Cambrian Rogersville Shale (Conasauga Group), Kentucky and West Virginia: A Potential New Unconventional Reservoir in the Appalachian Basin*

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Search and Discovery Article #10787 (2015)**
Posted January 18, 2016

*Adapted from oral presentation given at Tulsa Geological Society luncheon meeting, October 20, 2015.
Editor's note: This is an expanded and updated article of Search and Discovery Article #10764 (2015) and is closely related to Search and Discovery Article #10809 (2015).

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Abstract

Research at the Kentucky, Ohio, and West Virginia Geological Surveys from 1999-2002 refined the stratigraphic framework of a Cambrian-age extensional basin underlying the Appalachian Basin (Harris et al., 2004). This graben, called the Rome Trough, is filled with up to 10,000 ft of pre-Knox Group sedimentary rocks. Well log correlations indicate formations comprising the Cambrian Conasauga Group extend across parts of eastern Kentucky and include, in ascending order, the Pumpkin Valley Shale, Rutledge Limestone, Rogersville Shale, Maryville Limestone, Nolichucky Shale, and Maynardville Limestone. Regional distribution of these formations and the underlying Rome Formation is controlled by extensional faults that were active during and after Conasauga deposition. Stratigraphic correlation of these units reveals the presence of a westward-prograding carbonate ramp and distal intrashelf shale basin in the Rome Trough in eastern Kentucky. The Conasauga formations record several cycles of progradation from east to west into this basin.

Commercial hydrocarbon production from the Rome Trough includes the Homer Field in Elliott County, Kentucky. where sandstone reservoirs in the Rome and Conasauga formations have produced over 2 billion cubic feet of gas (Harris and Baranoski, 1996). Other Cambrian completions include short-lived gas and condensate production from older wells in Jackson County, West Virginia, and Boyd and Johnson Counties, Kentucky. In order to identify the source of these hydrocarbons, we analyzed numerous Cambrian shales from cores across the Rome Trough. Total organic carbon content (TOC) of these shales was less than 1 percent, with the exception of a core of the Rogersville Shale from the Exxon No. 1 Smith well in Wayne County, WV. TOC for the Rogersville Shale in this core ranges from 1.2 to 4.75 percent, with Tmax values of 446 to 469^{o}C. Low hydrogen indices, and Tmax data indicate a thermal maturity in the wet gas-condensate window. The Rogersville Shale in this core is a dark gray fissile shale, interbedded with thinly laminated and bioturbated siltstone. Hydrocarbon extracts from the Rogersville Shale core are geochemically very similar to produced condensate from Elliott and Boyd County, KY). Gas chromatographs of the Cambrian oils are similar to Ordovician-sourced oils, with strong predominance of odd-carbon normal alkanes. Organic carbon in Ordovician source rocks has been attributed to *G. prisca*, a marine alga, but this form has not been positively identified in the Cambrian Rogersville Shale to date.

The reservoir potential of the Rogersville was not considered back in 2002. It has suitable thickness, mineralogy, organic content, and thermal maturity to potentially produce gas or liquids if fractured to improve permeability. The Rogersville Shale ranges in thickness from 200 to over 1200 ft in eastern KY and western WV. The top of the Rogersville ranges from approximately 7000 to 10,000 feet below surface. X-ray diffraction analyses on six Rogersville Shale core samples shows an average composition of 38 percent quartz, feldspar and pyrite, 34 percent clays, and 28 percent carbonate. Mud logs provide an indication of the gas content of shales during drilling, but they are scarce for Rogersville wells in eastern KY. However, a mud log is available for the cored Exxon No. 1 Smith well in Wayne County, WV. It recorded elevated mud gas during drilling of the Rogersville interval, and a drill stem test was conducted over the lower Maryville and upper Rogersville interval.

Seven Rogersville test locations have been permitted in the last two years, and five have been drilled to date. The Bruin Exploration No. 1 Young well in Lawrence County, KY was drilled vertically to 11,967 ft into the Rome Formation in late 2013. Bruin completed a 576-ft interval in the Rogersville and reported initial production of 115 MCFGD and 19 BOPD. A surface shut-in pressure of 2599 psi was reported. While these volumes are modest, the first vertical well may not reflect the potential of the zone. A second well, the Cabot No. 50 Amherst Industries, was permitted in mid-2014 to 14,000 ft, targeting the Rogersville Shale in Putnam County, WV. Records have not been released, but the well is currently producing dry gas to a sales line. These wells are 18 miles west and 44 miles east along strike, respectively, from the Exxon Smith core location. Drilling of the Bruin well resulted in extensive leasing and sales of deep minerals rights in eastern KY in 2014-15.

Three additional wells have been drilled in KY: two vertical wells by Chesapeake Energy and one horizontal by Horizontal Technology Energy Corp. Results of these wells are still confidential. Recent permits were issued for a horizontal lateral from the original Bruin Young well, a second horizontal Bruin location, and a horizontal lateral from one of the Chesapeake vertical wells (all in Lawrence County, KY).

Challenges in developing a Rogersville Shale play include interpreting structure and stratigraphy in the deeper, fault-segmented parts of the Rome Trough and predicting the distribution of organic-rich intervals. The play concept has been proved, and economic viability will depend on the production rates established and fluid type.

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Cambrian Rogersville Shale (Conasauga Group) in the Rome Trough, Ky. and W. Va.:

a potential new unconventional reservoir in the Appalachian Basin

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Acknowledgements

- Rome Trough Consortium partners
  - Ohio, W. Va. and Kentucky Surveys
  - Industry and US DOE funding
- Bob Ryder, USGS (retired)
- Monte Hay, Hay Exploration

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Outline of Presentation

- Rome Trough regional geology and stratigraphy
- Production history
- Geochemistry and petroleum system
- New drilling activity and potential for a deep unconventional play

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Rome Trough Consortium 1999-2002

- Regional stratigraphic and structural study after first commercial field discovery in Elliott County (1994)
- Cross sections, core descriptions, paleogeographic maps, gross/net sandstone maps
- Hydrocarbon and source rock geochemistry
- Homer field study, Elliott County
- 2004 open-file report available at KGS

- Study did not consider the unconventional resource potential

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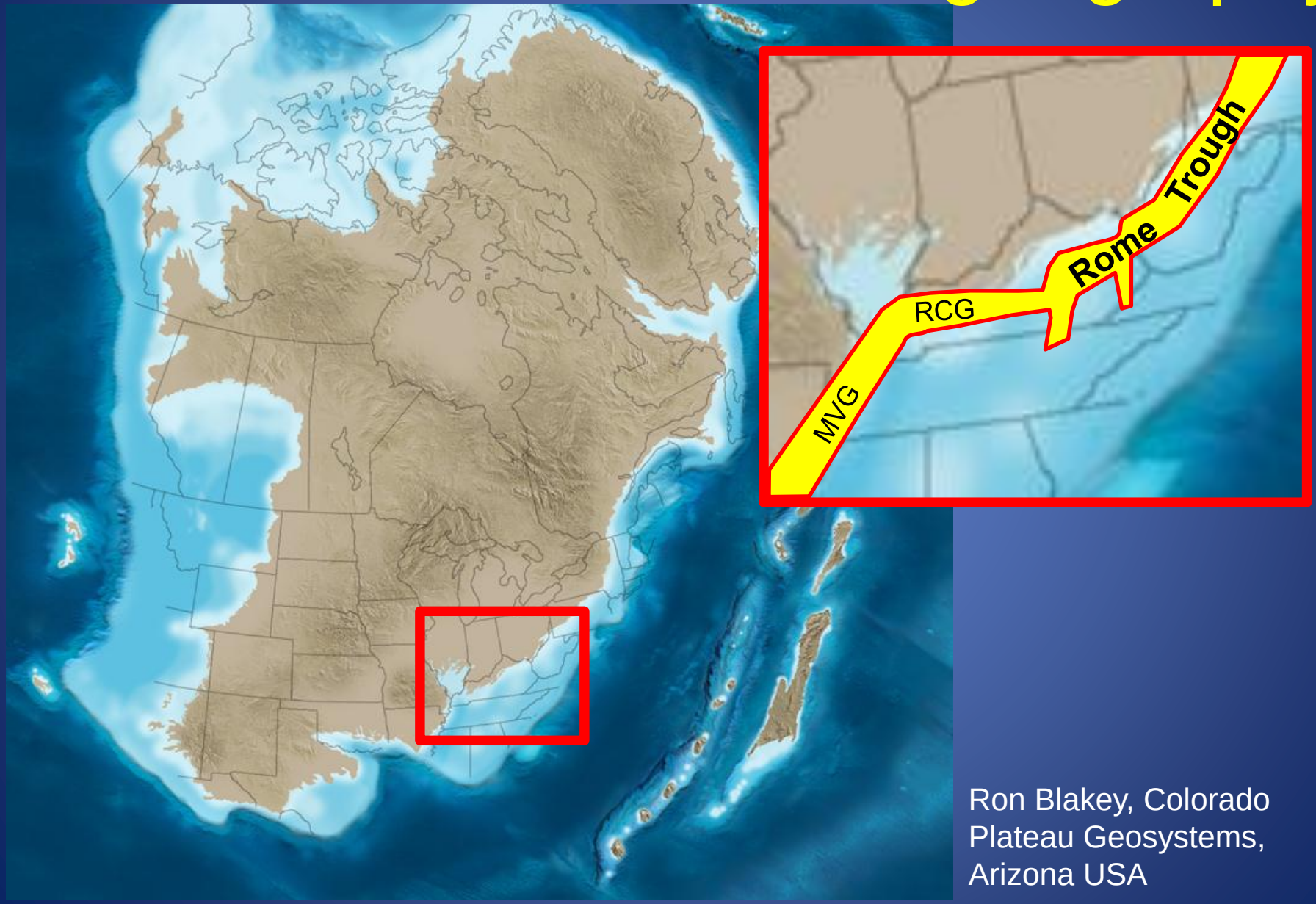
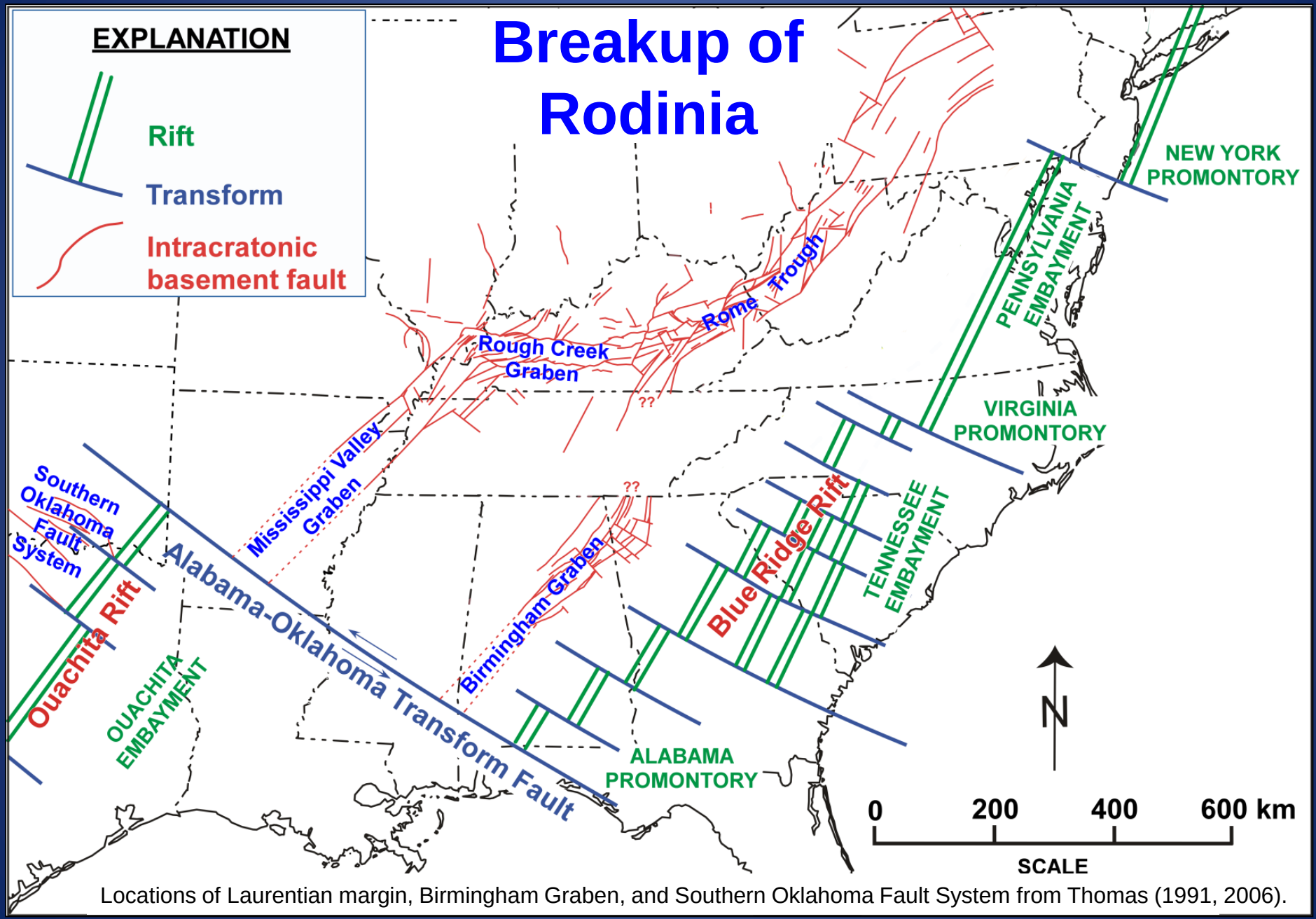
Middle Cambrian Paleogeography

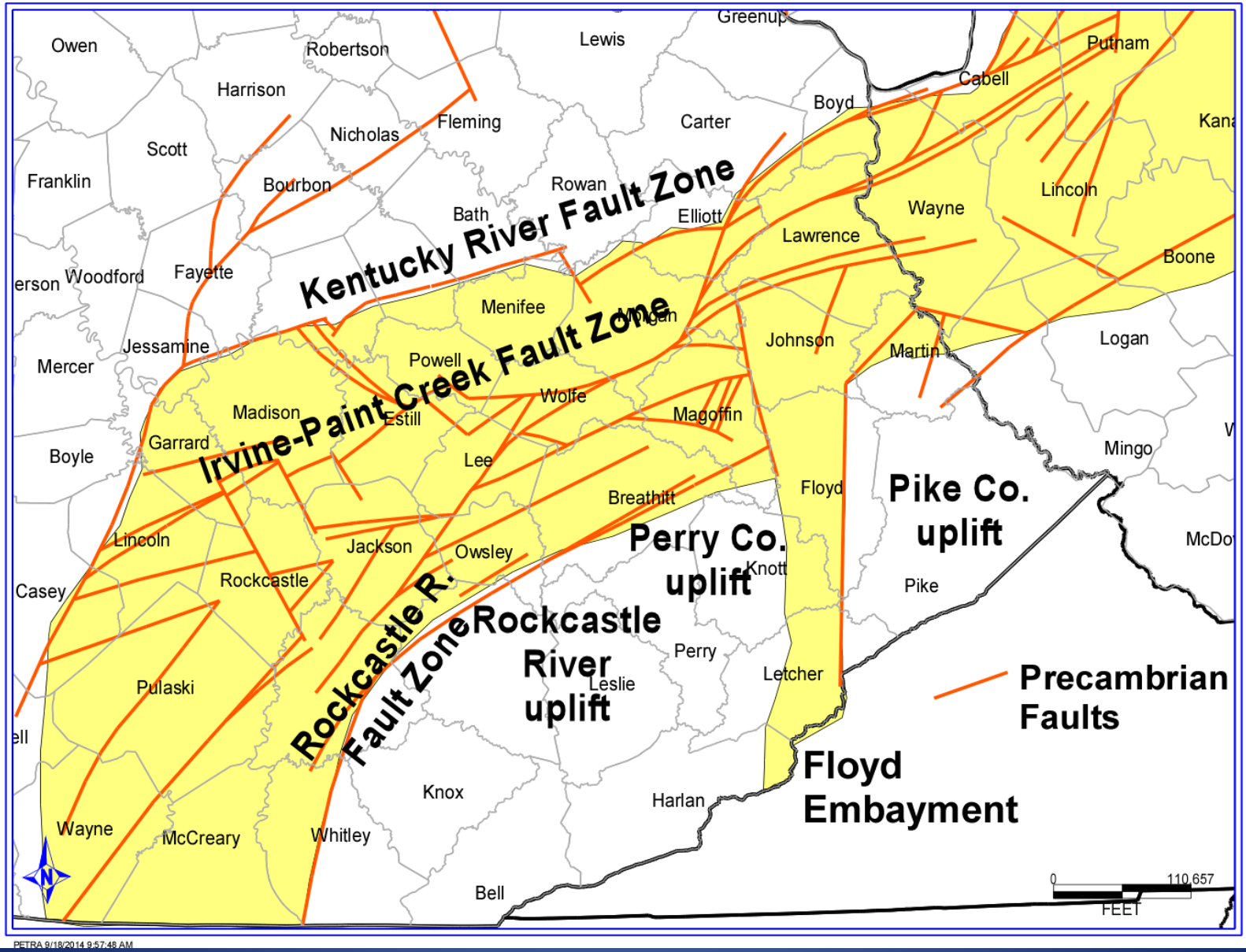


Ron Blakey, Colorado Plateau Geosystems, Arizona USA



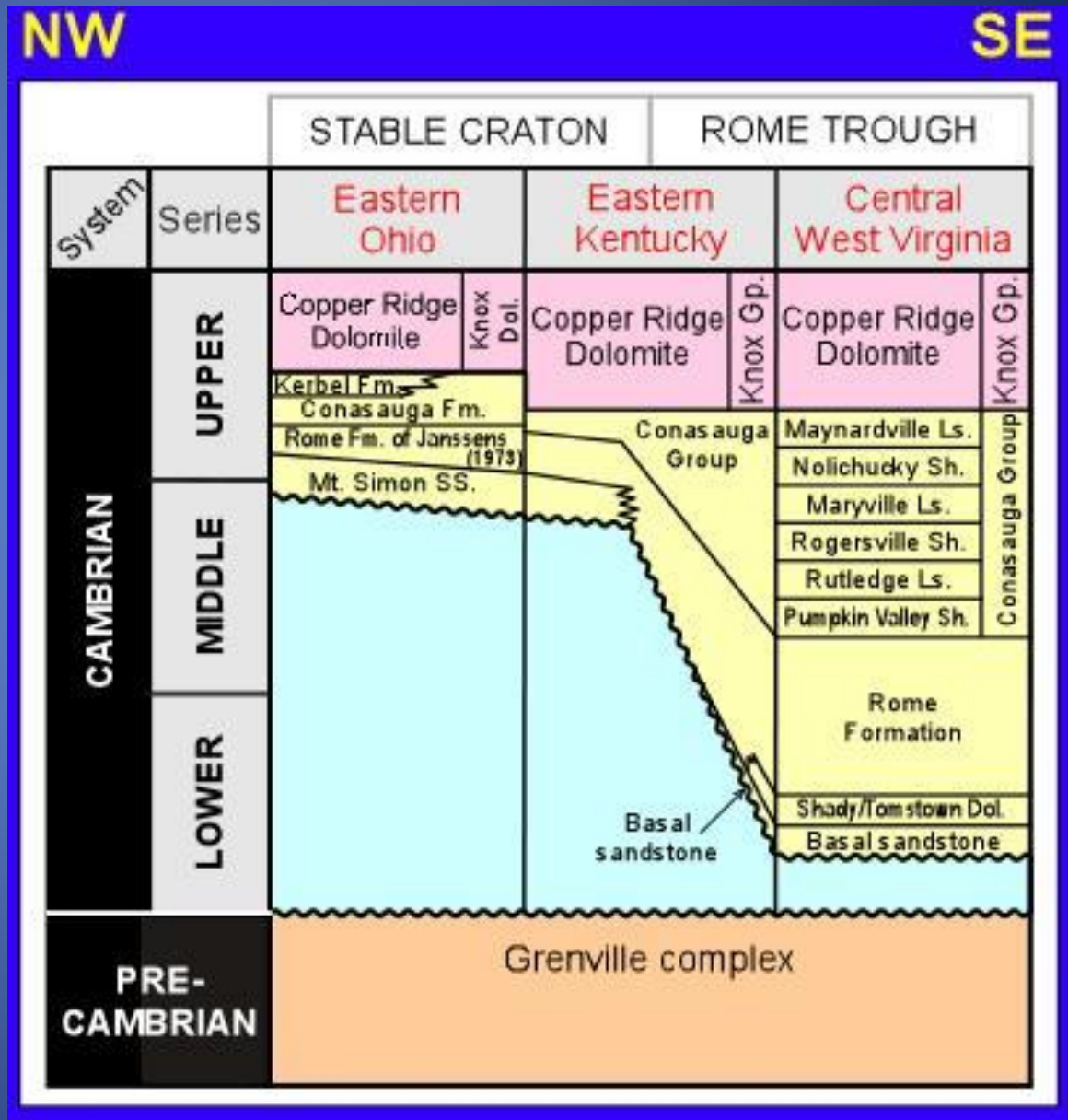
Locations of Laurentian margin, Birmingham Graben, and Southern Oklahoma Fault System from Thomas (1991, 2006).

