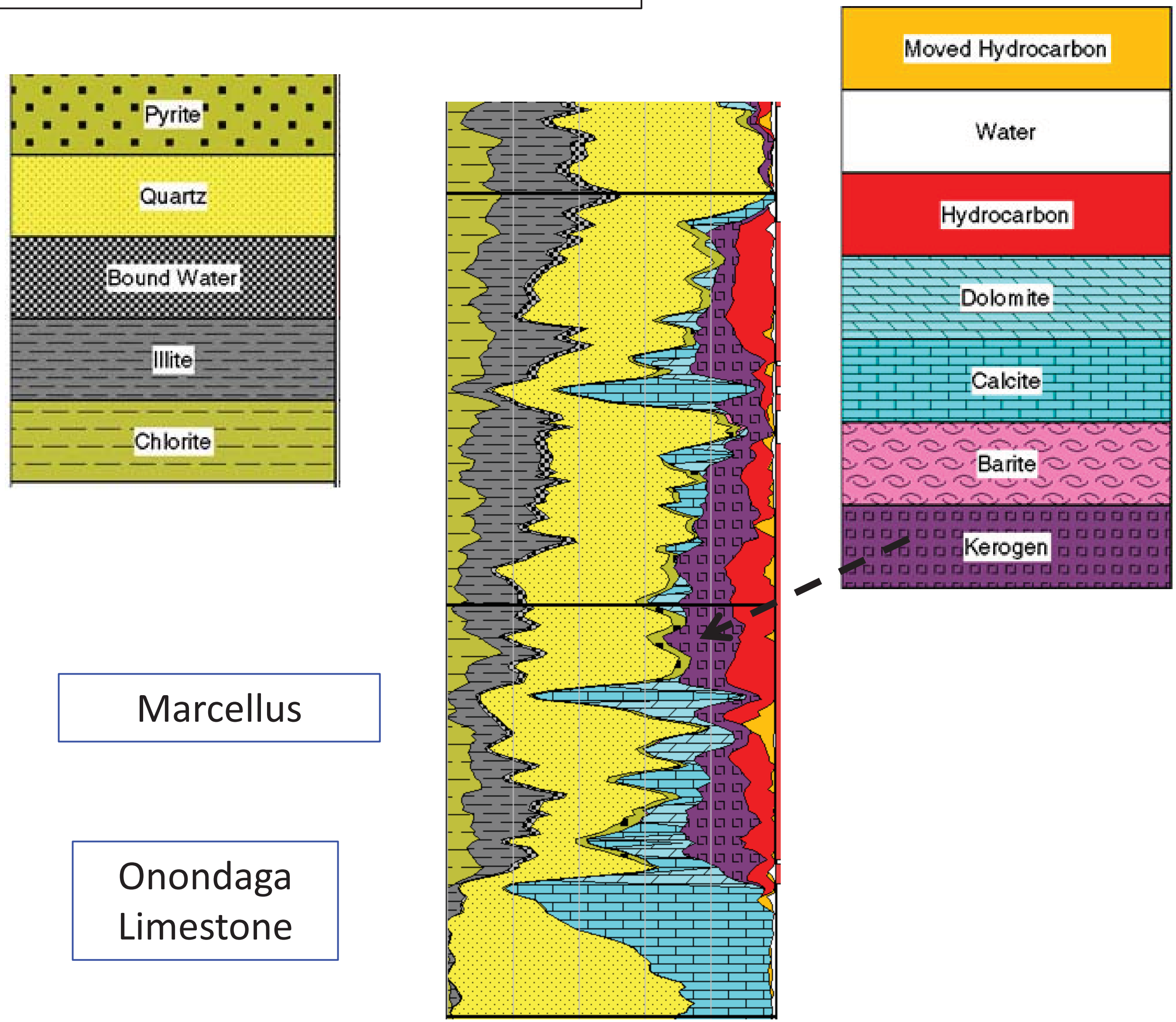
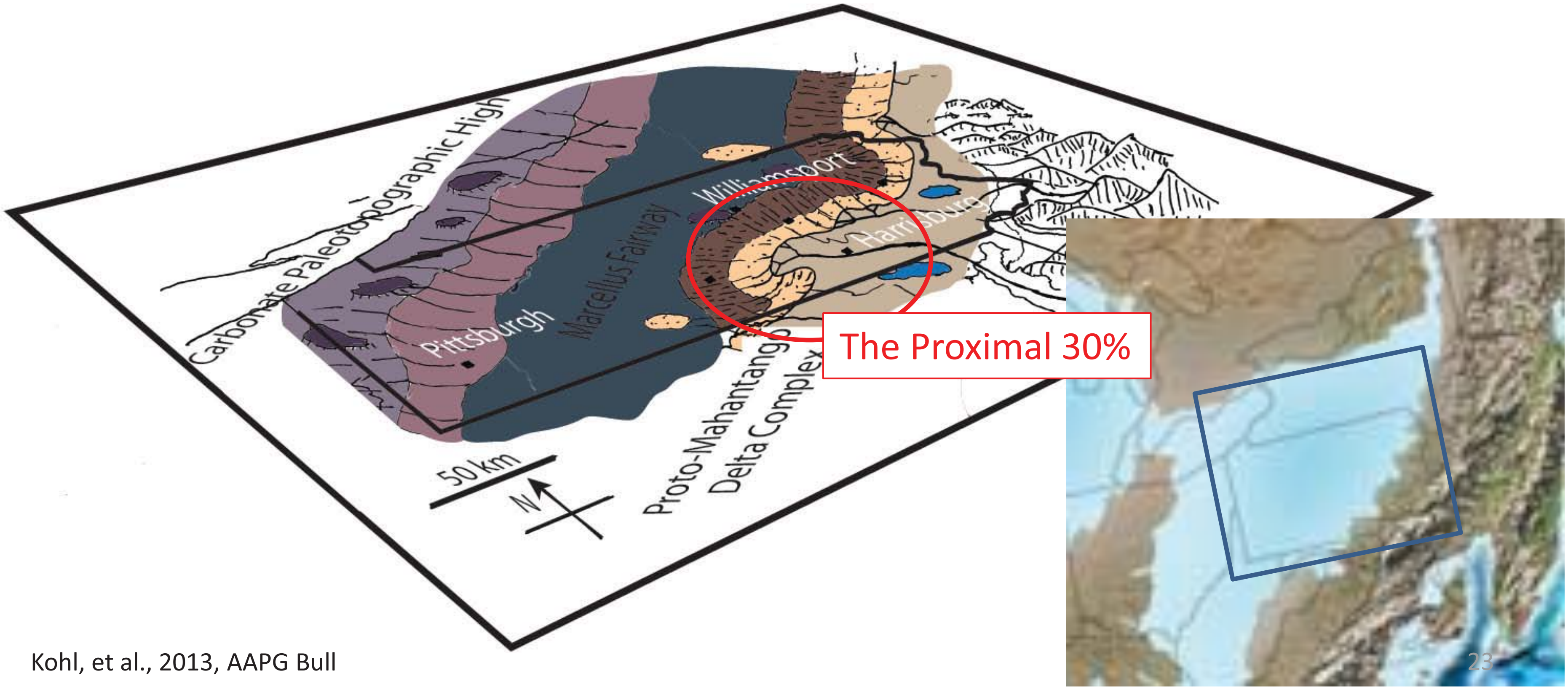
3. Total Organic Carbon Content



Schlumberger ELAN log

Background: Depositional Environment

- Carbonates dominated in west, associated with paleo-topographic high (Findlay Arch)
- Clastics dominated in east; derived from Acadian highlands and deposited in foredeep
- Proto-Mahantango Delta Complex in Central Pennsylvania (Prave et al., 1996)



