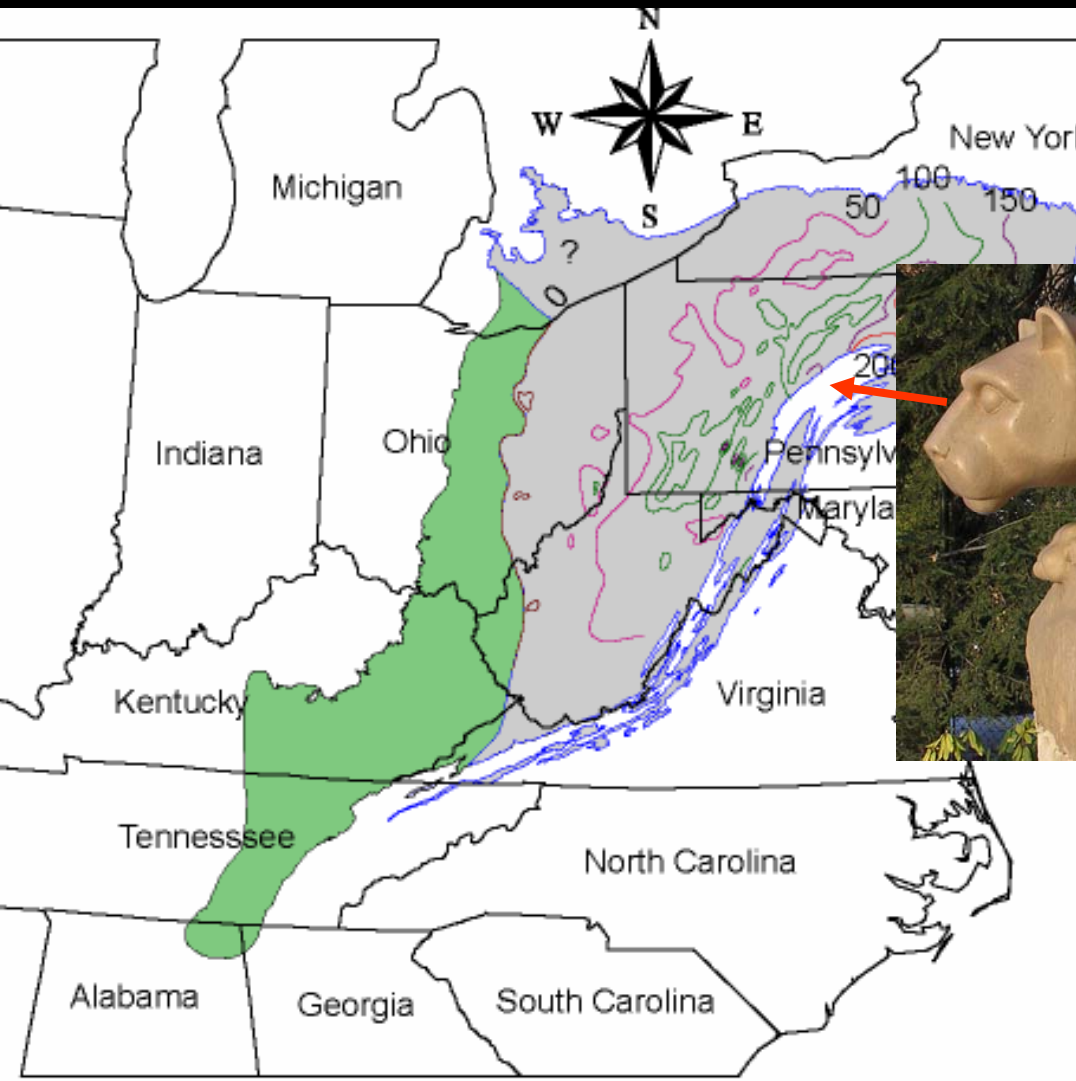
Nittany Lion watches over Marcellus play

A science briefing for
Congressman John Peterson



Extent of Devonian shale

Marcellus Shale

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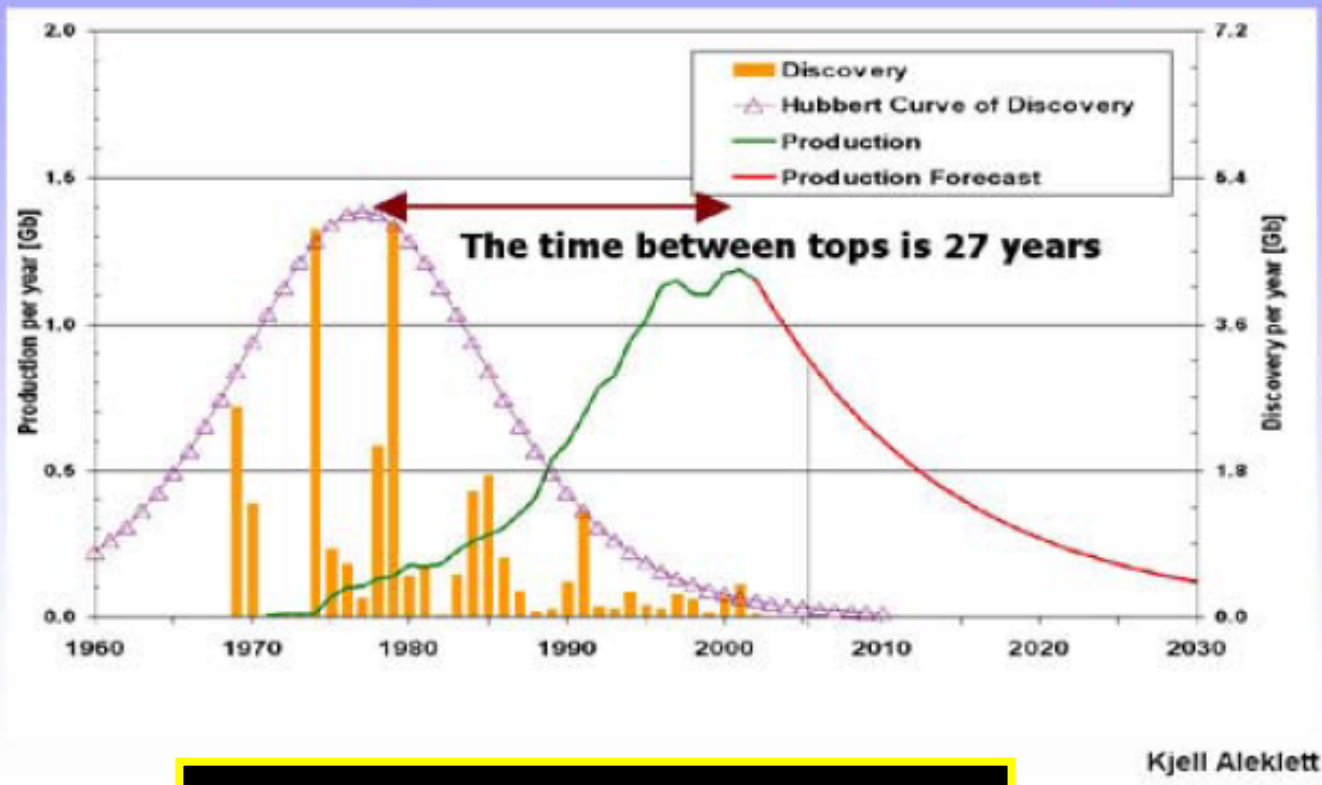
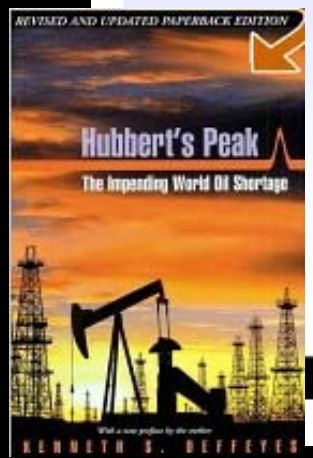
WHEN DISCOVERY DECLINES, PRODUCTION ALWAYS DECLINES LATER -- NORWAY

Found and produced oil in Norway

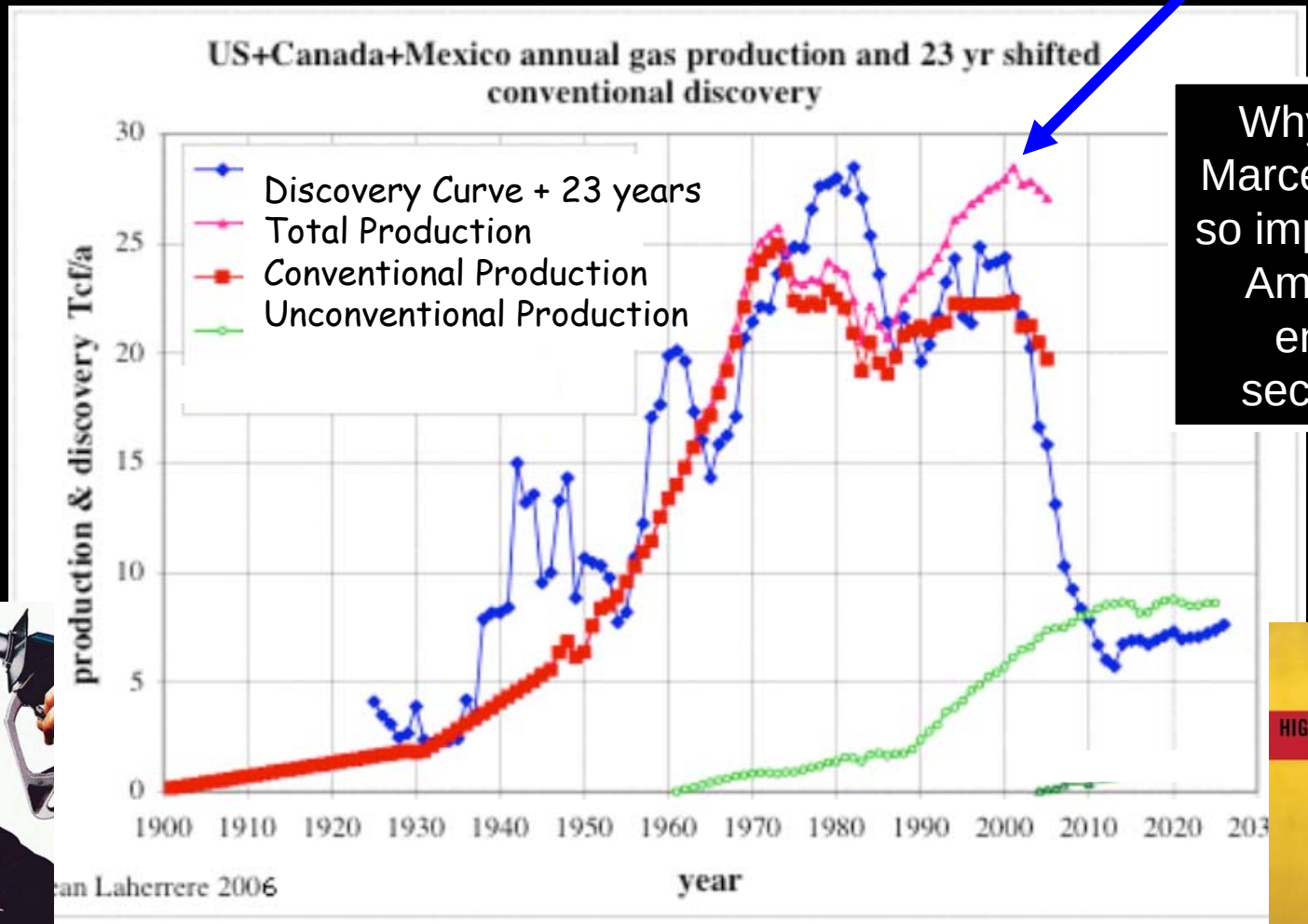




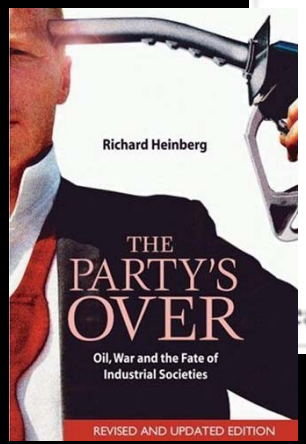
Hubbert's Peak

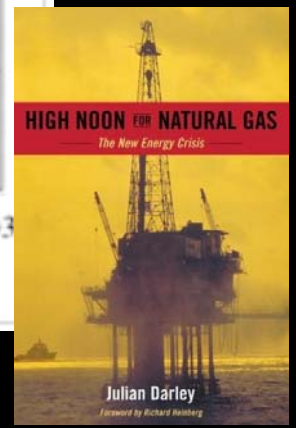
PSU Course: EM SC 101
Resource Wars

Hubbert's Peak (American Natural Gas = 2001)



Why is the Marcellus play so important to America's energy security??