Rome Trough Structural Features



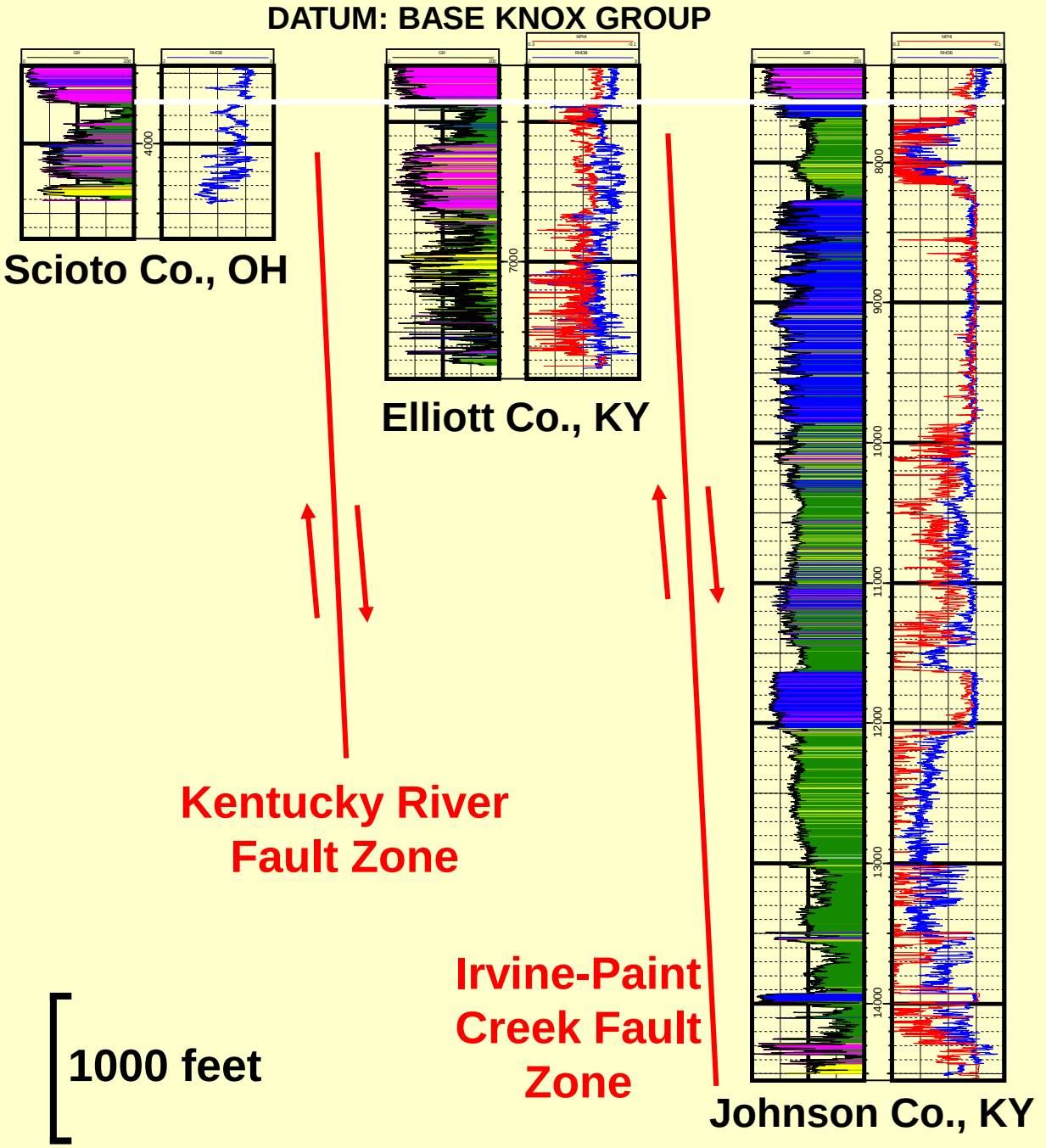
Pre-Knox Stratigraphy

- Inconsistent names across 3-state area
- Problems in defining Rome and Conasauga, Mt. Simon, basal sandstone
- Use of Rome in Ohio (Janssens, 1973)



Stratigraphic Problem

- Correlations across growth faults
- Biostrat data lacking
- Important for prediction of sandstone and shale distribution



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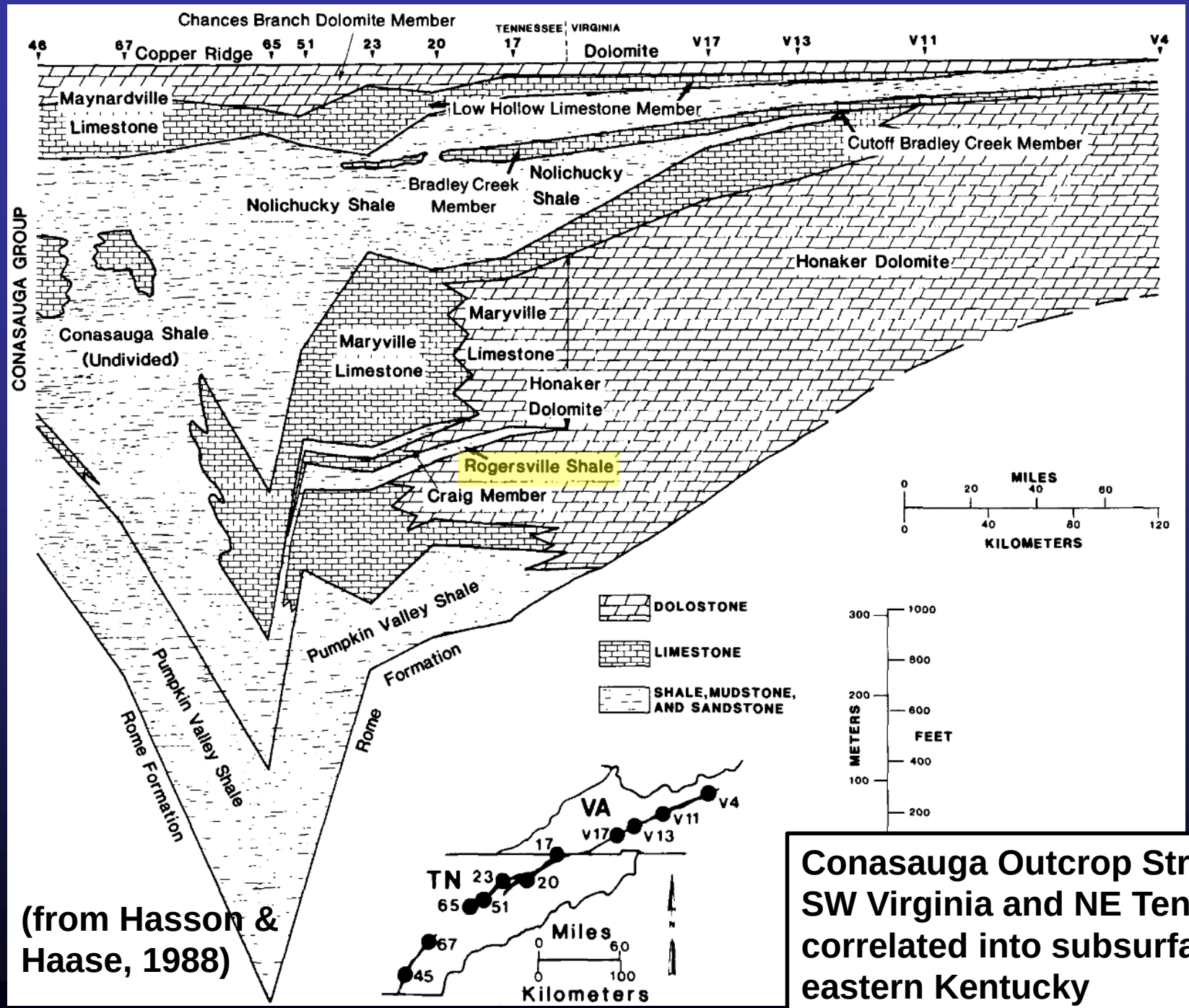


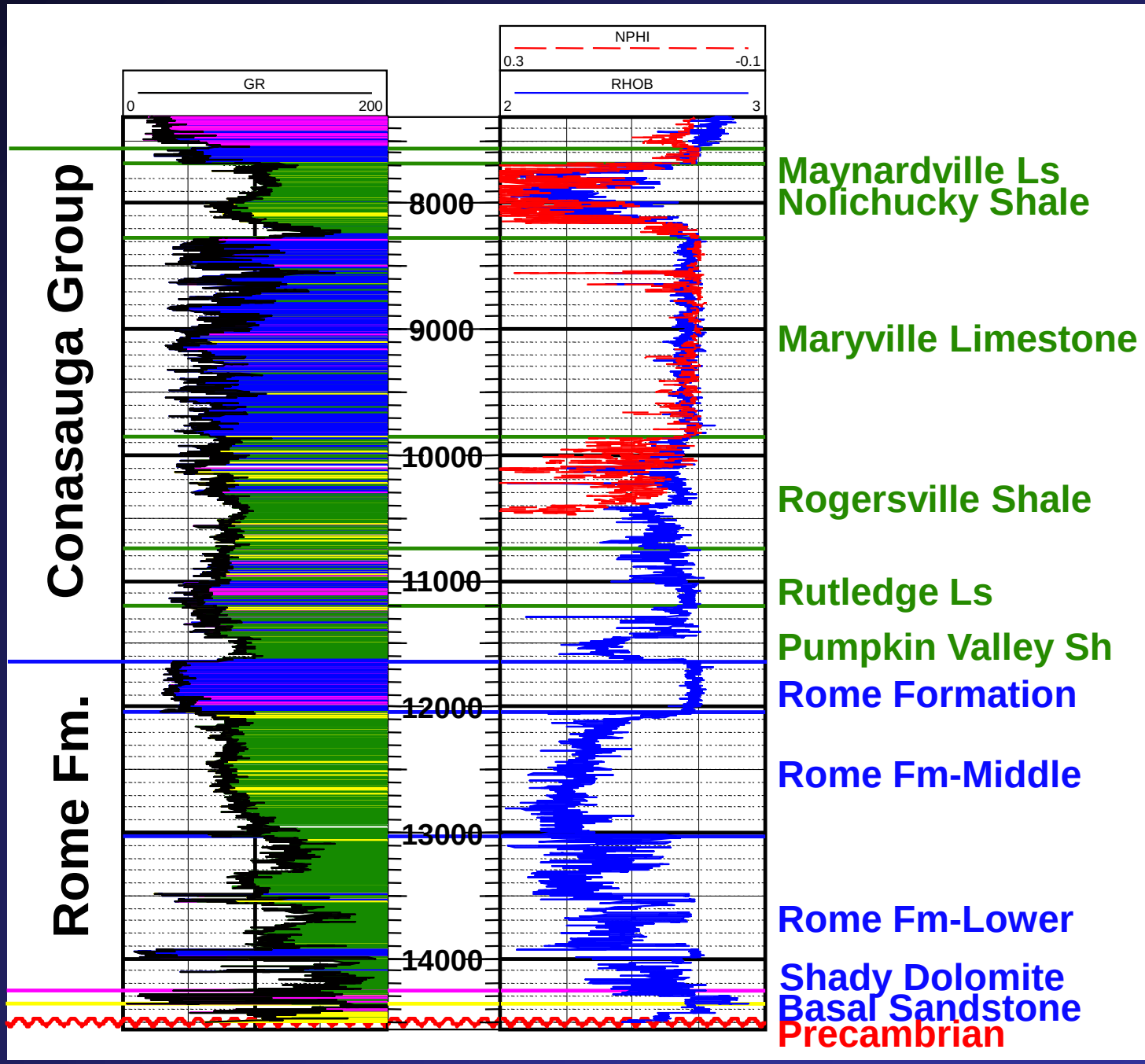
(from Hasson & Haase, 1988)

Conasauga Outcrop Stratigraphy SW Virginia and NE Tennessee correlated into subsurface in eastern Kentucky

