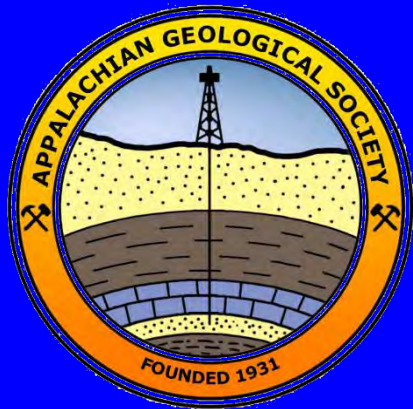


Structural Evolution and Petroleum Potential of a Cambrian Intracratonic Rift System in Kentucky

John Hickman

Kentucky Geological Survey

University of Kentucky



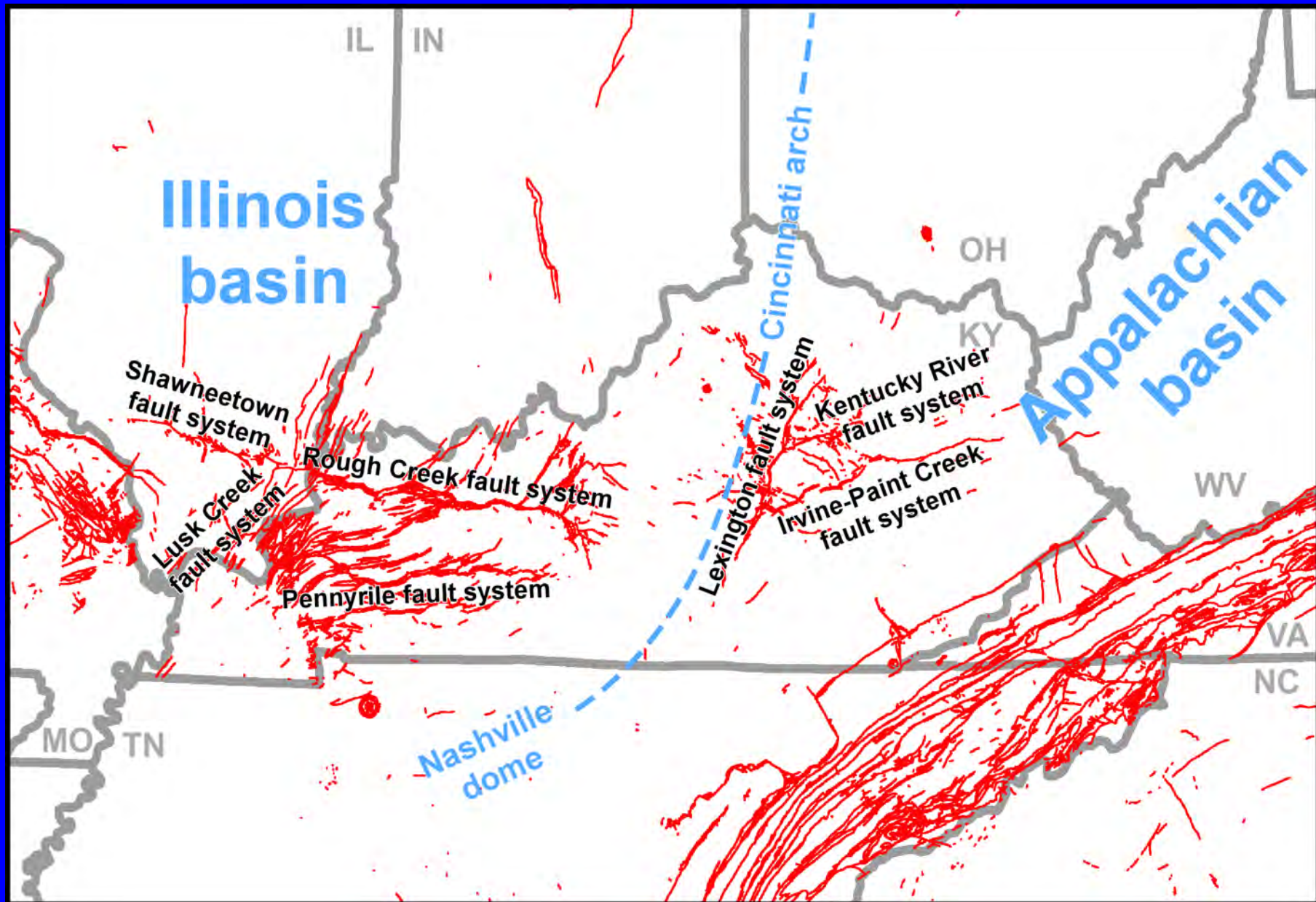
Marshall University Memorial Student Center

Huntington, WV

February 16, 2016



Current Surface Features



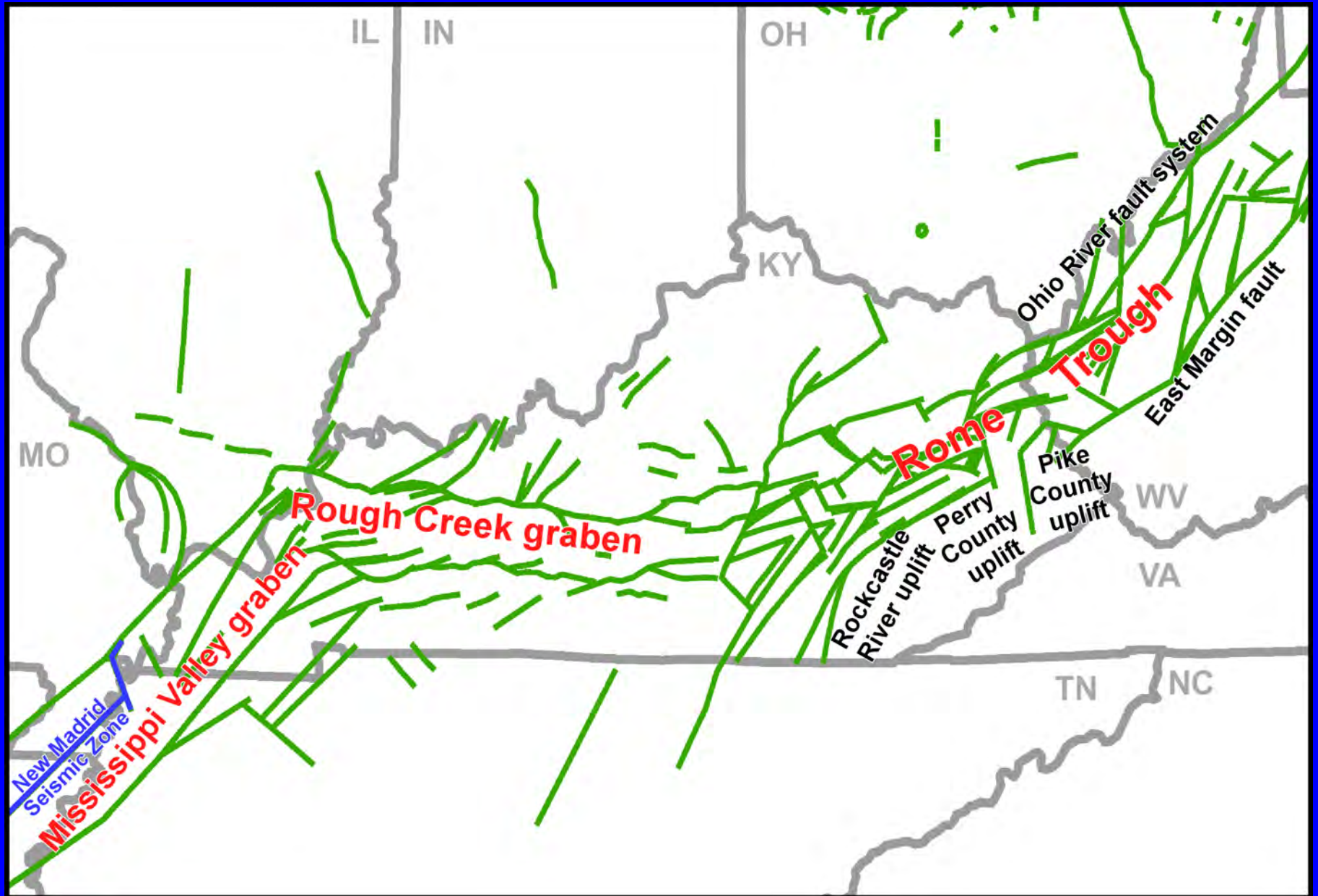
Regional Tectonic Setting:

pЄ Ediacaran to
Є Guzhangian

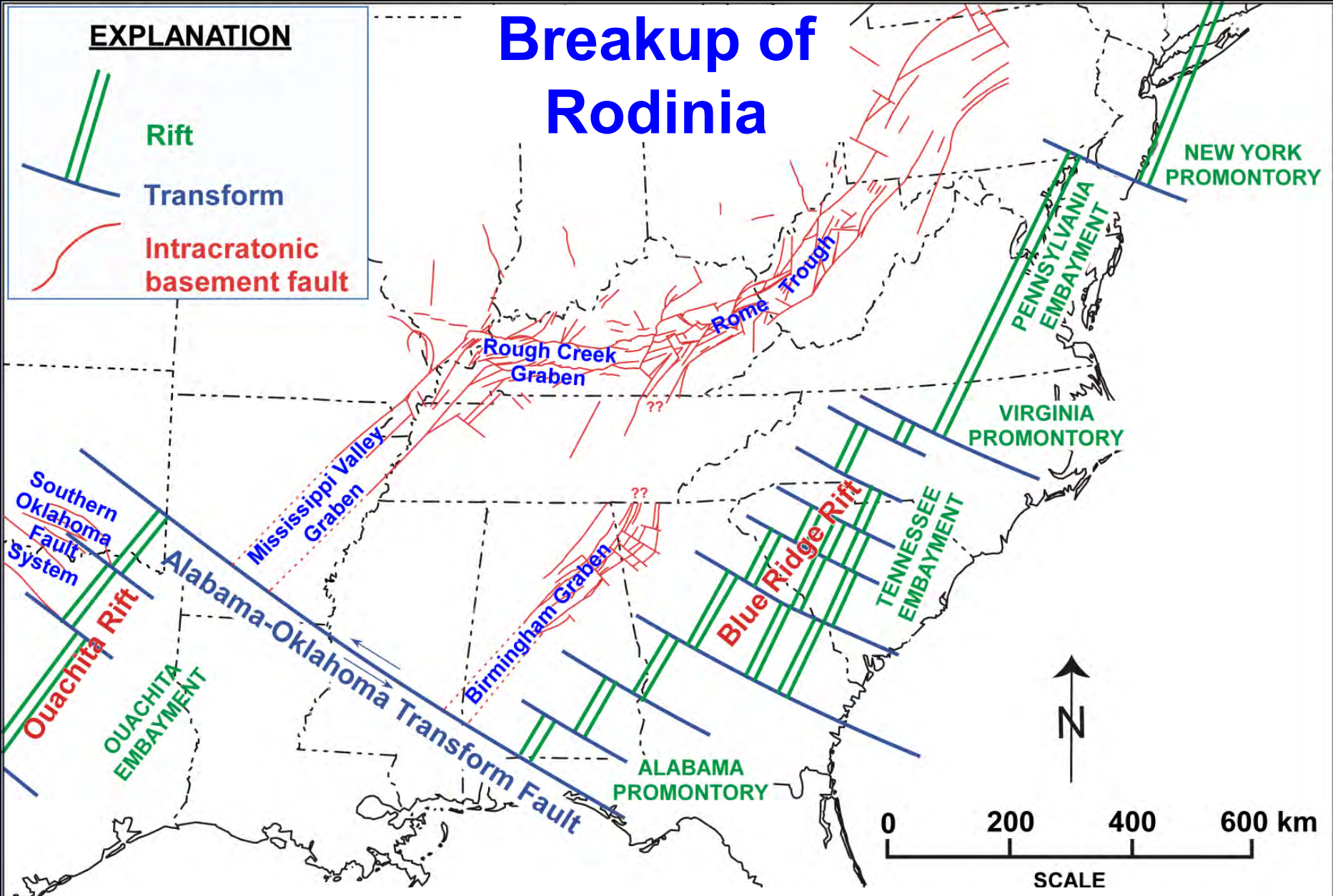
Eastern Interior Rift System

- Three tectonic features, one “failed” rift:
 - Rome Trough
 - Rough Creek Graben
 - Mississippi Valley Graben
(a.k.a. Reelfoot Rift)