Unconventional gas gave America a 20-year reprieve!

Unconventional Plays

- Gas reservoir is continuous and widespread
- Gas reservoir not controlled by:
  - structural or stratigraphic closure
- Reservoir rock is the source rock
- Gas not controlled by buoyancy

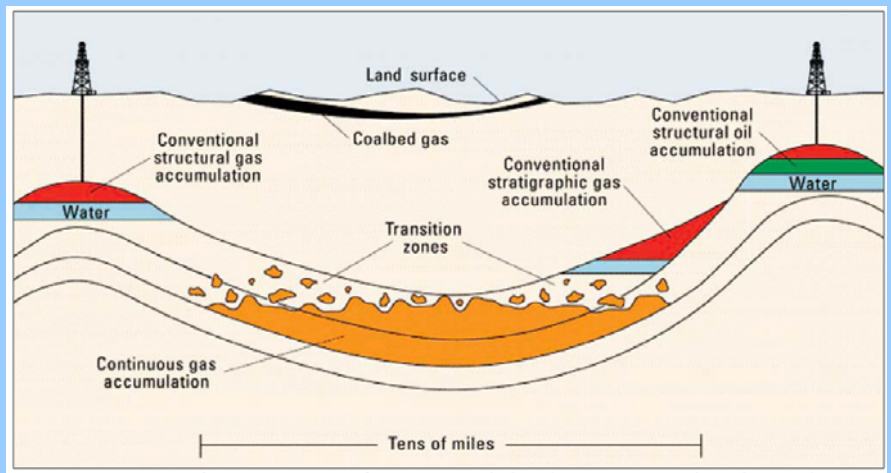
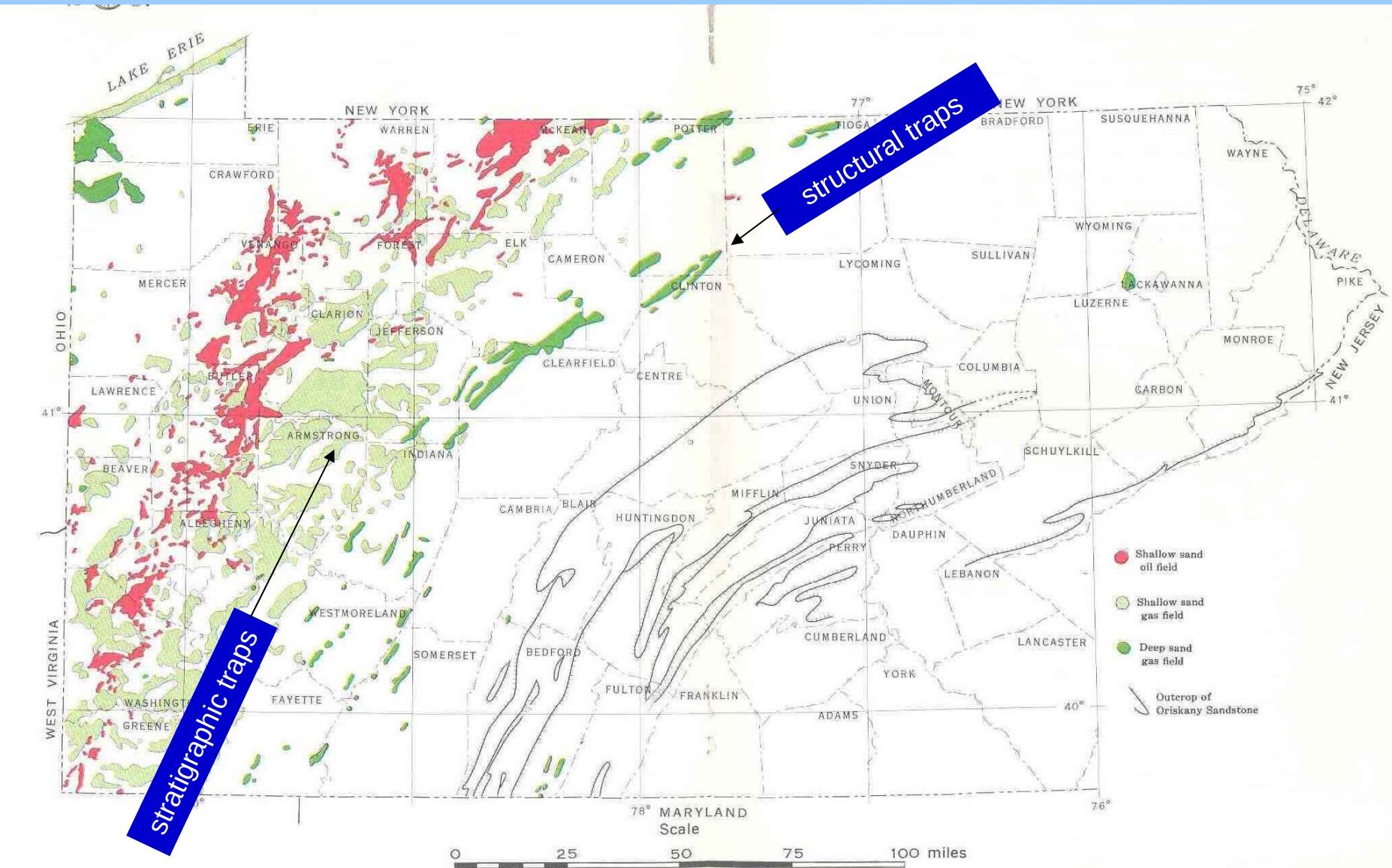


Figure 1. Conventional versus continuous/unconventional plays (Source: U.S. Geological Survey).

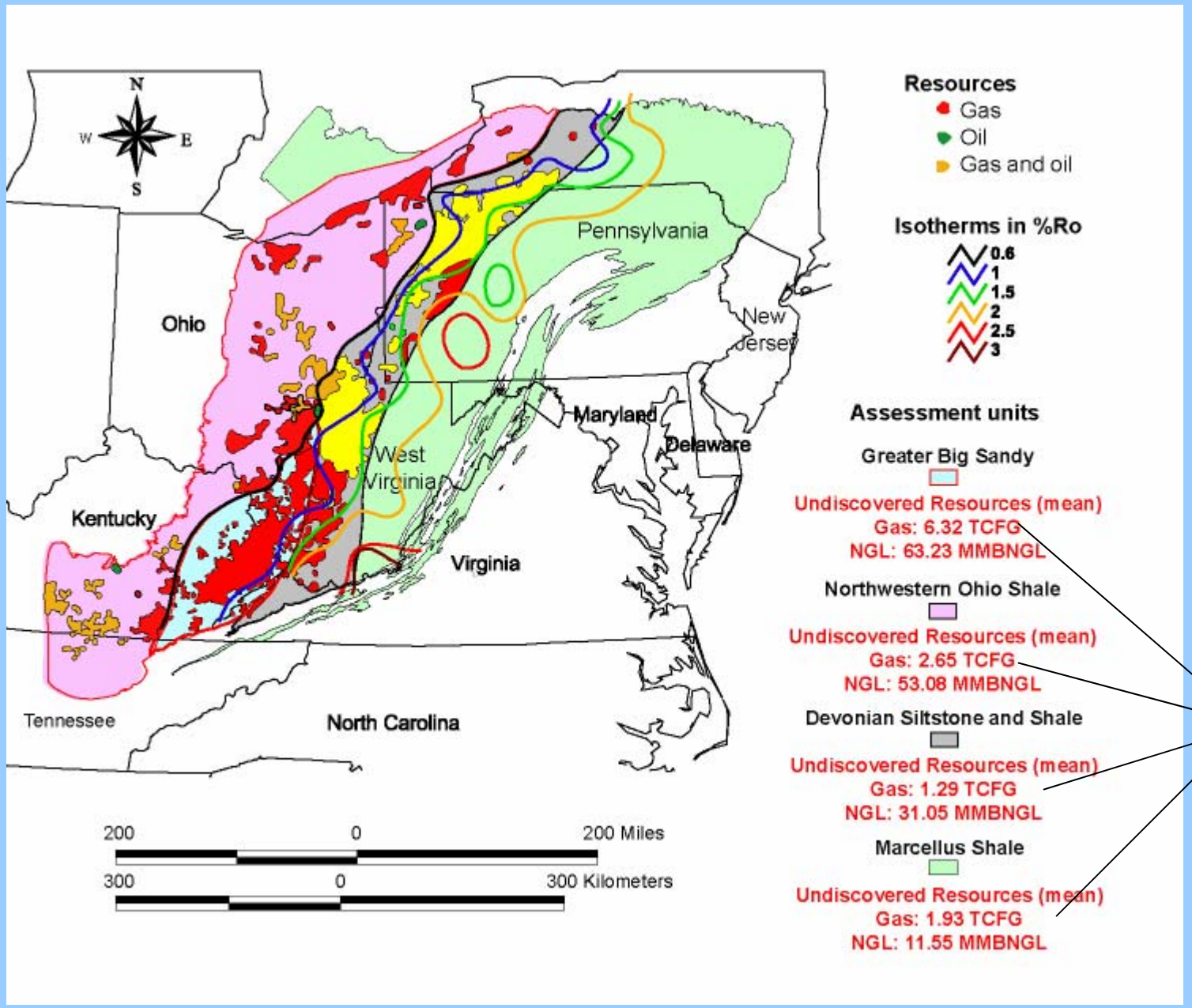
Brown et al, 2006

Pennsylvania Gas Production

Mainly conventional plays to date



Milici, USGS Open File Report (2005-1268)



12.19 Tcf

http://pubs.usgs.gov/of/2005/1268/

Where is the gas within the Marcellus?

Adsorbed Gas vs. Free?

On the surfaces of minerals

Gas Shale: Two rocks

Organic Clay Rich Shale
Produces adsorbed gas

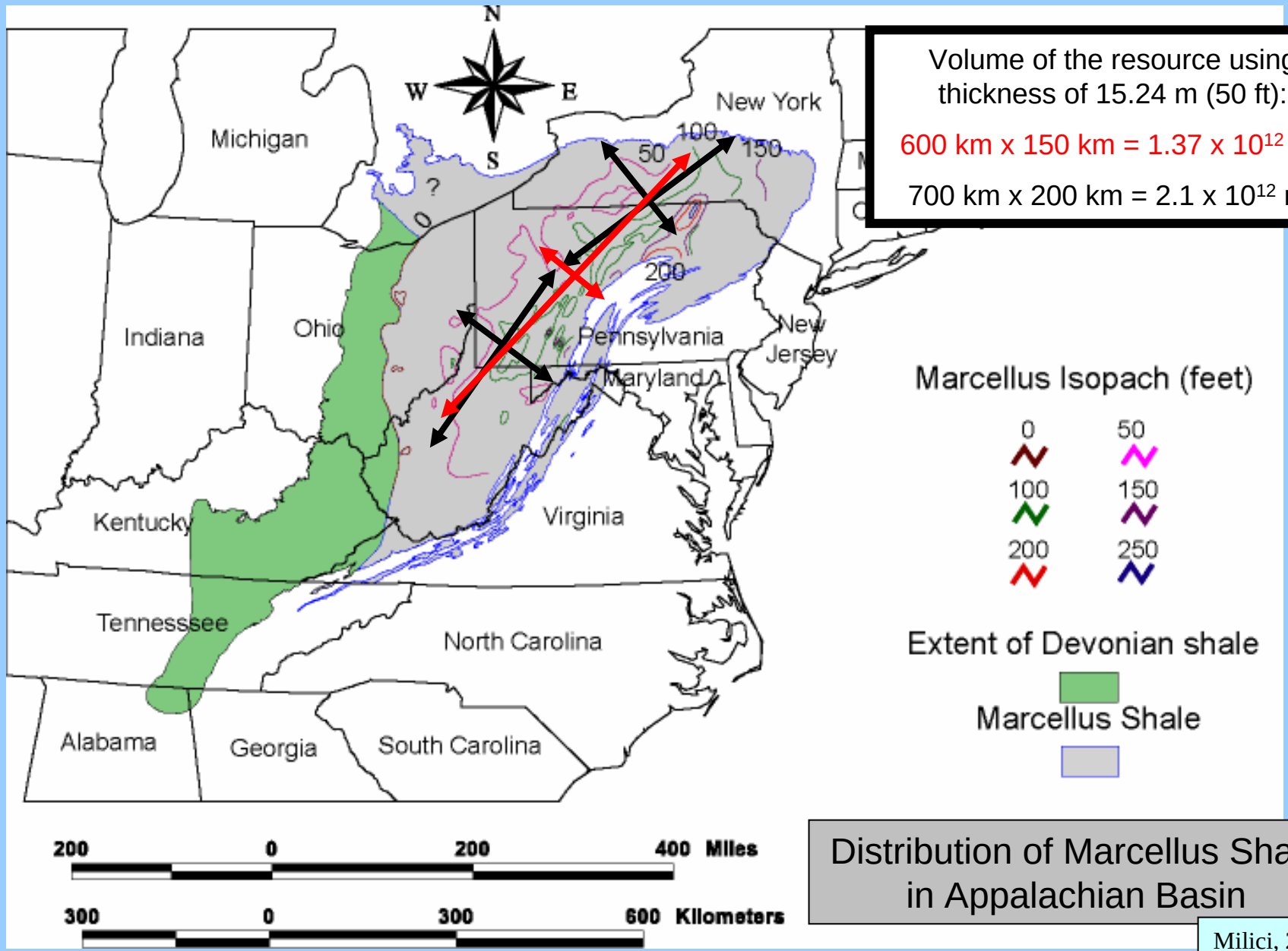
Quartz Rich Shale
Produces free gas

They may look the same.
They have very different production performance profiles.