Kohl, et al., 2013, AAPG Bull

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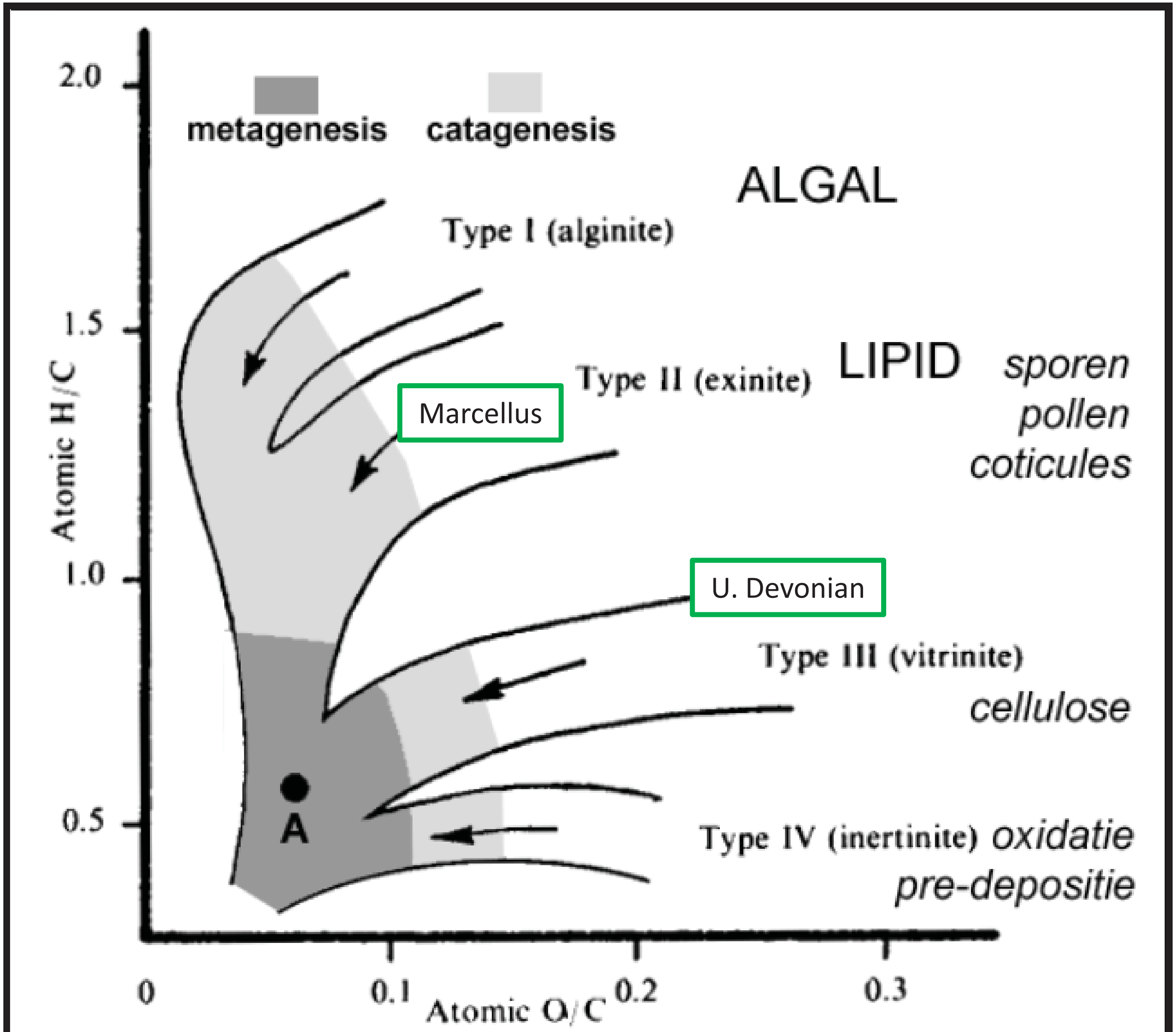
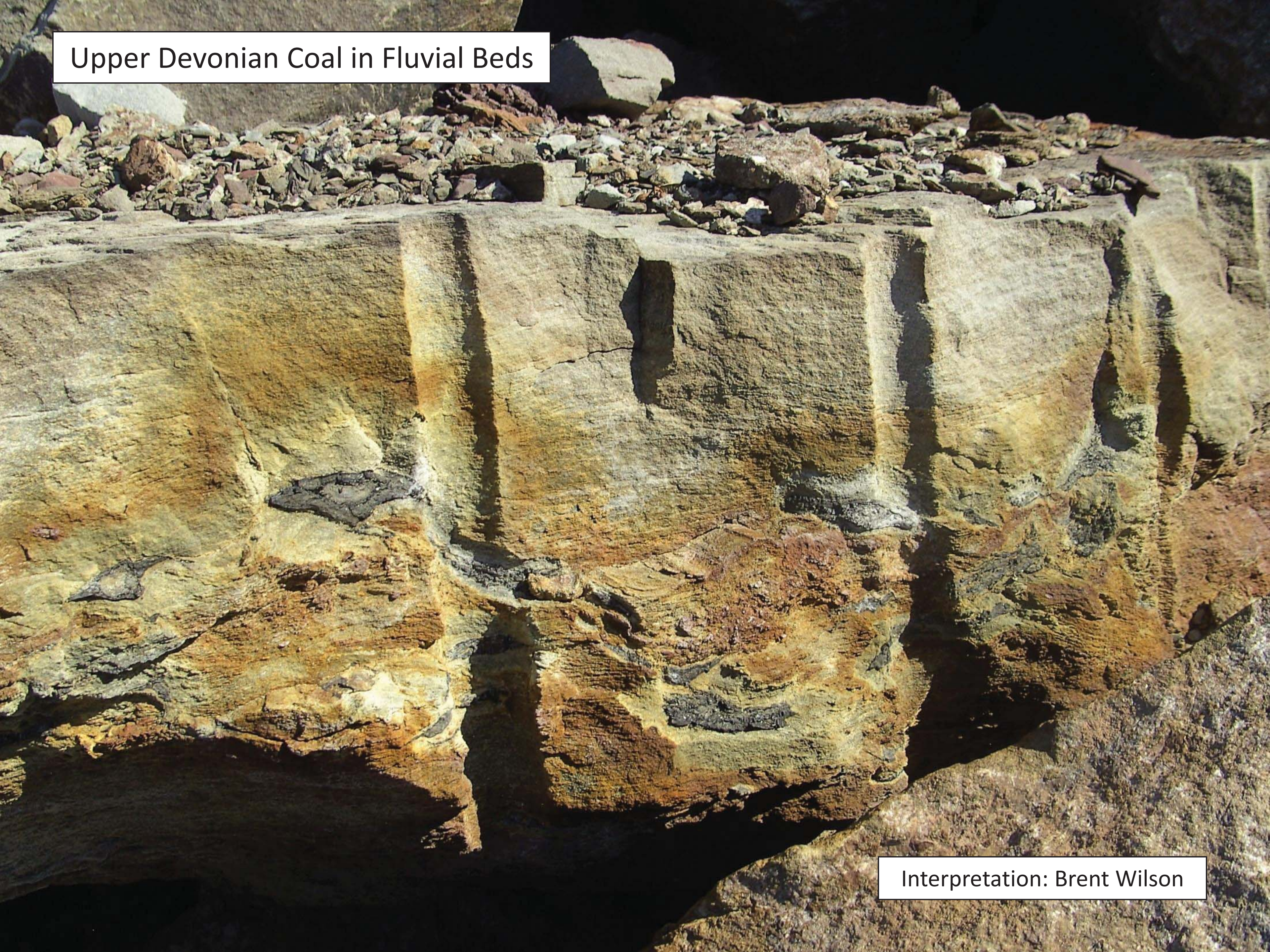
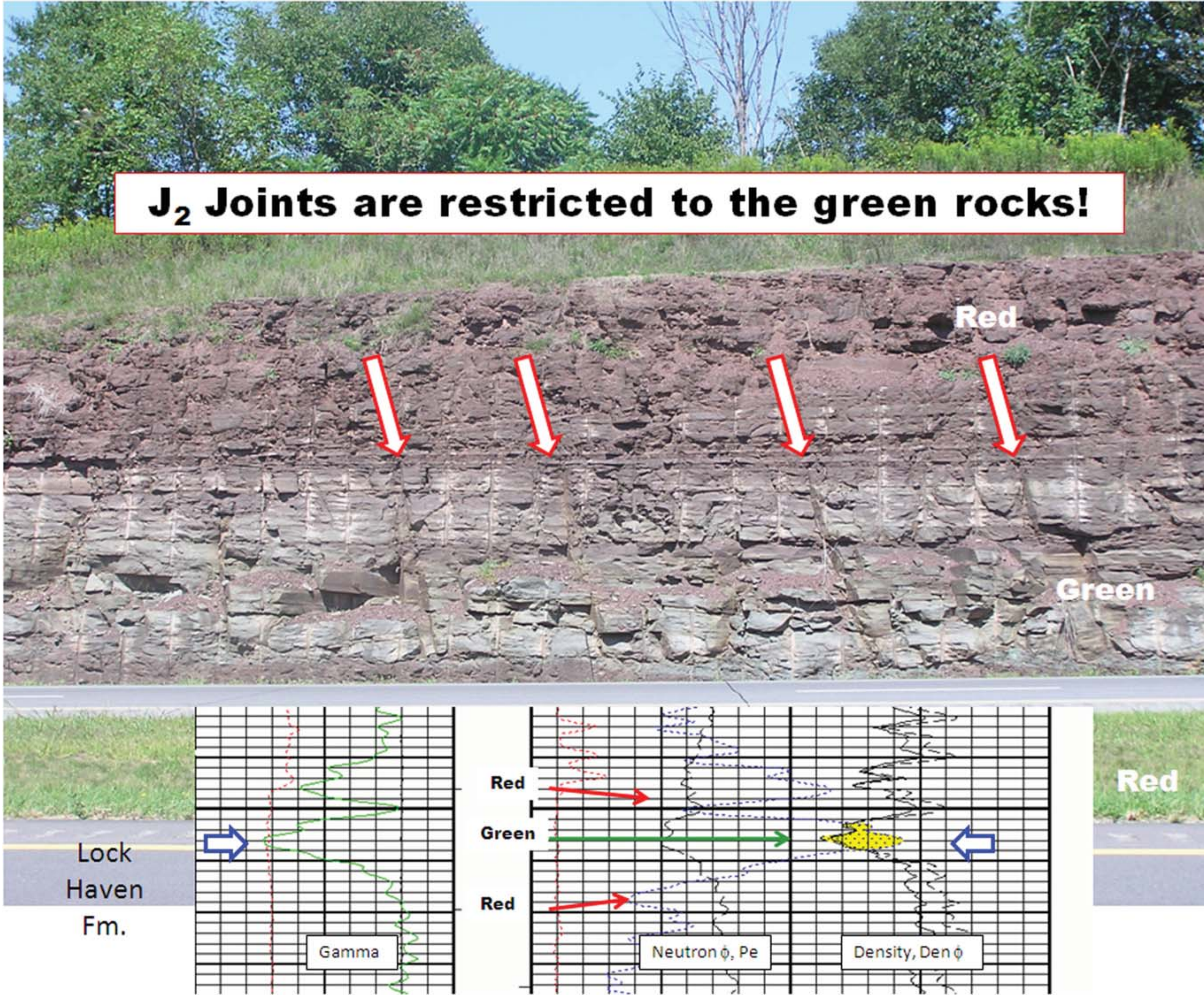
4. Kerogen Type




Joints in a gas shale: The Marcellus Formation
J2
These are gas charged in situ (otherwise they would be veins)!
These are the high permeability channels necessary for rapid production of gas but only when propped with sand!


Upper Devonian Coal in Fluvial Beds
Interpretation: Brent Wilson



J$_2$ Joints are restricted to the green rocks!
Red
Green
Red
Green
Red
Red
Lock
Haven
Fm.
Gamma
Neutron ϕ, Pe
Density, Den ϕ