Subsurface Features

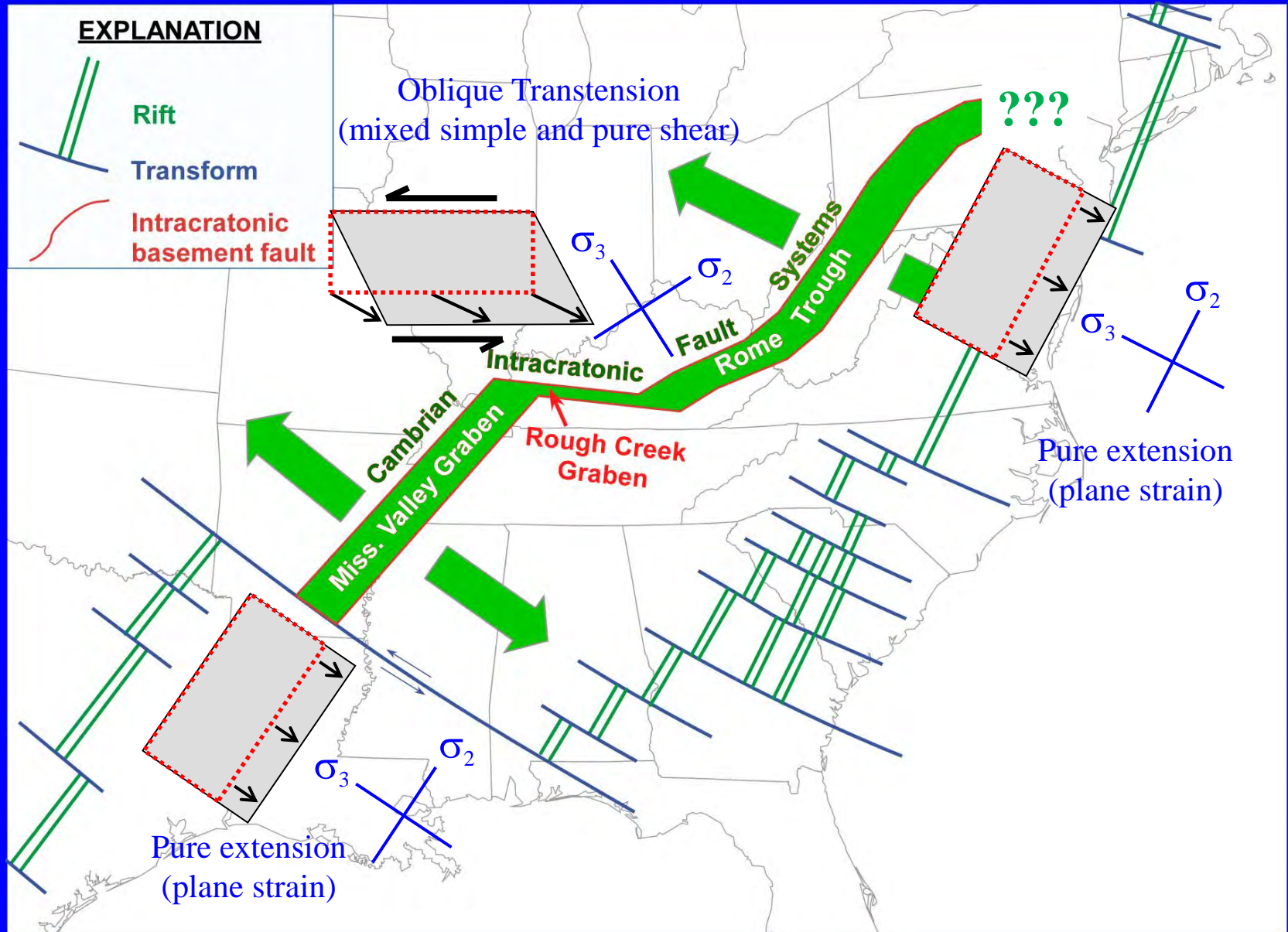


Breakup of Rodinia

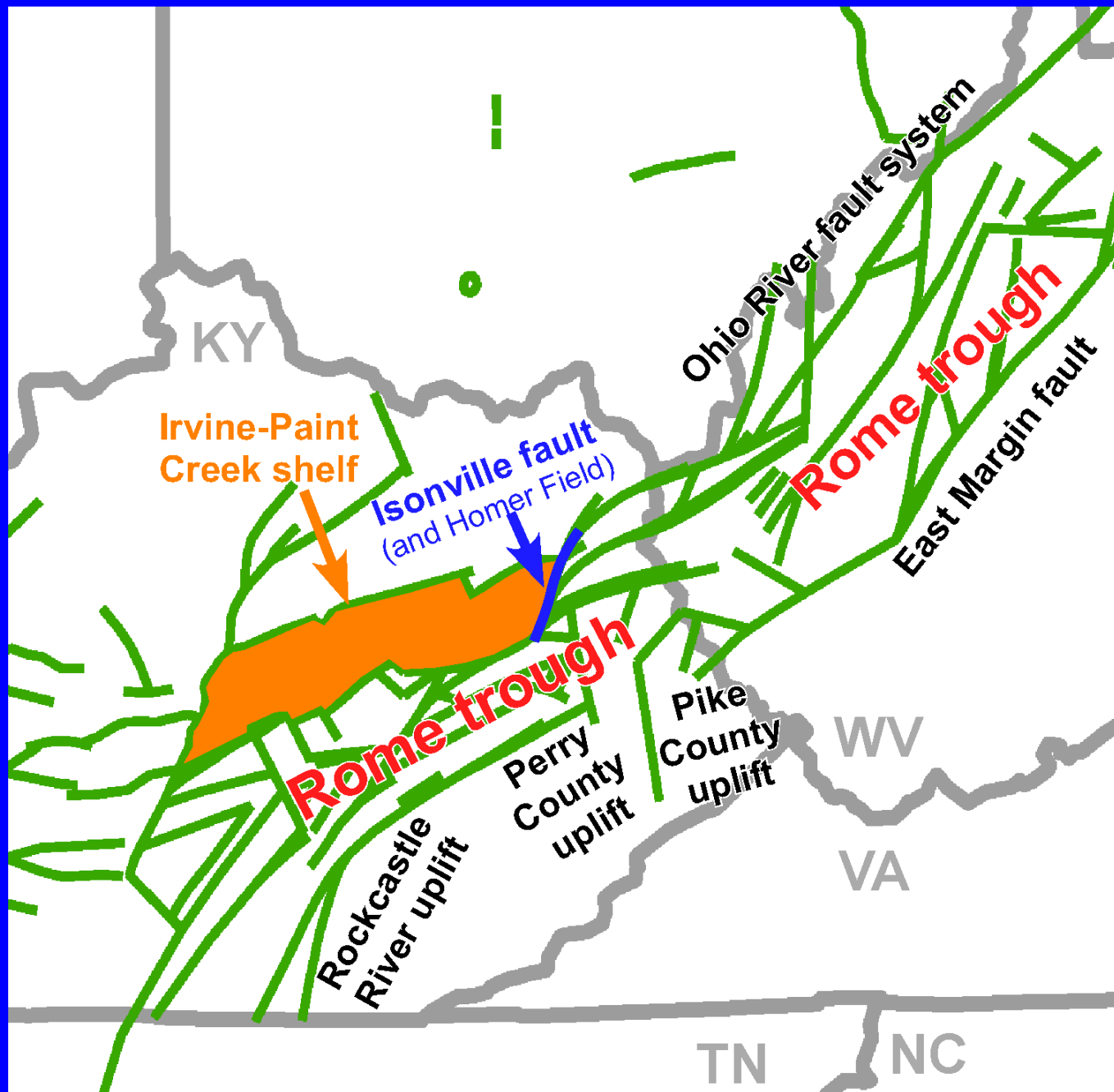


Locations of Laurentian margin, Birmingham Graben, and Southern Oklahoma Fault System from Thomas (1991, 2006).

p€-€ Intracratonic Rift System

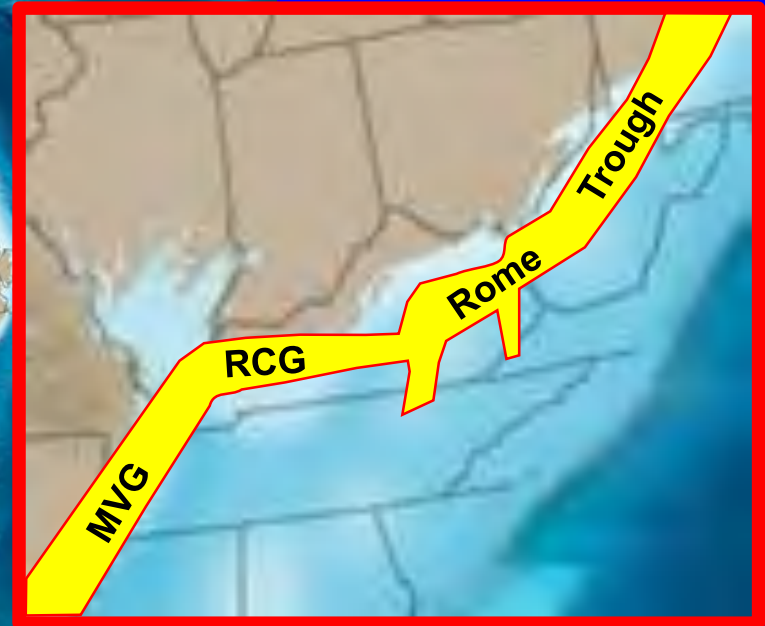
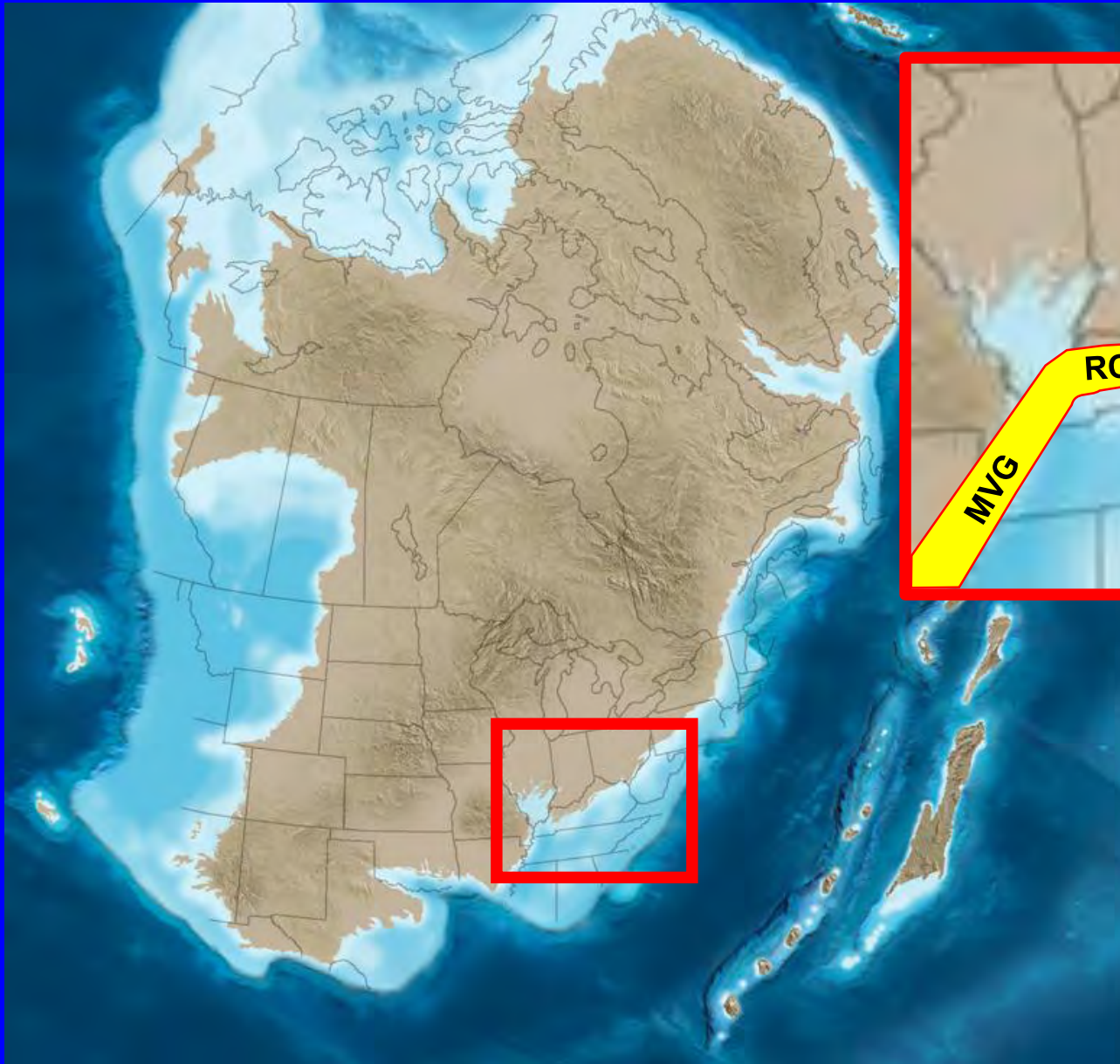