Pre-Knox Type Log

U.S. Signal
Elkhorn Coal
Johnson Co.
Kentucky

Gamma ray shaded By log-calculated lithologies



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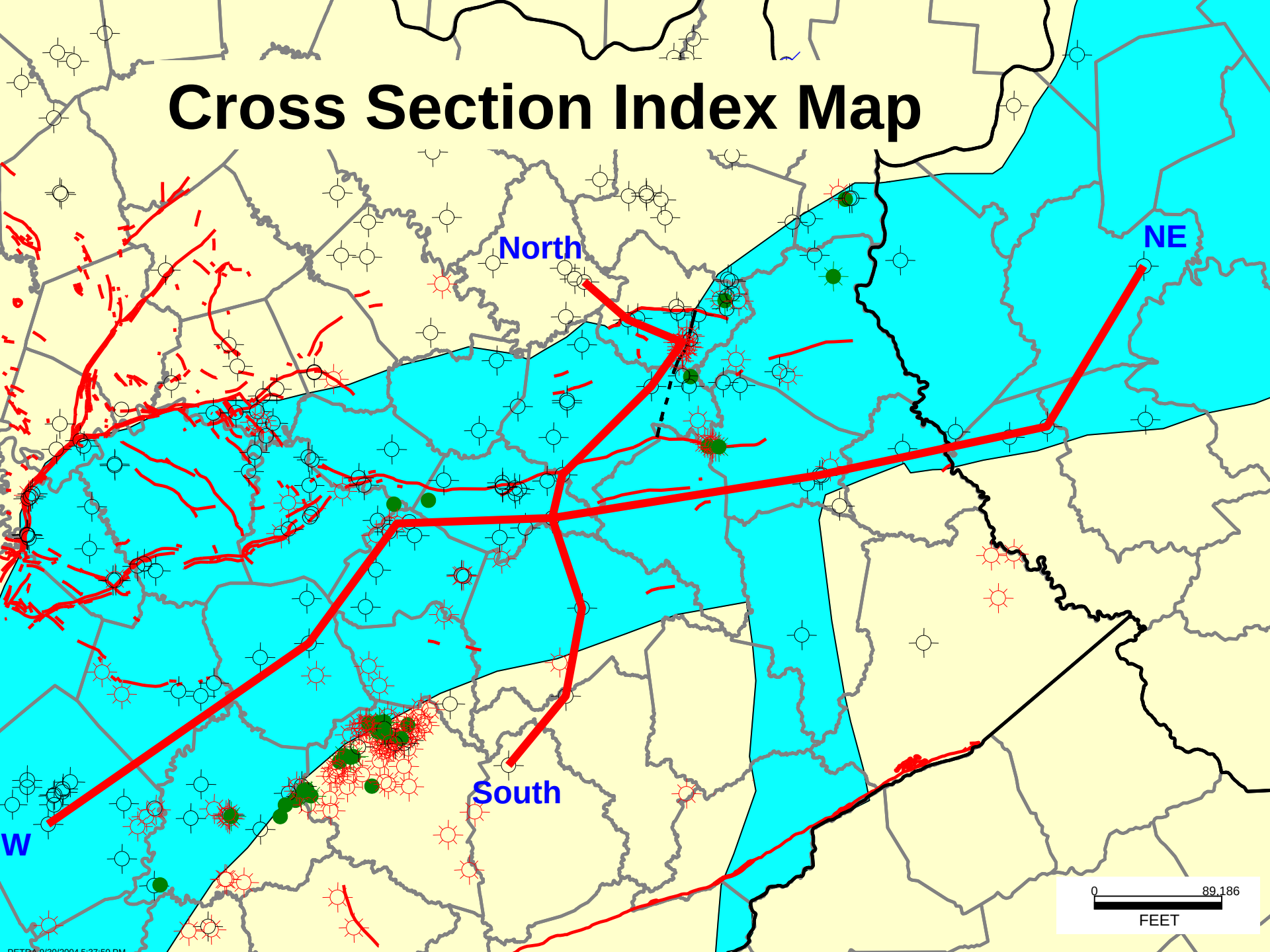
Cross Section Index Map
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South
W
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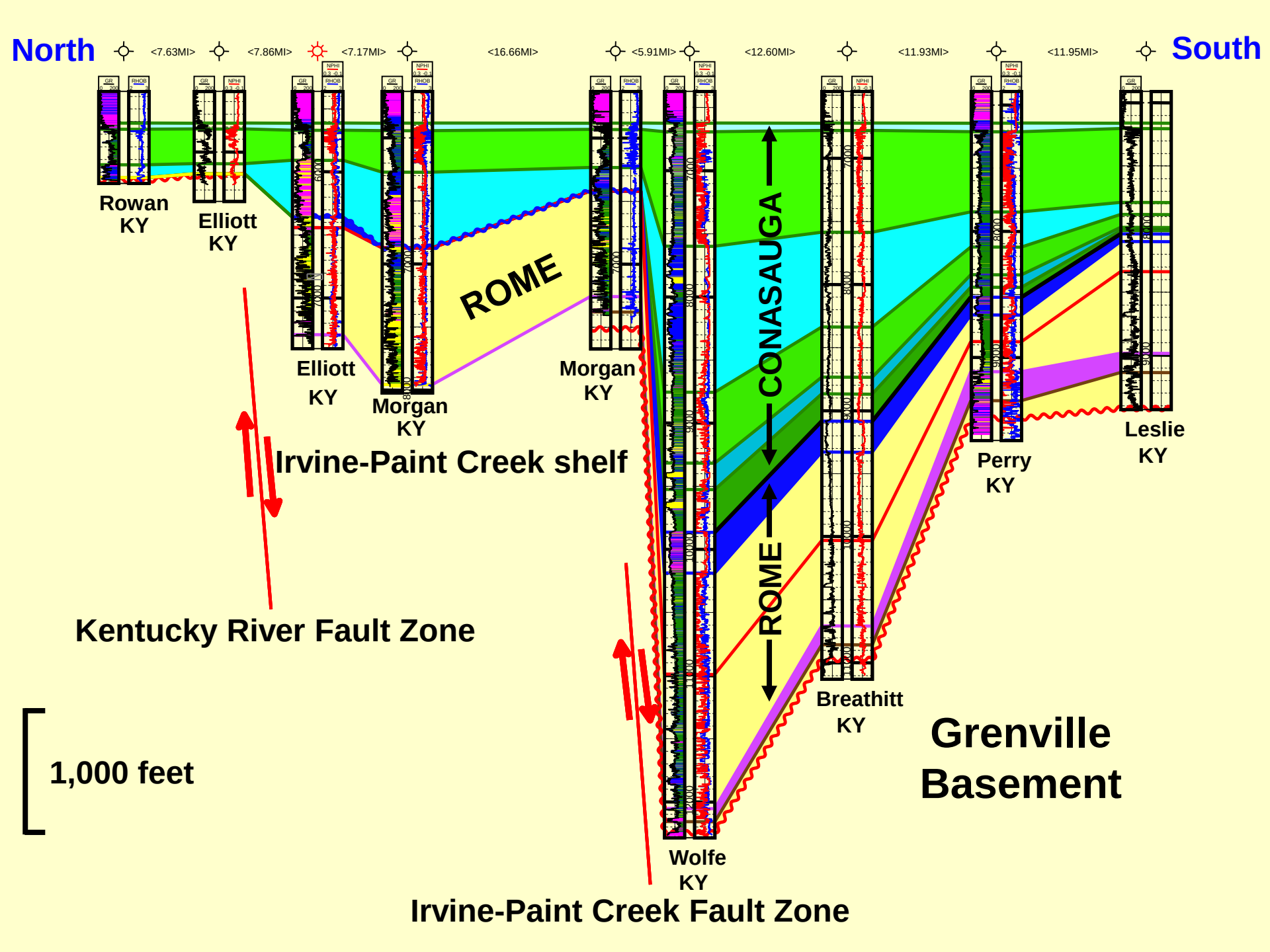
FEET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South
Rowan KY
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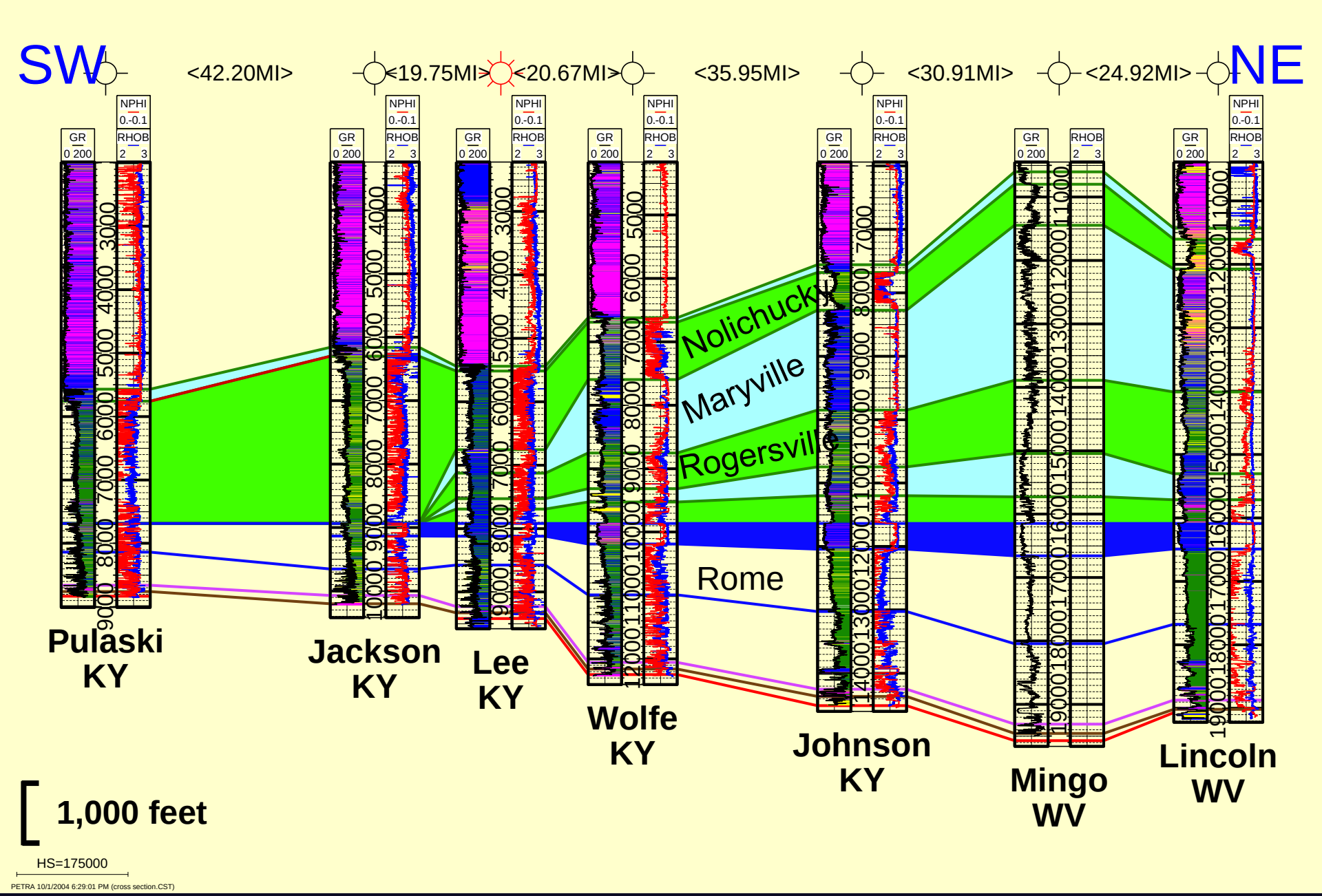
Elliott KY
Morgan KY
Morgan KY
Leslie KY
Perry KY
Breathitt KY
Wolfe KY
ROME
CONASAUGA
ROME
Irvine-Paint Creek shelf
Kentucky River Fault Zone
Irvine-Paint Creek Fault Zone
Grenville Basement
1,000 feet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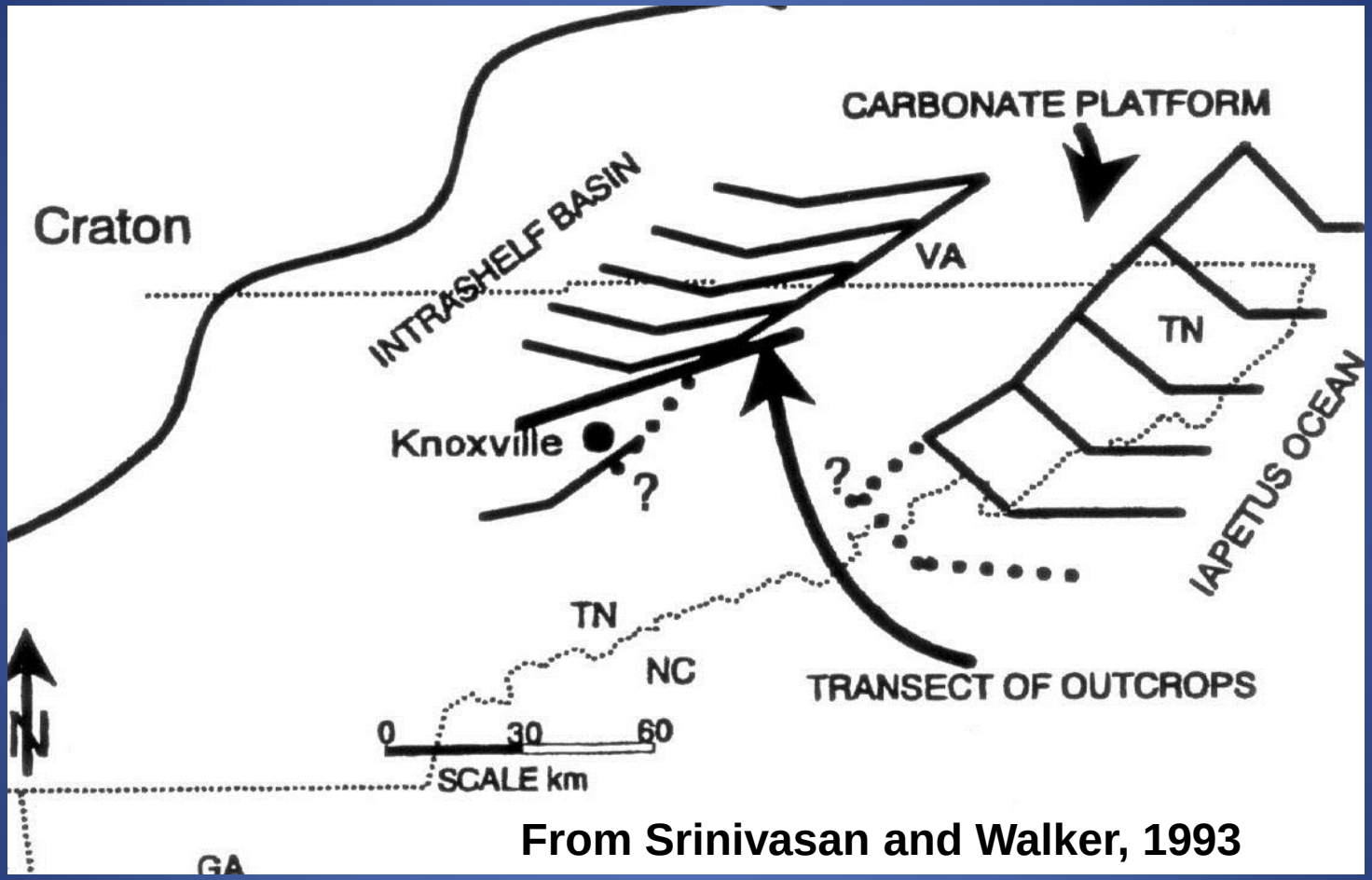
NE
NPHI
0.-0.1
RHOB
2 3
GR
0 200
Nolichucky
Maryville
Rogersville
Rome
Pulaski KY
Jackson KY
Lee KY
Wolfe KY
Johnson KY
Mingo WV
Lincoln WV
1,000 feet
HS=175000
PETRA 10/1/2004 6:29:01 PM (cross section.CST)

Conasauga Paleogeography



From Srinivasan and Walker, 1993

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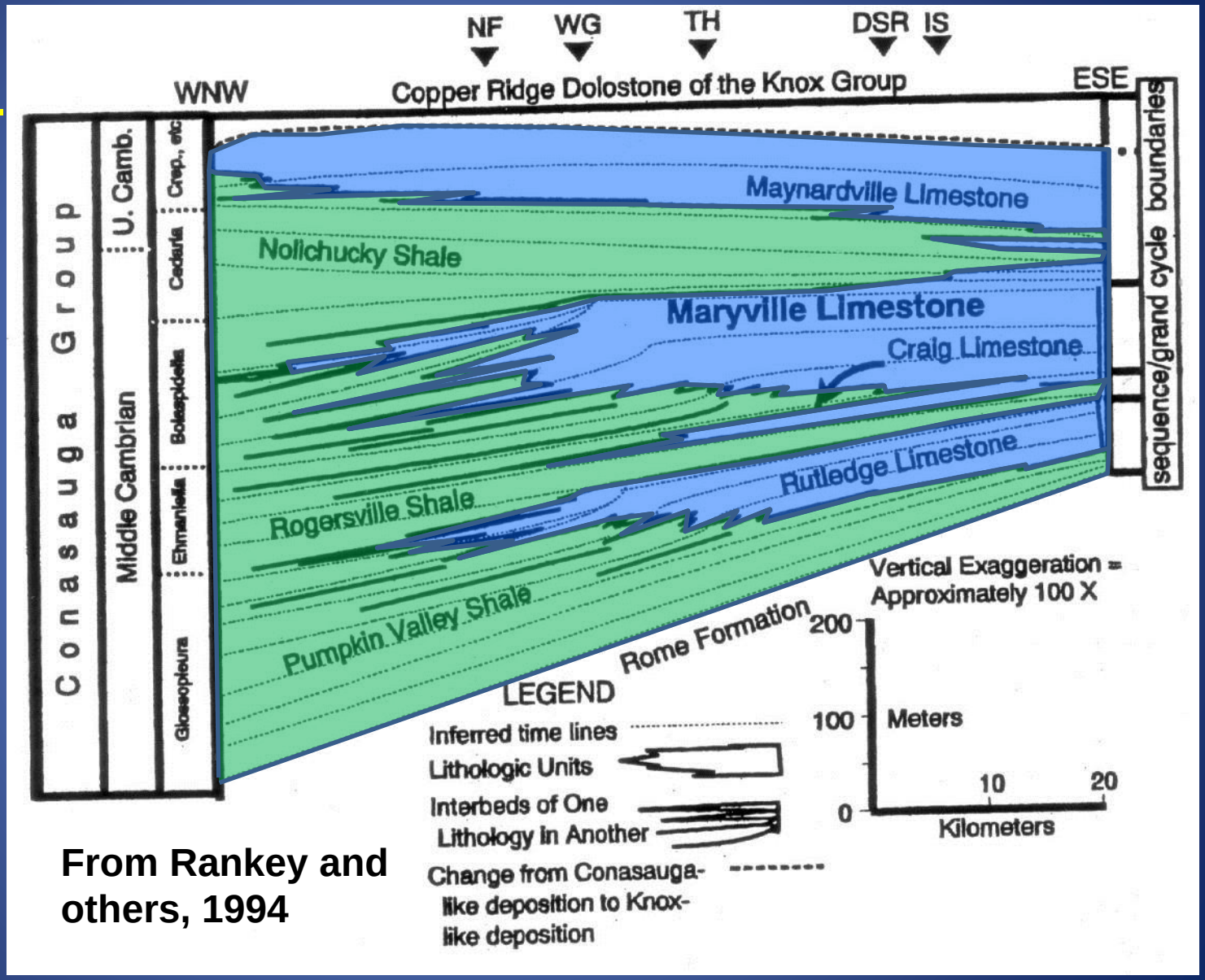
Conasauga Trangressive-Regressive Cycles