Within open pore space including fractures

http://www.landman.org/content/swli07/Drake%20-%20AAPL%20Unconventional%20Gas%20Plays.pdf

Marcellus black shale = unconventional play



Volume of the resource using thickness of 15.24 m (50 ft):

600 km x 150 km = 1.37×10^{12} m^3

700 km x 200 km = 2.1×10^{12} m^3

Marcellus Isopach (feet)

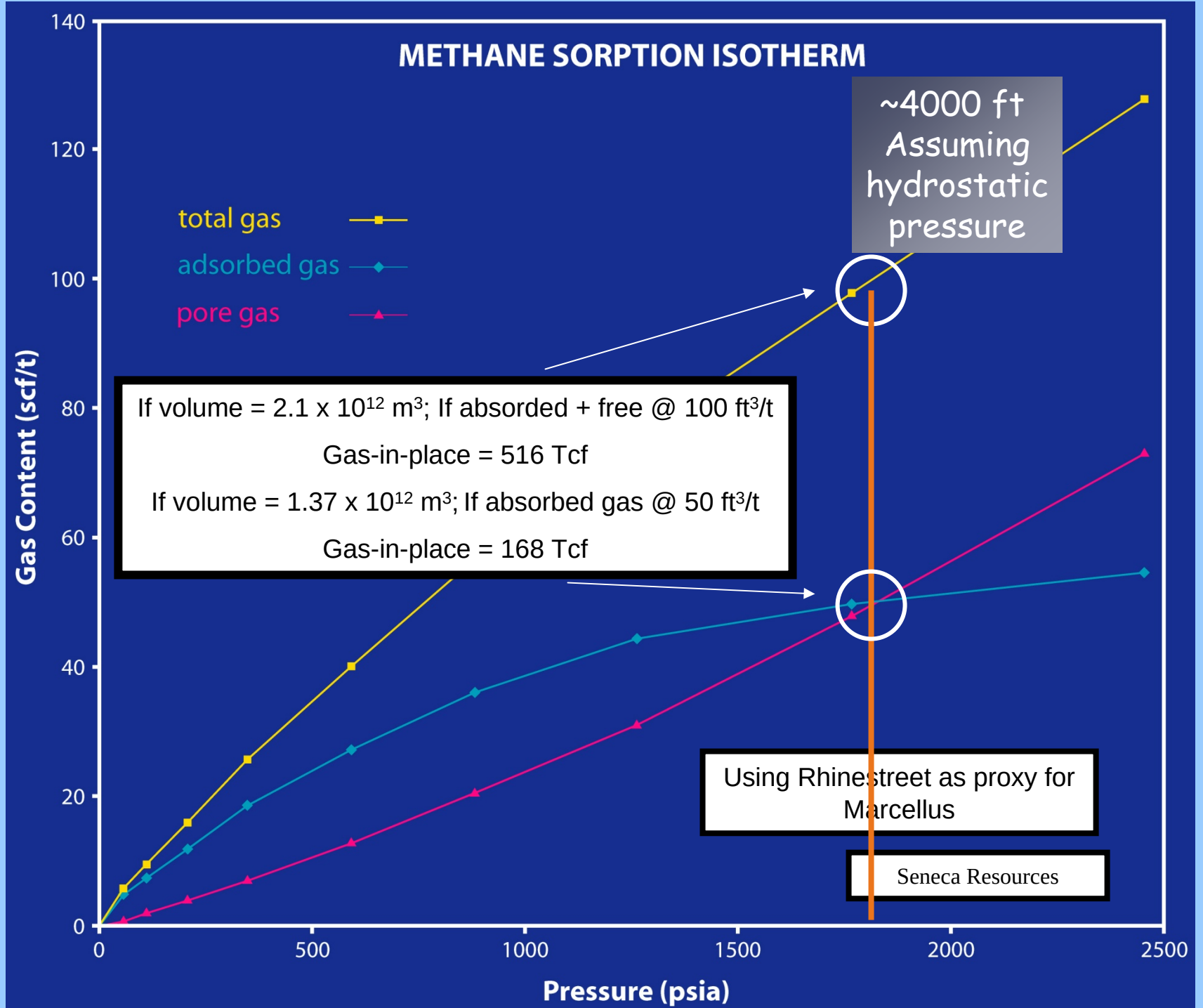
0 50 100 150 200 250

Extent of Devonian shale

Marcellus Shale

Distribution of Marcellus Shale in Appalachian Basin

Milici, 2005


METHANE SORPTION ISOTHERM
~4000 ft Assuming hydrostatic pressure
total gas
adsorbed gas
pore gas
If volume = 2.1 x 10^12 m^3; If absorded + free @ 100 ft^3/t
Gas-in-place = 516 Tcf
If volume = 1.37 x 10^12 m^3; If absorbed gas @ 50 ft^3/t
Gas-in-place = 168 Tcf
Using Rhinestreet as proxy for Marcellus
Seneca Resources
Gas Content (scf/t)
Pressure (psia)
0
20
40
60
80
100
120
140
0
500
1000
1500
2000
2500

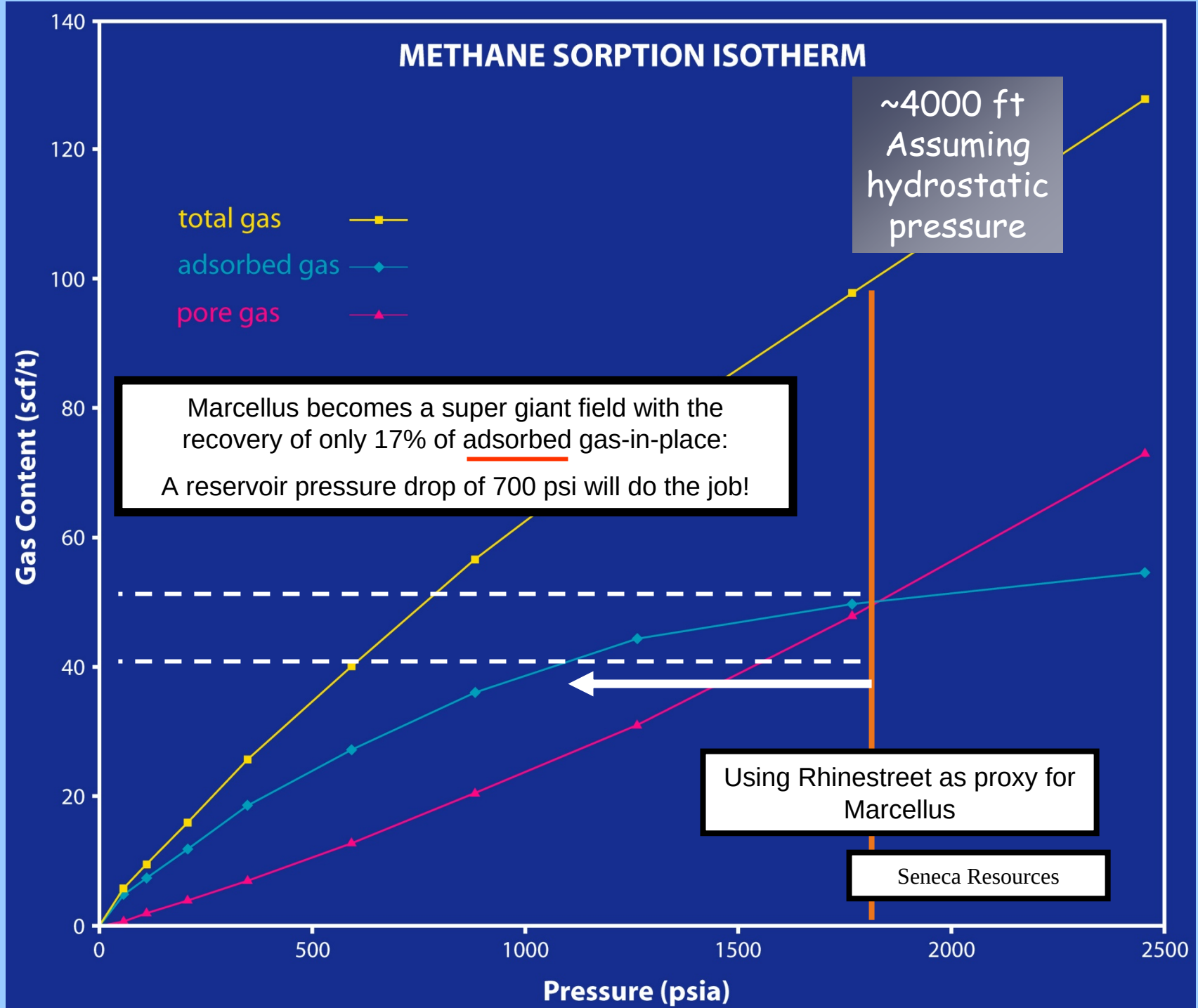
Classification of fields

- Super Giant Field
  - More than 5,000 million barrels of recoverable petroleum
- Giant Fields
  - Between 500 and 5,000 million barrels of recoverable petroleum

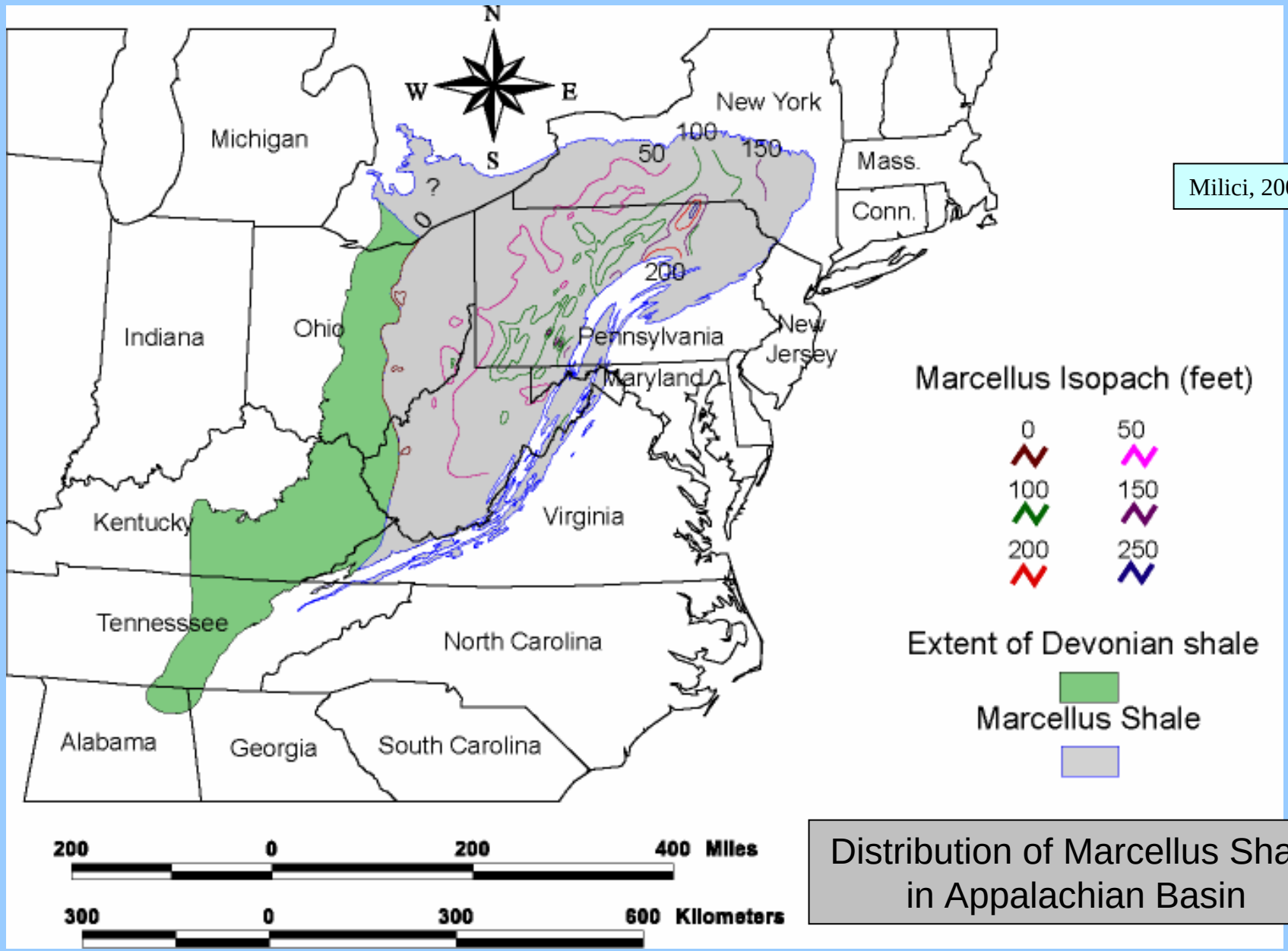
1 barrel of oil = 6,000 ft^3 of gas

- Field in which there is 30 Tcf of <u>recoverable gas</u> is a **SUPER GIANT**

http://books.google.com/books?id=X4yOjTbdy2EC&pg=PA138&lpg=PA138&dq=classification+of+size+of+petroleum+fields&source=web&ots=abZRzglPRb&sig=qbewSdLMWdkpx0Nz0qr8du3uM08#PPA139,M1