Basement Features in Rome Trough Region

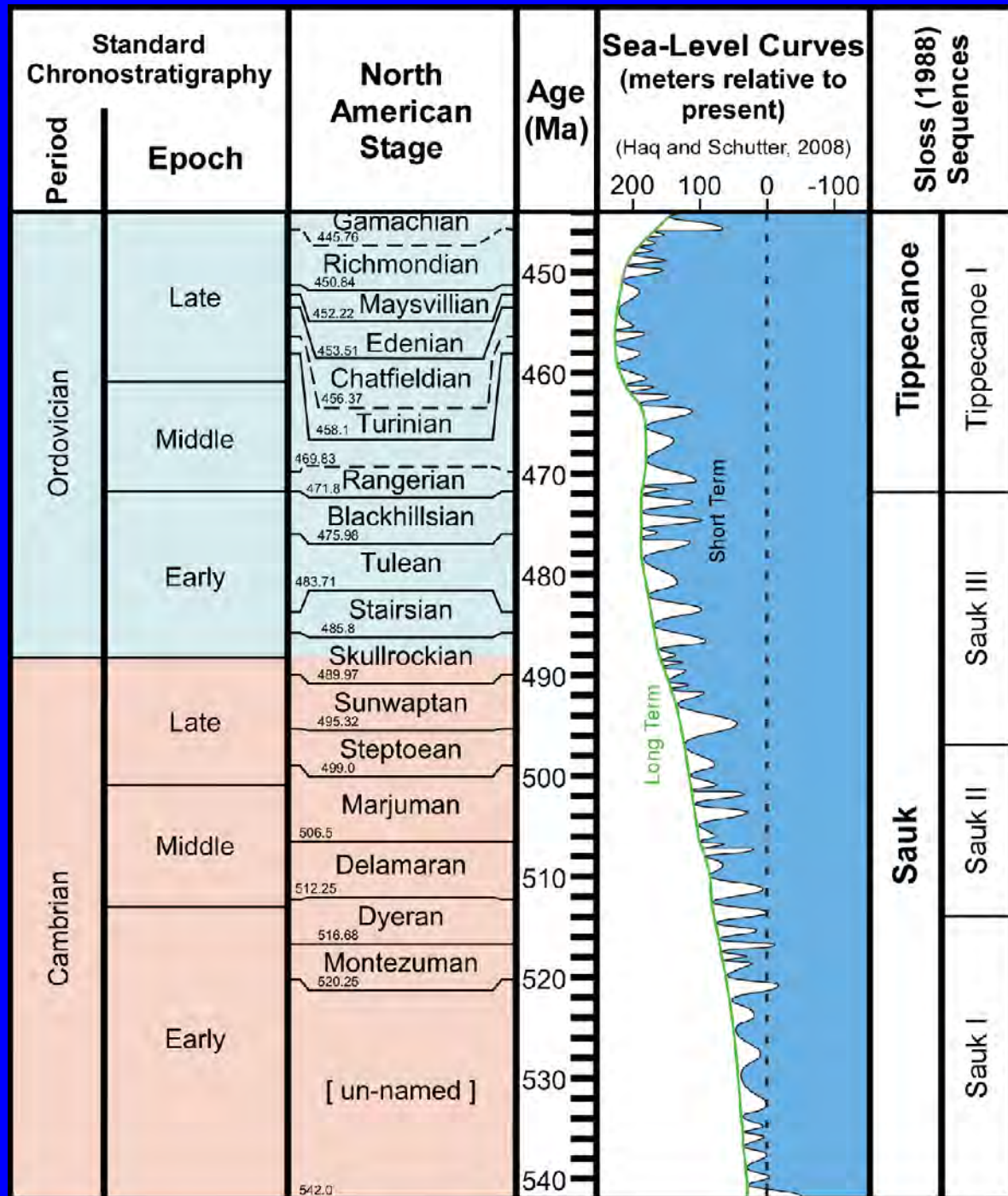


Cambrian Stratigraphy and Deposition

Middle Cambrian Paleogeography

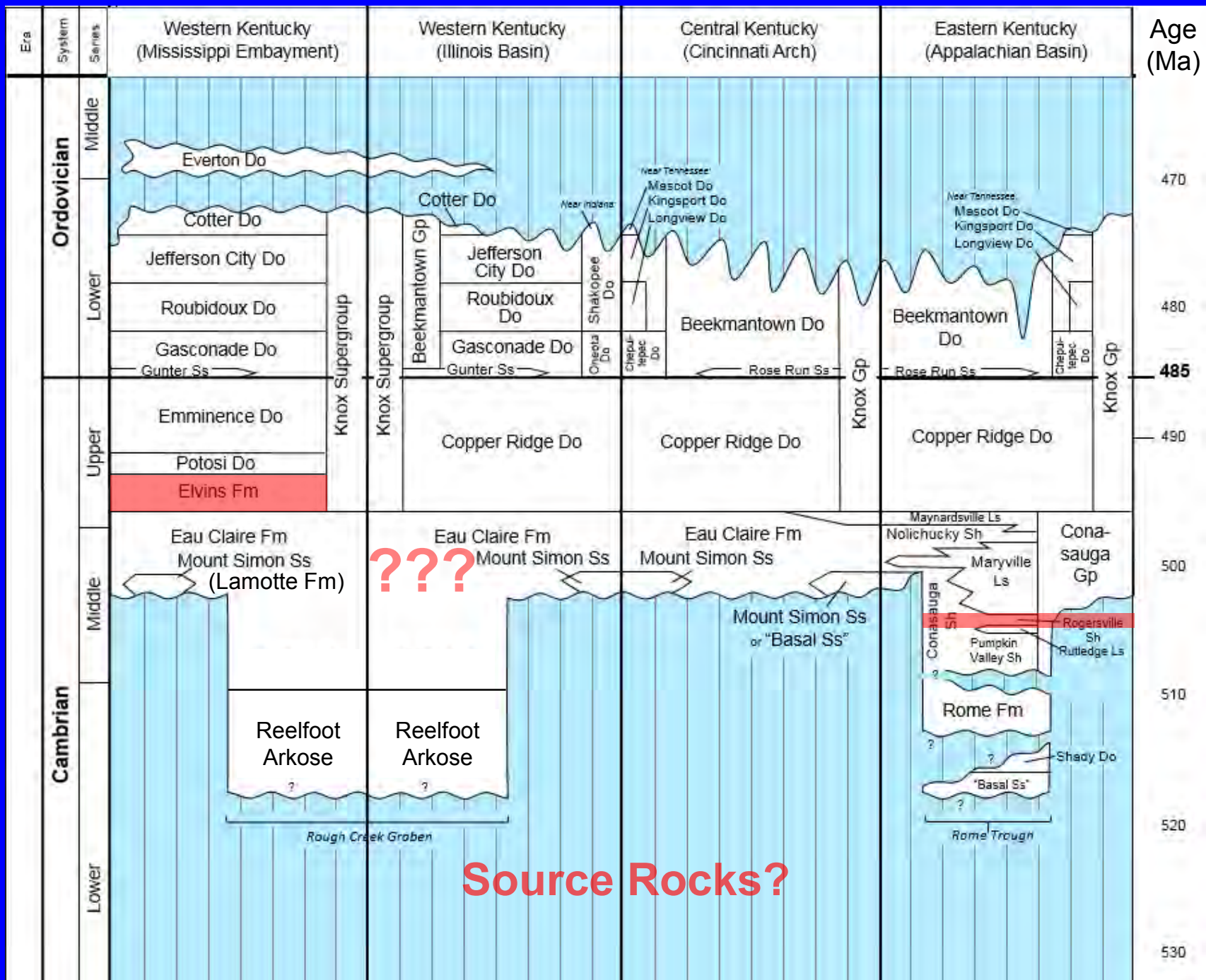


Ron Blakey, Colorado Plateau Geosystems, Arizona USA



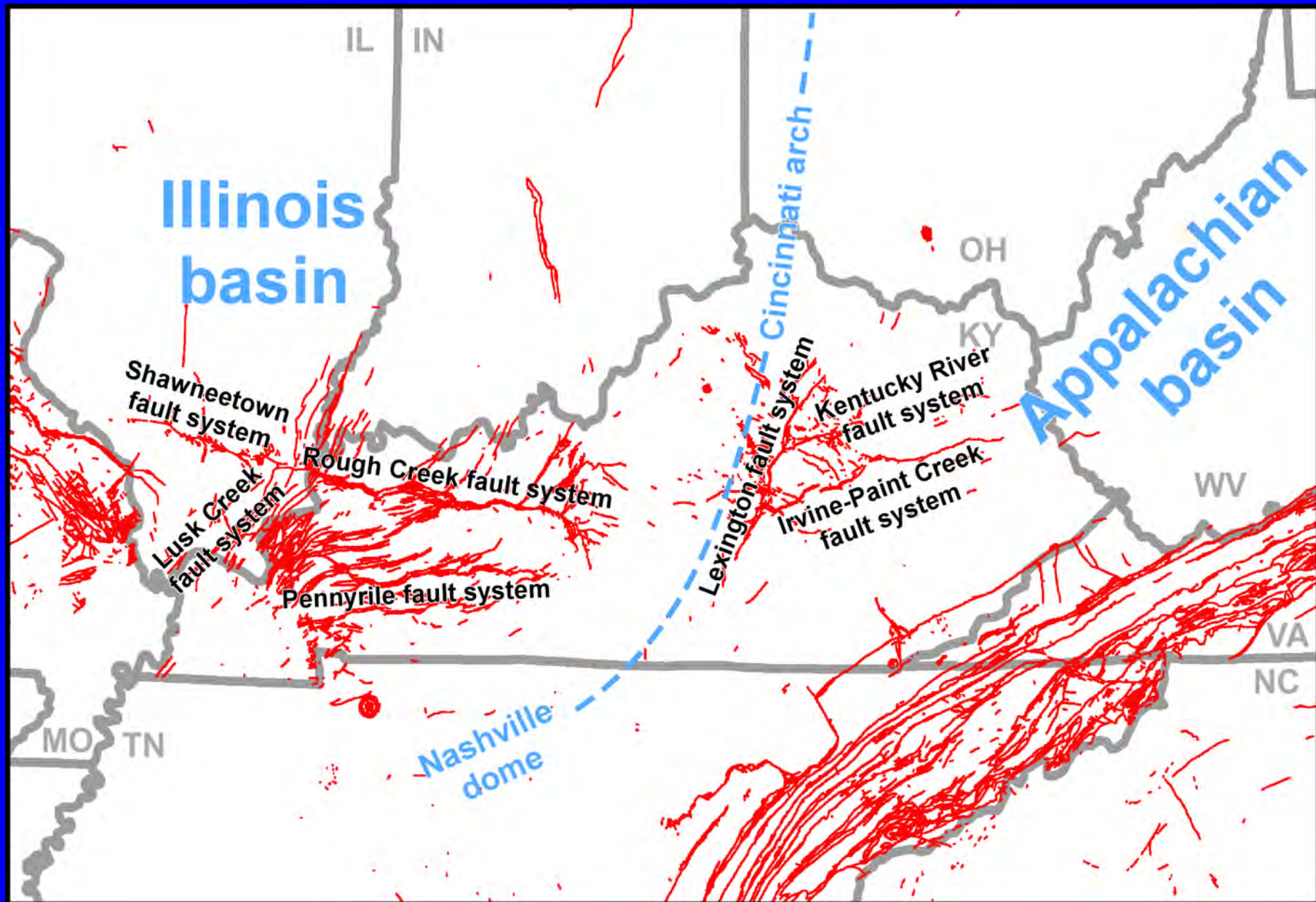
**Post-rift
Subsidence**

**Active
Rifting**

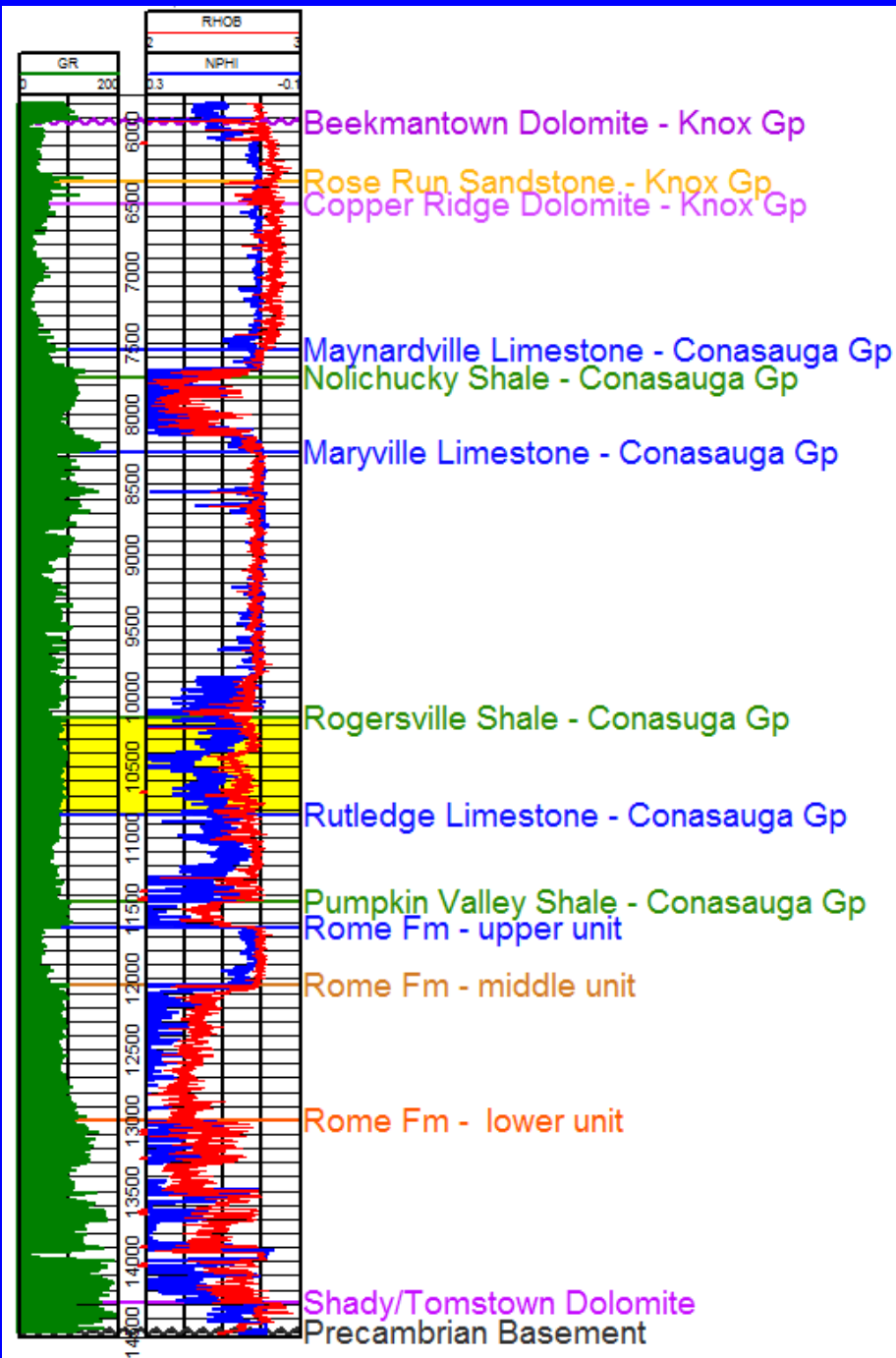


Rome Trough, Appalachian Basin

Current Surface Features



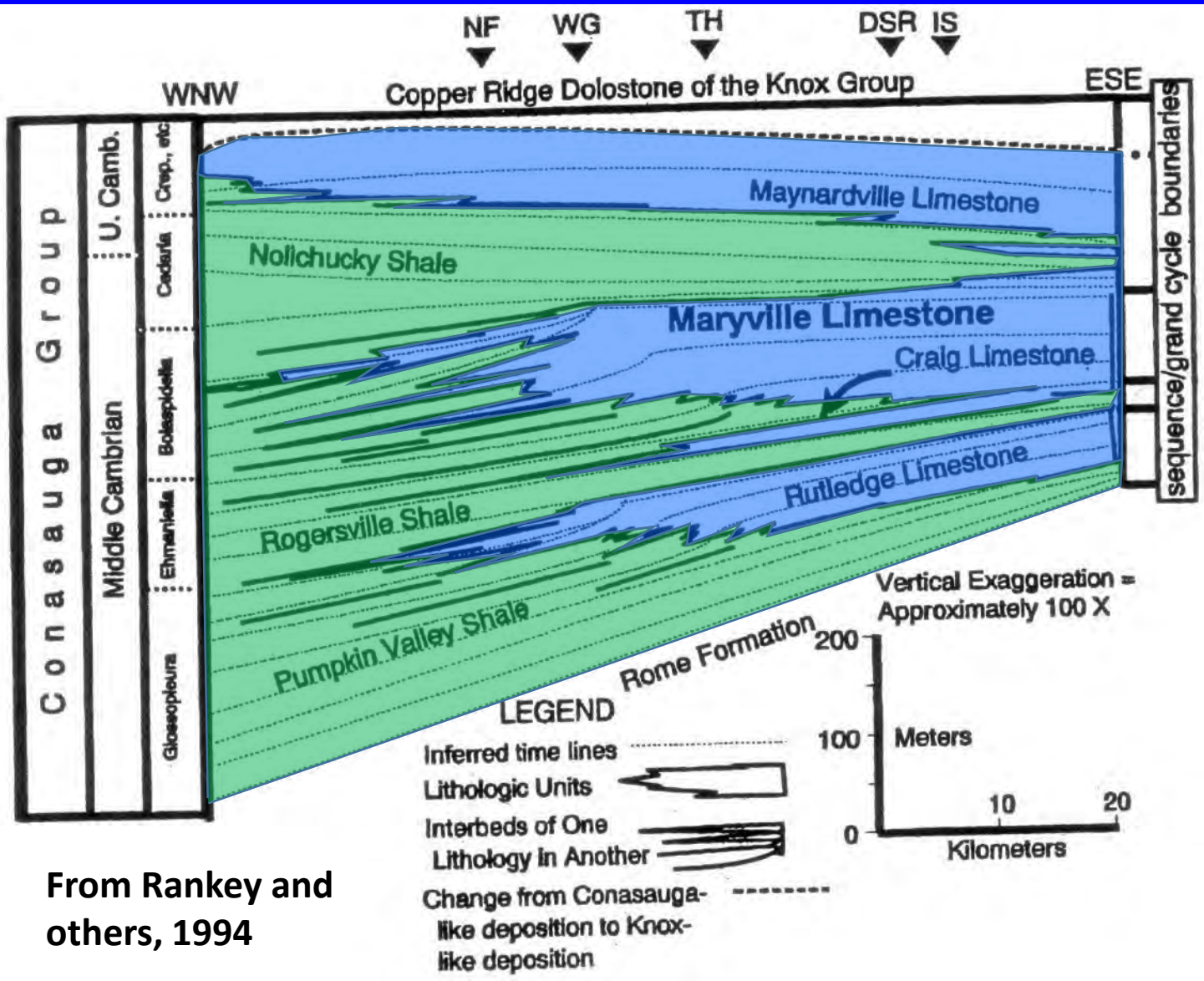
Precambrian - Early Ordovician Stratigraphy within Rome Trough