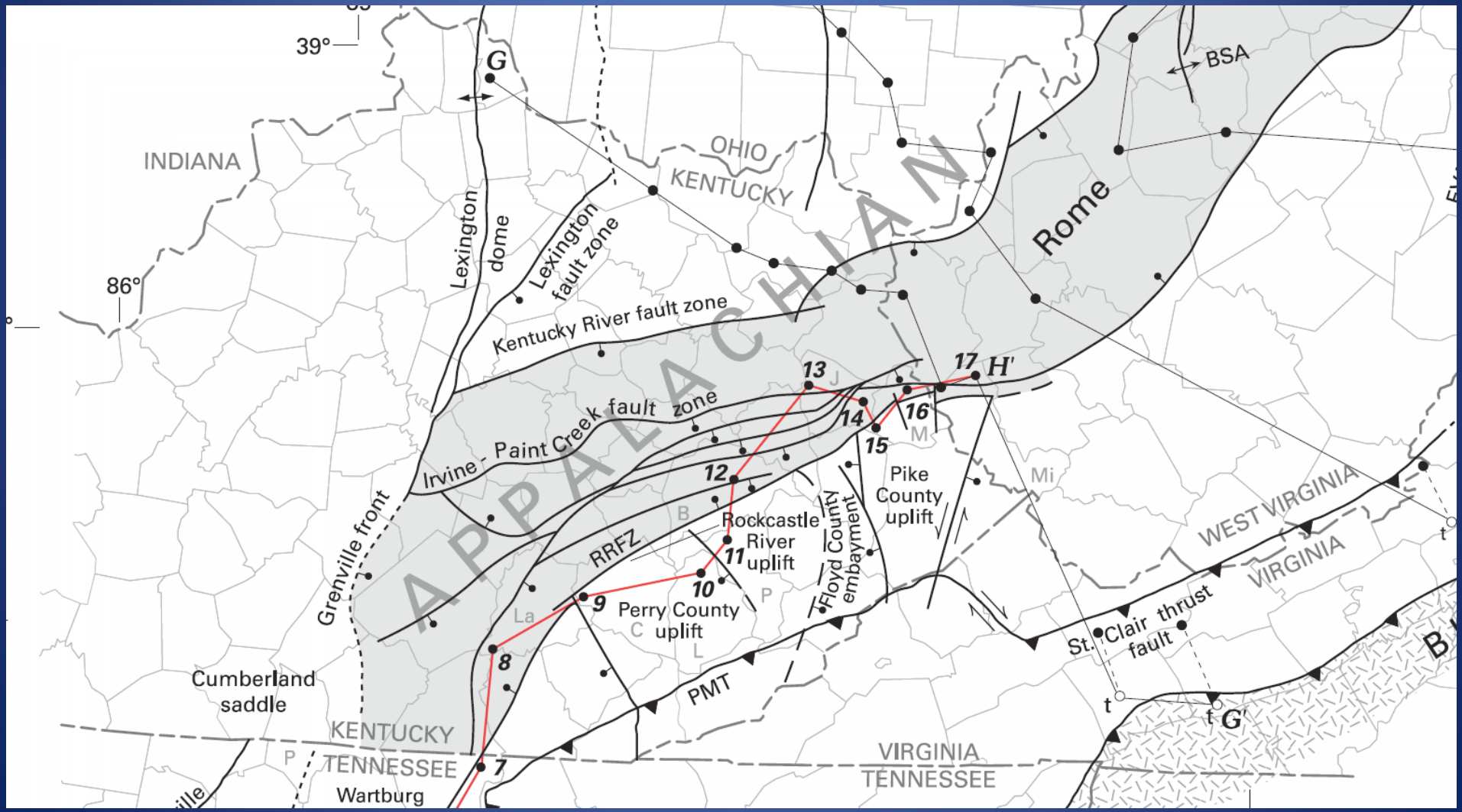
Eastern Tennessee Outcrops

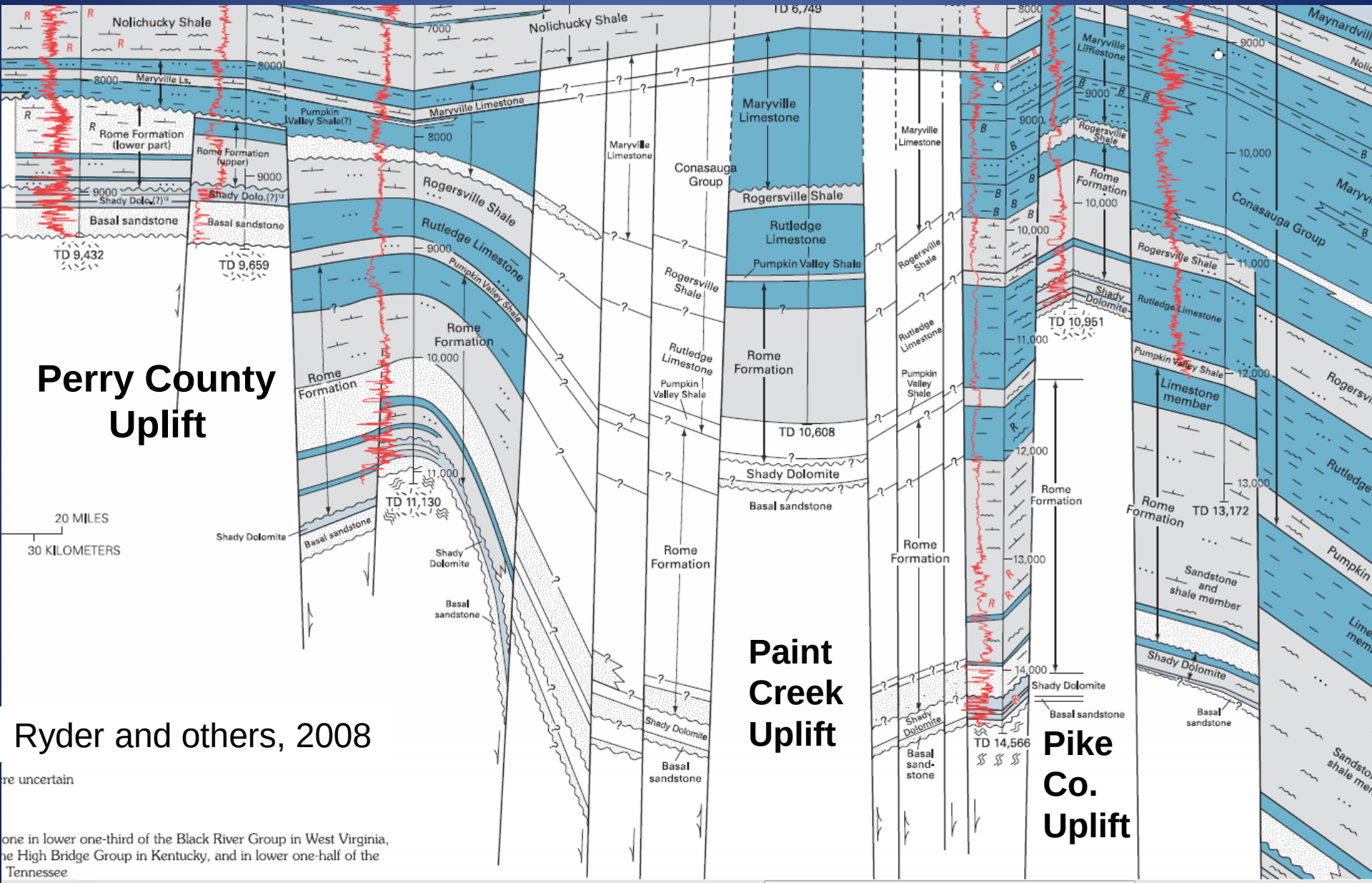


From Rankey and others, 1994

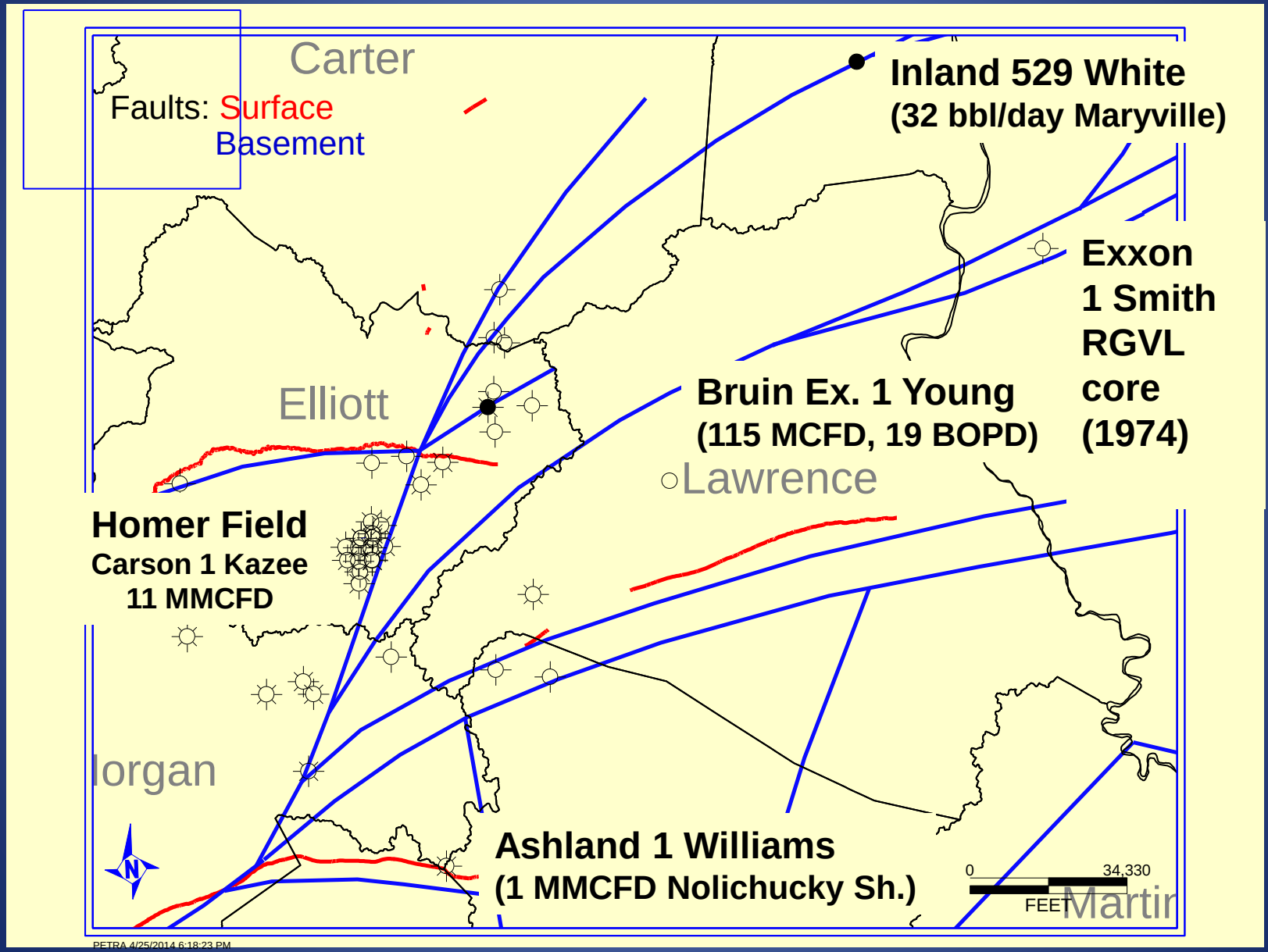
Structural cross section to show faulting and structural complexity

Ryder and others, 2008, Line H-H’

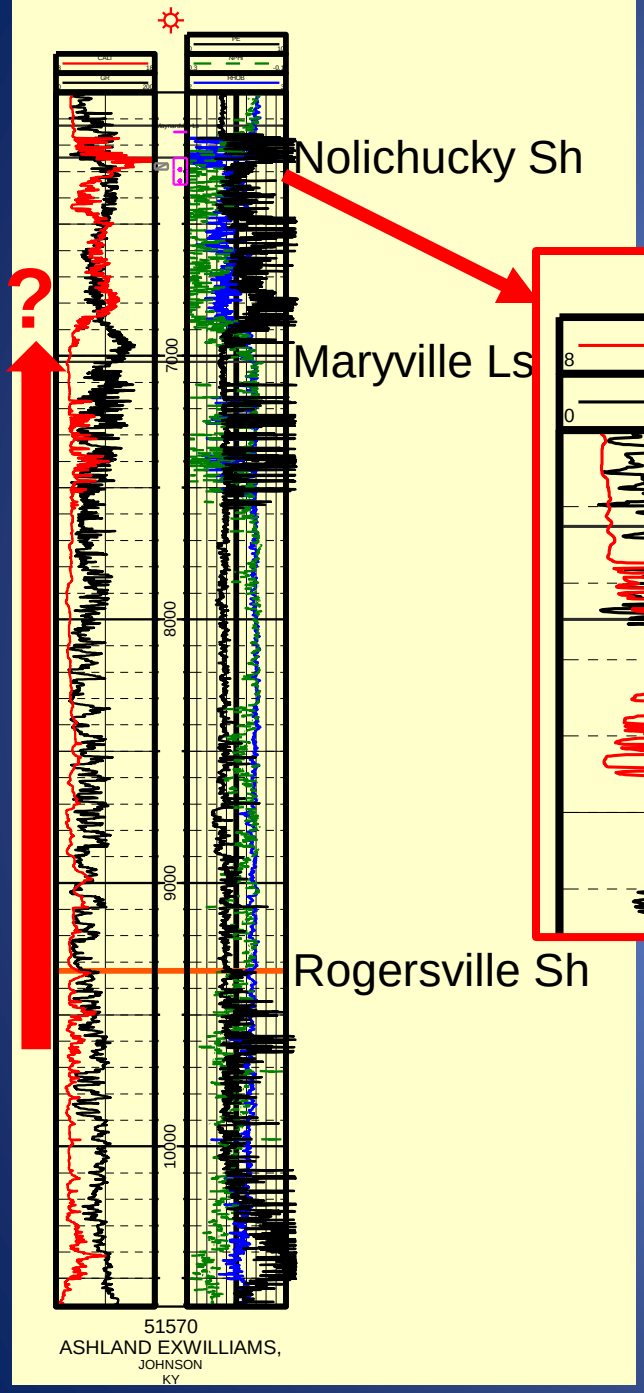


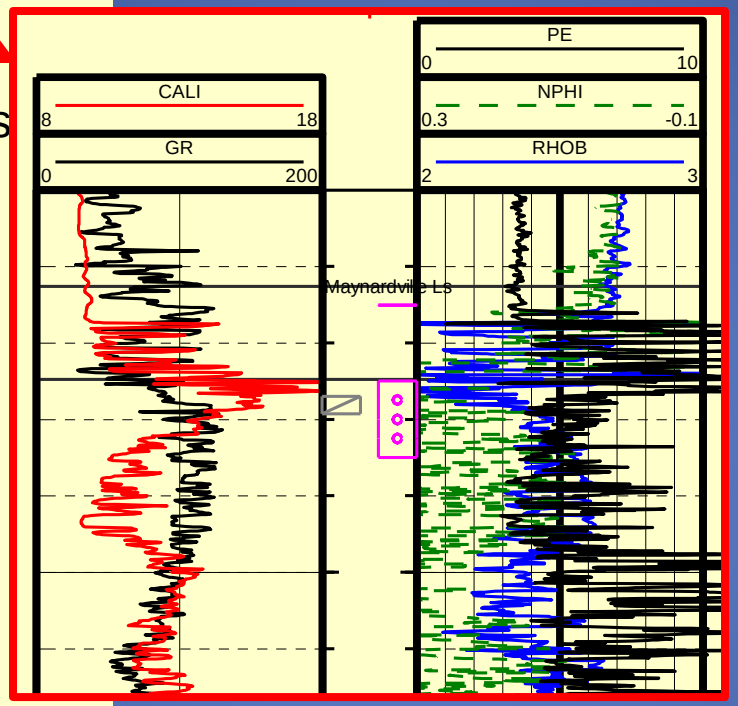

UFG Fordson (Leslie)
ARCO Duff (Perry)
UFG Williams (Breathitt)
Ashland Williams (Johnson)
Signal Elkhorn (Johnson)
ARCO KyWVa (Johnson)
UFG James (Martin)
Perry County Uplift
Paint Creek Uplift
Pike Co. Uplift
Nolichucky Shale
Maryville Ls.
Maryville Limestone
Pumpkin Valley Shale(?)
Rome Formation (lower part)
Rome Formation (upper)
Shady Dolo.(?)
Basal sandstone
Rogersville Shale
Rutledge Limestone
Pumpkin Valley Shale
Rome Formation
Conasauga Group
Shady Dolomite
Basal sandstone
Limestone member
Sandstone and shale member
TD 9,432
TD 9,659
TD 11,130
TD 6,749
TD 10,608
TD 10,951
TD 13,172
TD 14,566
20 MILES
30 KILOMETERS
Ryder and others, 2008
re uncertain
one in lower one-third of the Black River Group in West Virginia,
he High Bridge Group in Kentucky, and in lower one-half of the
Tennessee

Rome Trough Production



Ashland #1 Williams, Johnson Co.





IP 1.05 MMCFD from fractured Nolichucky Shale @ 6,250-6,350 ft
SIP = 3800 psi

Cumulative prod: 1.2BCF with 42,000 bbl condensate since 1985

Core in Nolichucky has low TOC - not the source (gas possibly migrated up from Rogersville)

2011 Production: 7.7 MMCFG with 171 bbl condensate

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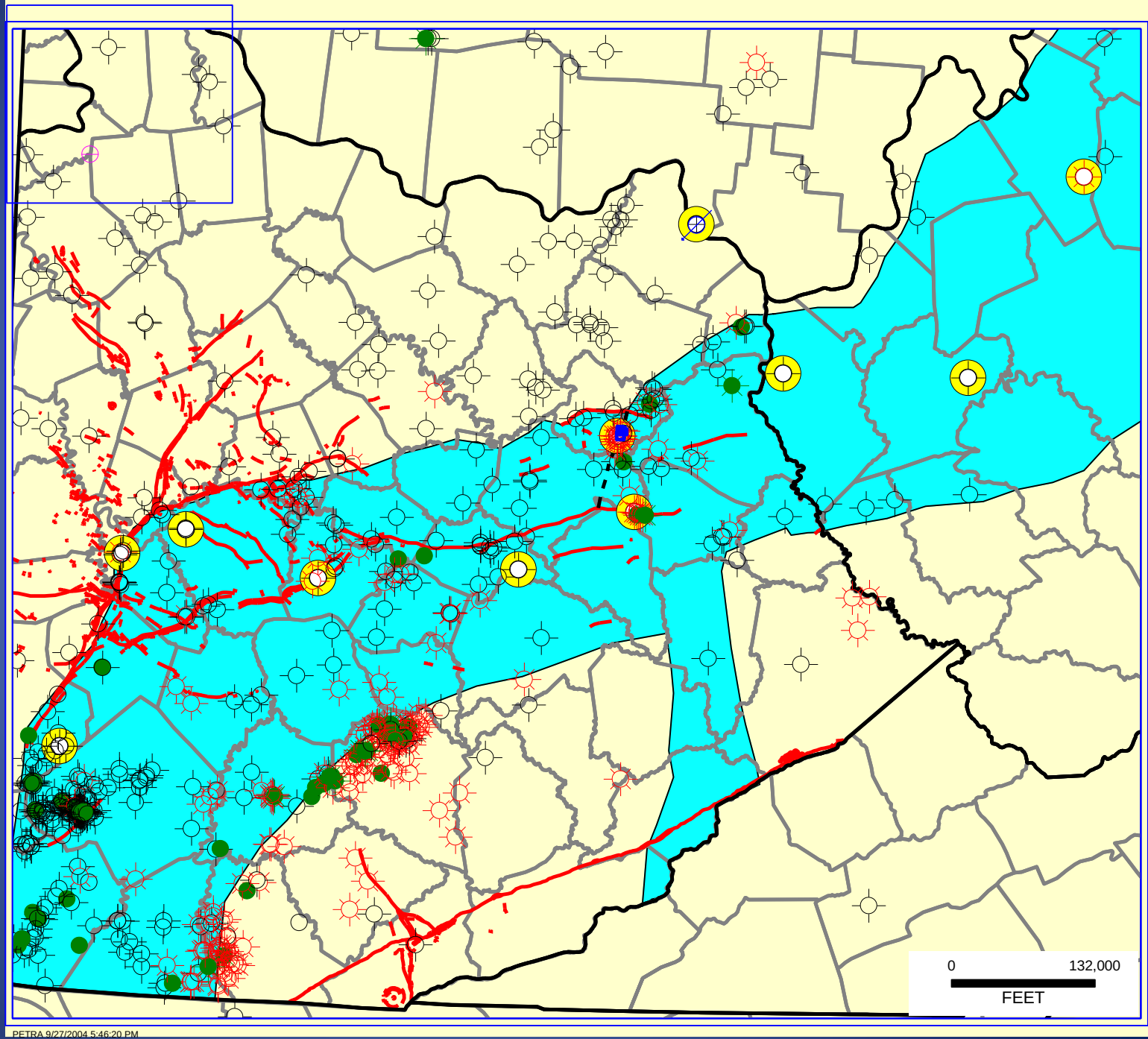
TOC/ Rock-Eval Analyses In original RTC study