METHANE SORPTION ISOTHERM
~4000 ft
Assuming
hydrostatic
pressure
total gas
adsorbed gas
pore gas
Marcellus becomes a super giant field with the recovery of only 17% of adsorbed gas-in-place:
A reservoir pressure drop of 700 psi will do the job!
Using Rhinestreet as proxy for Marcellus
Seneca Resources
Gas Content (scf/t)
Pressure (psia)
0
20
40
60
80
100
120
140
0
500
1000
1500
2000
2500

Devonian black shale = unconventional play

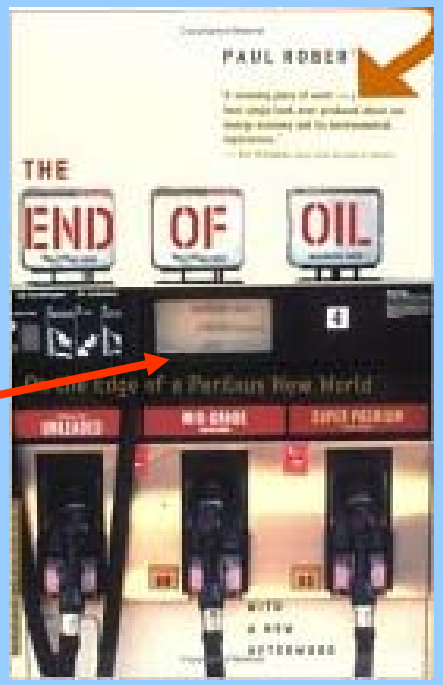


Milici, 2005

Distribution of Marcellus Shale in Appalachian Basin

Why is the 2005 USGS prediction concerning the Marcellus play so conservative?

This is an understandable response to criticism of the pessimists like Paul Roberts who have accused the USGS of being overly optimistic



US Geological Survey (1982)

The United States Geological Survey, in 1982, estimated gas in-place for the Appalachian Basin to be 844 Tcf,

Kuuskraa et al., 1985, SPE 14503

National Petroleum Council

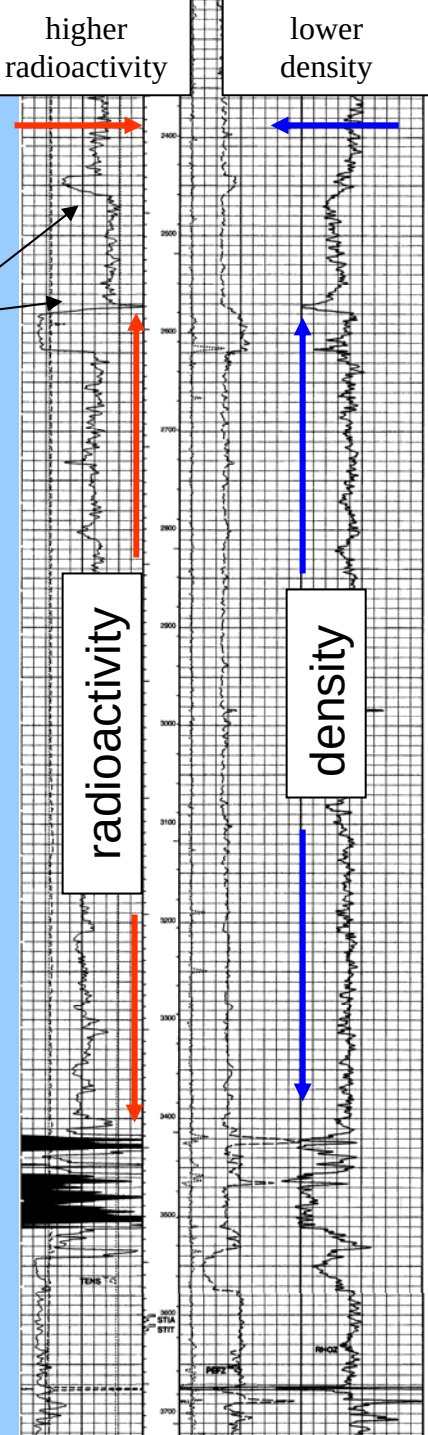
The natural gas resource estimates for Devonian-age shales in the Appalachian Basin vary widely. Estimates range from a low of 225 Tcf to a high of 2,579 Tcf (National Petroleum Council, 1980, Zielinski, 1982). The estimates vary based on type of shale included in the analysis (black and or gray), reservoir thickness and gas content per cubic foot of reservoir. Estimates for the Devonian Shale resource in New York were calculated in the 1980 National Petroleum Council Study, Table 4.1.

http://www.pe.tamu.edu/wattenbarger/public_html/Selected_papers/--Shale%20Gas/fractured%20shale%20gas%20potential%20in%20new%20york.pdf

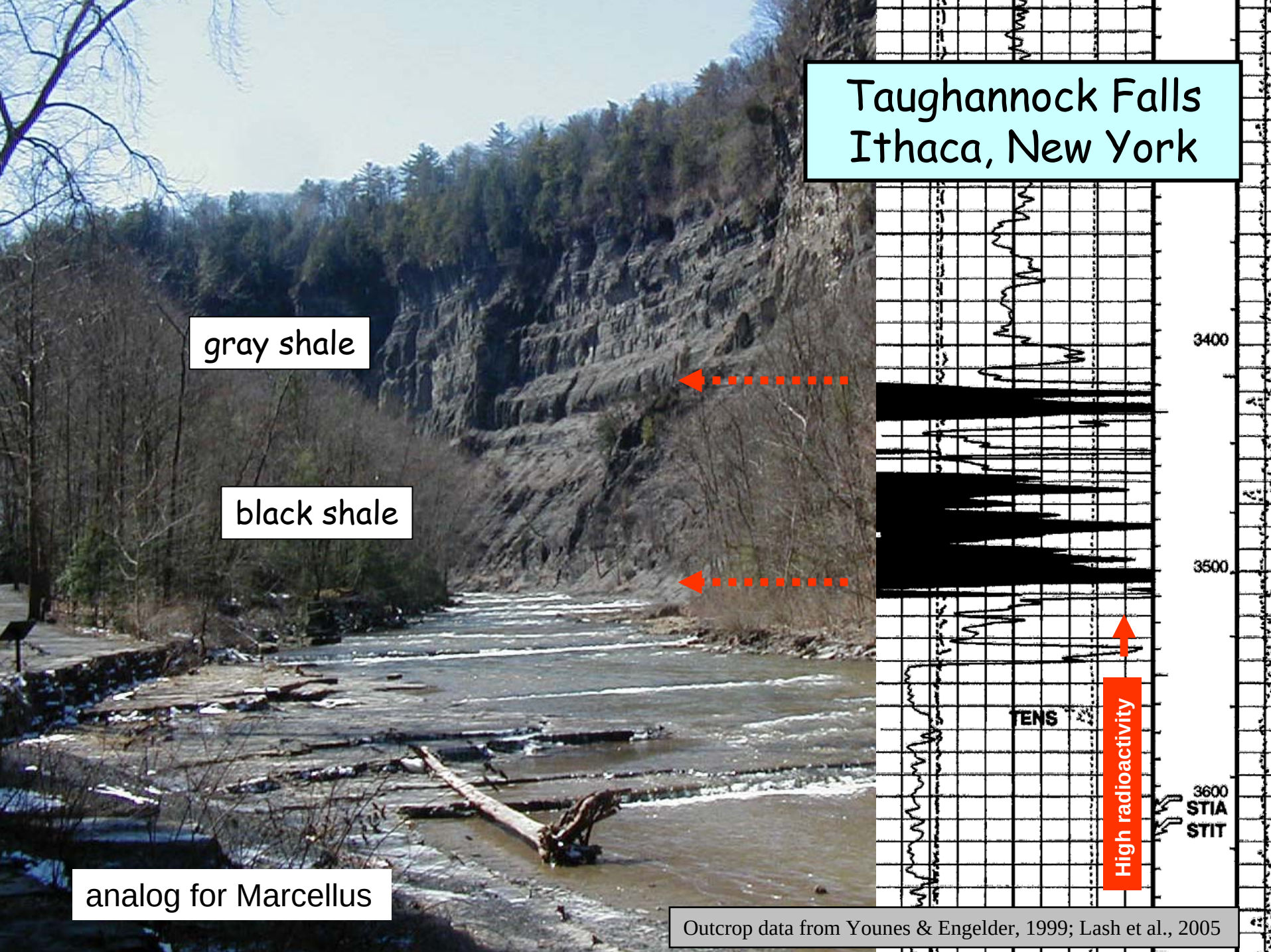
What makes the Marcellus an interesting prospect? Electric logs show:

- Higher radioactivity
- correlates with organic content
  - Organic content necessary for CH_4

- Lower formation density
  - correlates with matrix porosity



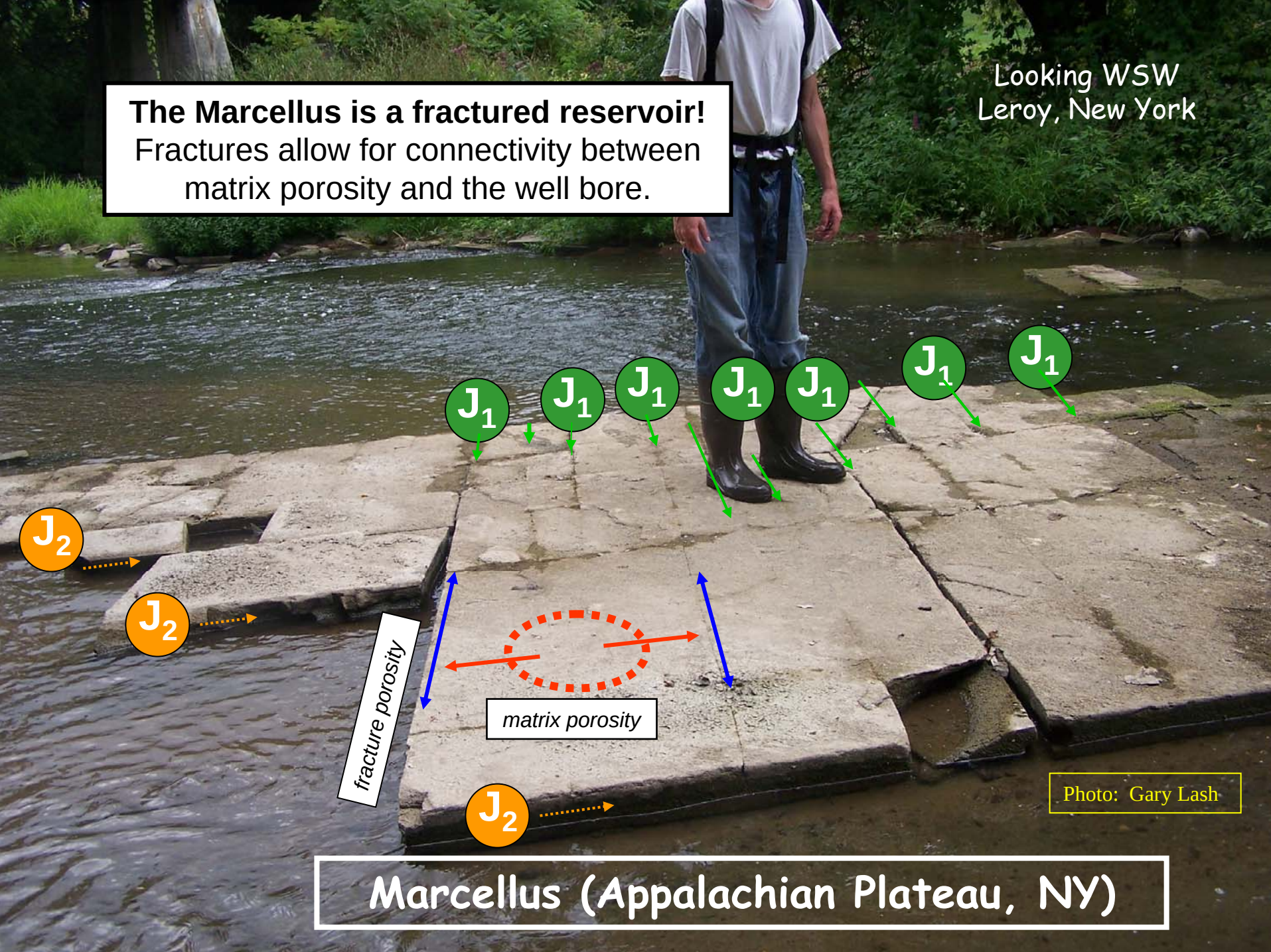
PSU BS thesis, L. Arnold, 2008


Taughannock Falls
Ithaca, New York
gray shale
black shale
analog for Marcellus
3400
3500
3600
TENS
STIA
STIT
High radioactivity
Outcrop data from Younes & Engelder, 1999; Lash et al., 2005

Geological Risk

- Because hydrocarbons are ubiquitous, very high percentage of locations have flowable gas.
- Uncertainties with black shale play:
  - Initial production rate (***fracture porosity***)
    - How many fractures were intersected in well?
  - Long term decline rates (***matrix porosity***)
    - How well is matrix porosity connected through fracture porosity to the well bore?