U.S. Signal #1
Elkhorn Coal
Johnson Co.
Kentucky

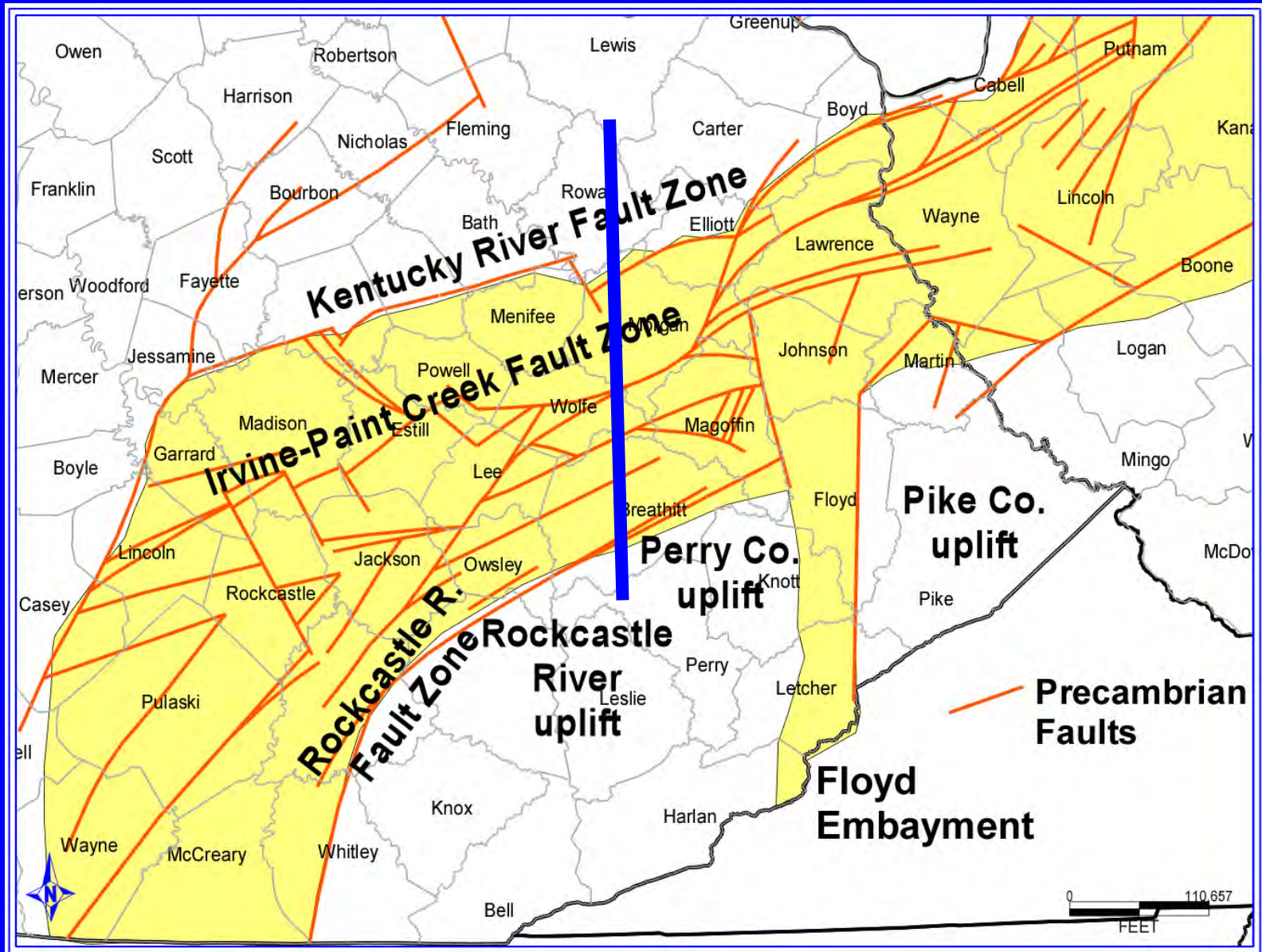
Conasauga Transgressive- Regressive Cycles

Eastern Tennessee Outcrops

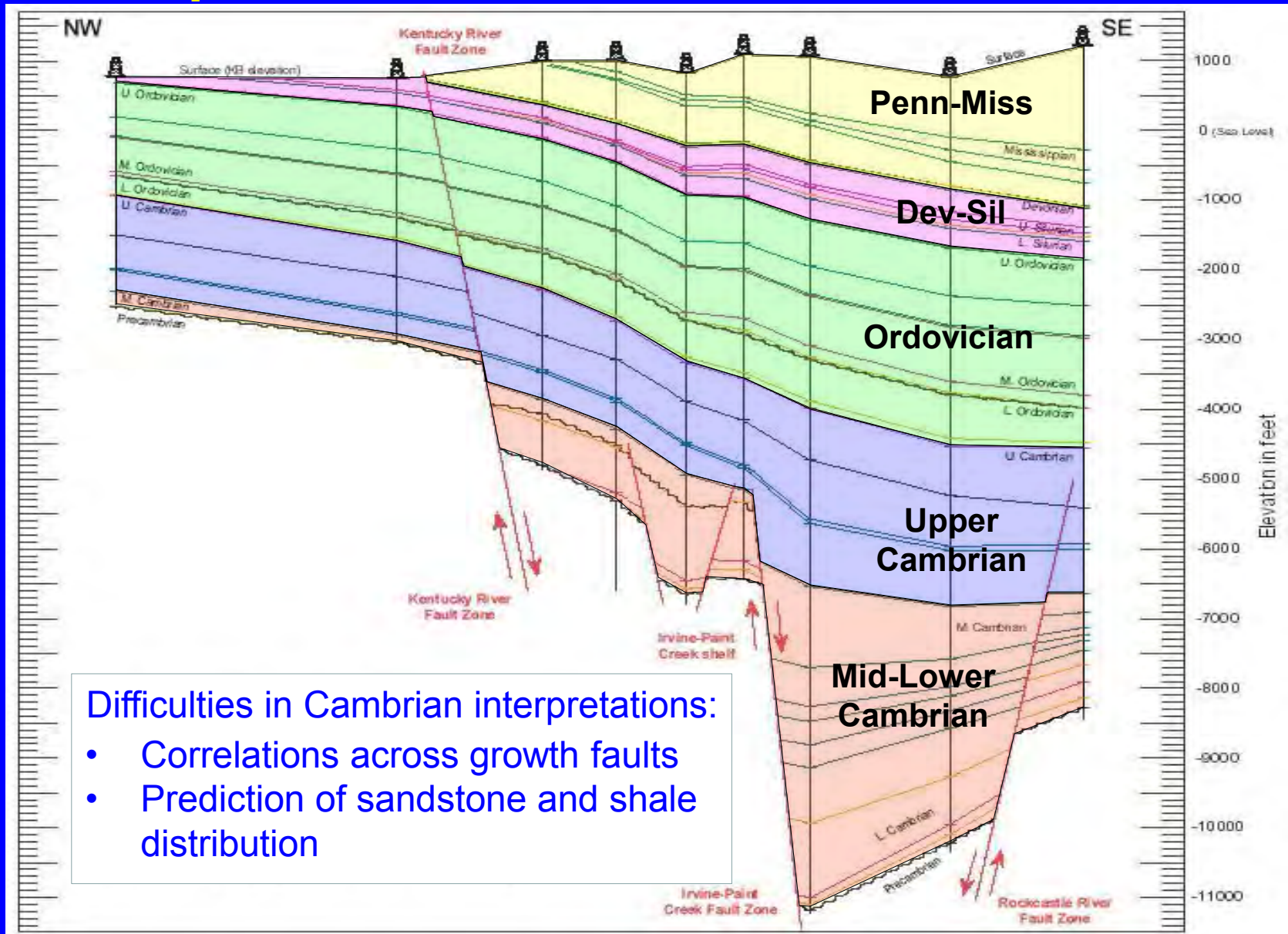


From Rankey and others, 1994

Rome Trough Structure



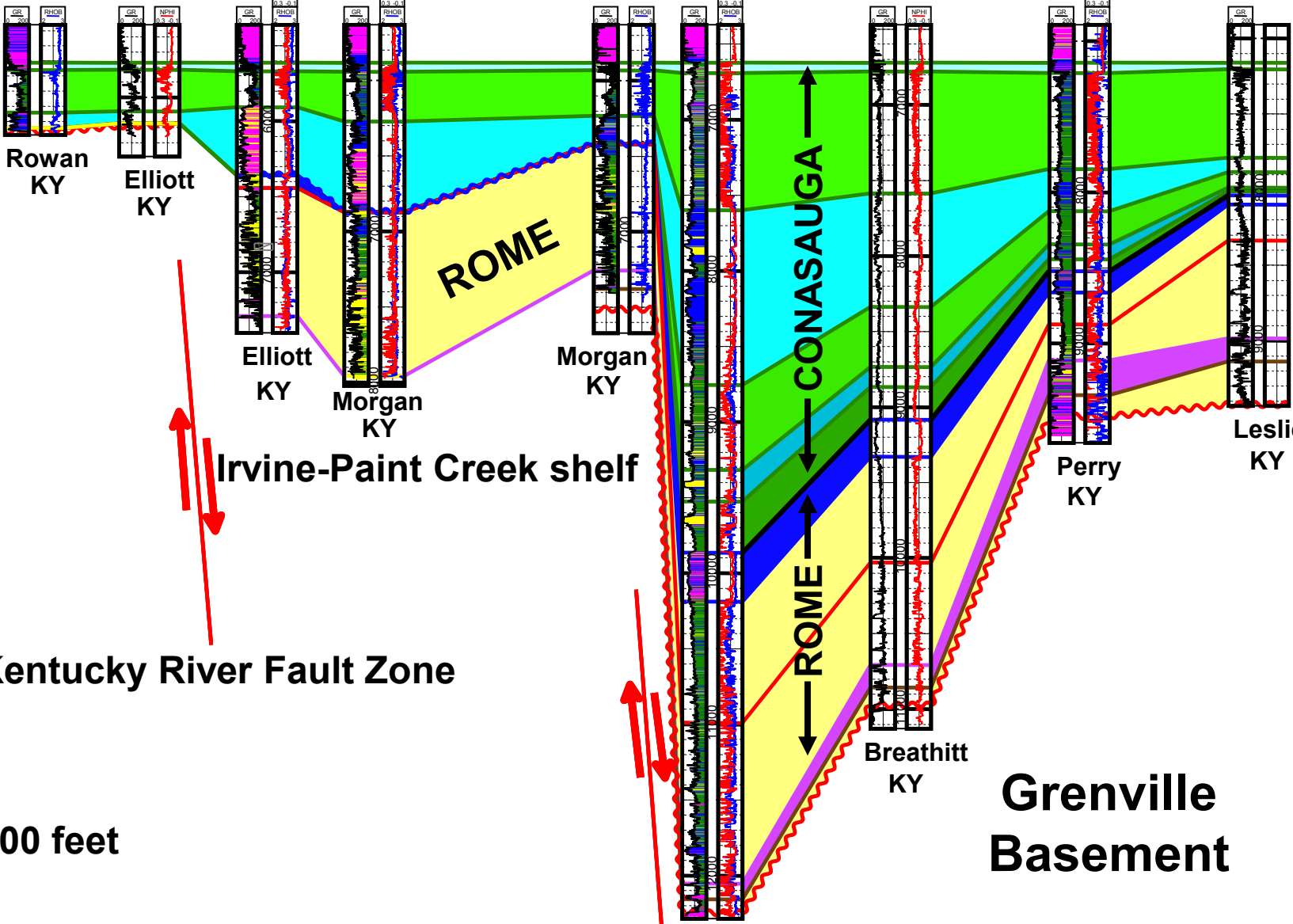
Simplified E. KY Cross Section



Difficulties in Cambrian interpretations:

- Correlations across growth faults
- Prediction of sandstone and shale distribution

North <7.63MI> <7.86MI> <7.17MI> <16.66MI> <5.91MI> <12.60MI> <11.93MI> <11.95MI> South



Irvine-Paint Creek shelf

Kentucky River Fault Zone

1,000 feet

Irvine-Paint Creek Fault Zone

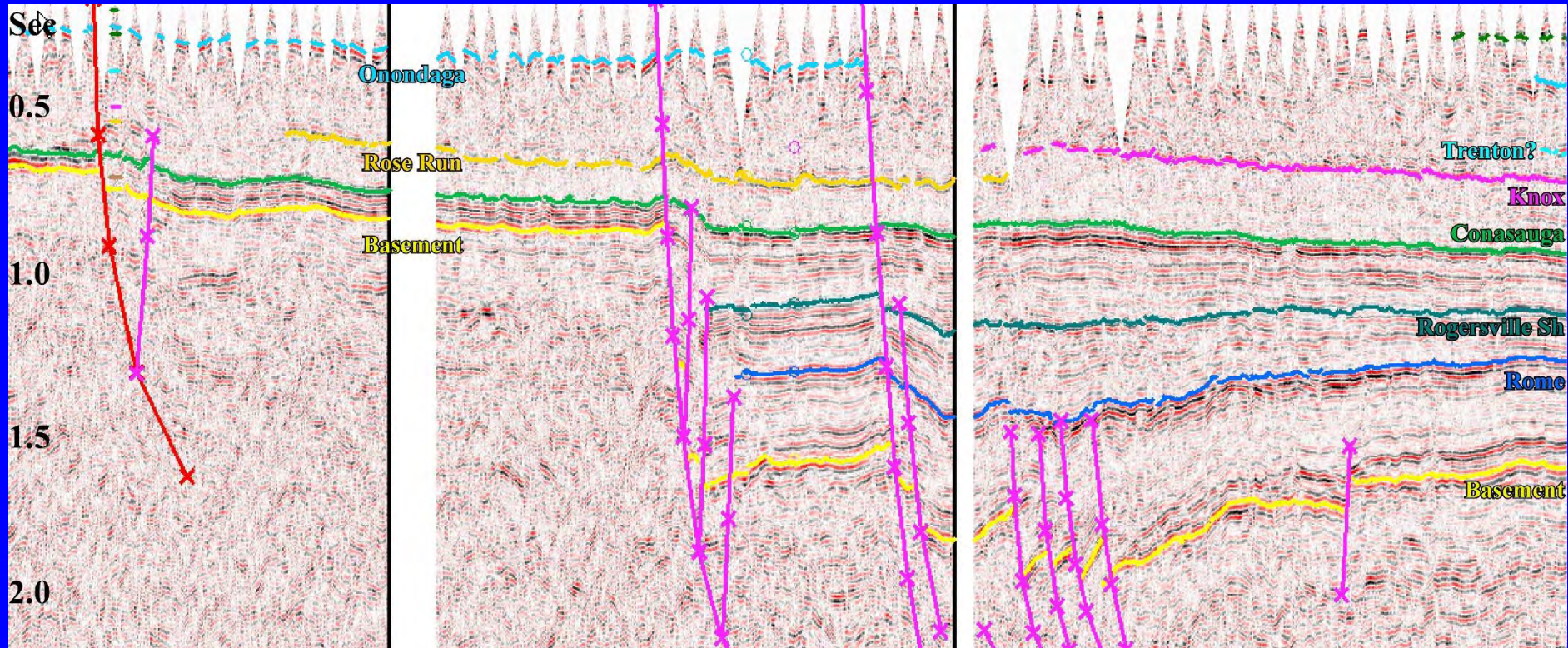
Grenville Basement

Eastern Kentucky Regional Seismic Example

NNW

Morgan to Magoffin County, KY

SSE



Approximate length of section is 49 miles.