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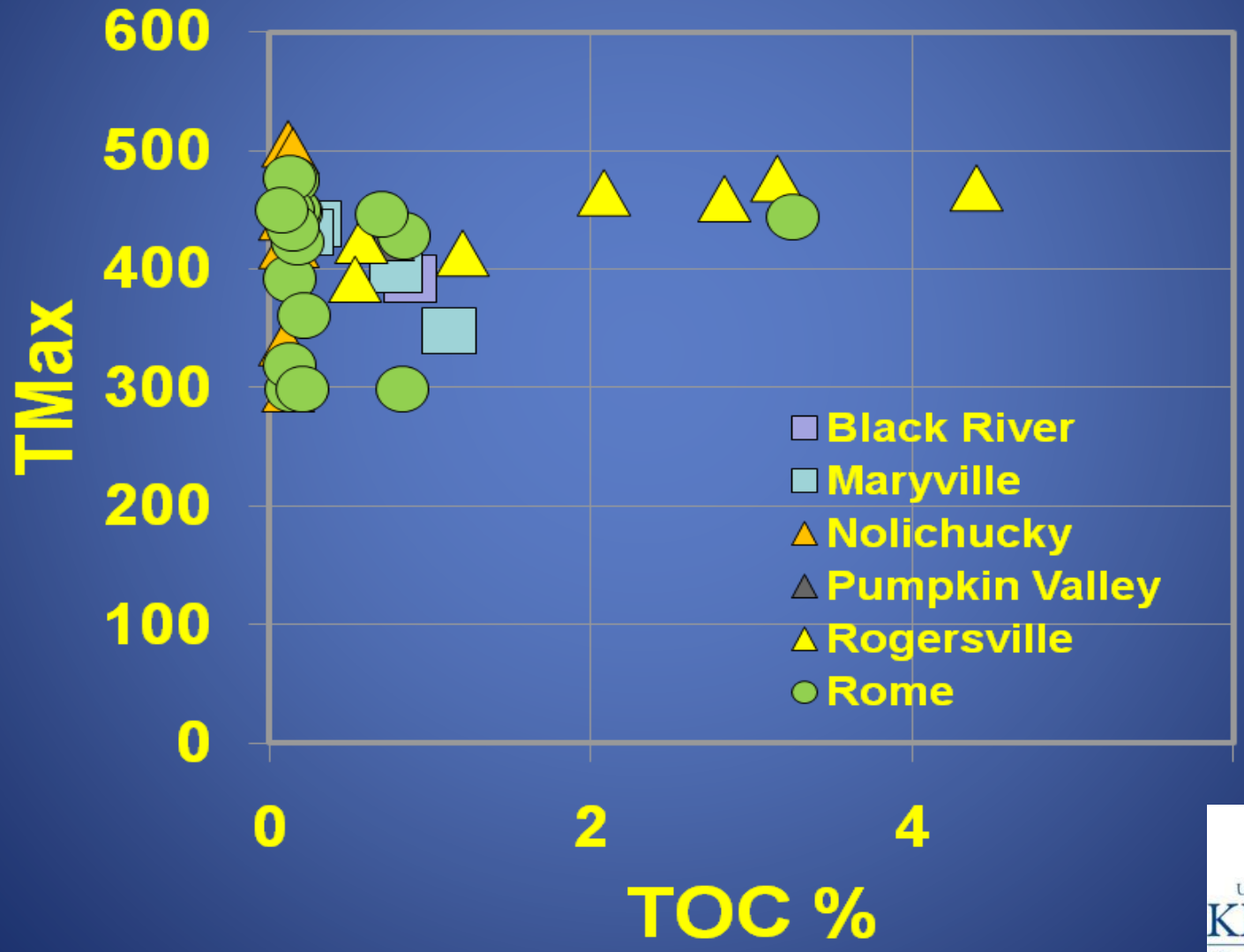
Cambrian Source Rocks in Rome Trough



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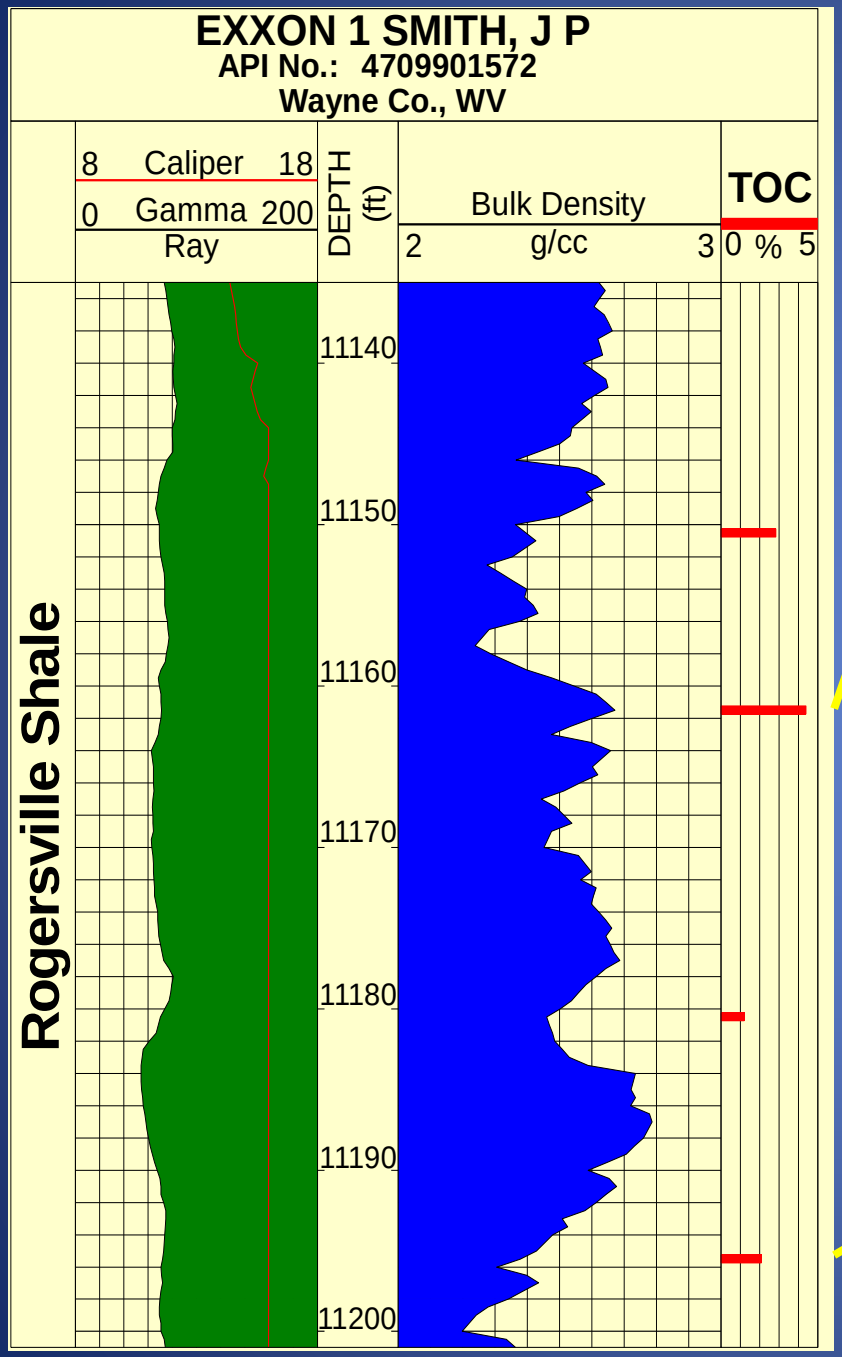
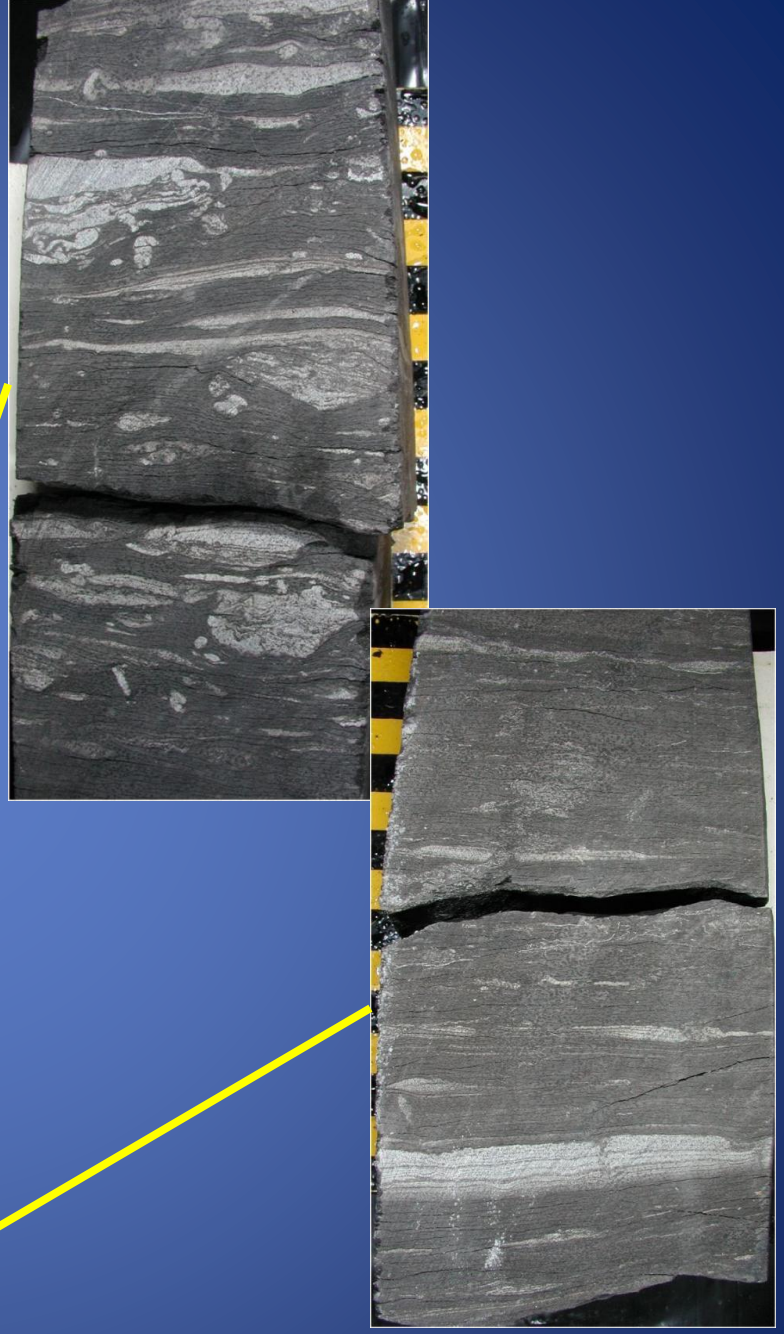


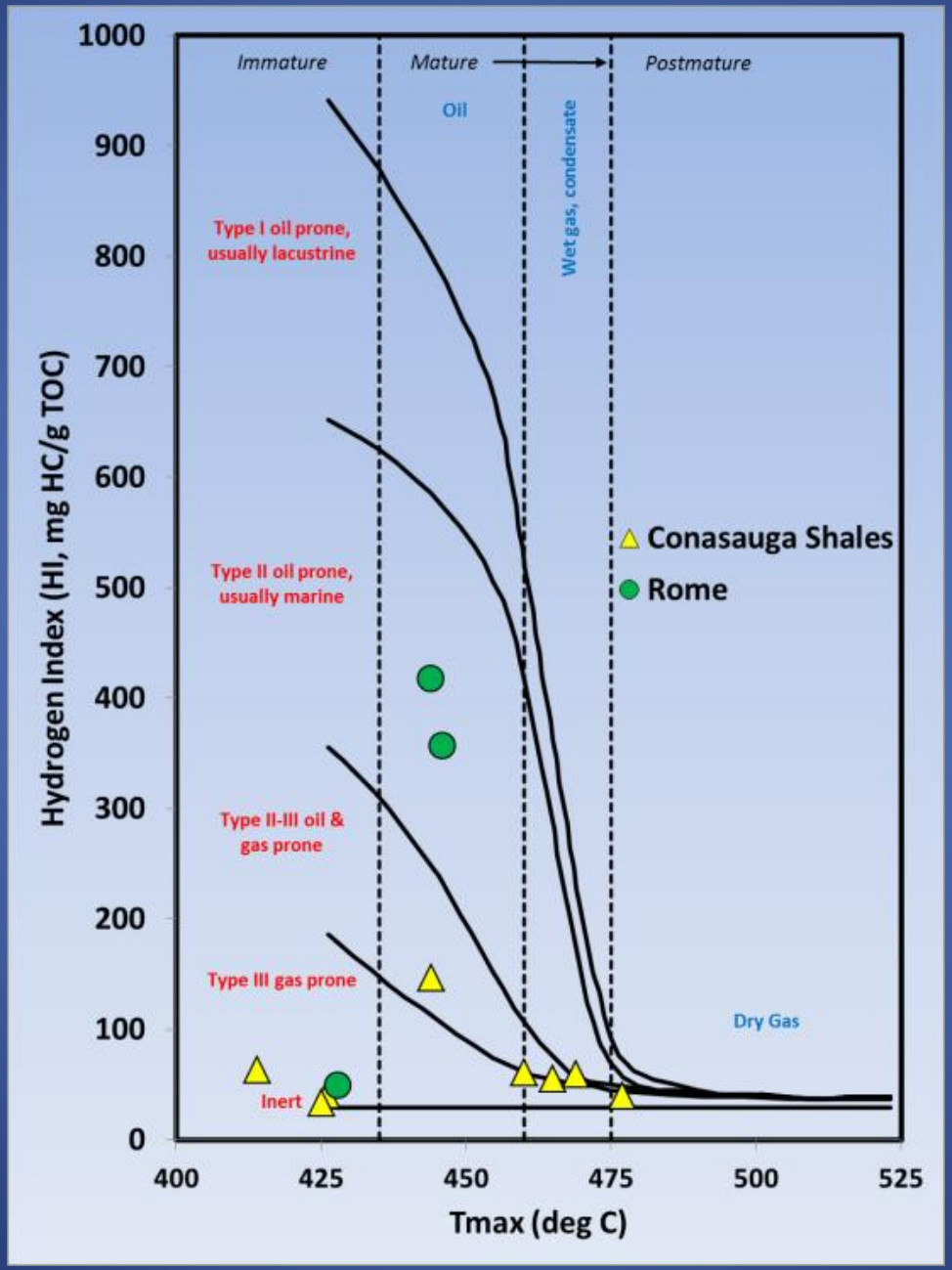


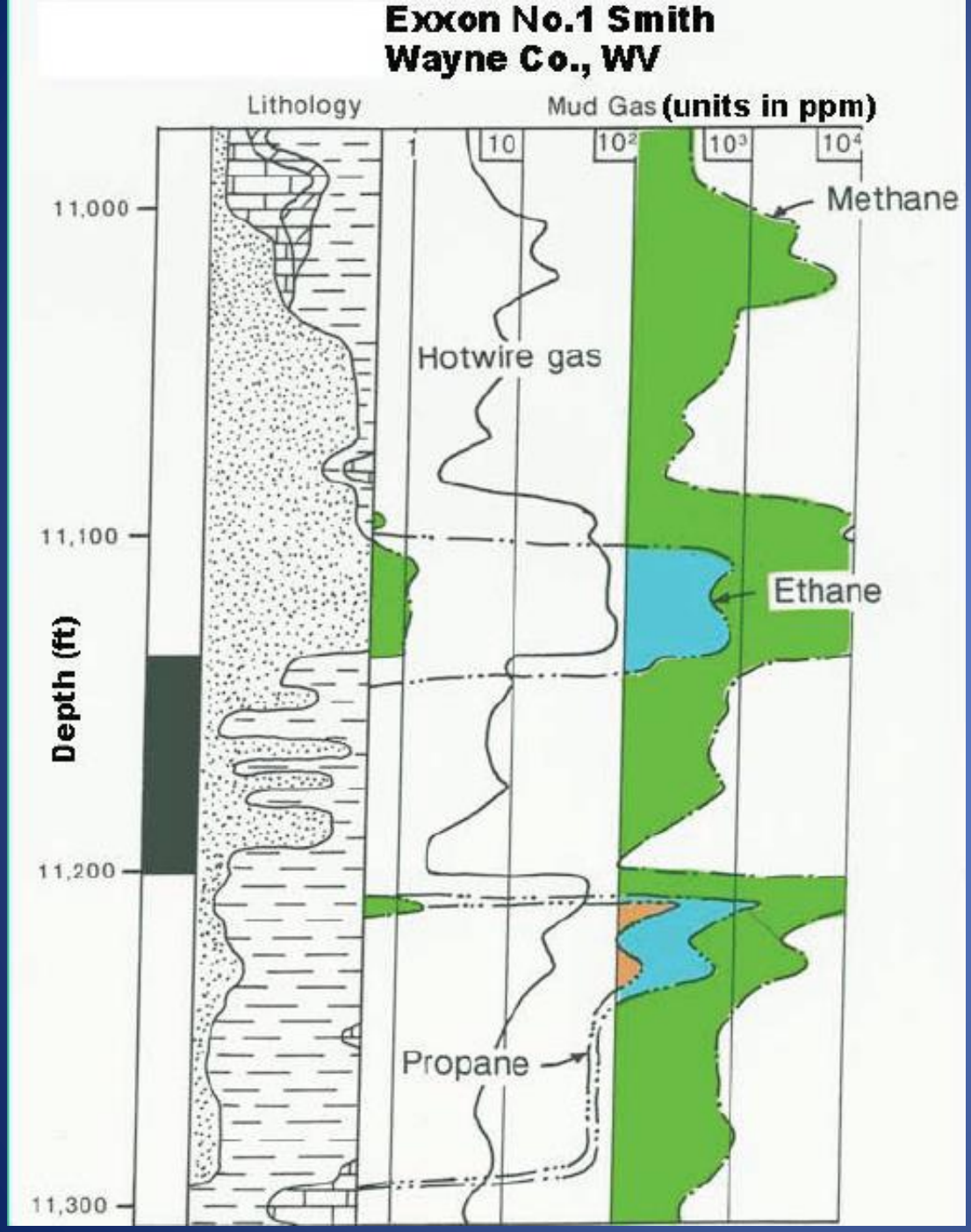
TOC range 1.2–4.4%, n=4

Exxon #1 Smith core: 11,191-11,200’

Exxon #1 Smith core: 11,146-11,157’