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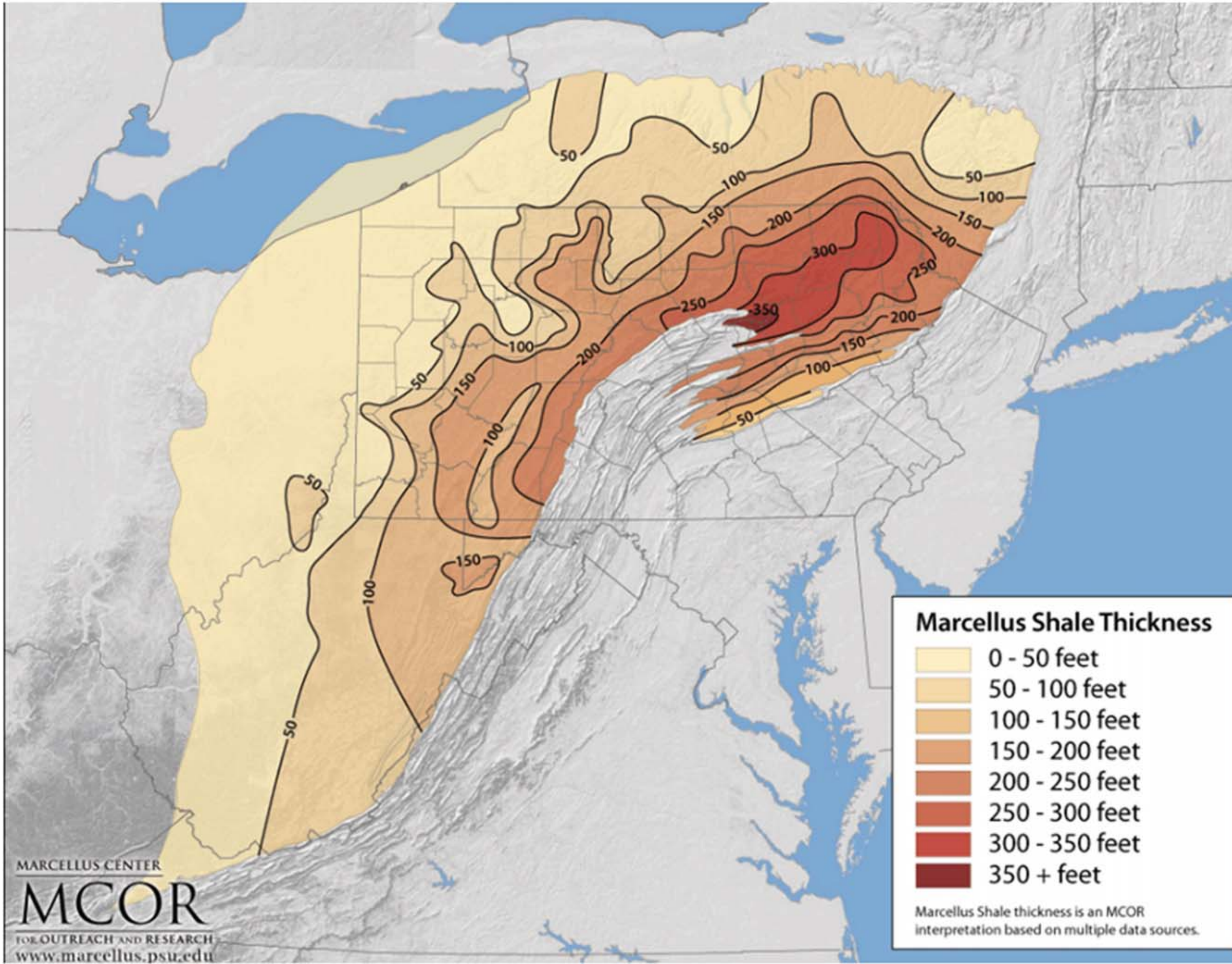
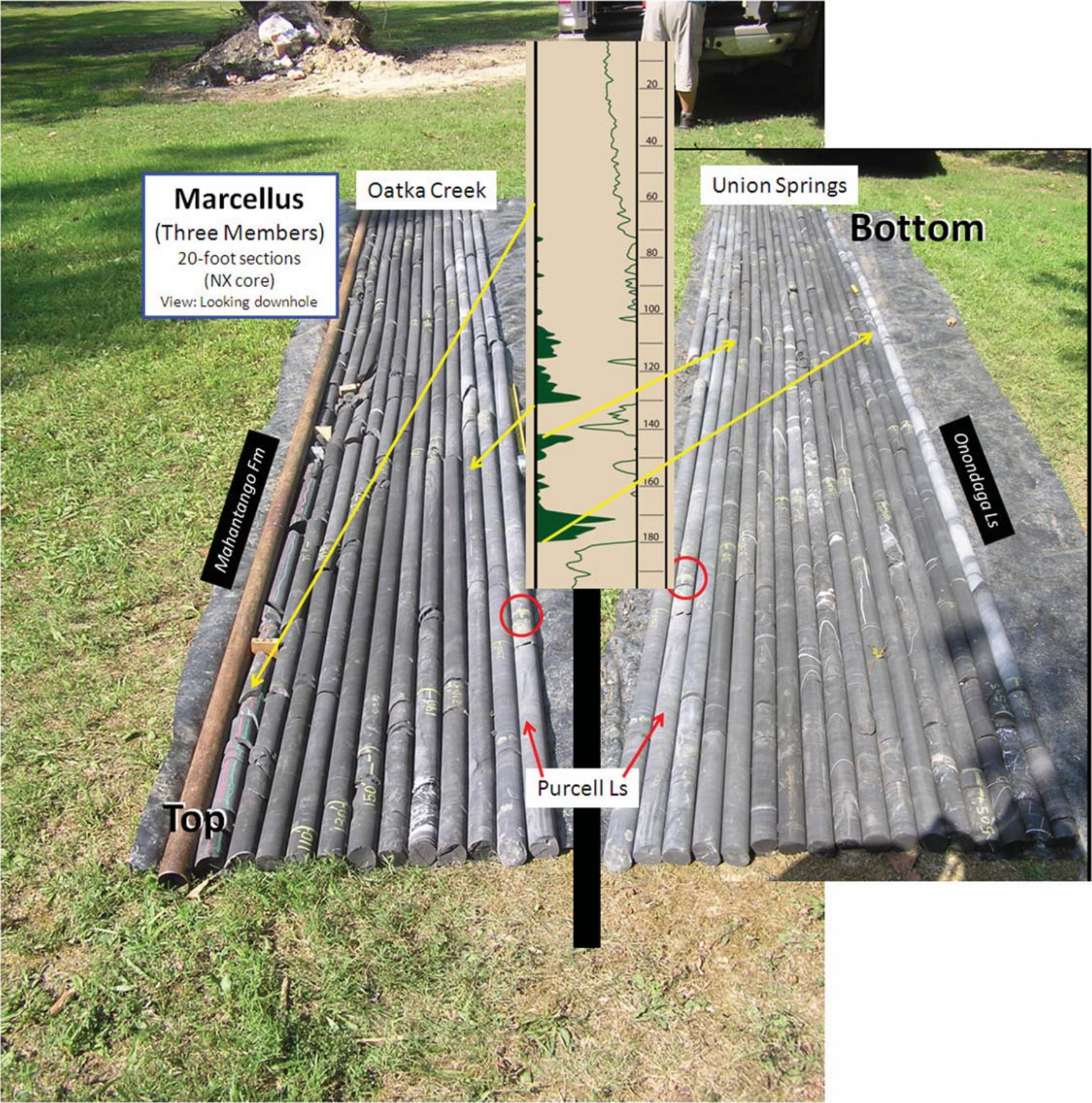
5. Thickness

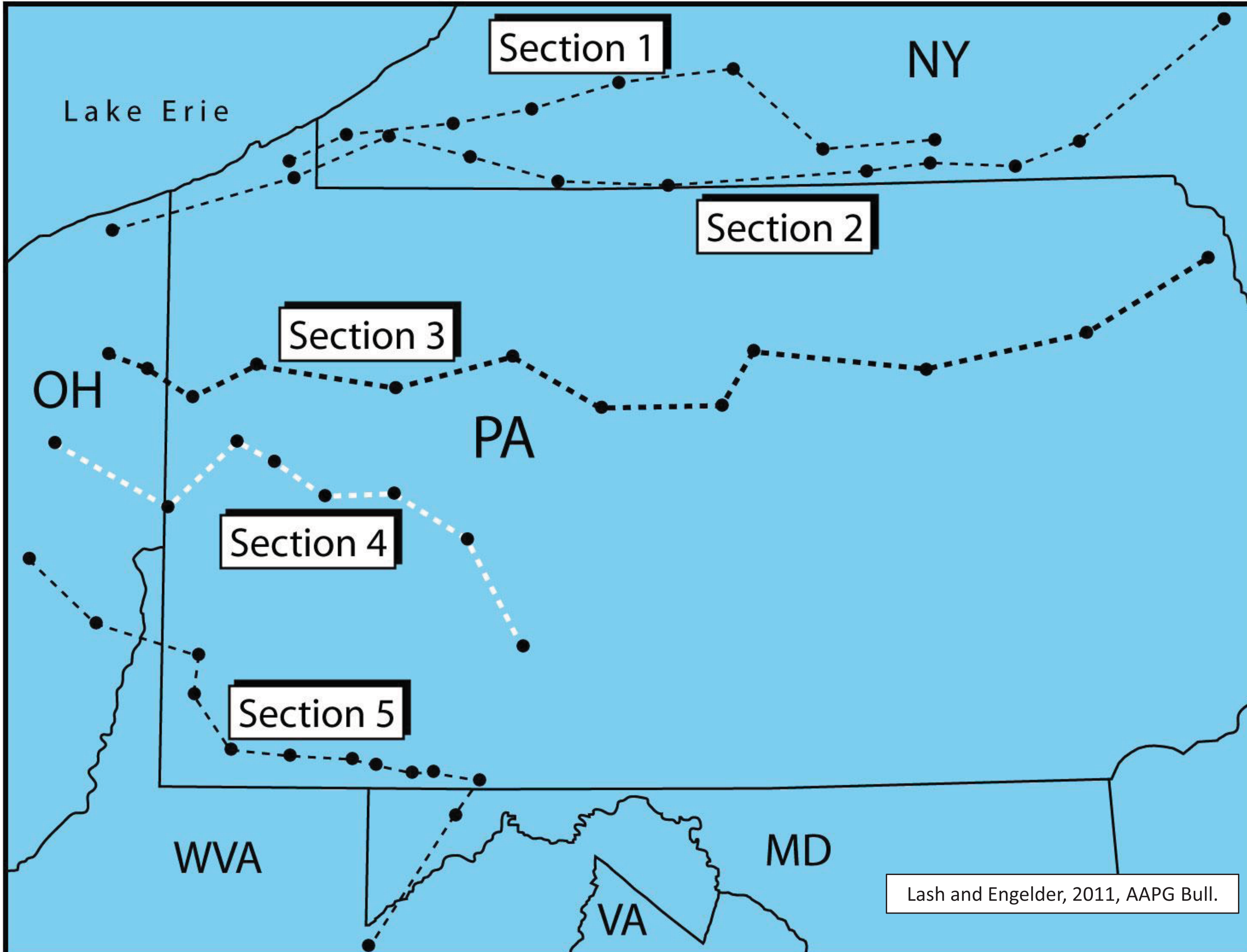


Marcellus Shale Thickness
0 - 50 feet
50 - 100 feet
100 - 150 feet
150 - 200 feet
200 - 250 feet
250 - 300 feet
300 - 350 feet
350 + feet
Marcellus Shale thickness is an MCOR interpretation based on multiple data sources.
MARCELLUS CENTER
MCOR
FOR OUTREACH AND RESEARCH
www.marcellus.psu.edu

Penn State research
south of Sunbury,
Northumberland County, PA



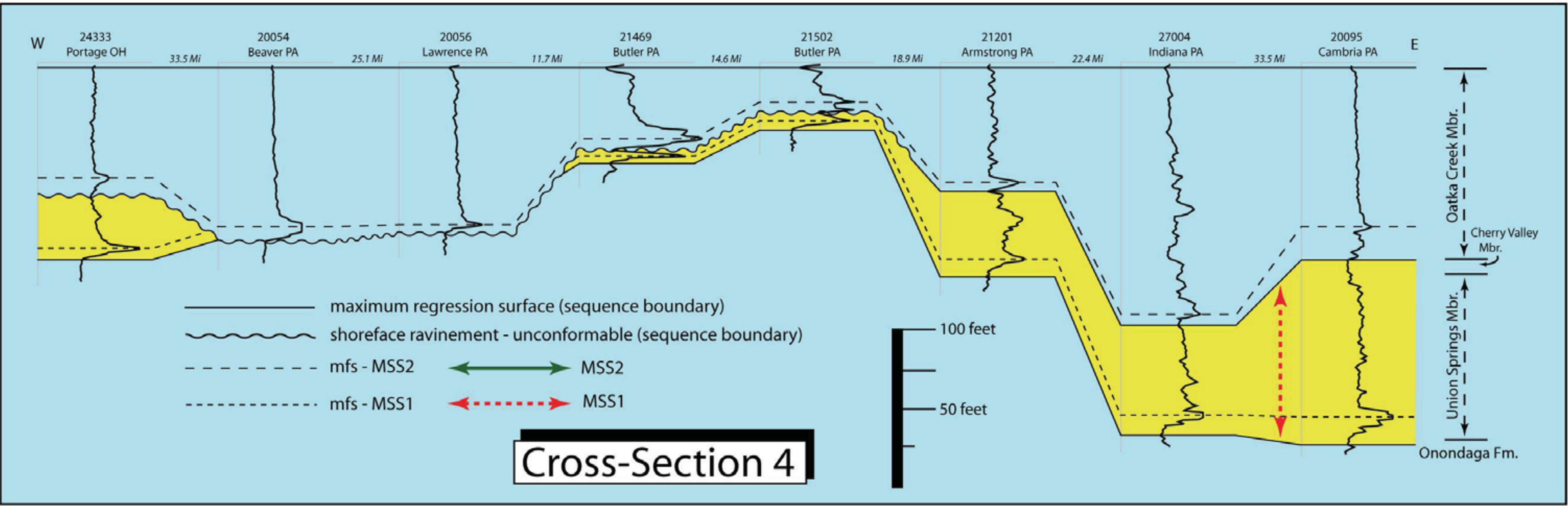
Marcellus
(Three Members)
20-foot sections
(NX core)
View: Looking downhole
Oatka Creek
Union Springs
Bottom
Mahantango Fm
Onondaga Ls
Purcell Ls
Top
20
40
60
80
100
120
140
160
180



Section 1
NY
Lake Erie
Section 2
Section 3
OH
PA
Section 4
Section 5
WVA
MD
VA
Lash and Engelder, 2011, AAPG Bull.