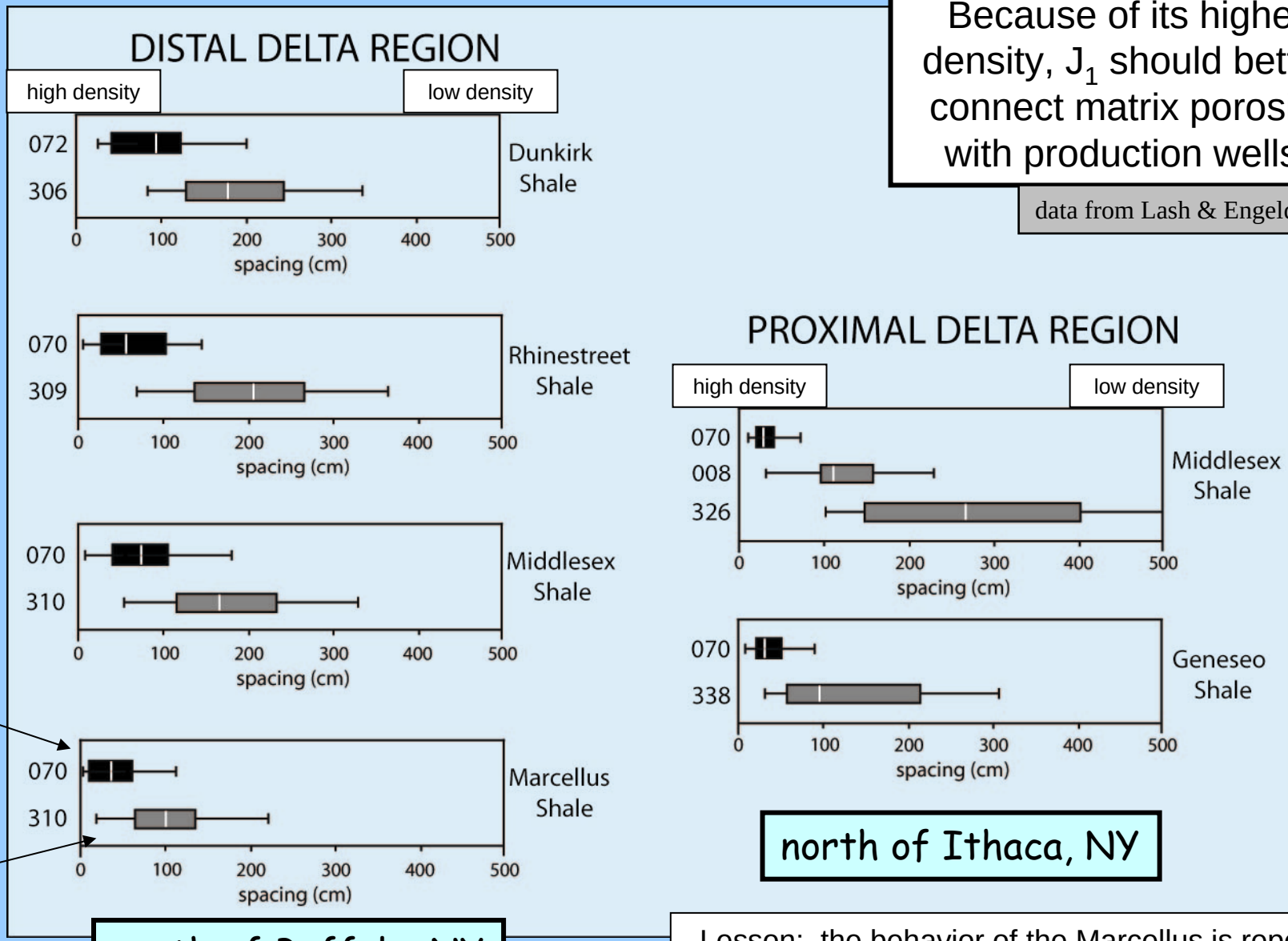
Why are fractures so important to the Marcellus play?
Looking WSW
Leroy, New York
J2
J1
J1
Photo: Gary Lash
Marcellus (Appalachian Plateau, NY)


The Marcellus is a fractured reservoir!
Fractures allow for connectivity between matrix porosity and the well bore.
Looking WSW
Leroy, New York
J1
J1
J1
J1
J1
J1
J1
J2
J2
J2
fracture porosity
matrix porosity
Photo: Gary Lash
Marcellus (Appalachian Plateau, NY)

Fracture density: Devonian black shale

Because of its higher density, J_1 should better connect matrix porosity with production wells!

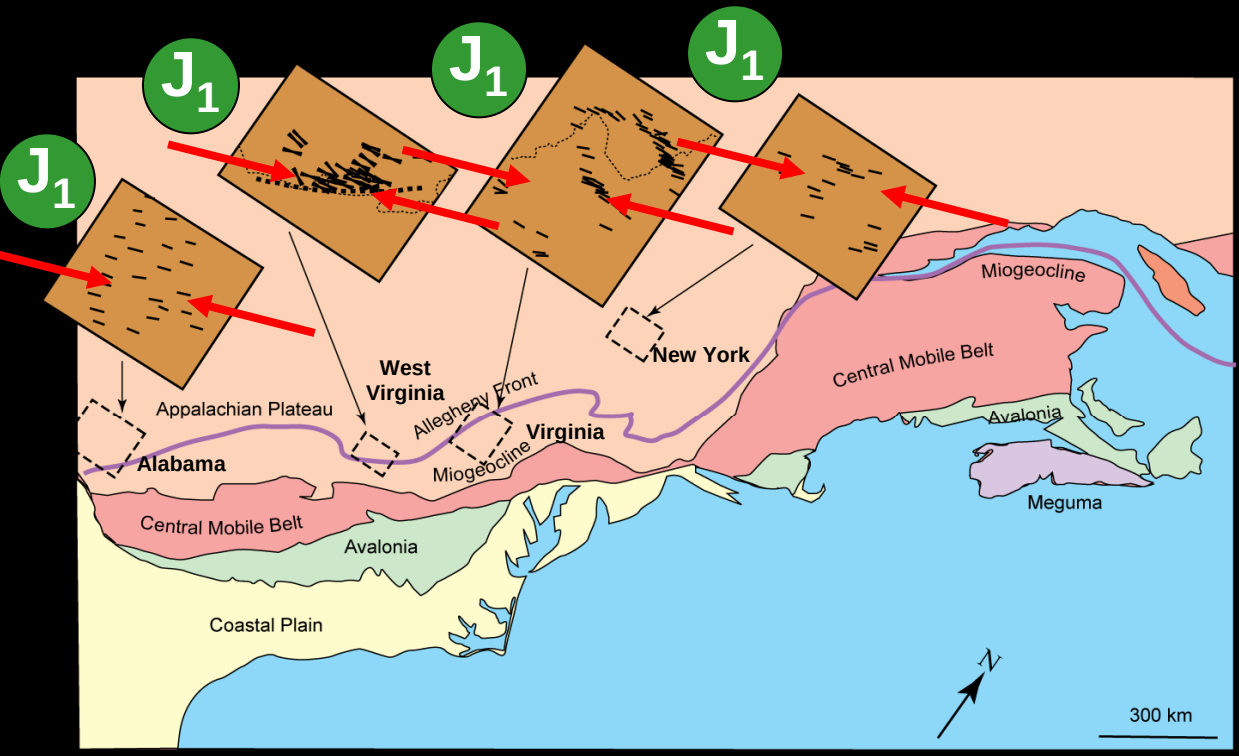
data from Lash & Engelder, 2008



Lesson: the behavior of the Marcellus is repeated in other black shale of the Appalachian Basin

Geological Risk

- Because hydrocarbons are ubiquitous, very high percentage of locations have flowable gas.
- BUT, is the fracture porosity as ubiquitous as the flowable gas?
  - Engelder and Whitaker (2006 *GEOLOGY* paper) were first to recognize a basin-wide fracture system on which an Appalachian Basin black shale play can be based.

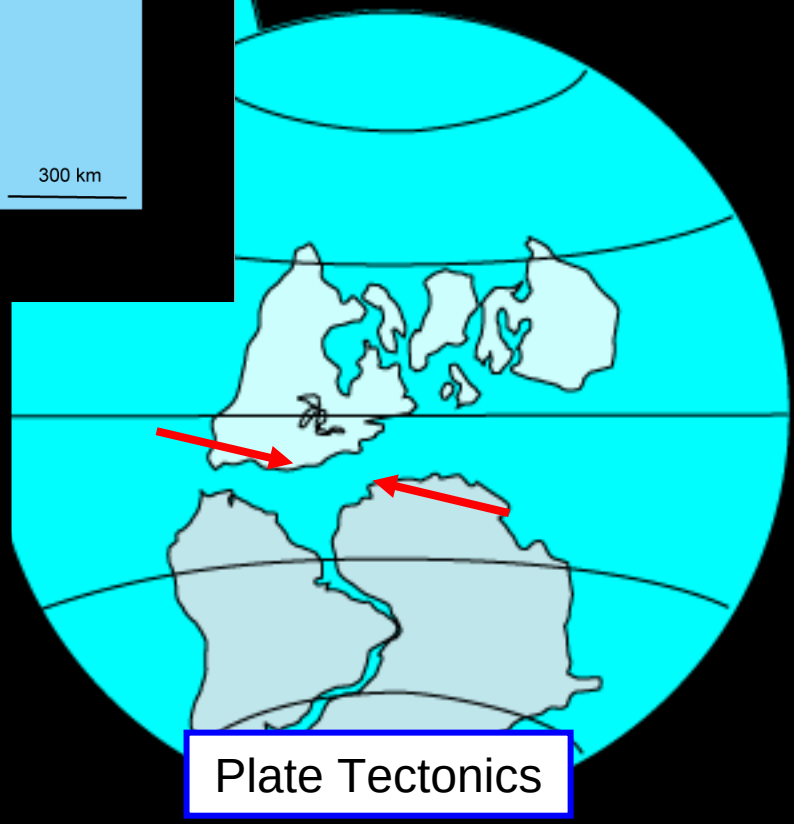


The Earth 300,000,000 years ago!