Maturity and Kerogen Data





Mud Log Show

Rogersville Shale Interval, Exxon #1 Smith Wayne County, WV

From Ryder and others, 2005
USGS open file report

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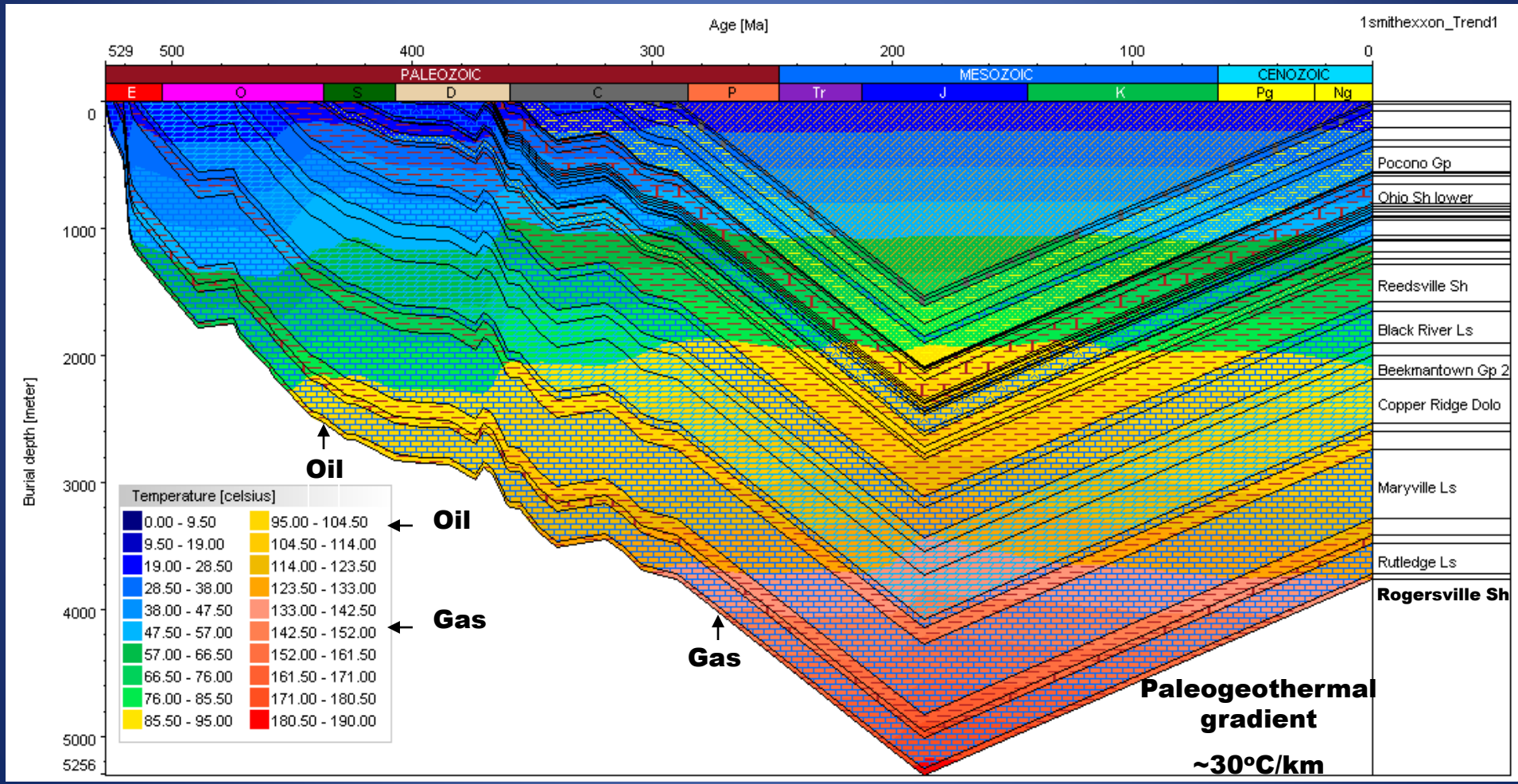
Burial History Model for the No. 1 Smith well



PetroMod model by: Mark Pawlewicz, USGS, Denver

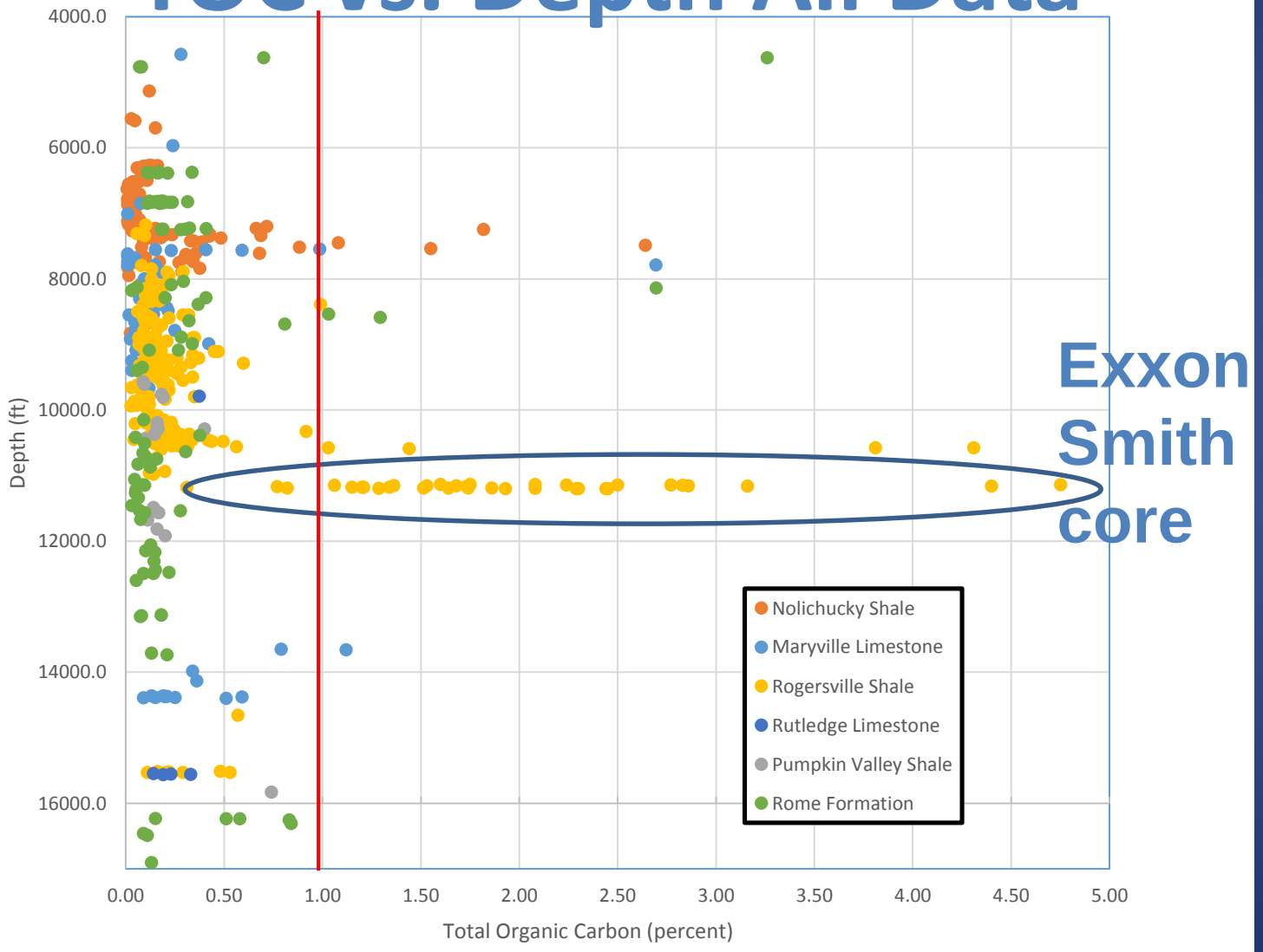
Newer TOC/Rock-Eval Data

- GeoMark data set, 2007
  - Confirmed TOC in Exxon Smith core (1.3 and 2.4%)
- Talisman data set, 2009
  - Rock-Eval/TOC for 96 cuttings samples, 8 Ky. wells
  - No reliable results > 1%
- KGS-industry RE/XRD study, 2010
  - 6 Rogersville core samples (Smith) ranged from 1.3 to 4.8% TOC
  - 4 Nolichucky samples (Williams) were all lean (0.12-0.16% TOC)

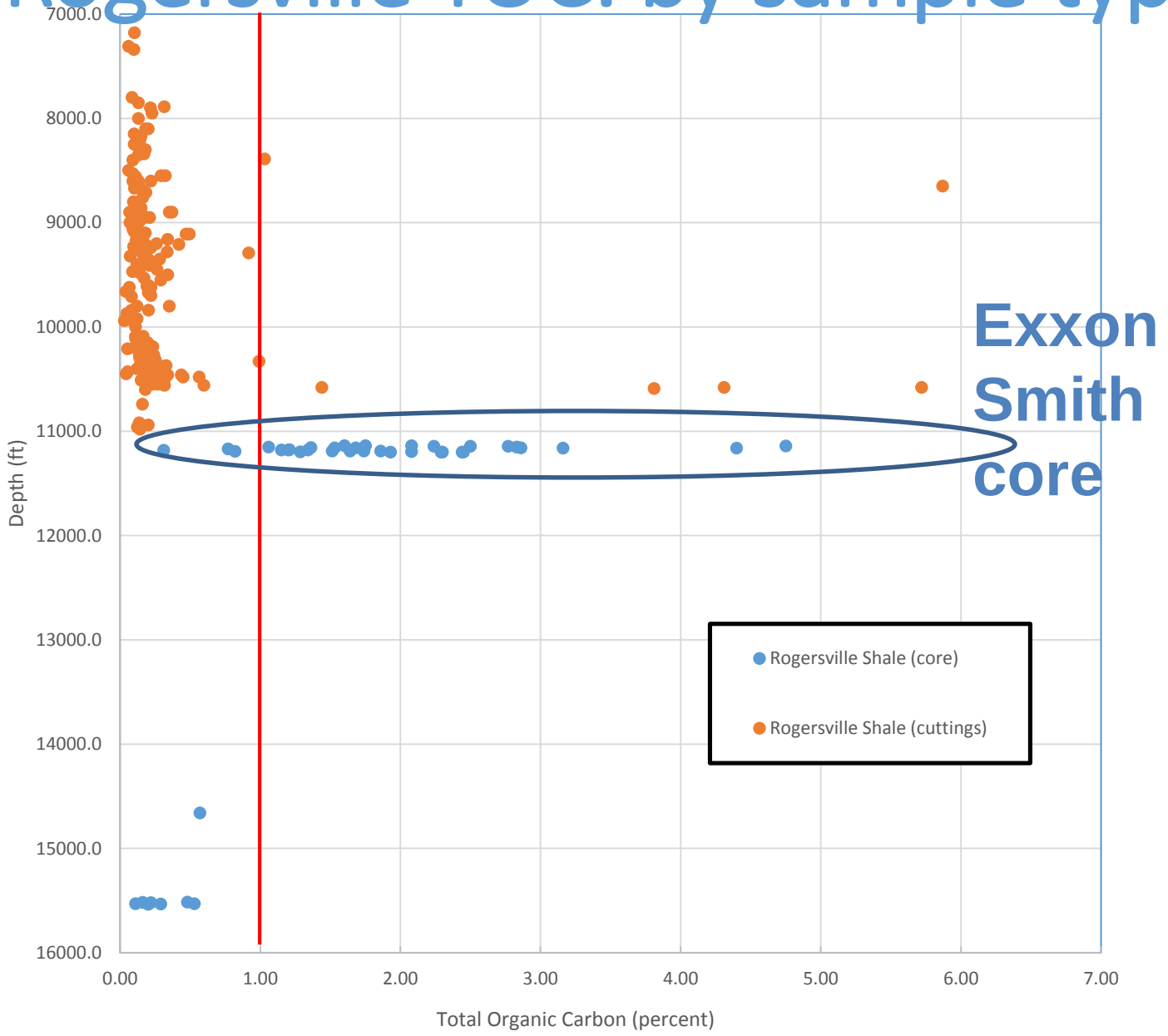
Newer TOC/RE Data (cont.)

- Petro-Hunt data set, 2011
  - Rock-Eval/TOC data for 137 samples, 12 Ky. wells
  - Disappointing results: highest TOC was 0.24%
- Cimarex data (2012 and 2014)
  - Sampled Rogersville interval in 12 Ky. and W. Va. wells
  - Of 156 samples only 4 had TOC > 1% (Exxon Smith and Ashland Williams wells)

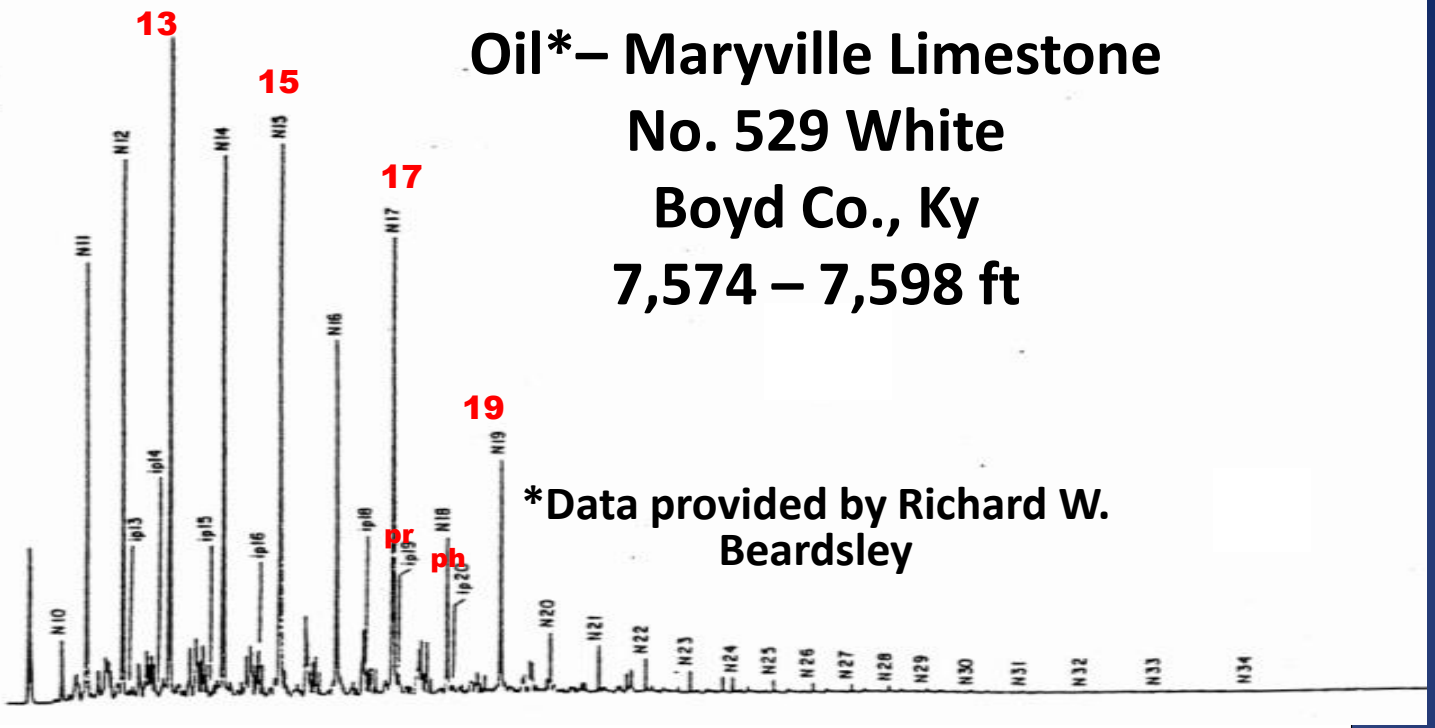
TOC vs. Depth All Data



Rogersville TOC: by sample type

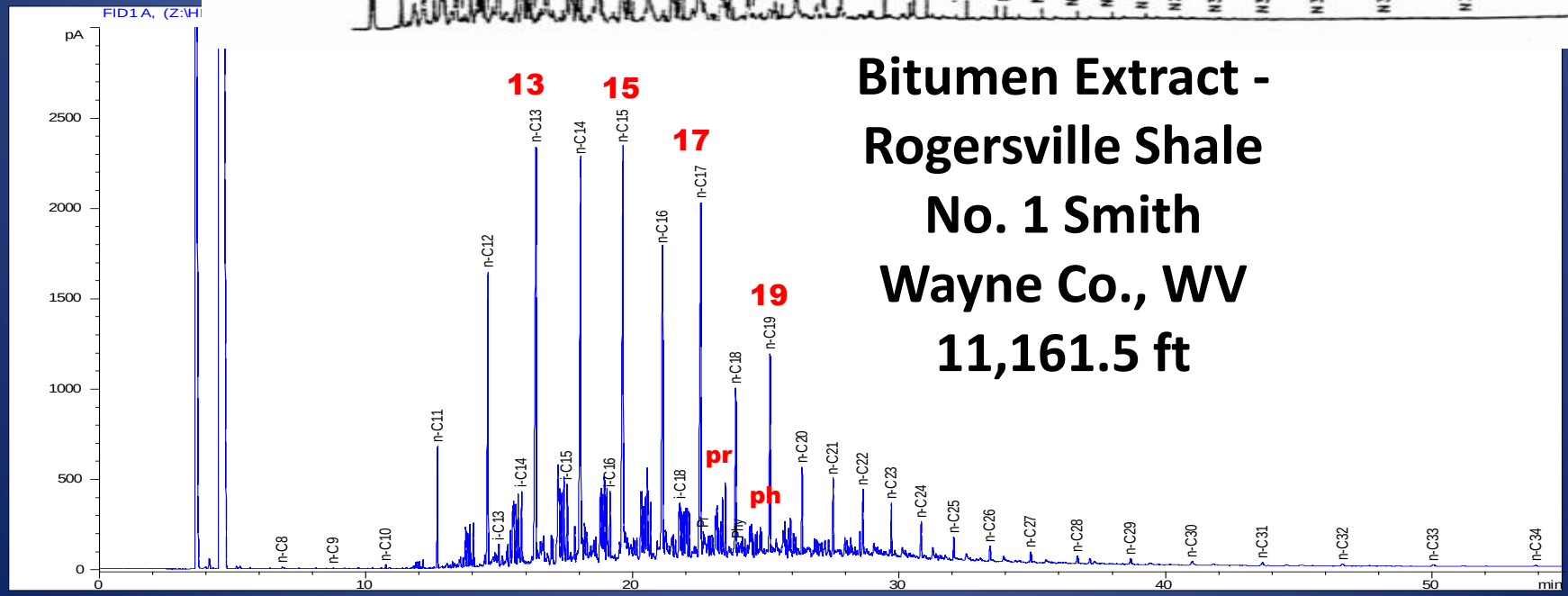


Oil – Source Rock Correlation



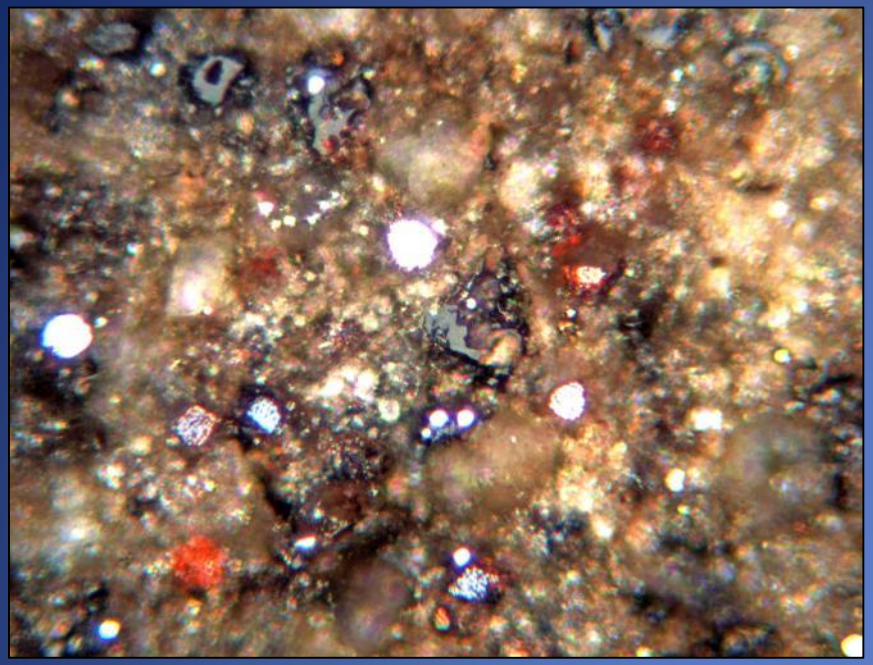
Oil*– Maryville Limestone
No. 529 White
Boyd Co., Ky
7,574 – 7,598 ft