4. Thickness

local complete erosion of MSS1

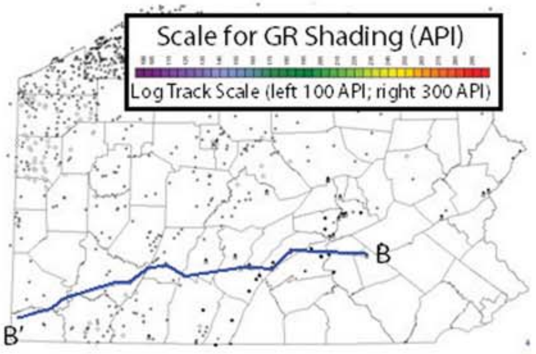


Lash and Engelder, 2011, AAPG Bull.

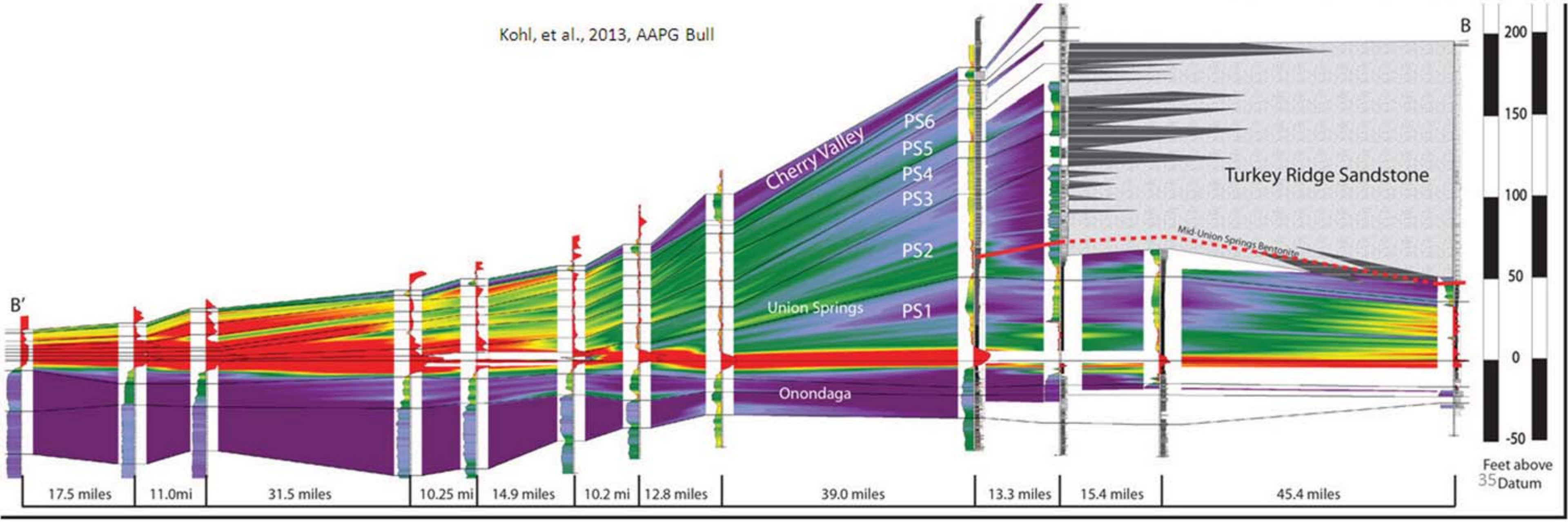
4. Thickness

Outcrop to SW PA

- Union Springs Mbr. (~1.5-2 Ma duration, 390 – 388 ma)
- Six parasequences



Datum-Maximum Flooding Surface, Union Springs Max. Gamma Ray, Min. Density Values



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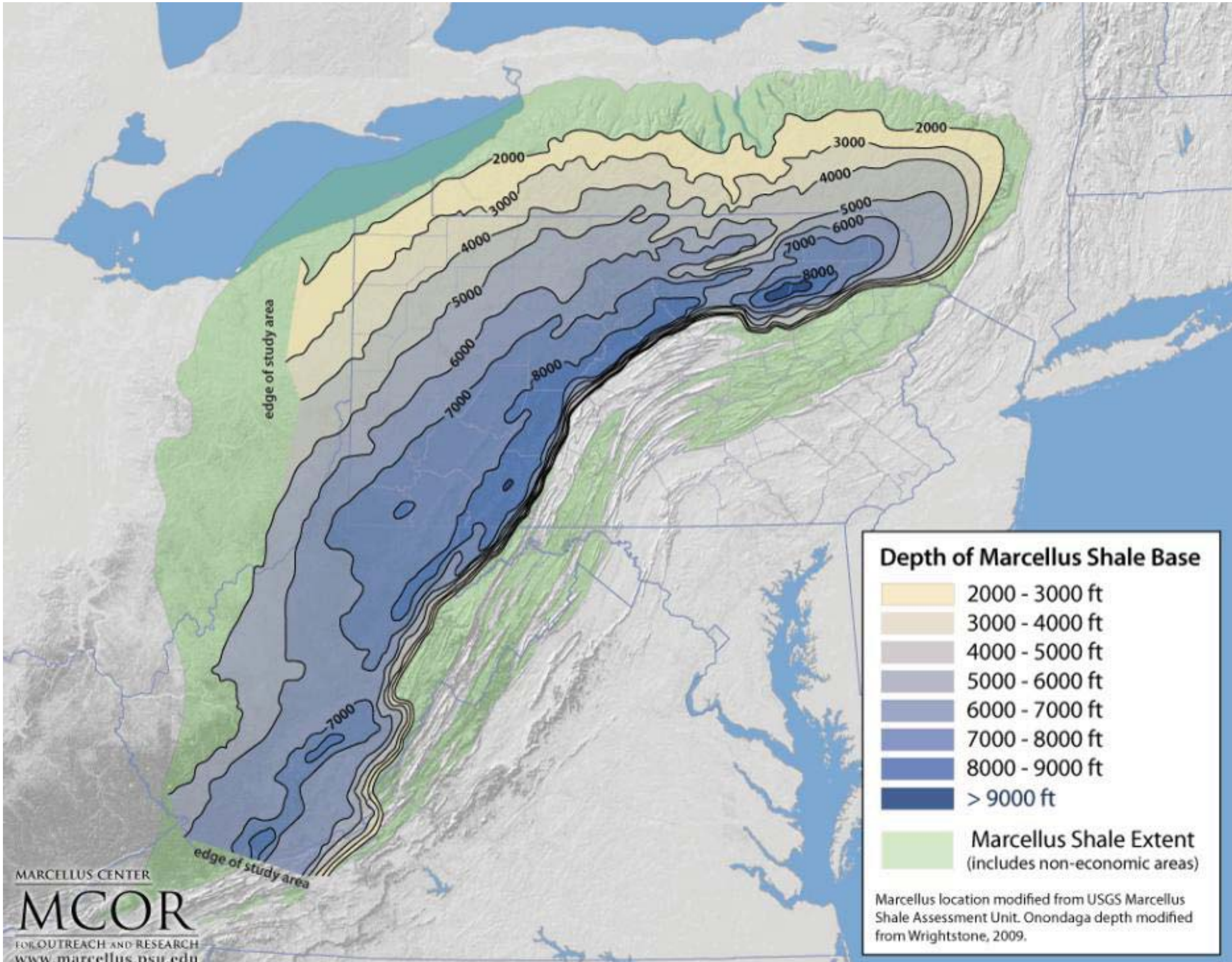
6. Depth


Depth of Marcellus Shale Base
2000 - 3000 ft
3000 - 4000 ft
4000 - 5000 ft
5000 - 6000 ft
6000 - 7000 ft
7000 - 8000 ft
8000 - 9000 ft
> 9000 ft
Marcellus Shale Extent
(includes non-economic areas)
Marcellus location modified from USGS Marcellus Shale Assessment Unit. Onondaga depth modified from Wrightstone, 2009.
edge of study area
edge of study area
2000
3000
4000
5000
6000
7000
8000
MARCELLUS CENTER
MCOR
FOR OUTREACH AND RESEARCH
www.marcellus.psu.edu

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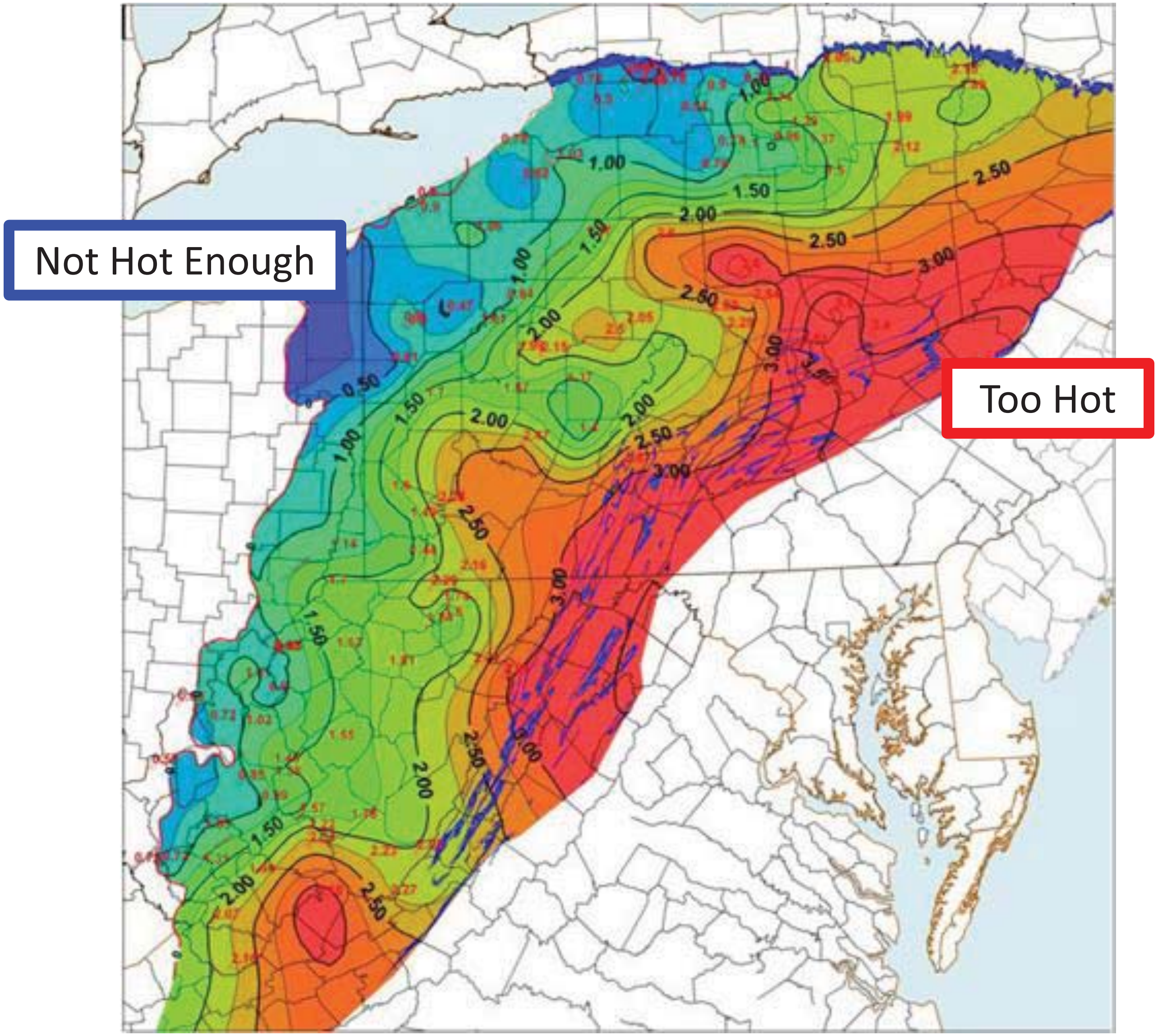
7. Thermal Maturity