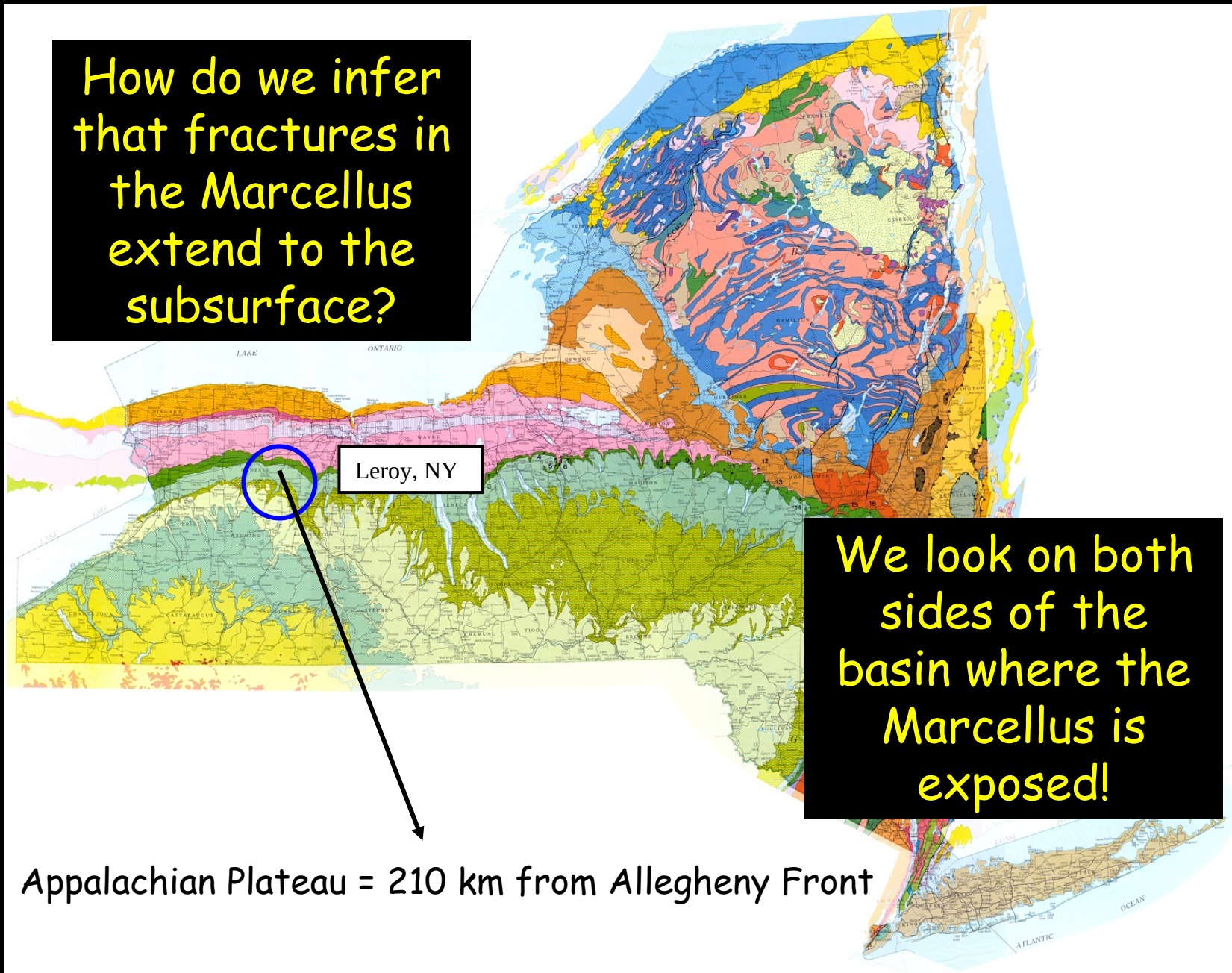
Engelder & Whitaker, 2006, ***GEOLOGY***

Appalachian Wide Stress Field (AWSF)

J_1 is a basin-wide joint set controlled by plate-margin tractions associated with <u>dextral strike-slip faulting</u> driven by the oblique convergence of Laurentia and Gondwana



How do we infer that fractures in the Marcellus extend to the subsurface?

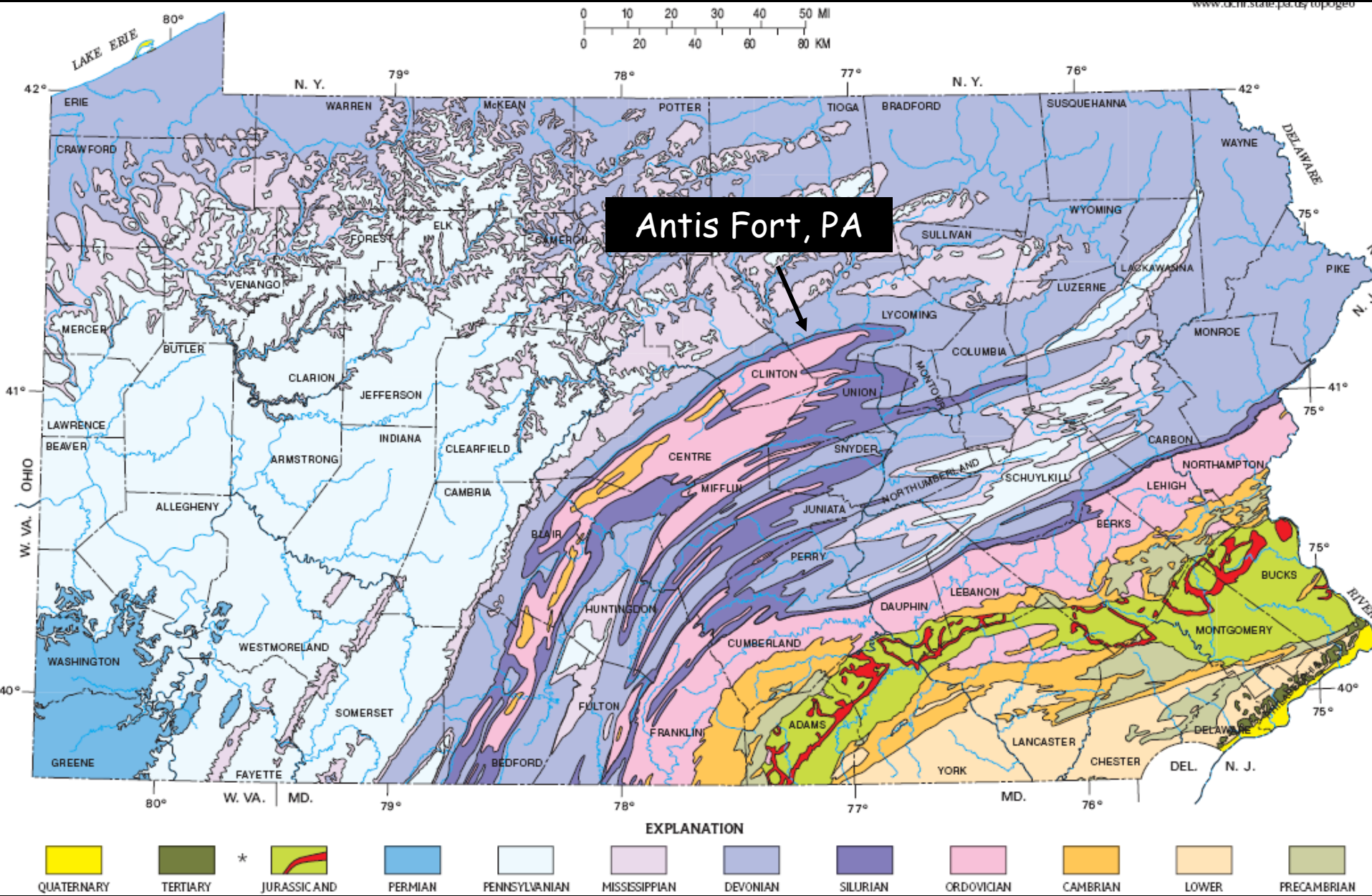


We look on both sides of the basin where the Marcellus is exposed!

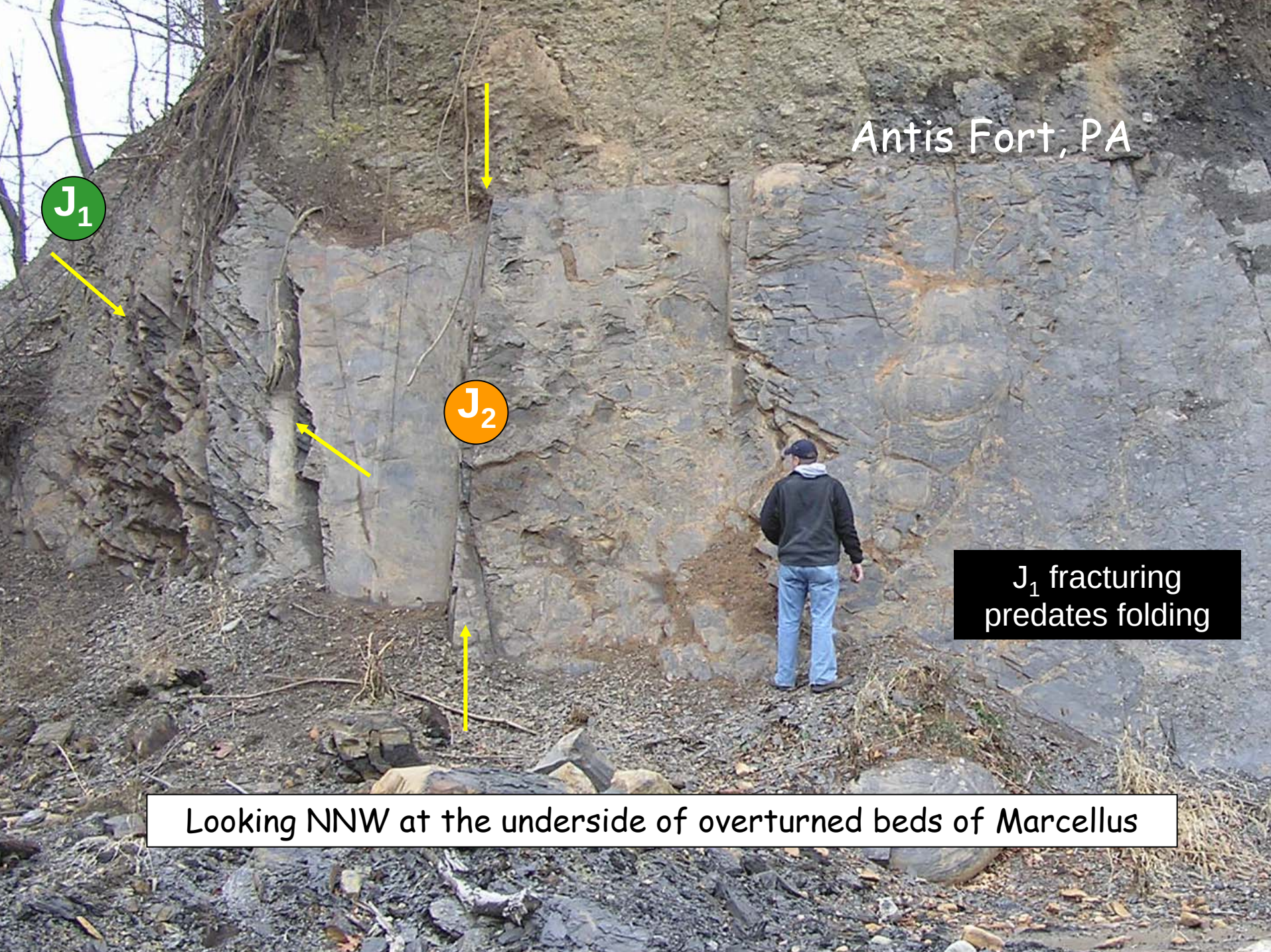
Appalachian Plateau = 210 km from Allegheny Front

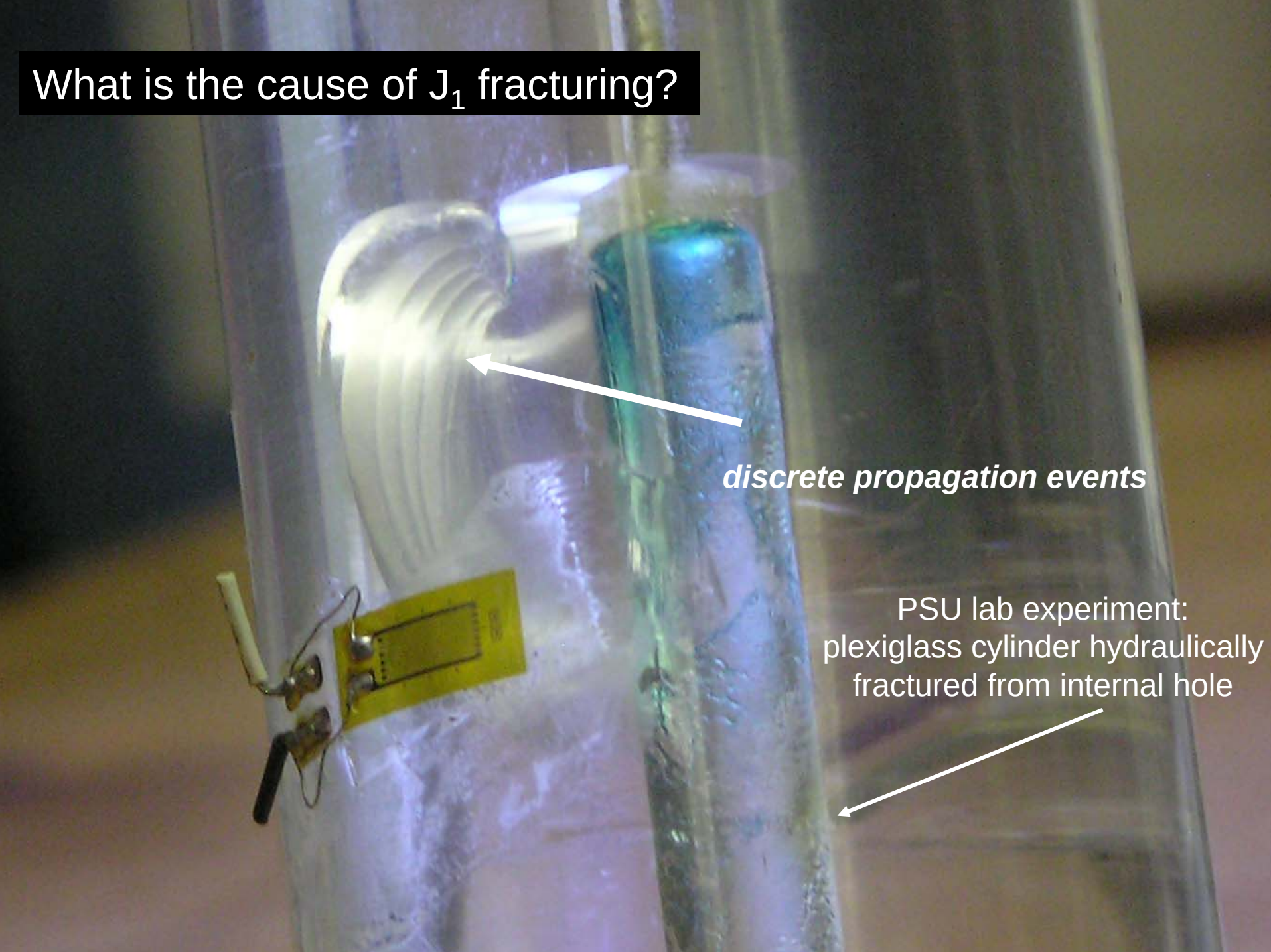
Marcellus (Appalachian Plateau, NY)