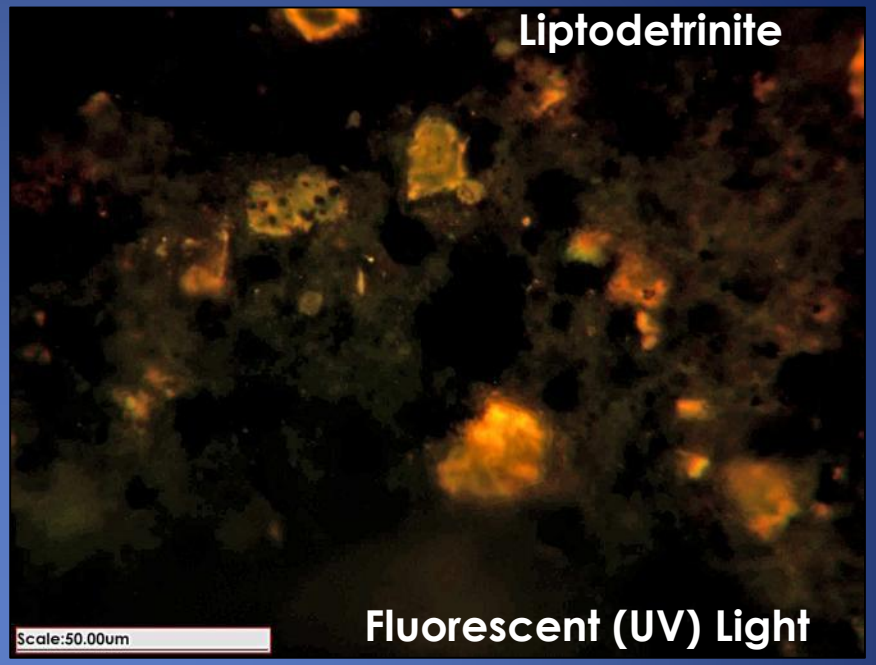
***Data provided by Richard W. Beardsley**

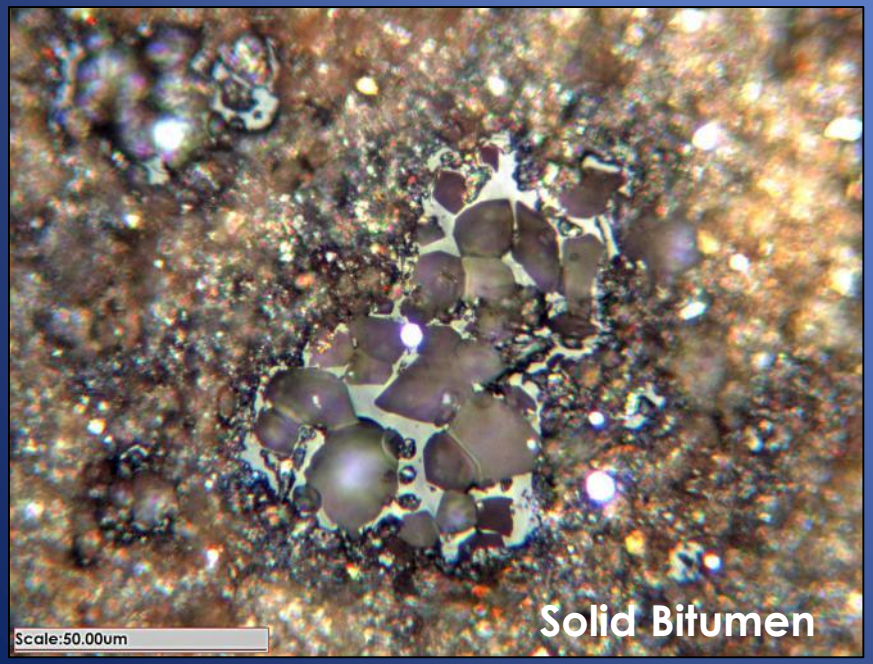


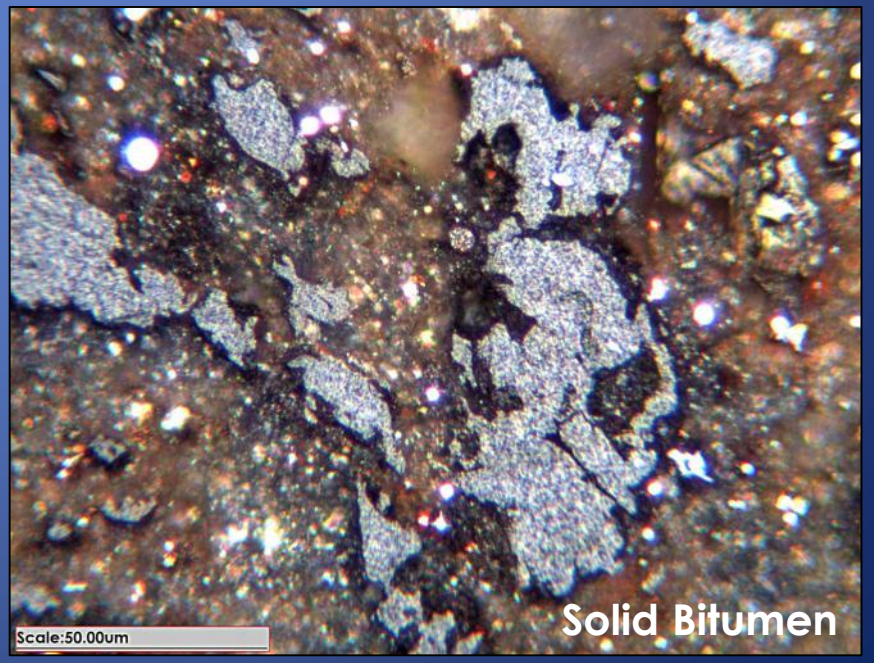
Bitumen Extract - Rogersville Shale
No. 1 Smith
Wayne Co., WV
11,161.5 ft

Rogersville Organic Petrography









Exxon Smith Bitumen Reflectance

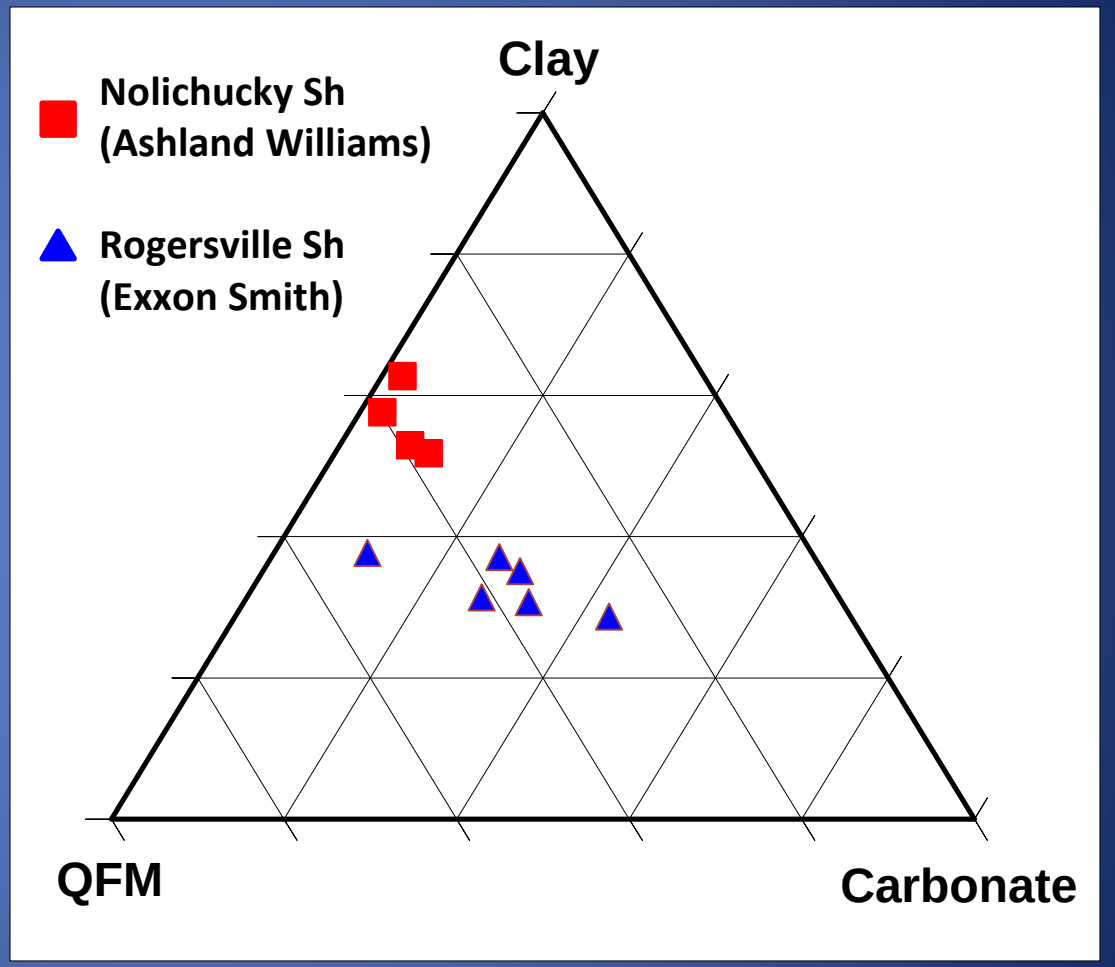
	11167	11178	11191	11197
Average Ro random	**1.76**	**1.80**	**1.80**	**1.84**
Maximum Ro random	2.11	2.11	2.04	2.10
Minimum Ro random	1.50	1.47	1.53	1.59
Standard deviation	0.14	0.16	0.13	0.13
Observations	50.00	50.00	50.00	50.00
Calculated Ro equivalent (Ro random * 0.618) + 0.4 (Jacob, 1989)	**1.49**	**1.51**	**1.51**	**1.54**
Indicated Tmax from calculated Ro equiv.	**480**	**482**	**482**	**484**

Spectral Fluorescence

	11167	11178	11191	11197
Lambda maximum	638	648	648	645
Indicated Ro	1.35	1.45	1.45	1.45
Indicated Tmax from Lambda max.	**473**	**479**	**479**	**479**

Shale Mineralogy

- XRD data from the Rogersville and Nolichucky shales
- Rogersville has:
  - Less clay
  - More quartz & carbonate
- Increased brittleness



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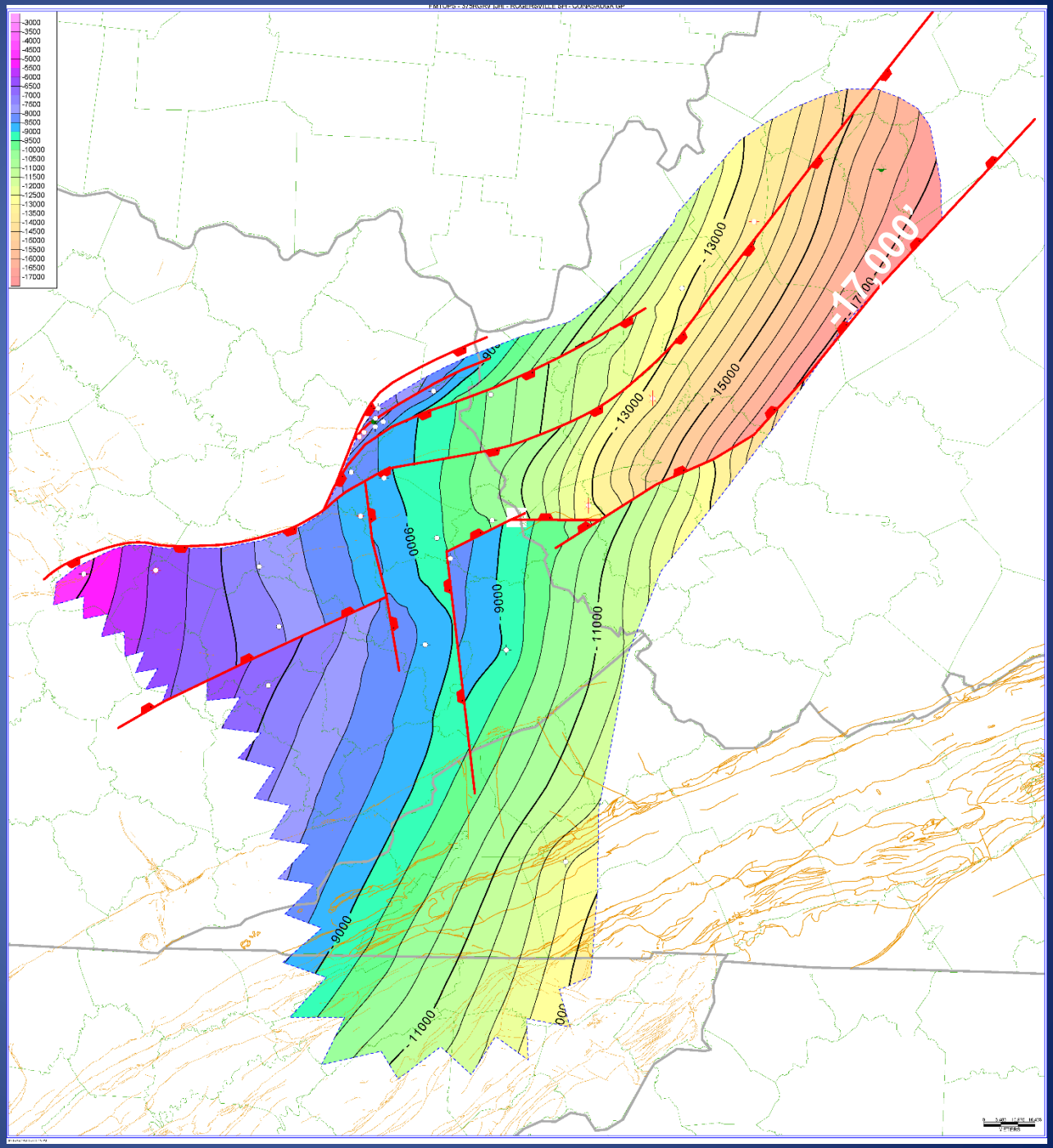
Rogersville Shale Structure Map