Wrightstone, 2009, Search and Discovery

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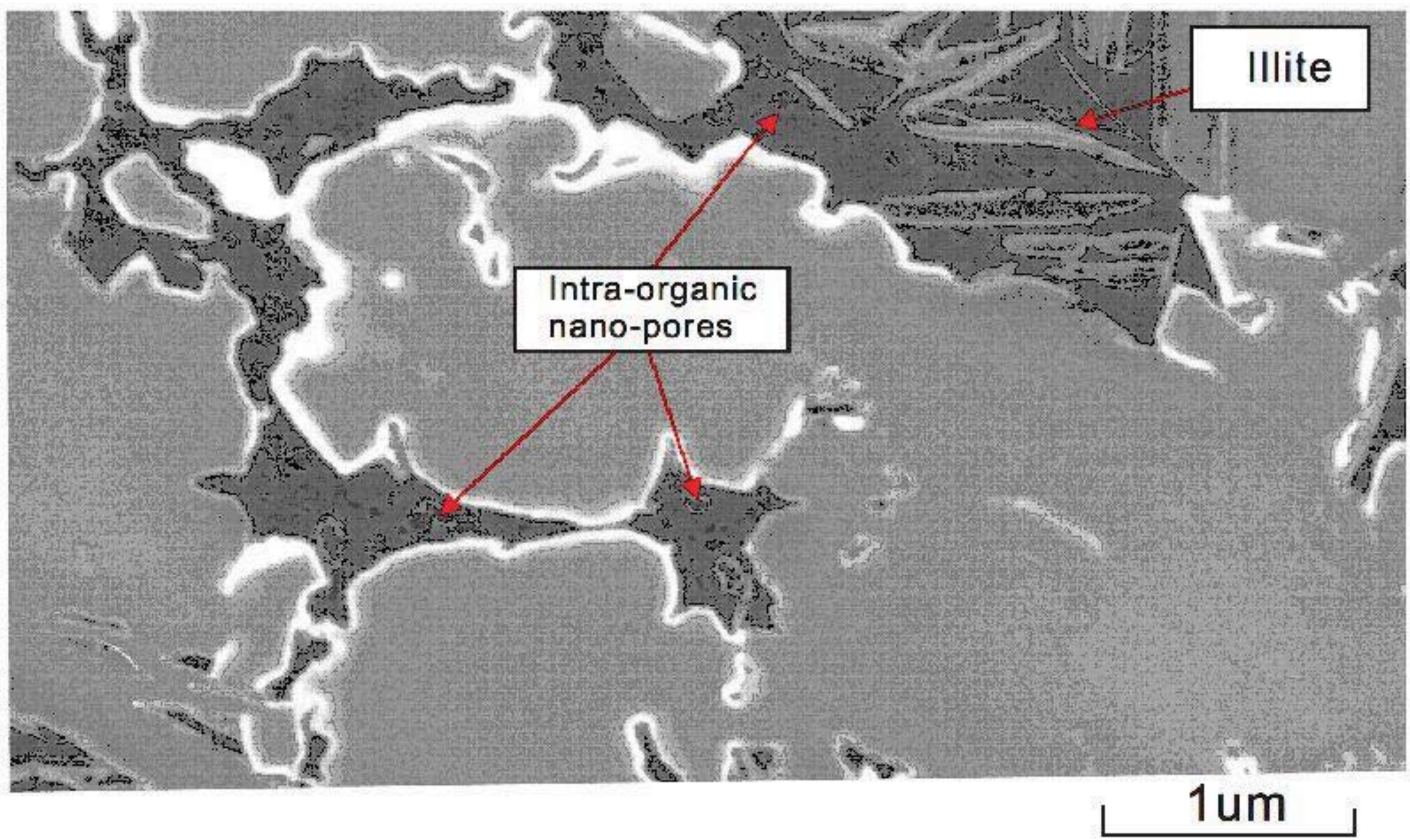
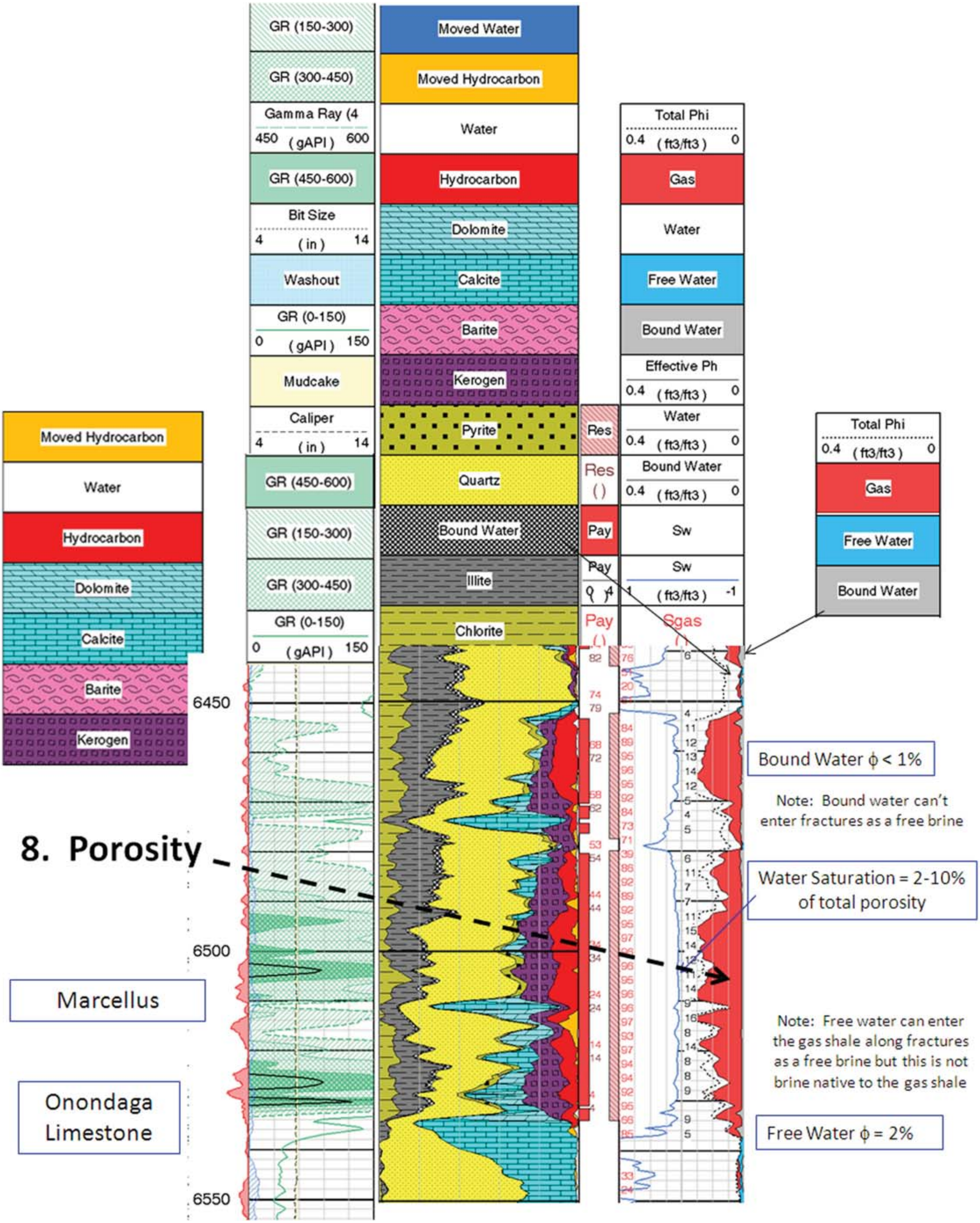
8. Porosity



Wikipedia Download



8. Porosity
GR (150-300)
GR (300-450)
Gamma Ray (4
450 (gAPI) 600
GR (450-600)
Bit Size
4 (in) 14
Washout
GR (0-150)
0 (gAPI) 150
Mudcake
Caliper
4 (in) 14
Moved Water
Moved Hydrocarbon
Water
Hydrocarbon
Dolomite
Calcite
Barite
Kerogen
Pyrite
Quartz
Bound Water
Illite
Chlorite
Res
Res ( )
Pay
Pay
Pay ( )
Total Phi
0.4 (ft3/ft3) 0
Gas
Water
Free Water
Bound Water
Effective Ph
0.4 (ft3/ft3) 0
Water
0.4 (ft3/ft3) 0
Bound Water
0.4 (ft3/ft3) 0
Sw
Sw
1 (ft3/ft3) -1
Sgas
6450
6500
6550
Marcellus
Onondaga Limestone
Bound Water ϕ < 1%
Note: Bound water can't enter fractures as a free brine
Water Saturation = 2-10% of total porosity
Note: Free water can enter the gas shale along fractures as a free brine but this is not brine native to the gas shale
Free Water ϕ = 2%