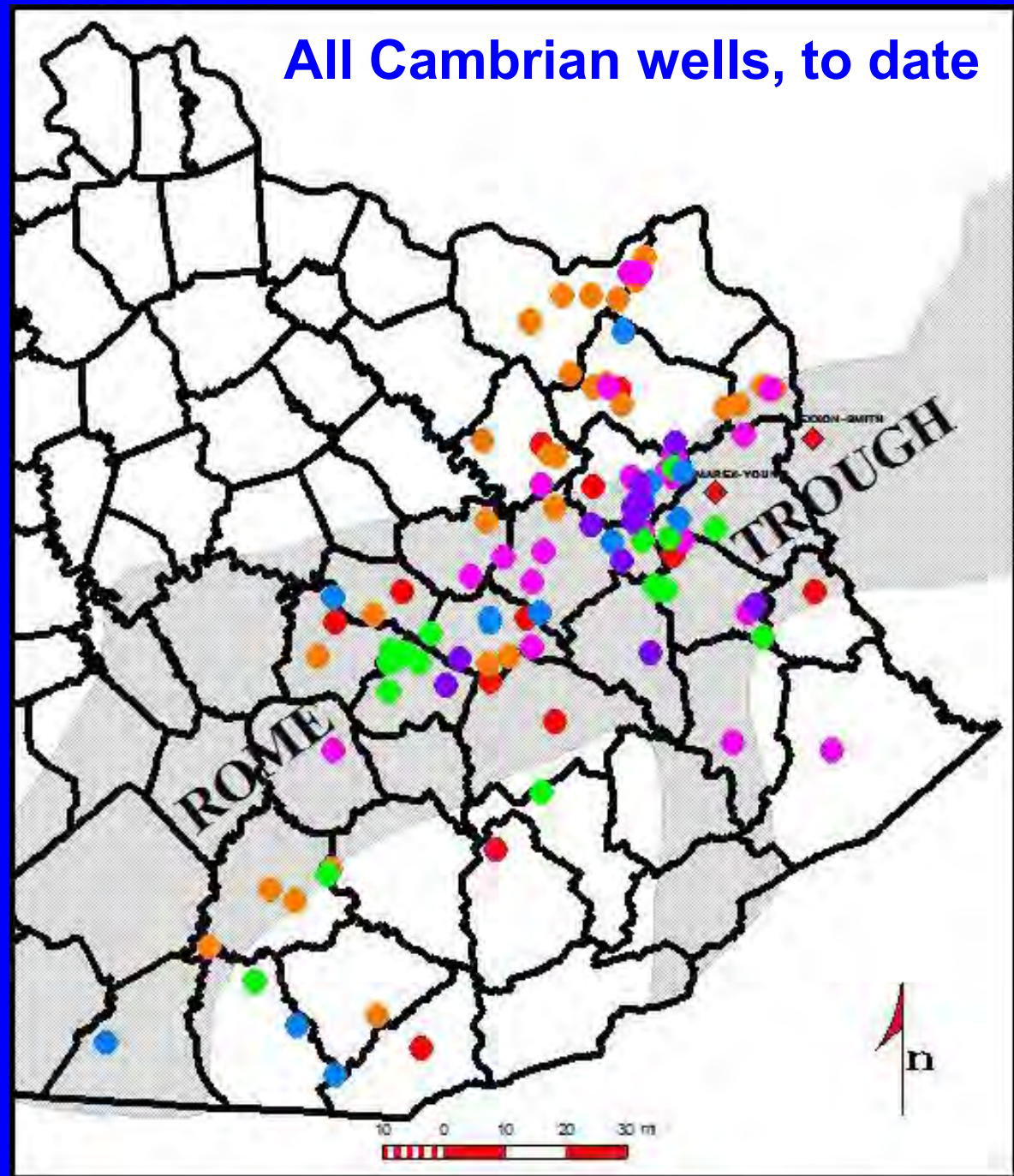
Exploration History within the Rome Trough

All Cambrian wells, to date

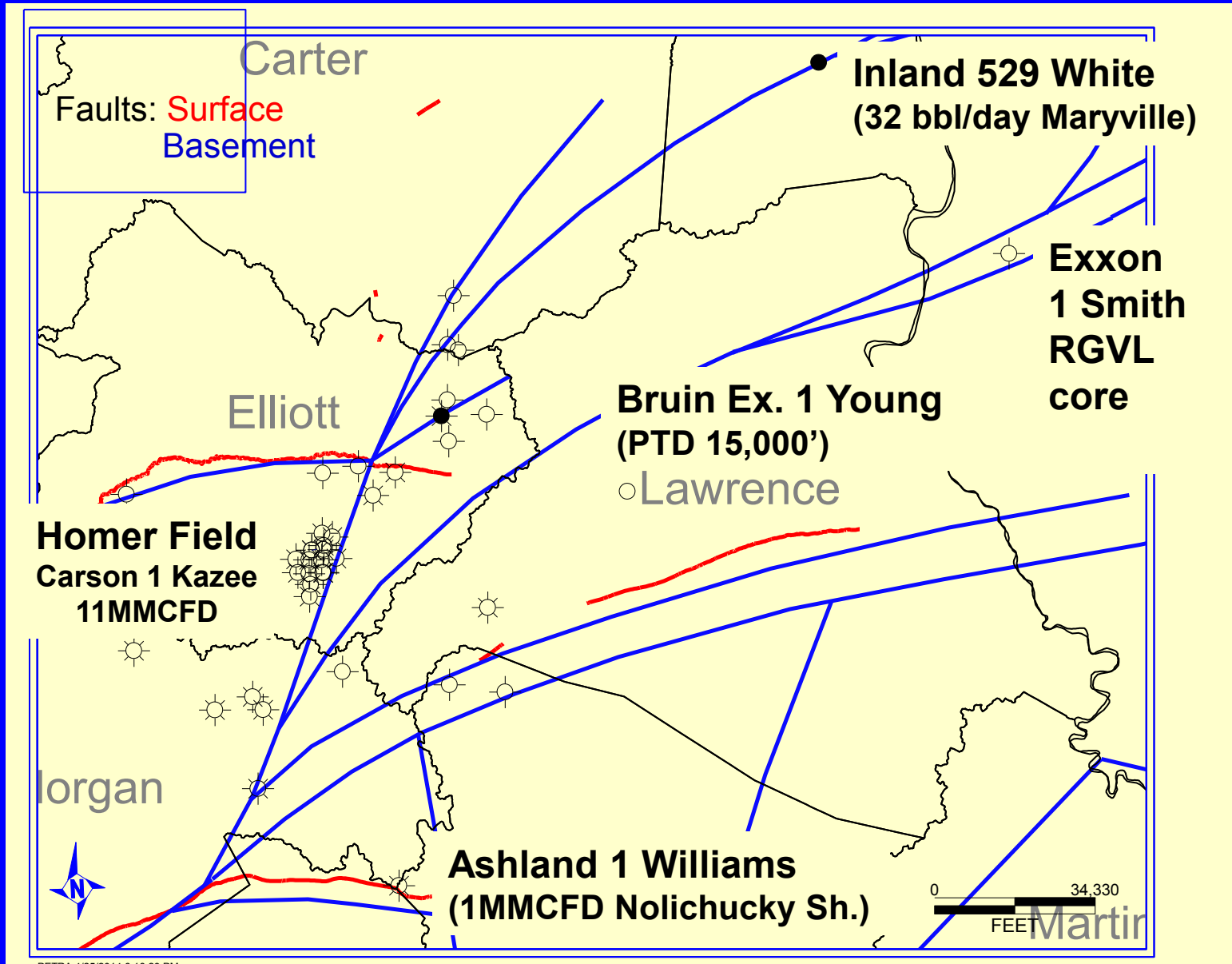
- Pre-1960 wells
- 1960's wells
- 1970's wells
- 1980's wells
- 1990's wells
- Early 2000's wells
- ◆ New Rogersville Shale tests (2014-'15)

Most deep wells have hydrocarbon shows, however, almost all are not sustainable or repeatable.

Image courtesy of J. Jenkins, Abarta Energy



Rome Trough Production


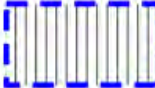




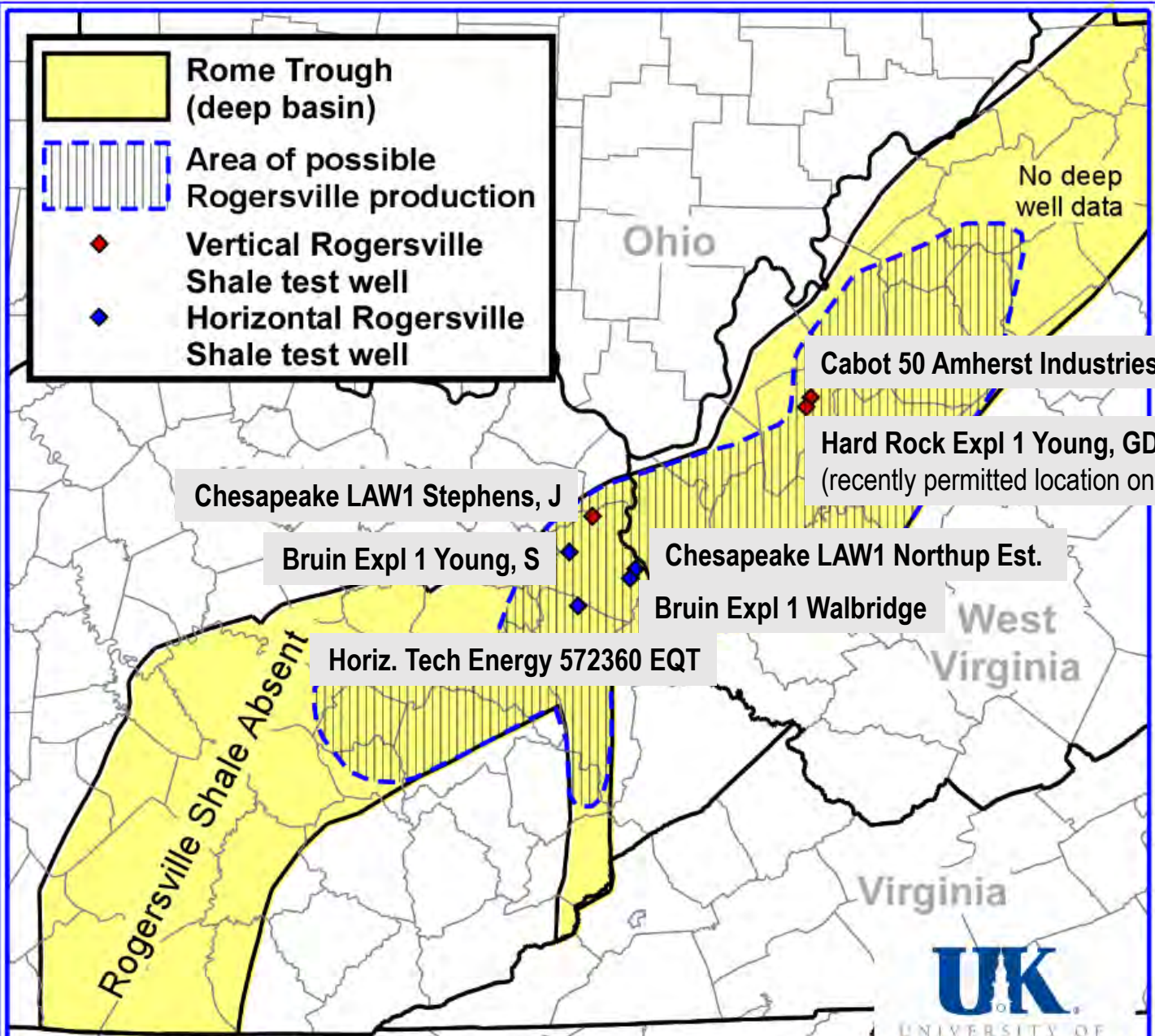
Bruin Exploration #1 Young Lawrence County, Kentucky

- Permitted as a stratigraphic test, and drilled to a total depth of 12,169 ft in late 2013.
- Logs, samples from stratigraphic test held confidential for 5 years.
- Re-permitted as oil and gas well in 2014 to complete and test well.
- New horizontal leg permitted 9/04/15.

New Leasing Activity

- After rumored success of the Bruin #1 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 June 2015 (Cate, 2015)
- Prices per acre are now \$250-300 where \$25-50 was common 5 years ago

	Rome Trough (deep basin)
	Area of possible Rogersville production
	Vertical Rogersville Shale test well
	Horizontal Rogersville Shale test well

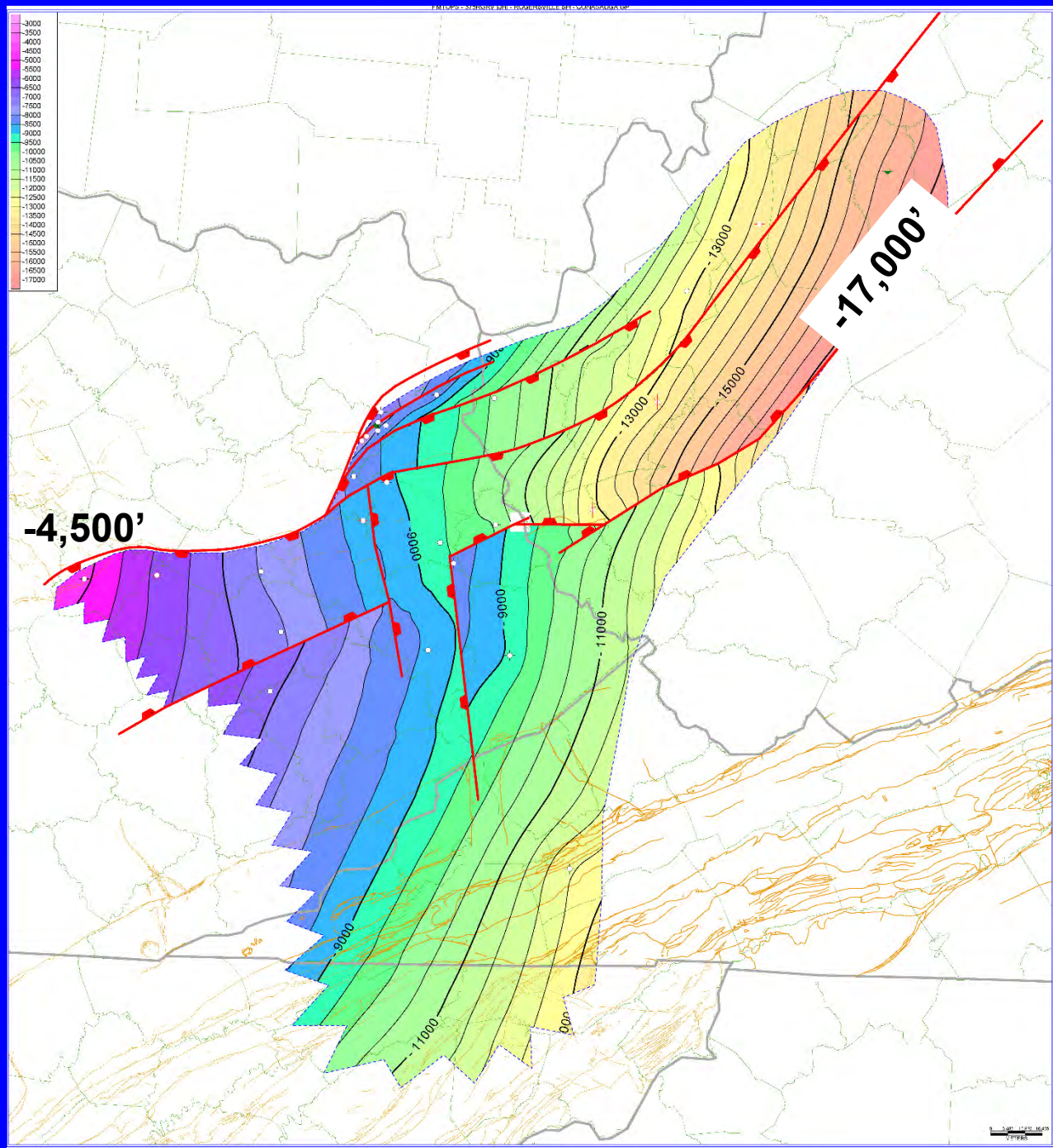


Note: Parts of Rogersville Shale may be too deep, or lack sufficient thickness and organic content for economic production