Contour Interval = 500 ft

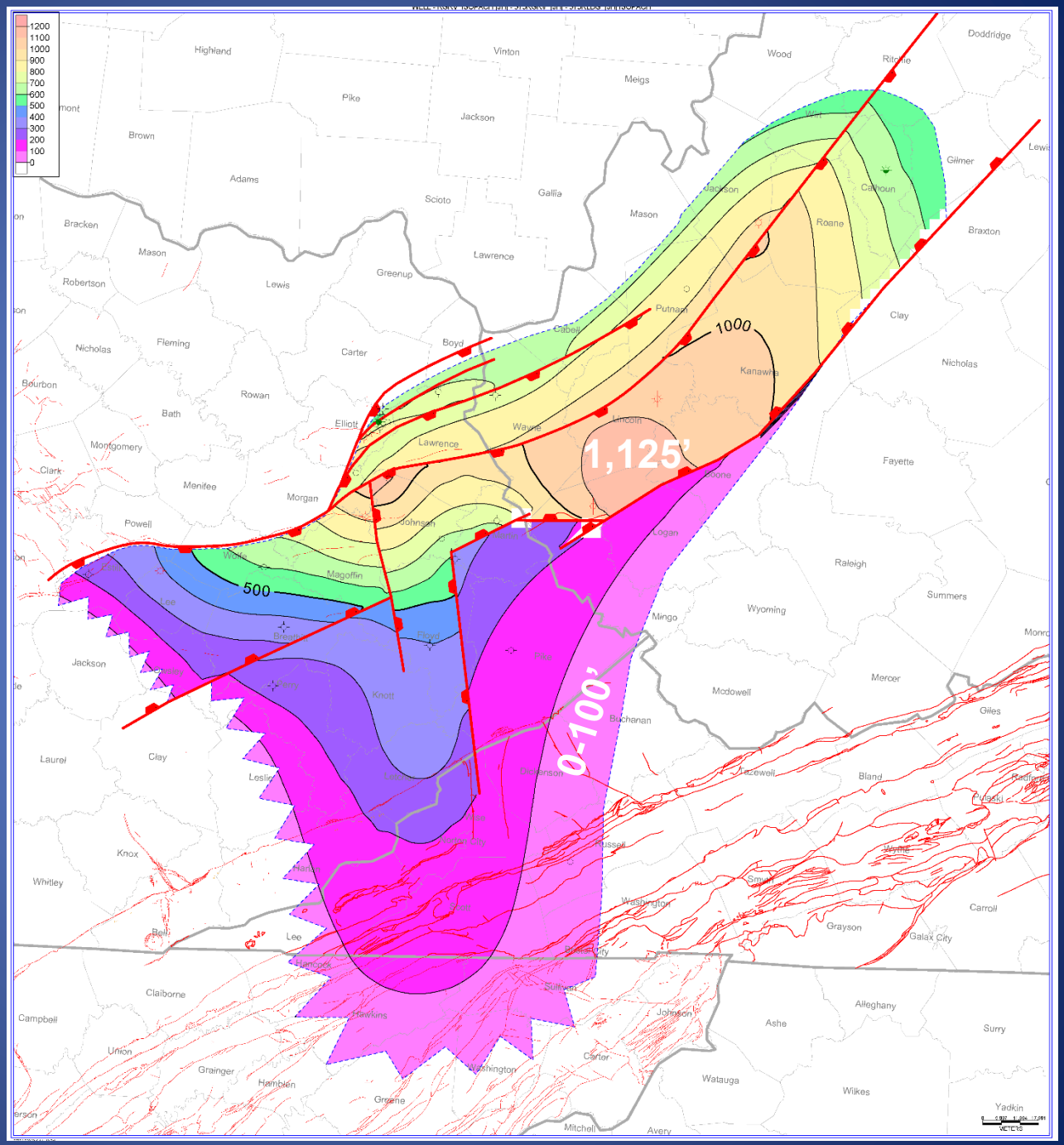
4,500 – 17,000 feet below sea level



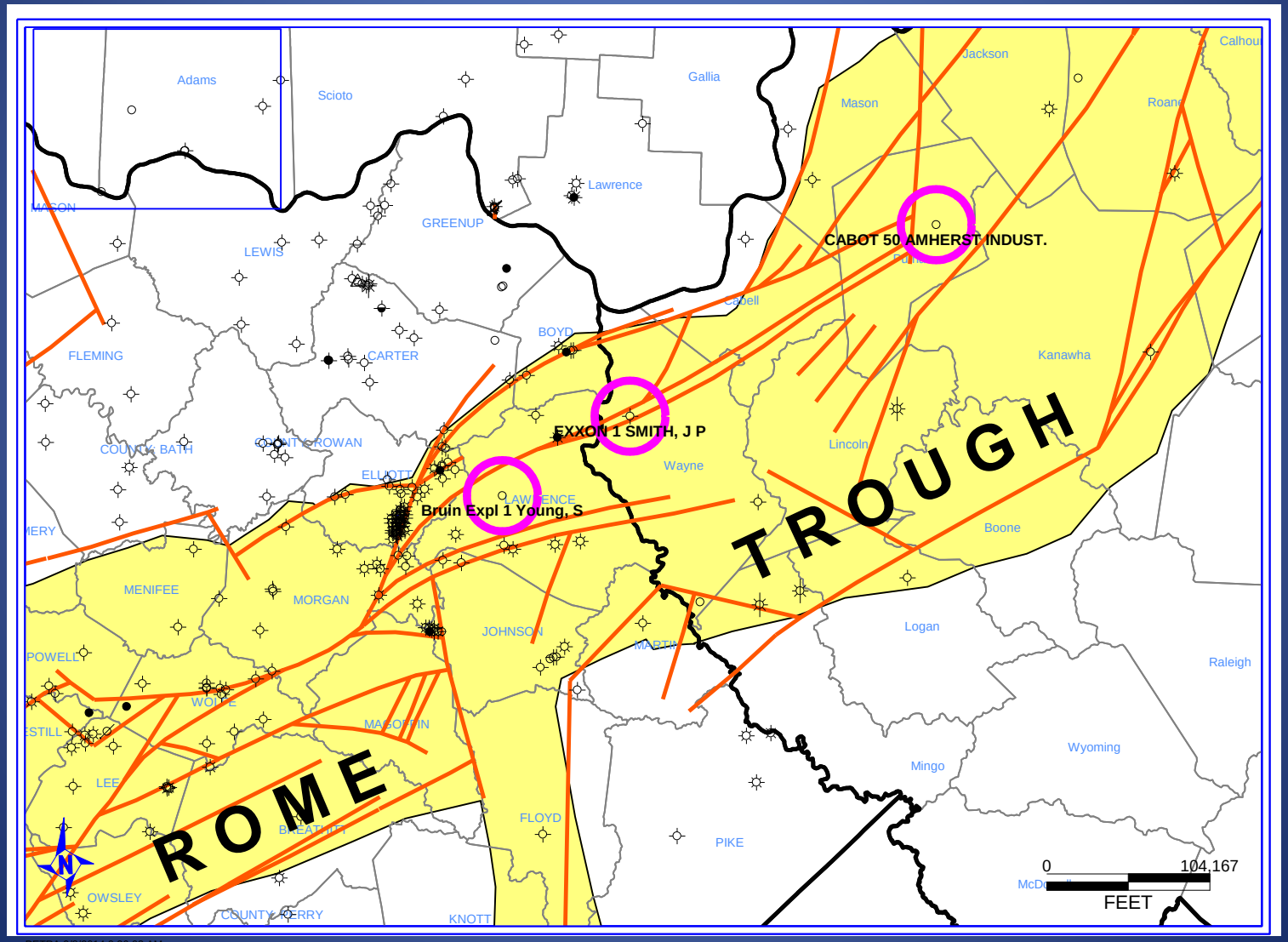
Rogersville Shale Isopach Map

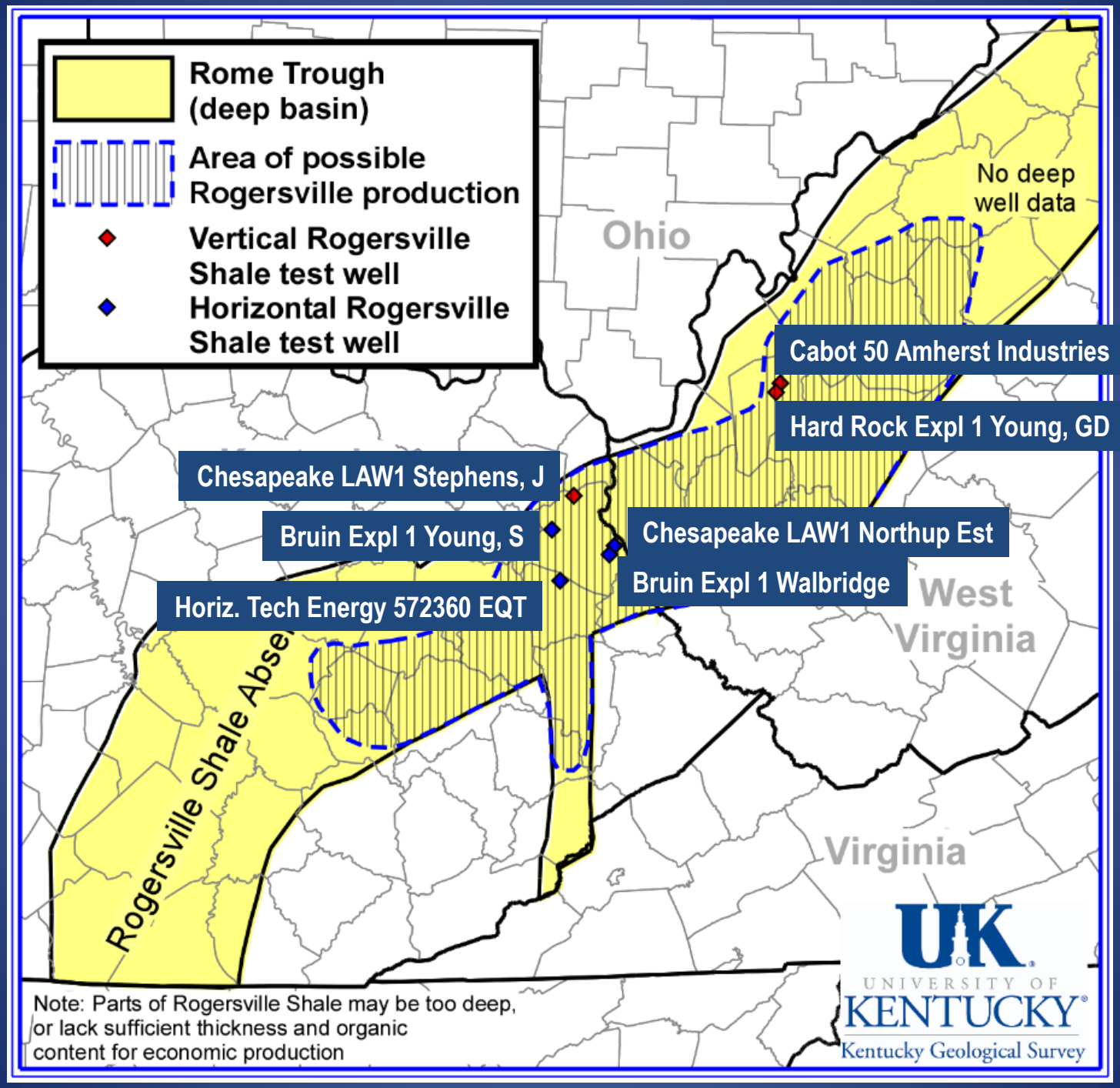
Contour interval = 100 ft

0 to ~1,125 feet thick



Emerging Cambrian Rogersville Shale Play 2014




Rome Trough (deep basin)
Area of possible Rogersville production
Vertical Rogersville Shale test well
Horizontal Rogersville Shale test well
No deep well data
Ohio
Cabot 50 Amherst Industries
Hard Rock Expl 1 Young, GD
Chesapeake LAW1 Stephens, J
Bruin Expl 1 Young, S
Chesapeake LAW1 Northup Est
Bruin Expl 1 Walbridge
Horiz. Tech Energy 572360 EQT
West Virginia
Rogersville Shale Absen
Virginia
Note: Parts of Rogersville Shale may be too deep, or lack sufficient thickness and organic content for economic production
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Bruin Exploration #1 Young Lawrence County, Kentucky

- Vertical stratigraphic test drilled in late 2013, TD 11,967 ft.
- Oil & gas permit issued in 2014 to test well
- Logs, samples from strat test held confidential for 5 years
- Completed 576 ft interval 16,113 bbl fluid, 600k lbs sand
- IP reported: 115 Mcfgd, 19 BOPD; 2599 psi SIP
- Third permit for 4,800 ft lateral issued

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Cabot #50 Amherst Industries, Putnam County, WV

- Permitted to 14,000 ft in Rogersville
- No data or results released
- Location along strike with Exxon Smith and Bruin wells
- Well completed in 2015 and is currently producing to sales
- New permit by different operator 3 miles SW

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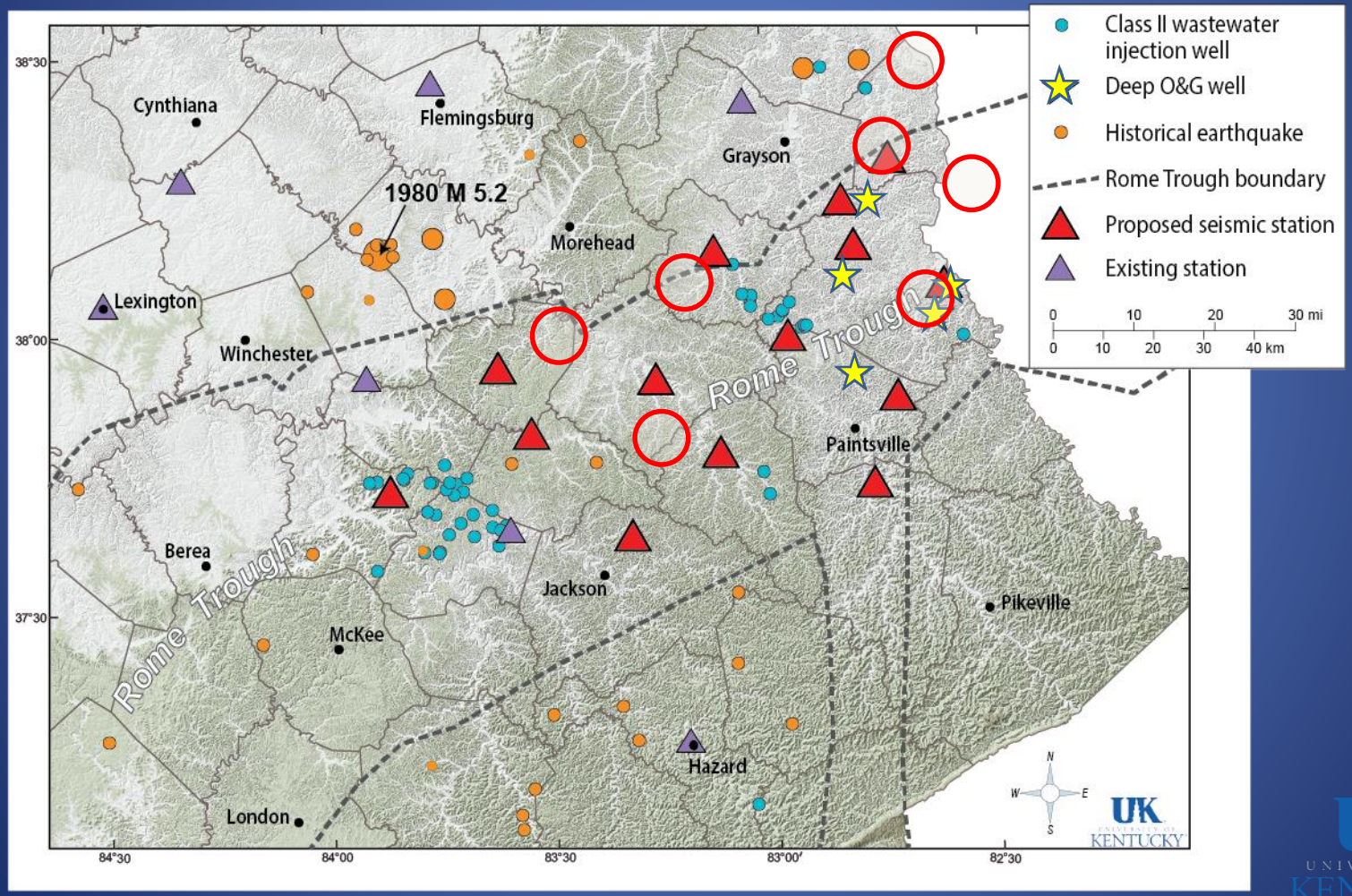
Other recent activity

- Horizontal Technology Energy Corp. (EQT) drilled a horizontal well in Johnson County
  - 4,300 ft lateral in Rogersville
  - No data or results have been released
- Chesapeake has drilled 2 stratigraphic test wells in Lawrence County
  - No data or results have been released
  - Both wells re-permitted as oil & gas wells to allow testing, the second as a 5,200 ft lateral
- Bruin Exploration has permitted a second horizontal location in Lawrence Co.

New Leasing Activity

- After rumored success of the Bruin #1 Silvia Young well, leasing boom for deep rights in Johnson, Magoffin, and Lawrence Cos., Ky
- More than 4,275 deep leases were sold in 18 months ending 6/15 (Cate, 2015)
- Prices per acre are now $250-300 where $25-50 was common 5 years ago

No induced seismic events related to oil and gas activity have been recorded in Kentucky to date. A program to gather baseline data is underway.



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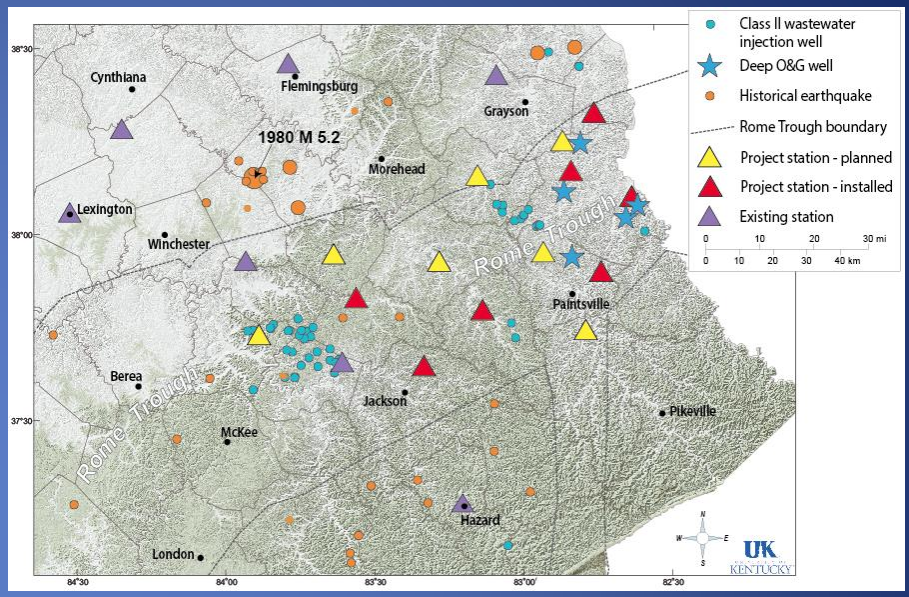
Monitoring Microseismicity in Eastern Kentucky:

Network

- Installed seven KGS stations (red)
- Eight more stations being installed
- Operate for ~3 years.



Data Analysis

- Data in real-time at KGS
- Real-time event detection
- Real-time event location in progress

Project Partnerships

- UK Dept. Earth & Environmental Sciences: Graduate Student RA
- Oil & Gas Industry – Instrumentation loan, Research
- Nanometrics, Inc. – Instrumentation purchase, Research
- Others?

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Rogersville Shale Summary

- 5,000 to 10,000 ft deep in eastern Kentucky
- 2–4.8% TOC in parts, and has generated gas & condensate
- Up to 1,100 ft thick in Kentucky, but limited to deeper parts of Rome Trough- and not all is organic-rich

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Conclusions

- Viable petroleum system exists in Rome Trough. Rogersville Shale (Conasauga Gp) is primary source interval.
- Conasauga stratigraphic framework for 3-state area is key to predicting source rock distribution
- Rogersville unconventional play concept has been proved, but needs to consider depth and economics.

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Conclusions (cont.)

- Source rock quality in Rogersville is variable– *not* a uniform rich source. Controls on TOC distribution not well understood.
- Shallower, less mature areas of RT likely more liquids-prone than deeper areas in W. Va.
- Structure data (seismic, gravity, magnetics) will be a key tool in developing the Rogersville

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