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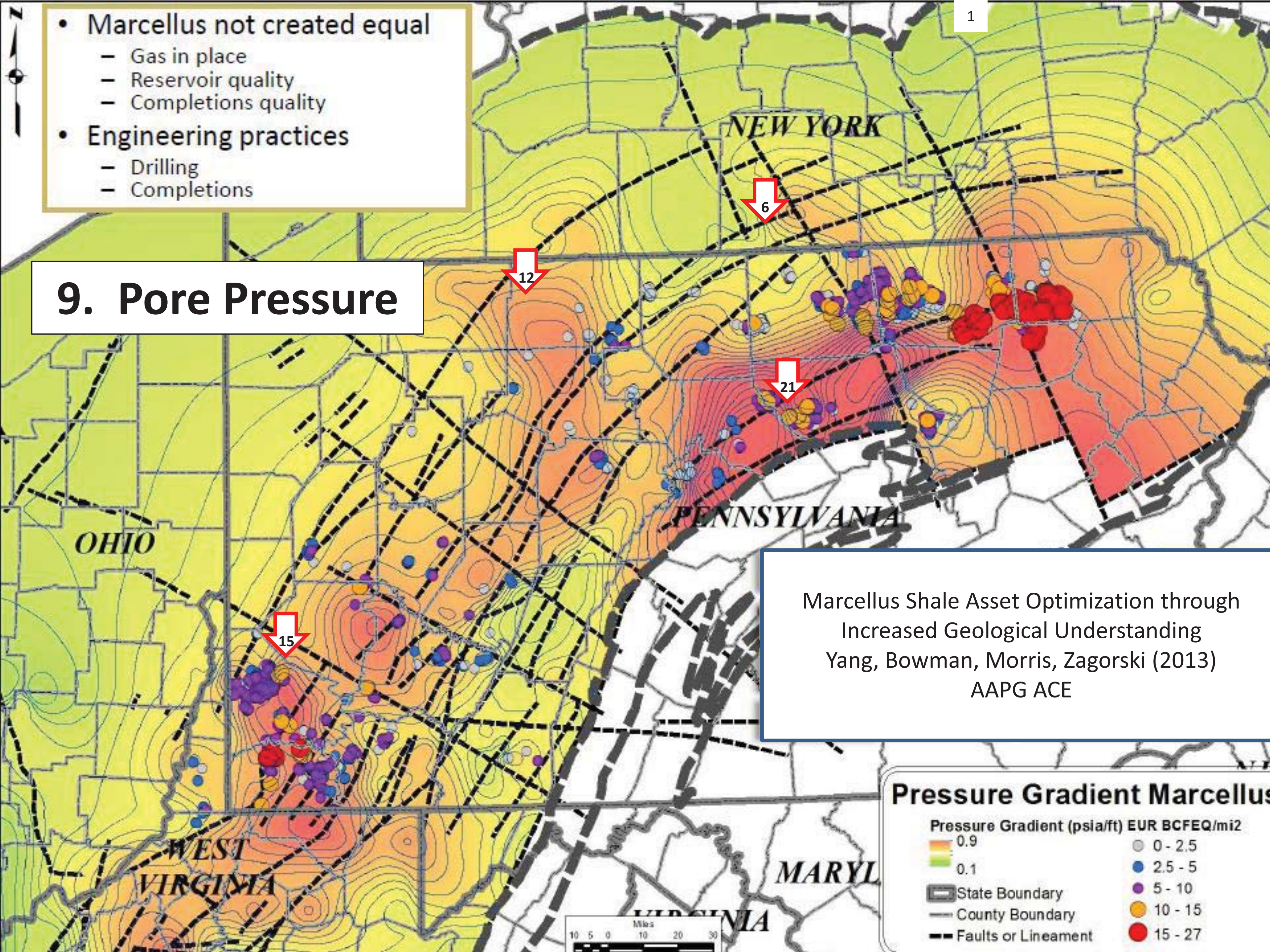
- Marcellus not created equal
  - Gas in place
  - Reservoir quality
  - Completions quality
- Engineering practices
  - Drilling
  - Completions

9. Pore Pressure

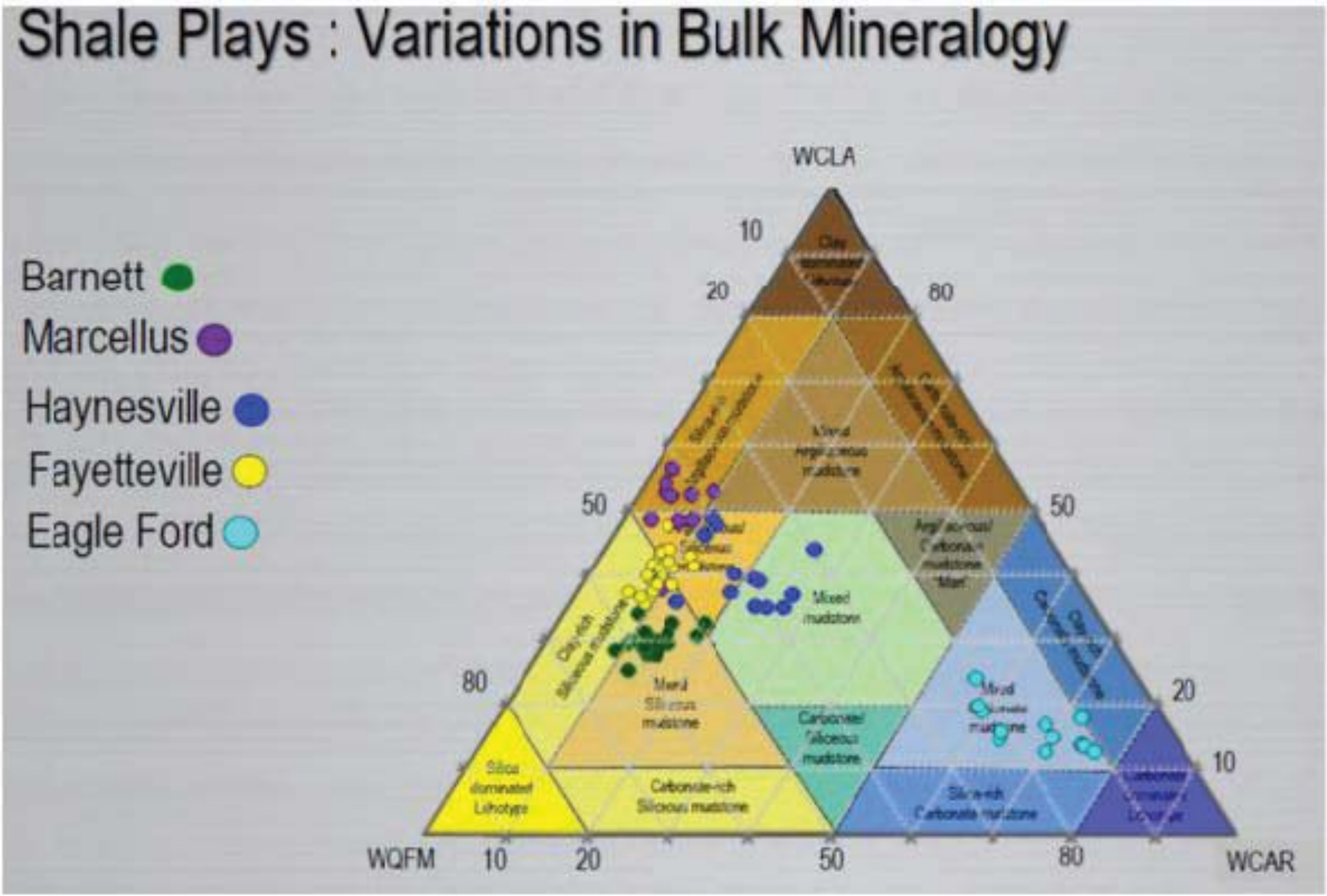


Marcellus Shale Asset Optimization through Increased Geological Understanding
Yang, Bowman, Morris, Zagorski (2013)
AAPG ACE

Qualities of a prospective gas shale

1. Public Domain Data Base
2. Free Market (Floating-Price) Commodity
3. Total Organic Carbon Content
4. Kerogen Type
5. Thickness
6. Depth
7. Thermal Maturity
8. Porosity
9. Pore Pressure
10. Low Clay Content
11. Total Technically Recoverable
12. Slight Structural Complexity
    i. Natural Hydraulic Fractures
    ii. No Thief Faulting

10. Clay Content



after Richardson, 2013, North American Shale Revolution and Potential and Prospects of Shale/Tight Oil and Shale Gas Production in Alberta.

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11. Total Technically Recoverable

	Shale Gas Resources		Shale Oil Resources	
	Distinct Plays (#)	Remaining Reserves and Undeveloped Resources (Tcf)	Distinct Plays (#)	Remaining Reserves and Undeveloped Resources (Billion Barrels)
1. Northeast				
• Marcellus	8	369	2	0.8
• Utica	3	111	2	2.5
• Other	3	29	-	-
2. Southeast				
• Haynesville	4	161	-	-
• Bossier	2	57	-	-
• Fayetteville	4	48	-	-
3. Mid-Continent				
• Woodford*	9	77	5	1.9
• Antrim	1	5	-	-
• New Albany	1	2	-	-
4. Texas				
• Eagle Ford	6	119	4	13.6
• Barnett**	5	72	2	0.4
• Permian***	9	34	9	9.7
5. Rockies/Great Plains				
• Niobrara****	8	57	6	4.1
• Lewis	1	1	-	-
• Bakken/Three Forks	6	19	5	14.7
TOTAL	**70**	**1161**	**35**	**47.7**

Present: Marcellus: 16 bcf/d --- Qatar: 25 bcf/d
Future: Marcellus plus Utica: 30 bcf/d