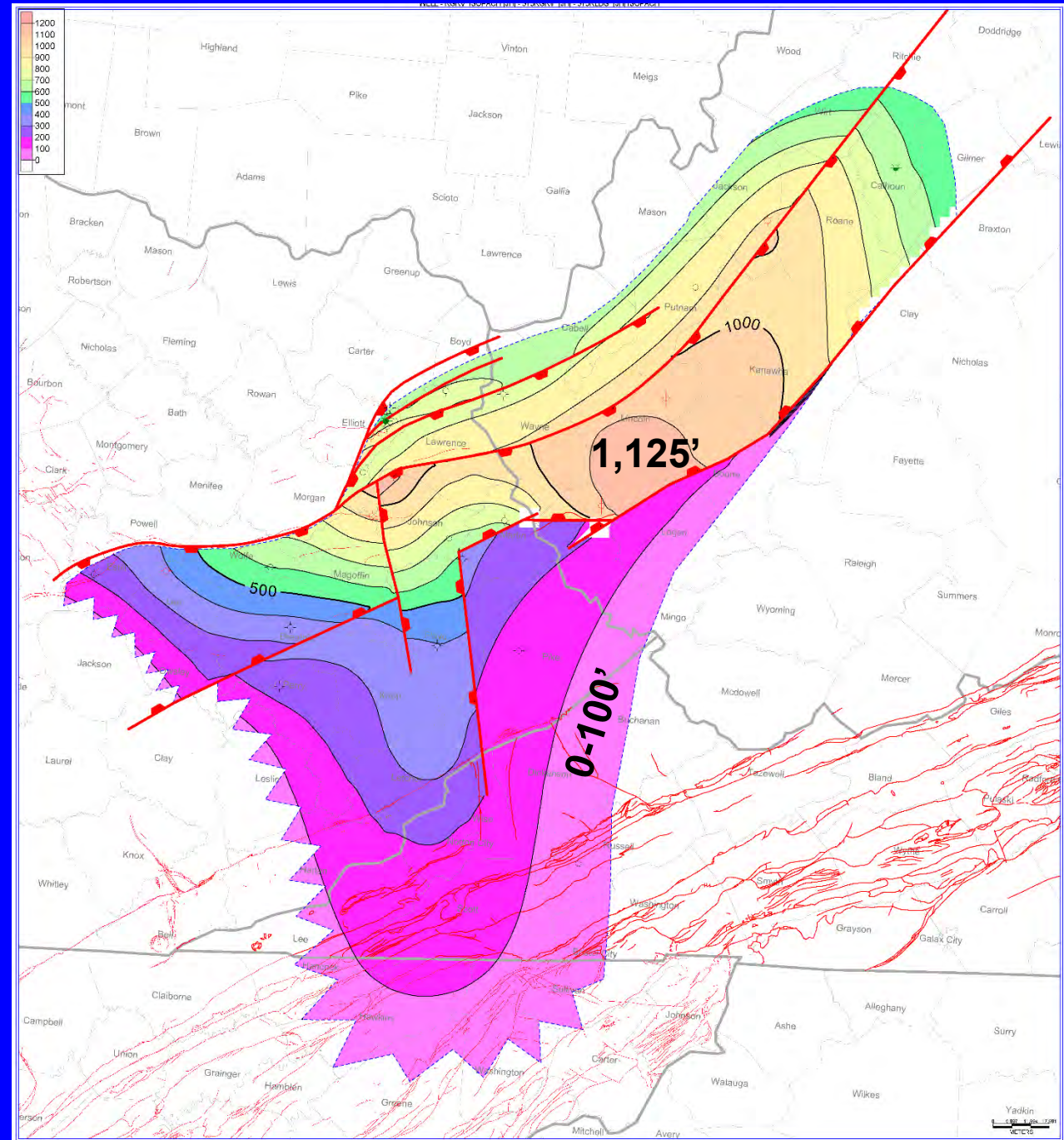
Rogersville Shale Structure Map

4,500 – 17,000 feet below sea level



Rogersville Shale Isopach Map

0 to ~1,125
feet thick



**Rogersville Shale
Source Rock Quality
and Thermal Maturity**

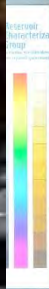
Exxon #1 Smith
core:
11,191-11,200'



Exxon #1 Smith
core:
11,168-11,179.5'



Exxon #1 Smith
core:
11,146-11,157'

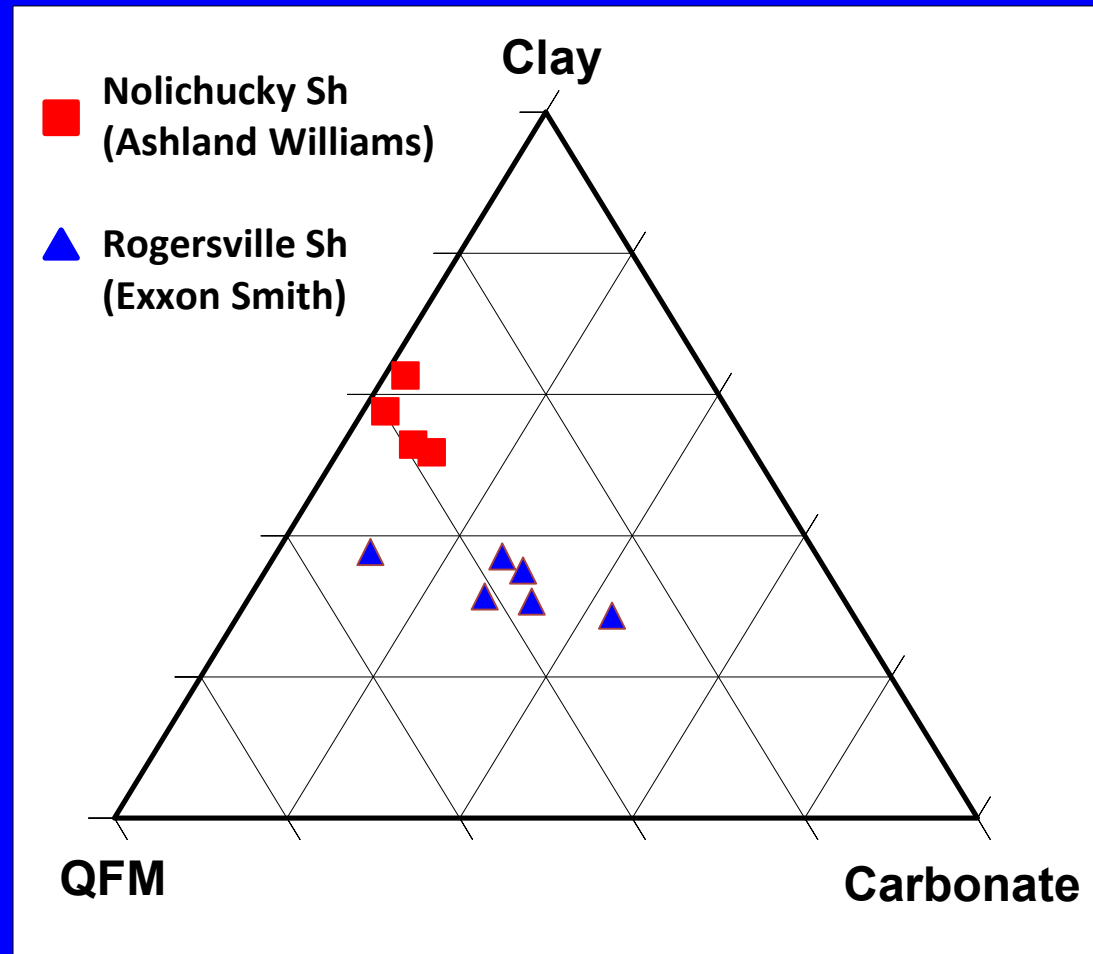


Rogersville Shale Deposition

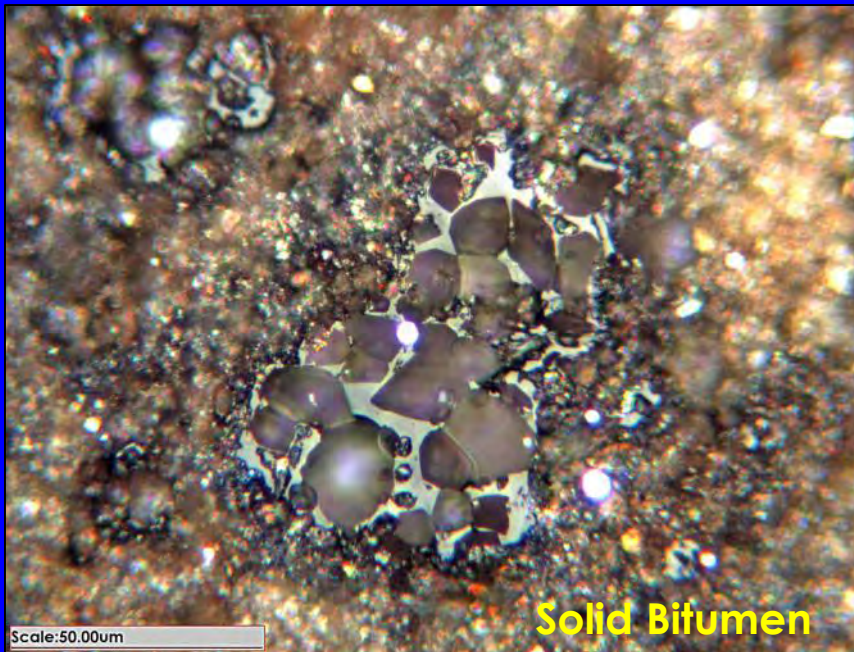
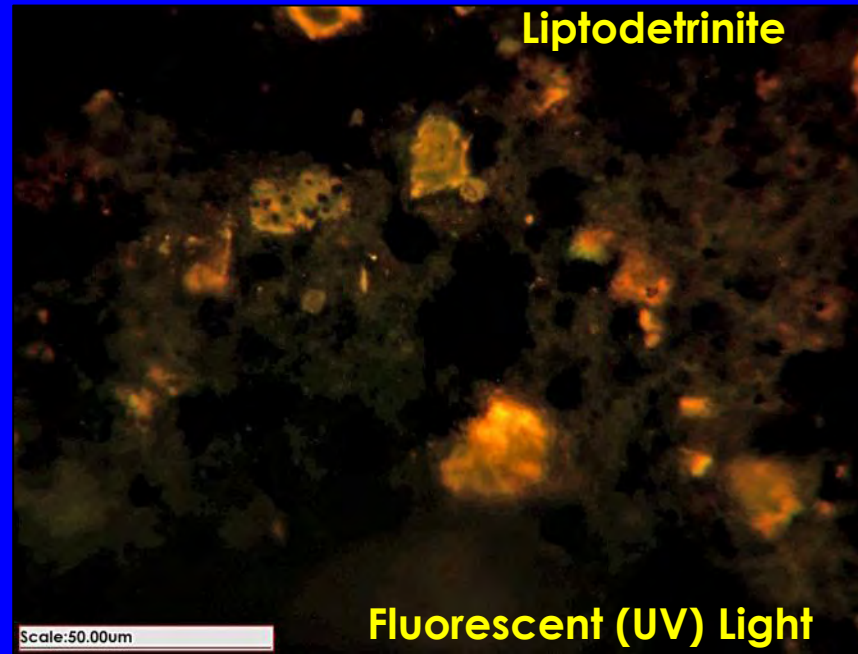
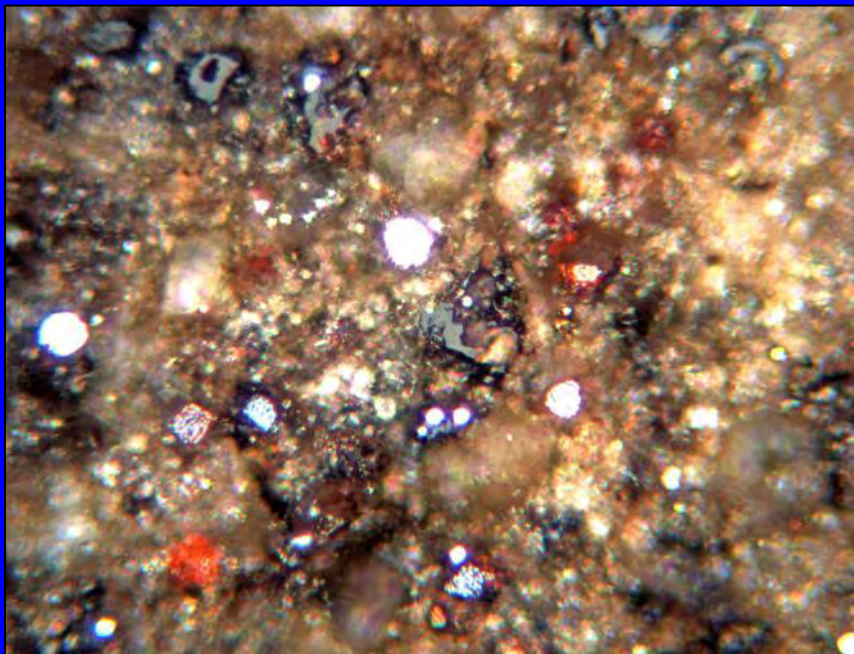
- Shallow marine shale, with minor amounts of limestone and sandstone
- Peritidal bedding textures
- Numerous zones contain bioturbation features

Shale Mineralogy

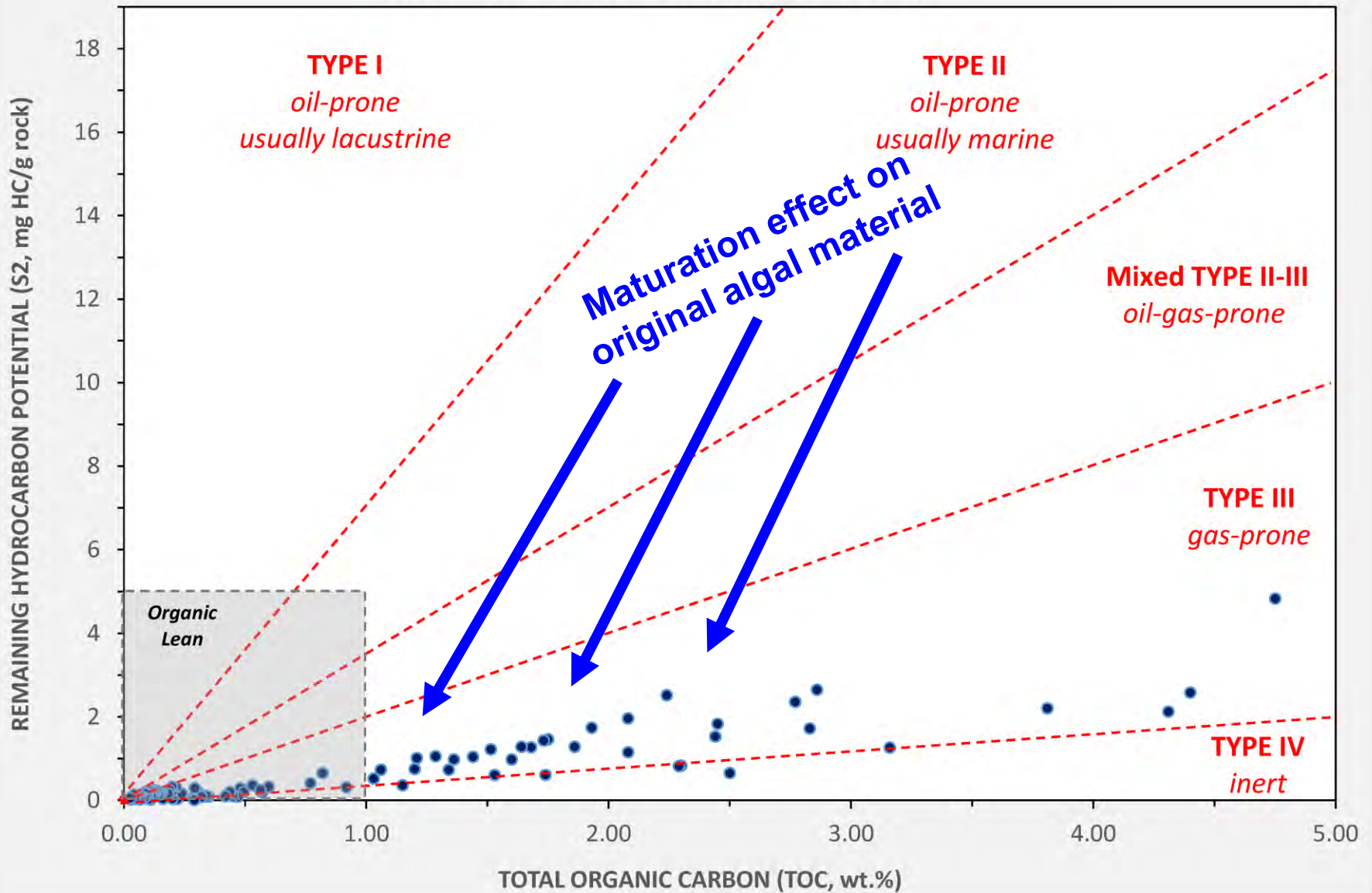
- XRD data from the Rogersville and Nolichucky shales
- Rogersville has:
 - Less clay
 - More quartz and carbonate
- Increased brittleness