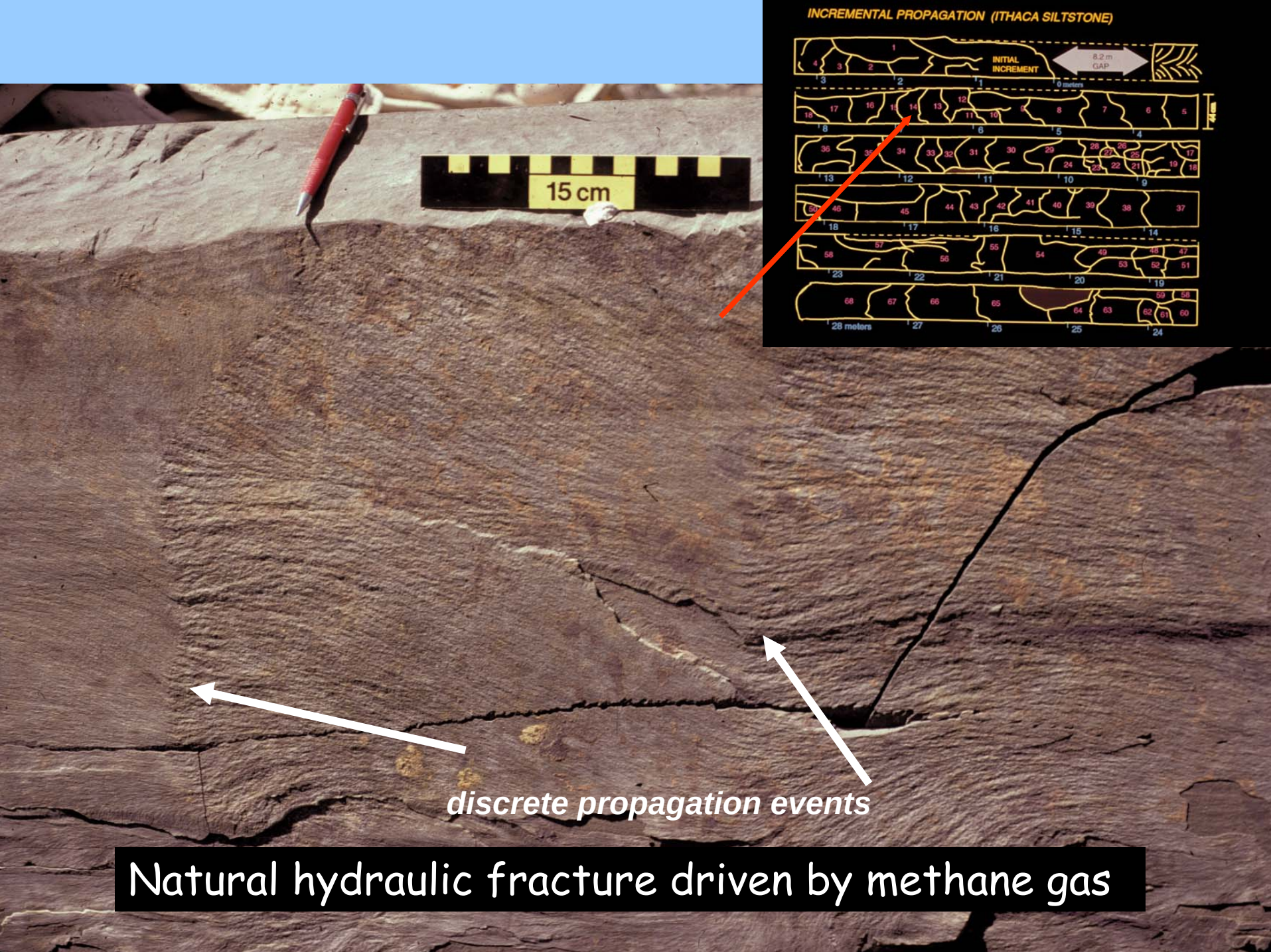
Appalachian Plateau = 2 km from Allegheny Front



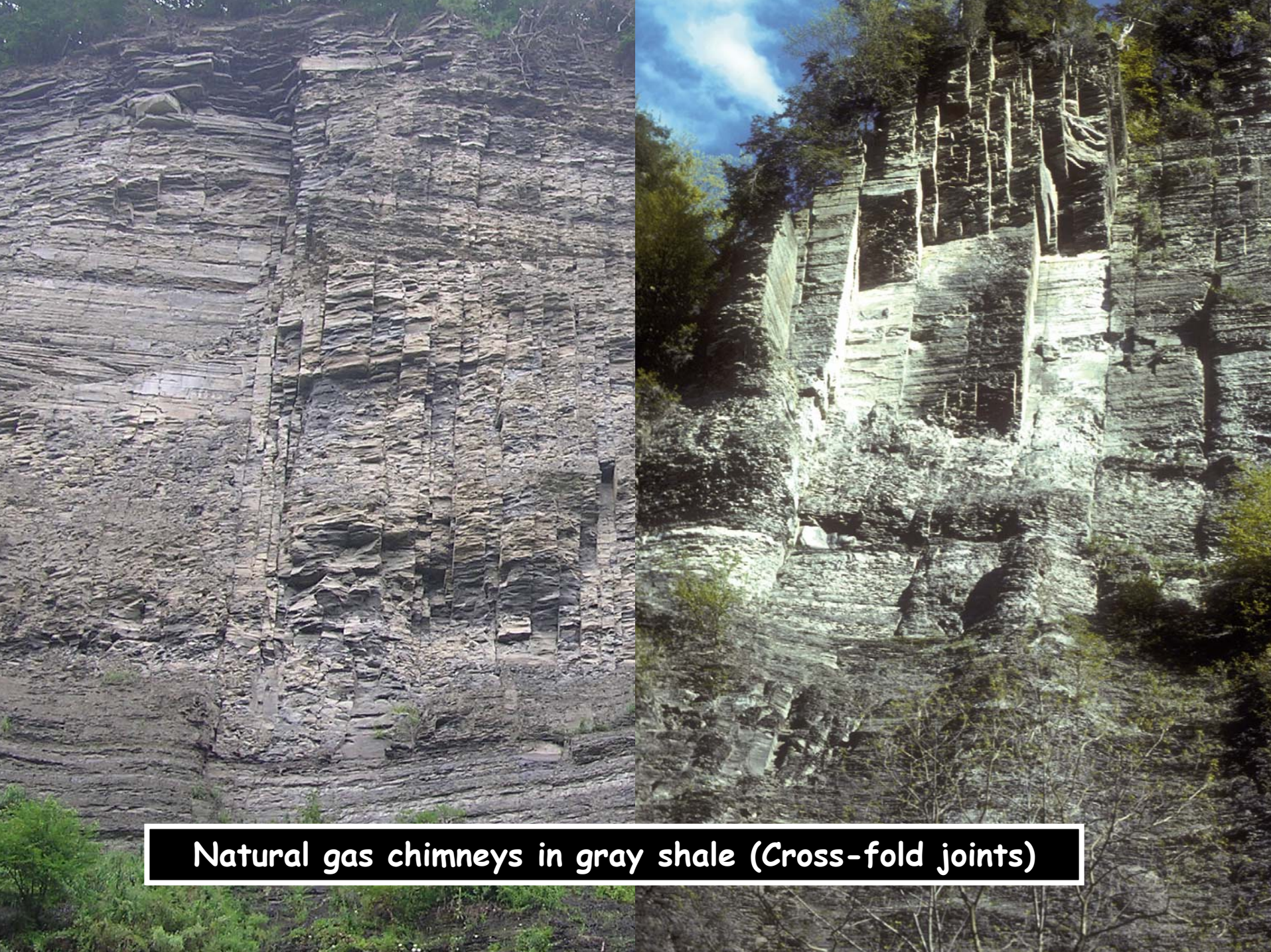
Allegheny Front marked by outcrops of nearly vertical to slightly overturned Tuscarora


Antis Fort, PA
J1
J2
J1 fracturing predates folding
Looking NNW at the underside of overturned beds of Marcellus


What is the cause of J_1 fracturing?
discrete propagation events
PSU lab experiment:
plexiglass cylinder hydraulically
fractured from internal hole