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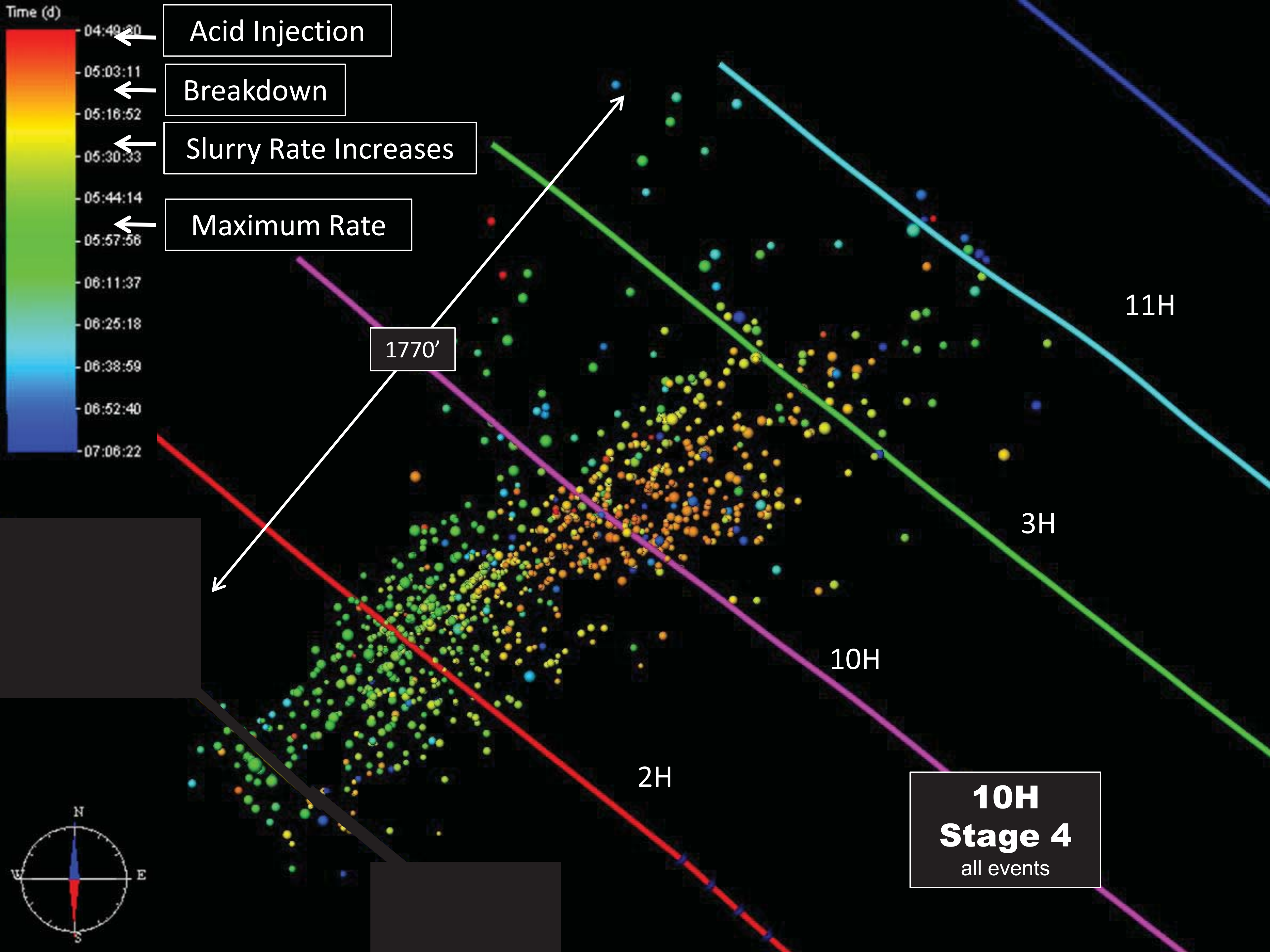
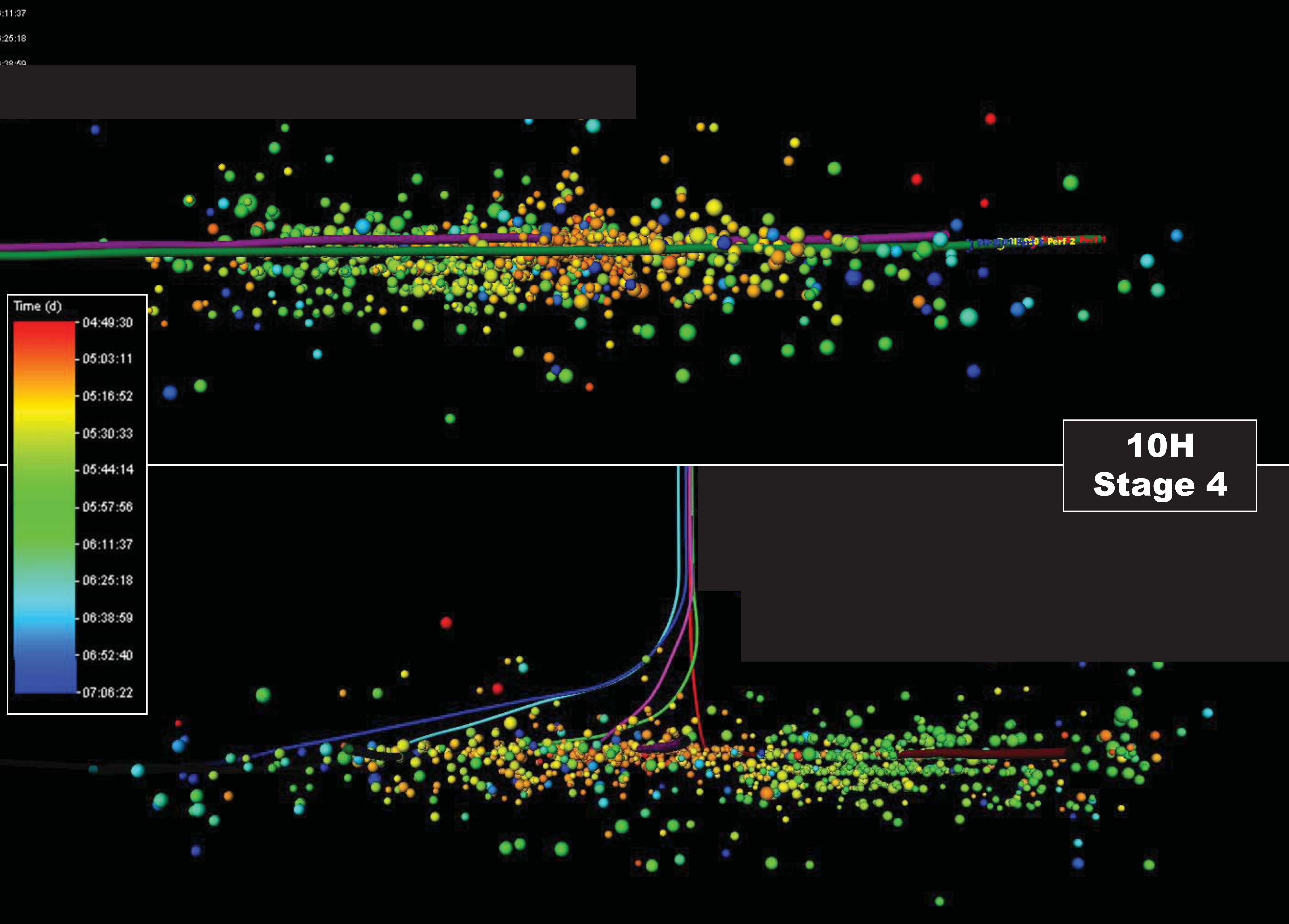
12. Structural Complexity
J_2
J_1
Geneseo/Burket gas shale:
Two natural hydraulic fracture sets



Time (d)
05:03:11
05:16:52
05:30:33
05:44:14
05:57:56
06:11:37
06:25:18
06:38:59
06:52:40
07:06:22
Acid Injection
Breakdown
Slurry Rate Increases
Maximum Rate
1770'
11H
3H
10H
2H
10H
Stage 4
all events
N
E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05:16:52
05:30:33
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06:11:37
06:25:18
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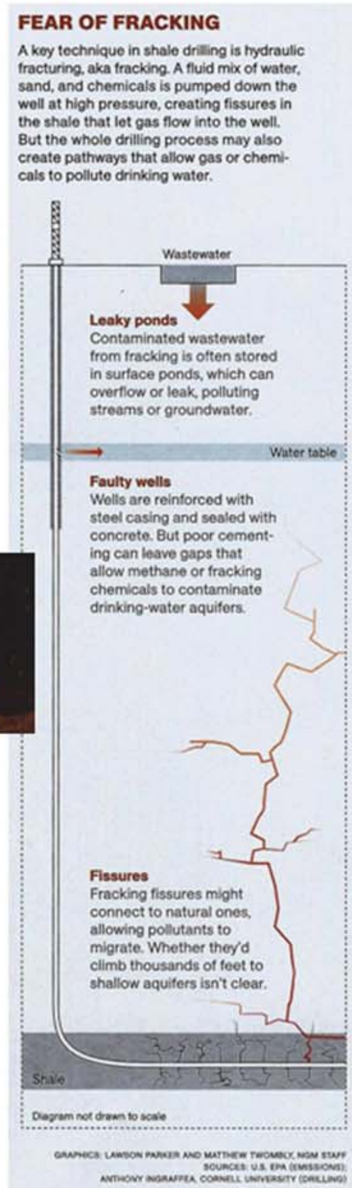
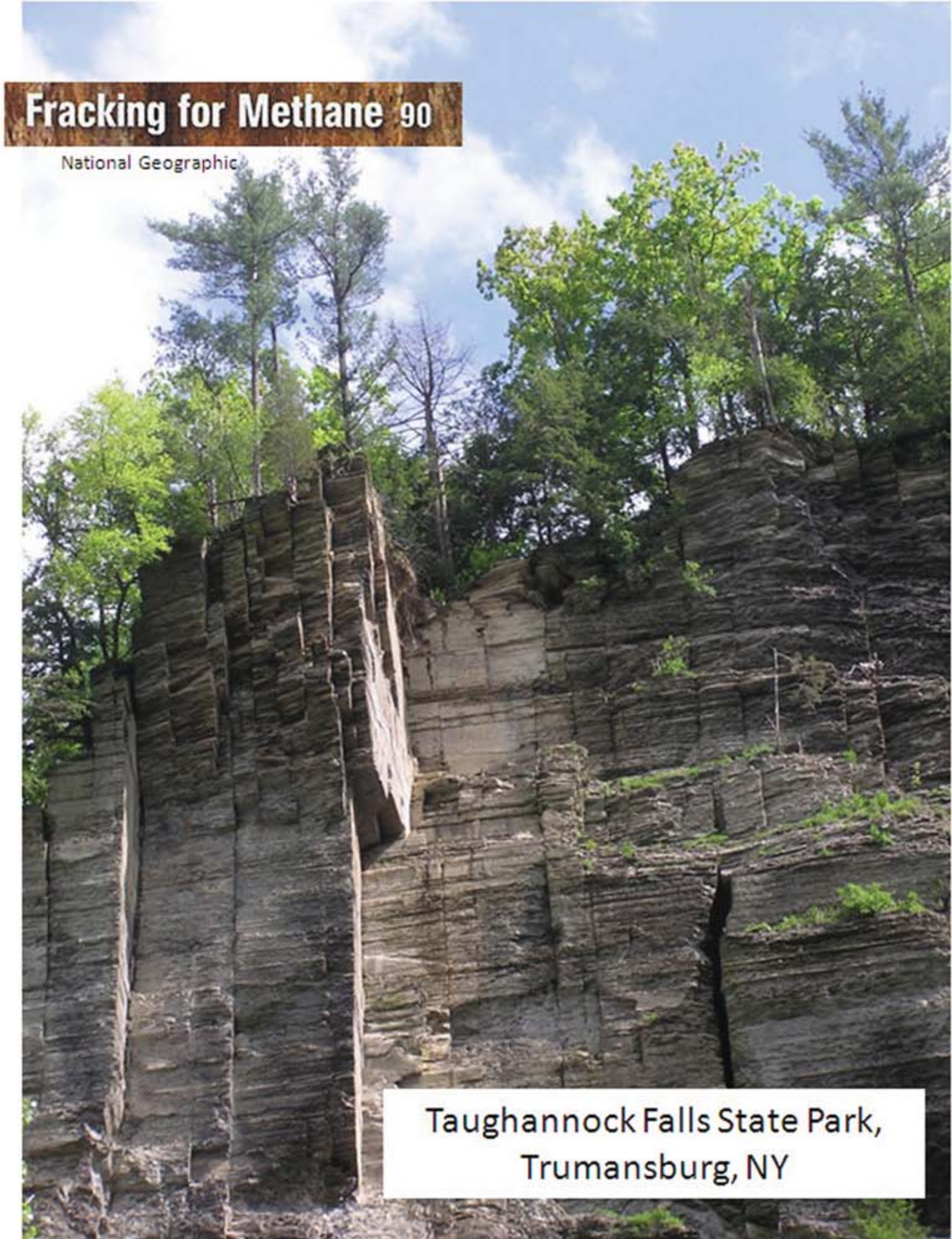
06:52:40
07:06:22
10H
Stage 4