Rogersville Organic Petrography



Rogersville Shale Kerogen Quality



Source Rock Maturity

4709901572 - Exxon #1 Smith, Wayne Co., WV

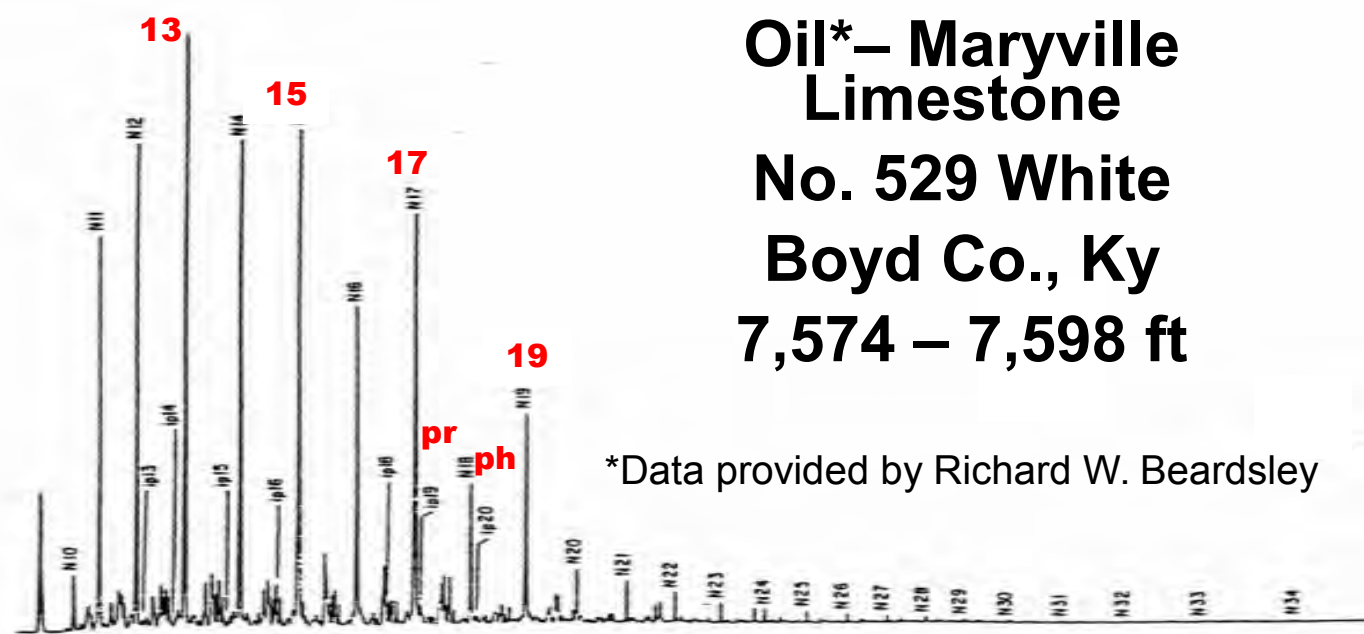
Bitumen Reflectance				
Core Depth (ft, md)	11167	11178	11191	11197
Average R_o random	1.76	1.80	1.80	1.84
Maximum R_o random	2.11	2.11	2.04	2.10
Minimum R_o random	1.50	1.47	1.53	1.59
Standard deviation	0.14	0.16	0.13	0.13
Observations/sample	50	50	50	50
Calculated R_o equivalent	1.49	1.51	1.51	1.54
$(R_o \text{ random} * 0.618) + 0.4$				
(Jacob, 1989)				
Indicated T_{max} from				
calculated R_o equiv.	480	482	482	484

Rogersville HC Potential

- Rogersville appears to have sufficient organic material to generate hydrocarbons.
- Rogersville appears to have been thermally matured to at least a “wet gas” level.
- Has the Rogersville Shale produced and expelled hydrocarbons in the past?

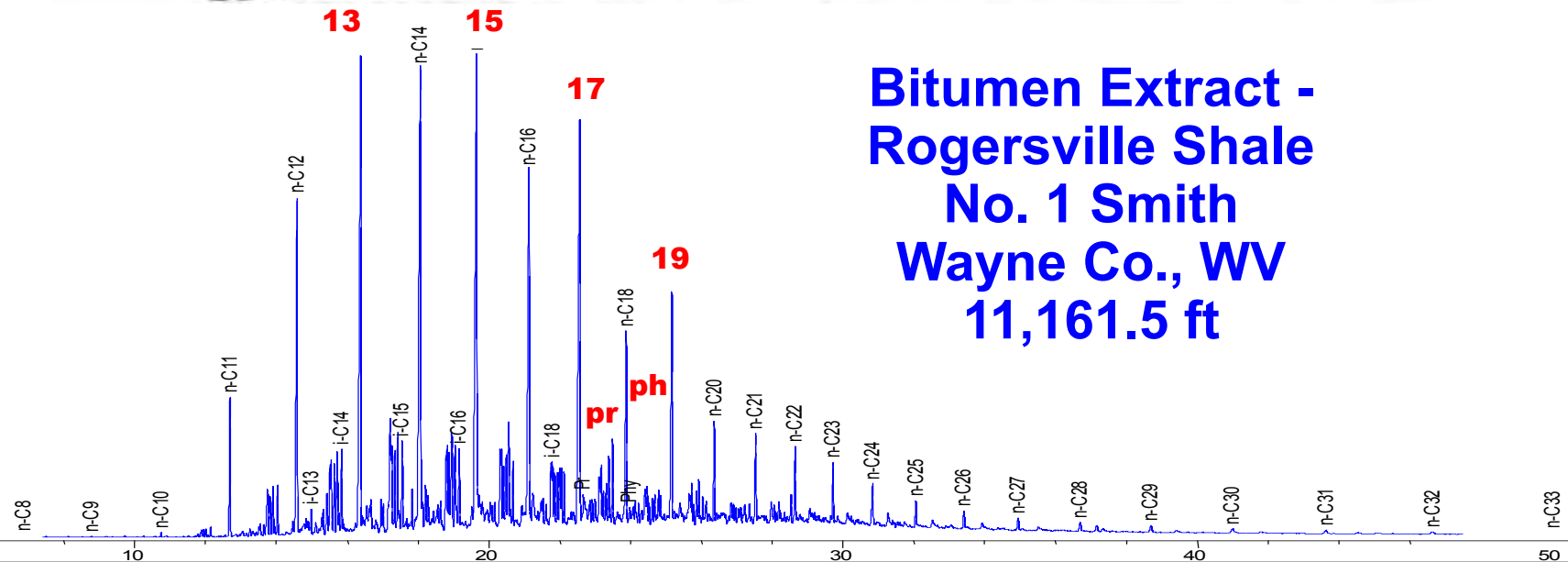
Oil to Source "Fingerprinting"

**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**

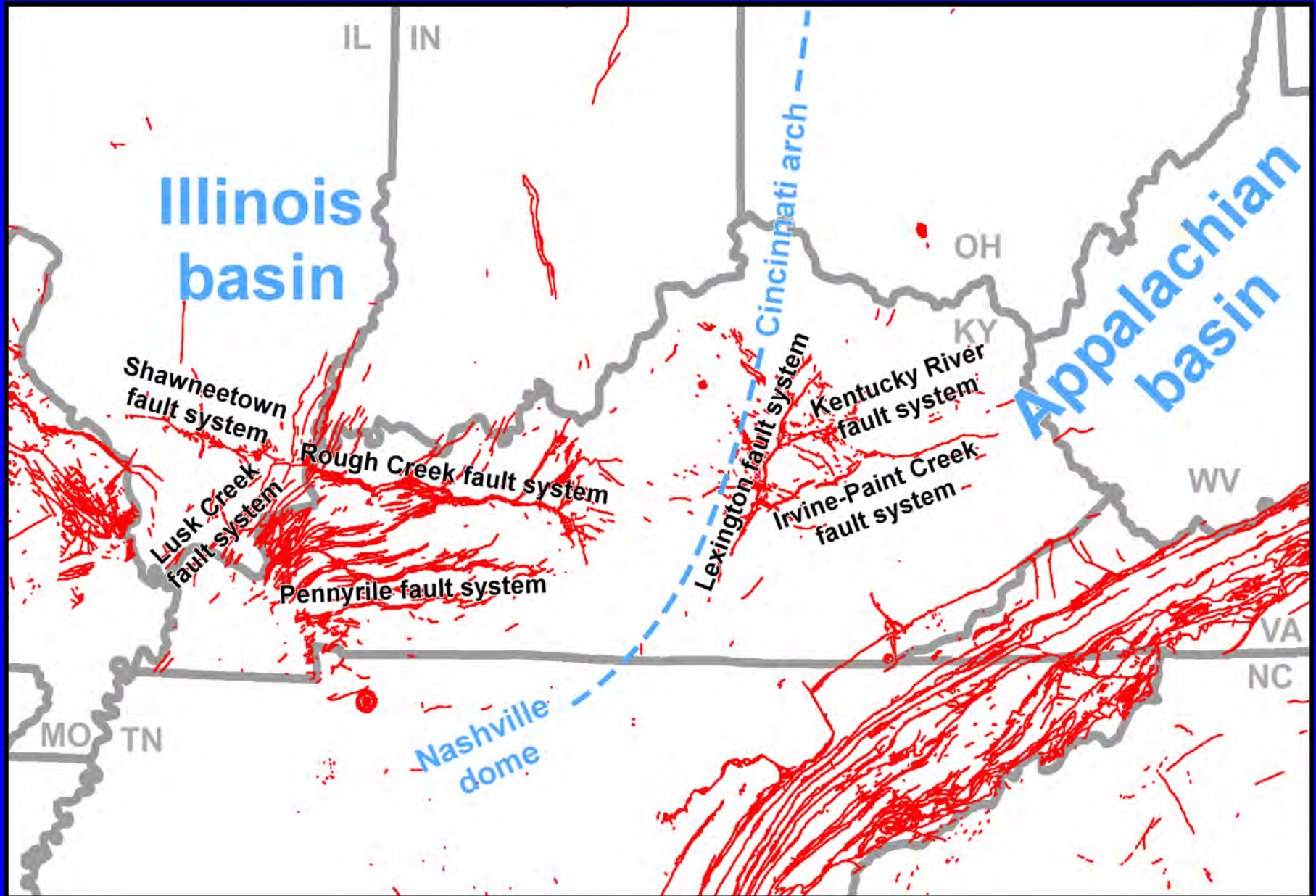


Rogersville Shale Summary

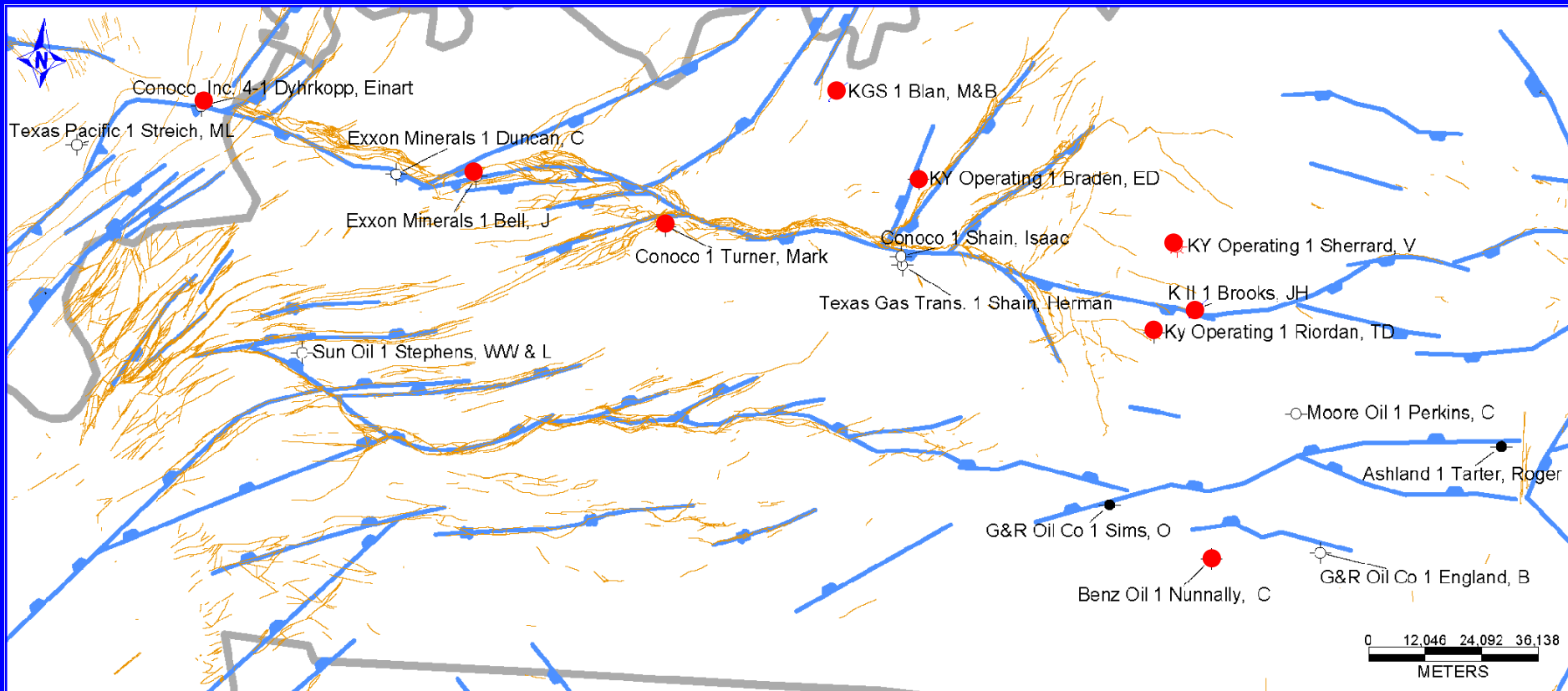
- 5,000 to 18,000 ft deep within Rome Trough
- Up to 1,100 ft thick, but limited to deeper parts of Rome Trough
- Contains up to 4.8% TOC in parts, but not all is organic rich
- Current maturity near wet gas – dry gas transition
- Has generated gas and condensate