Natural hydraulic fracture driven by methane gas

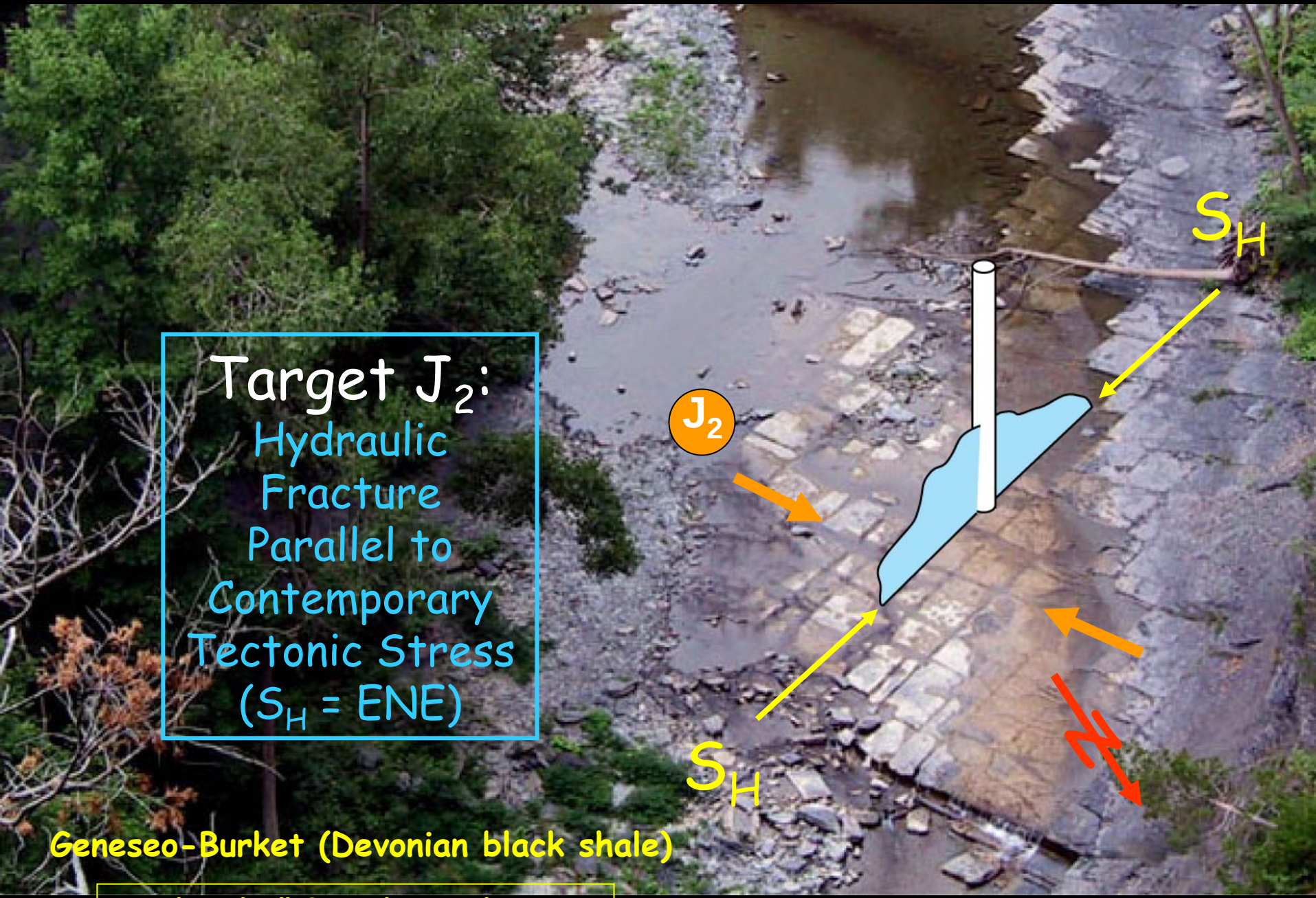


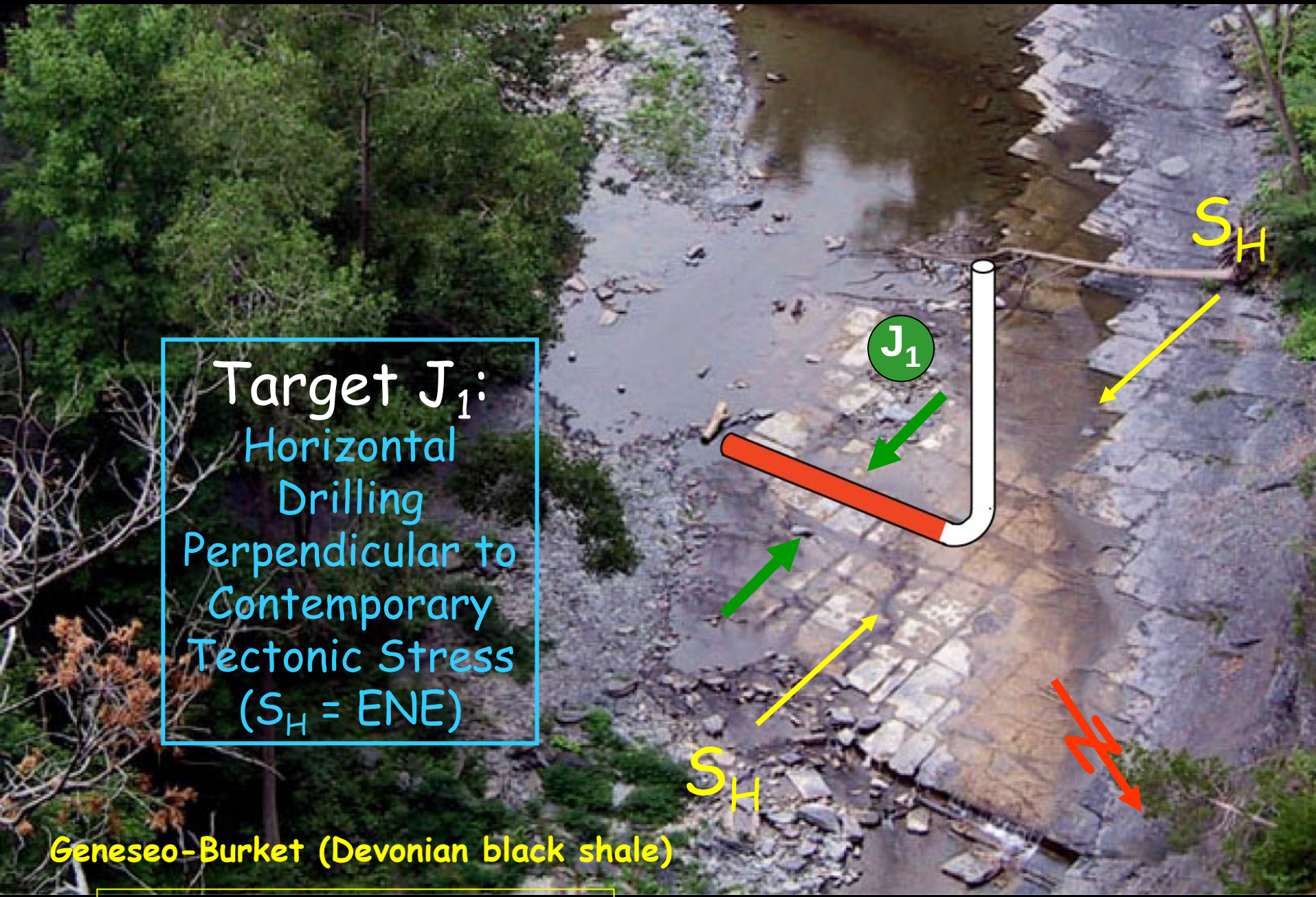
Natural gas chimneys in gray shale (Cross-fold joints)

Well Completion Techniques

- Conventional vertical well
  - Unlikely to intersect very many fractures
- Hydraulic fracture treatment of vertical well
    - Controlled by earth stress to propagate to ENE
  - Likely to intersect only lower density J_2 fractures
- Horizontal drilling to the WNW
  - Likely to intersect many higher density J_1 fractures

Third completion technique is key to economic success of black shale play


Target J_2:
Hydraulic Fracture Parallel to Contemporary Tectonic Stress (S_H = ENE)
J_2
S_H
S_H
N
Geneseo-Burket (Devonian black shale)
Taughannock Falls State Park, Trumansburg, N.Y.


Target J_1:
Horizontal Drilling Perpendicular to Contemporary Tectonic Stress (S_H = ENE)
S_H
J_1
S_H
N
Geneseo-Burket (Devonian black shale)
Taughannock Falls State Park, Trumansburg, N.Y.

Risk Evaluation of Unconventional Plays

- Unconventional ventures require pilot programs
  - This means several pilot wells
    - Horizontal drilling in Devonian black shale
- Successful pilot programs:
  - Range Resources:
    - 12/9/07 news release: Marcellus horizontal play (PA) continues to achieve encouraging results
      - Five horizontal wells: 1.4, 3.2, 3.7, 4.3 and 4.7 Mmcfe per day

There are differences in interpretation of the state of the subsurface concerning the Marcellus play

AAPG Explorer, April 2007

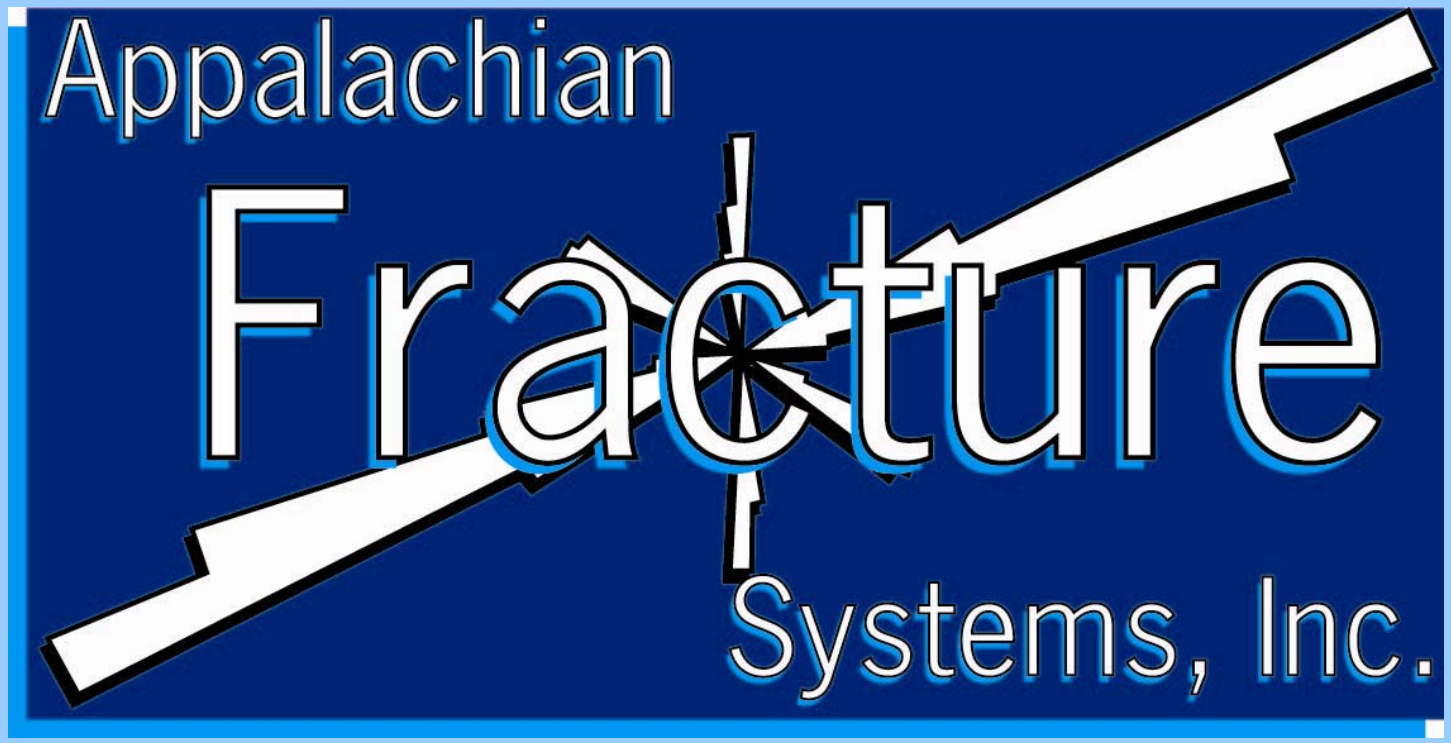
- Jeffery Ventura (*Range Resources COO*) said “In the northern part of the basin, from the West Virginia-Pennsylvania border north, there’s a lot of gas in place but you don’t have that natural fracturing, so the stimulation methods of utilizing nitroglycerin or newer foam hydraulic fracturing don’t work.”
- Here the thought is that stimulating the Marcellus by a completion technique also known as hydraulic fracturing makes for the best production provided there are NO natural fractures present.

Conclusion

- The investment firm of Jefferies & Company, Inc. predicts that 2008 will see the Marcellus black shale play of the Appalachian Basin become the “breakout play of the year”
- The principals of Appalachian Fracture Systems Inc. concur

Key references on which the 2008 black shale play will be built!

- Engelder, T., 2004, Tectonic implications drawn from differences in the surface morphology on two joint sets in the Appalachian Valley and Ridge, Virginia: Geology, v. 32, p. 413-416.
- Engelder, T. and Geiser, P., 1980, On the use of regional joint sets as trajectories of paleostress fields during the development of the Appalachian Plateau, New York: Journal of Geophysical Research, v. 85, p. 6319-6341.
- Engelder T., and Lash, G.G., 2008, Systematic joints in Devonian black shale: A target for horizontal drilling in the Appalachian Basin: American Association of Petroleum Geologists Bulletin, (submitted for review)
- Engelder, T., and Whitaker, A., 2006, Early jointing in coal and black shale: Evidence for an Appalachian-wide stress field as a prelude to the Alleghanian orogeny: Geology, v. 34, p. 581-584.
- Gale, J.F.W., Reed, R.M., and Holder, J., 2007, Natural fractures in the Barnett Shale and their importance for hydraulic fracture treatments: American Association of Petroleum Geologists Bulletin, v. 91, p. 603-622.
- Lash, G.G., and Engelder, T., 2005, An analysis of horizontal microcracking during catagenesis: Example from the Catskill Delta Complex: American Association of Petroleum Geologists Bulletin, v. 89, p. 1433-1449.
- Lash G.G., and Engelder T, 2007, Jointing within the outer arc of a forebulge at the onset of the Alleghanian Orogeny: Journal of Structural Geology, v. 29, p. 774-786.
- Lash, G.G., and Engelder, T., 2008, Crosscutting versus abutting joints: Styles of joint intersection that reflect different contact stresses: Geological Society of America Bulletin (post-review)
- Lash, G.G., Loewy, S., and Engelder, T., 2004, Preferential jointing of Upper Devonian black shale, Appalachian Plateau, USA: Evidence supporting hydrocarbon generation as a joint-driving mechanism: in Cosgrove, J. W., and Engelder, T., eds., The initiation, propagation, and arrest of joints and other fractures: Geological Society of London Special Publications, v. 231, p. 129-151.
- Younes, A.I., and Engelder, T., 1999, Fringe cracks: key structures for the interpretation of the progressive Alleghanian deformation of the Appalachian plateau: Geological Society of America Bulletin, v. 111, p. 219-239.



Science behind the Marcellus Play

The Devonian Black Shale Play of the Appalachian Basin