National Geographic's version of a lightening bolt

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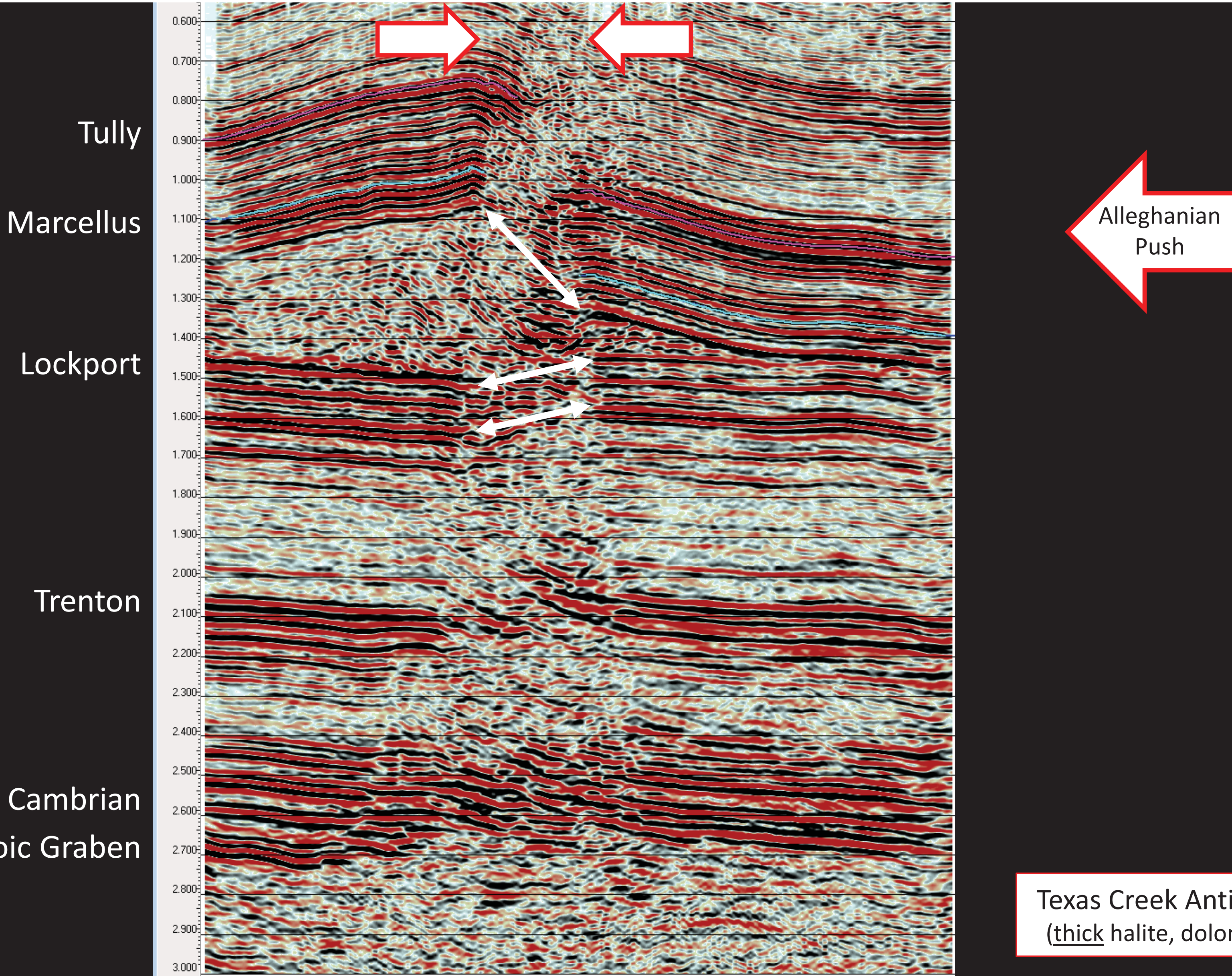
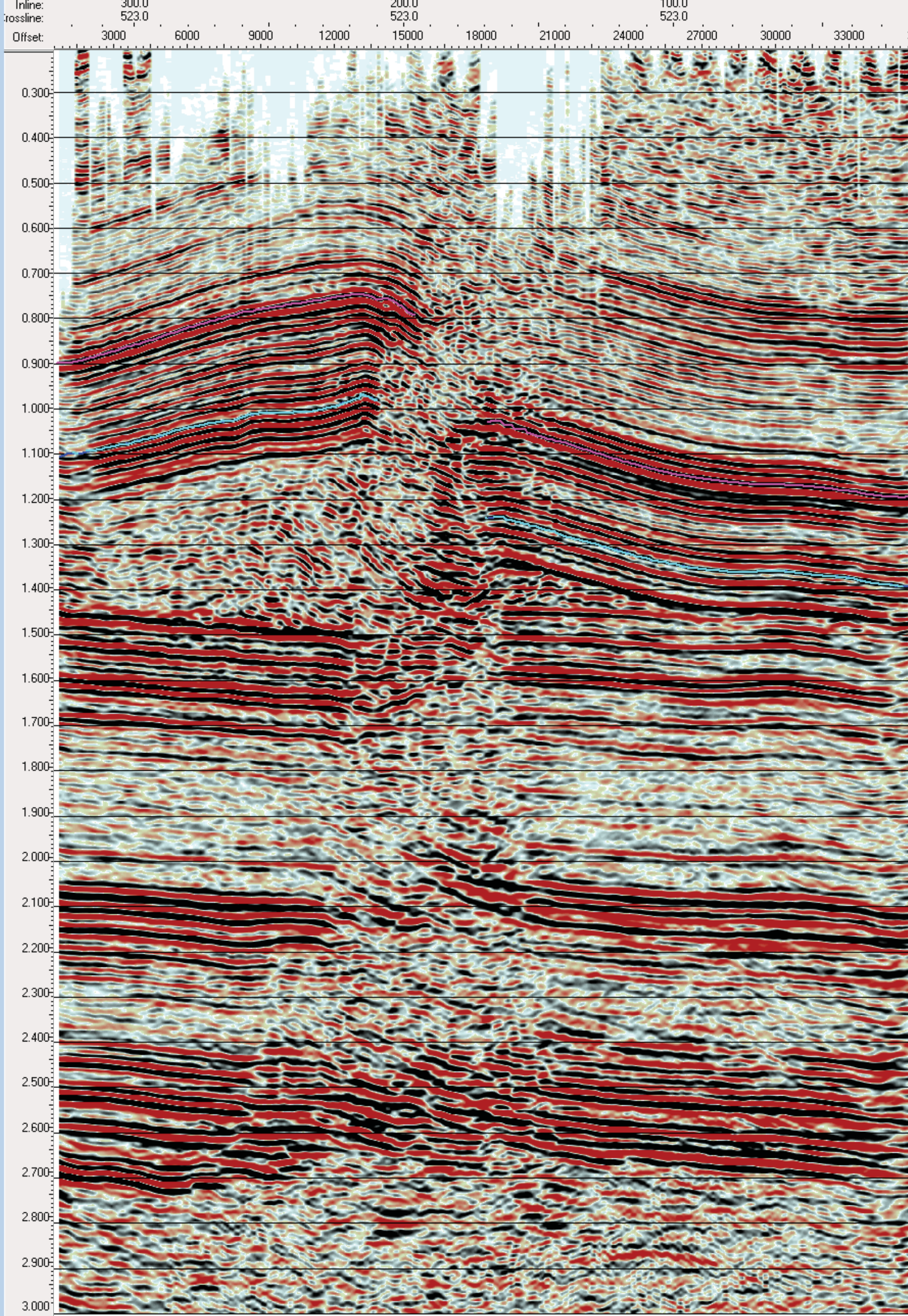
Vertical Fracture Zones:

<u>Zones of No Drilling</u>: Engelder (2009) resource estimate risked the Marcellus at 30% (i.e., fraction of Marcellus that is too badly fractured to permit economic drilling



Texas Creek Anticline
(<u>thick</u> halite, dolomite)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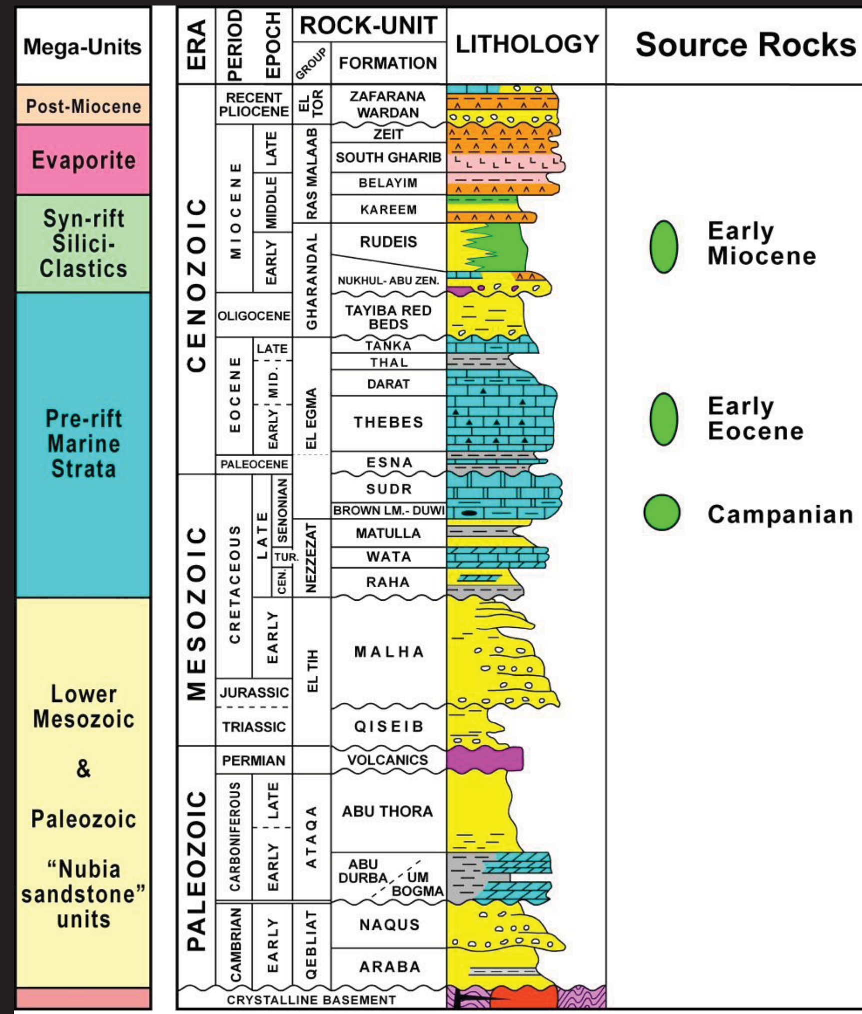
Crossline: 523.0 523.0 523.0
Offset: 3000 6000 9000 12000 15000 18000 21000 24000 27000 30000 33000
0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000 1.100 1.200 1.300 1.400 1.500 1.600 1.700 1.800 1.900 2.000 2.100 2.200 2.300 2.400 2.500 2.600 2.700 2.800 2.900 3.000


Mega-Units
Post-Miocene
Evaporite
Syn-rift Silici-Clastics
Pre-rift Marine Strata
Lower Mesozoic & Paleozoic "Nubia sandstone" units
ERA
PERIOD
EPOCH
ROCK-UNIT
GROUP
FORMATION
LITHOLOGY
Source Rocks
CENOZOIC
MESOZOIC
PALEOZOIC
RECENT PLIOCENE
MIOCENE
LATE
MIDDLE
EARLY
OLIGOCENE
EOCENE
MID.
PALEOCENE
CRETACEOUS
SENONIAN
TUR.
CEN.
JURASSIC
TRIASSIC
PERMIAN
CARBONIFEROUS
CAMBRIAN
EL TOR
RAS MALAAB
GHARANDAL
EL EGMA
NEZZEZAT
EL TIH
ATAQA
QEBLIAT
ZAFARANA
WARDAN
ZEIT
SOUTH GHARIB
BELAYIM
KAREEM
RUDEIS
NUKHUL- ABU ZEN.
TAYIBA RED BEDS
TANKA
THAL
DARAT
THEBES
ESNA
SUDR
BROWN LM.- DUWI
MATULLA
WATA
RAHA
MALHA
QISEIB
VOLCANICS
ABU THORA
ABU DURBA
UM BOGMA
NAQUS
ARABA
CRYSTALLINE BASEMENT
Early Miocene
Early Eocene
Campanian

Gulf of Suez