**Rough Creek Graben,
Cambrian depocenter
in the southernmost
Illinois Basin**

Current Surface Features

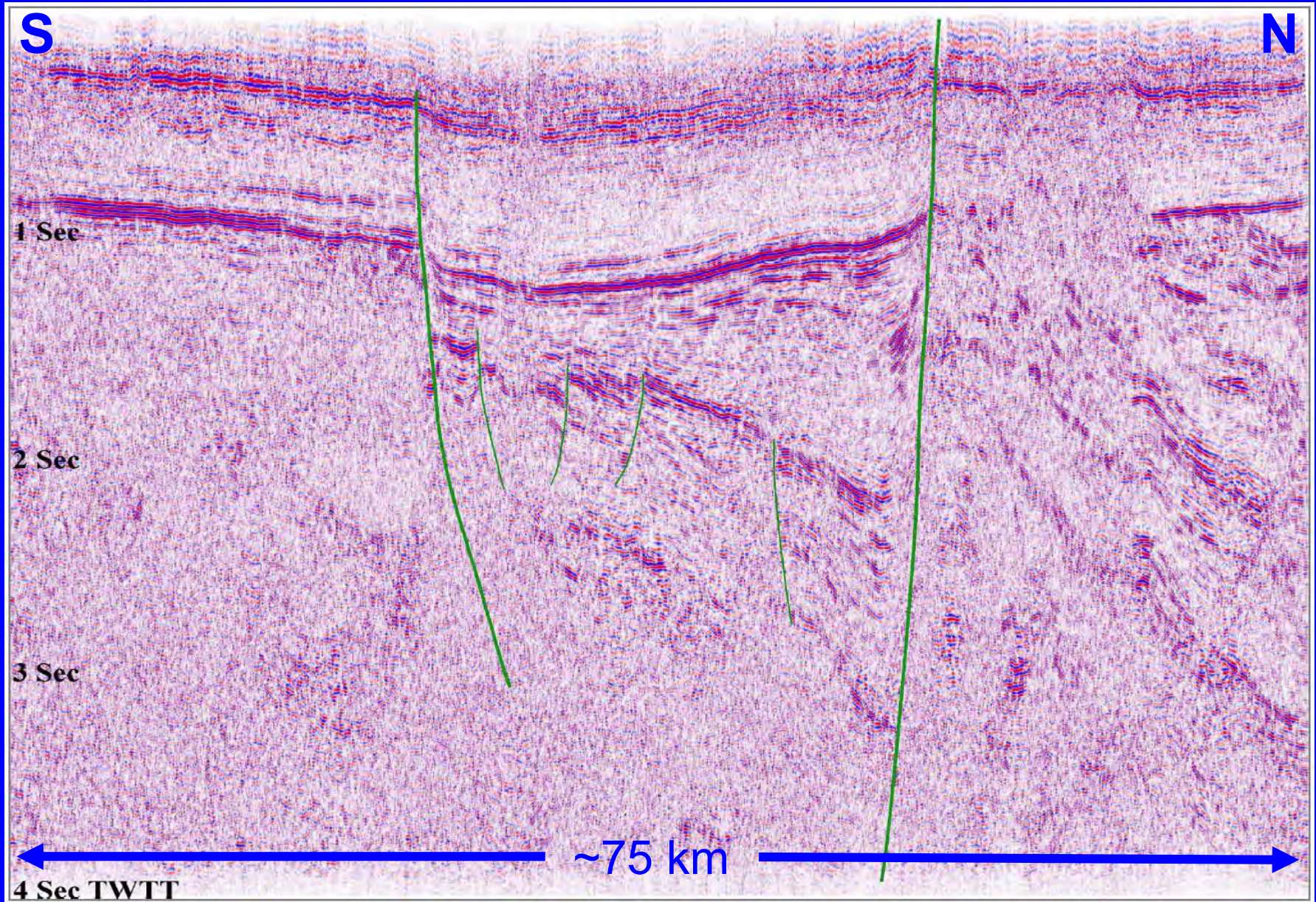


Rough Creek Graben Exploration

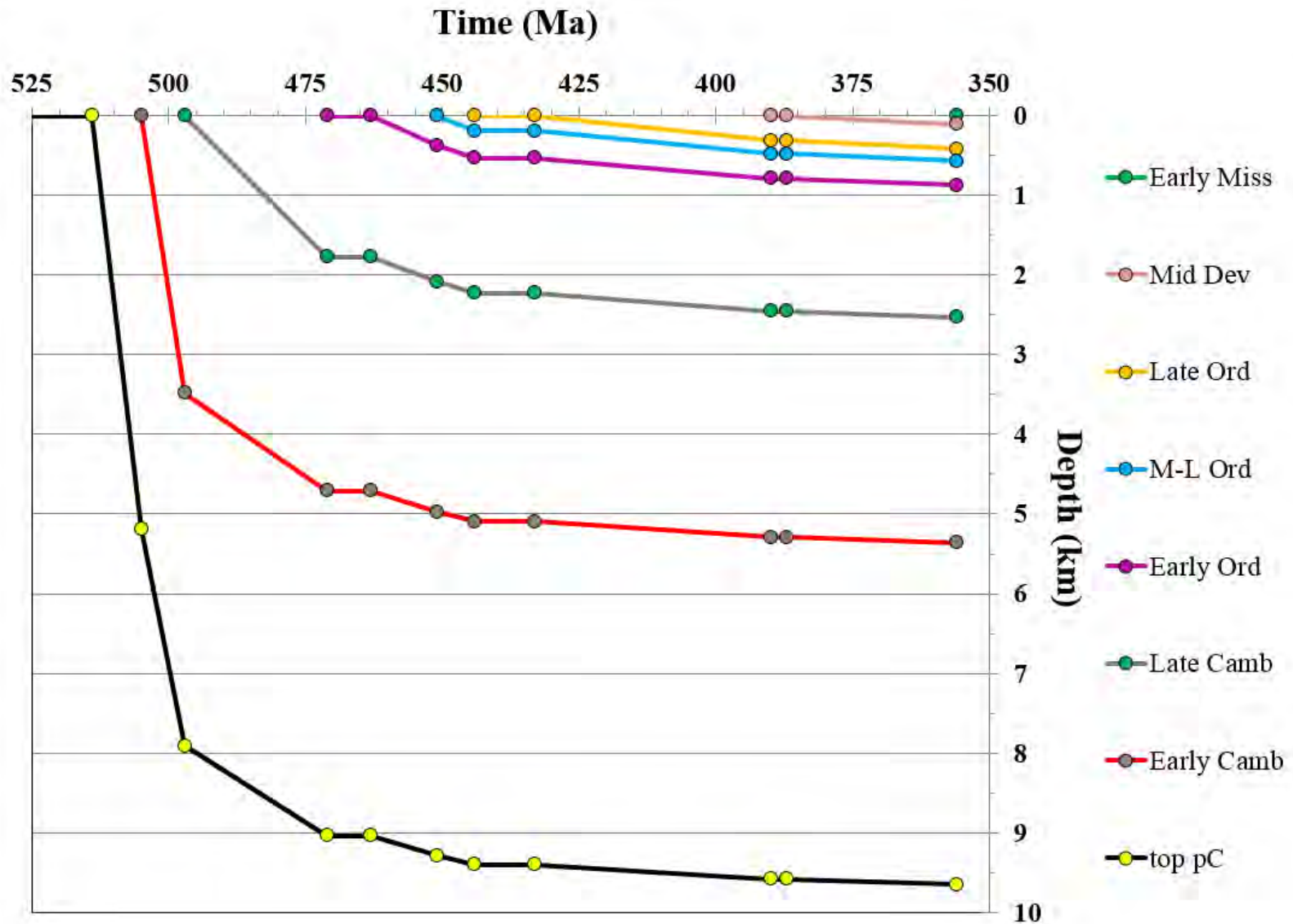


Eighteen wells drilled deeper than Knox Group (Arbuckle equiv.) in region.
Nine basement tests (in red), all along (or just outside) graben boundary faults.

Rough Creek Graben seismic profile

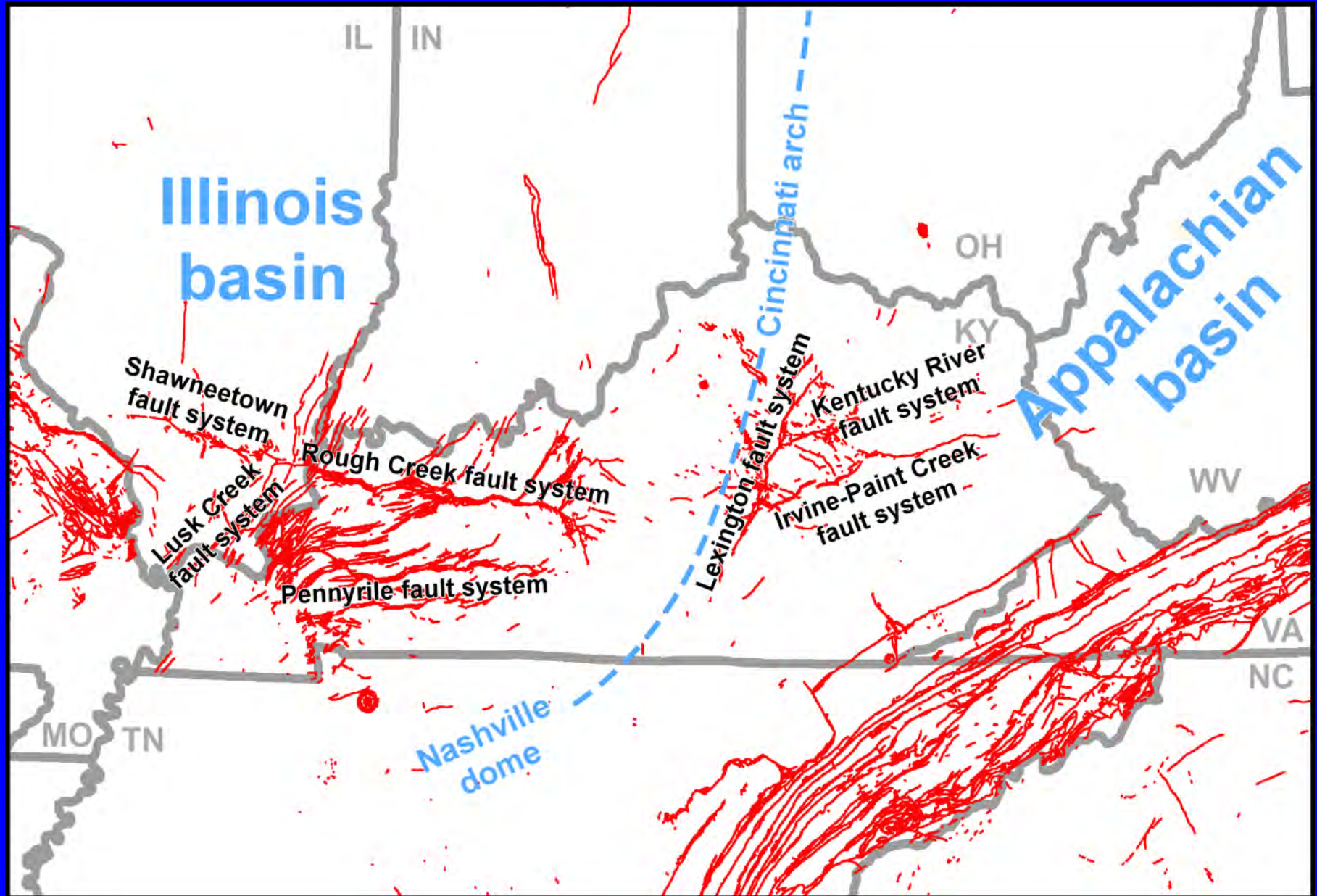


RCG Burial History

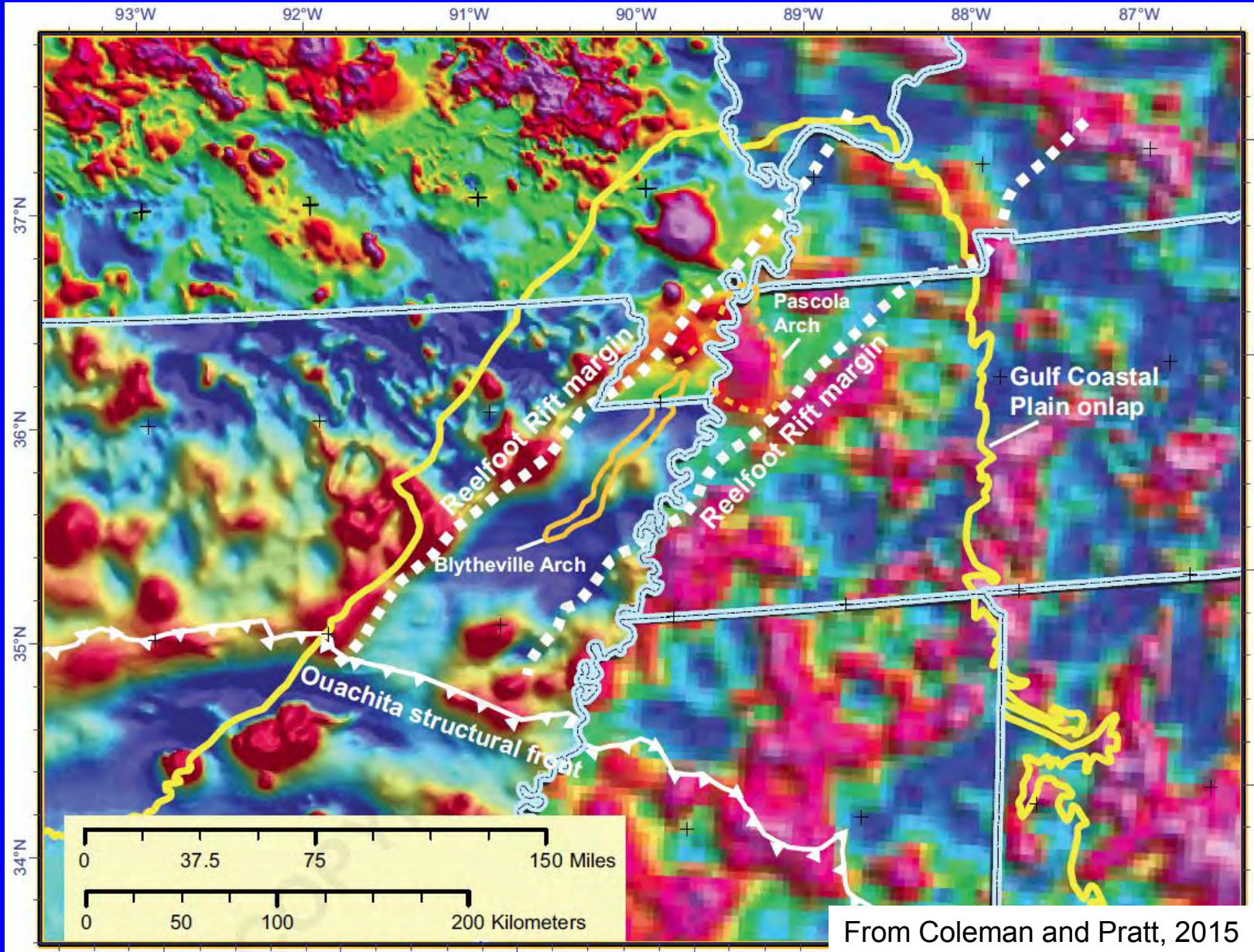


**Mississippi Valley Graben
(a.k.a. Reelfoot Rift),
Cambrian depocenter
below the northernmost
Mississippi Embayment**

Current Surface Features



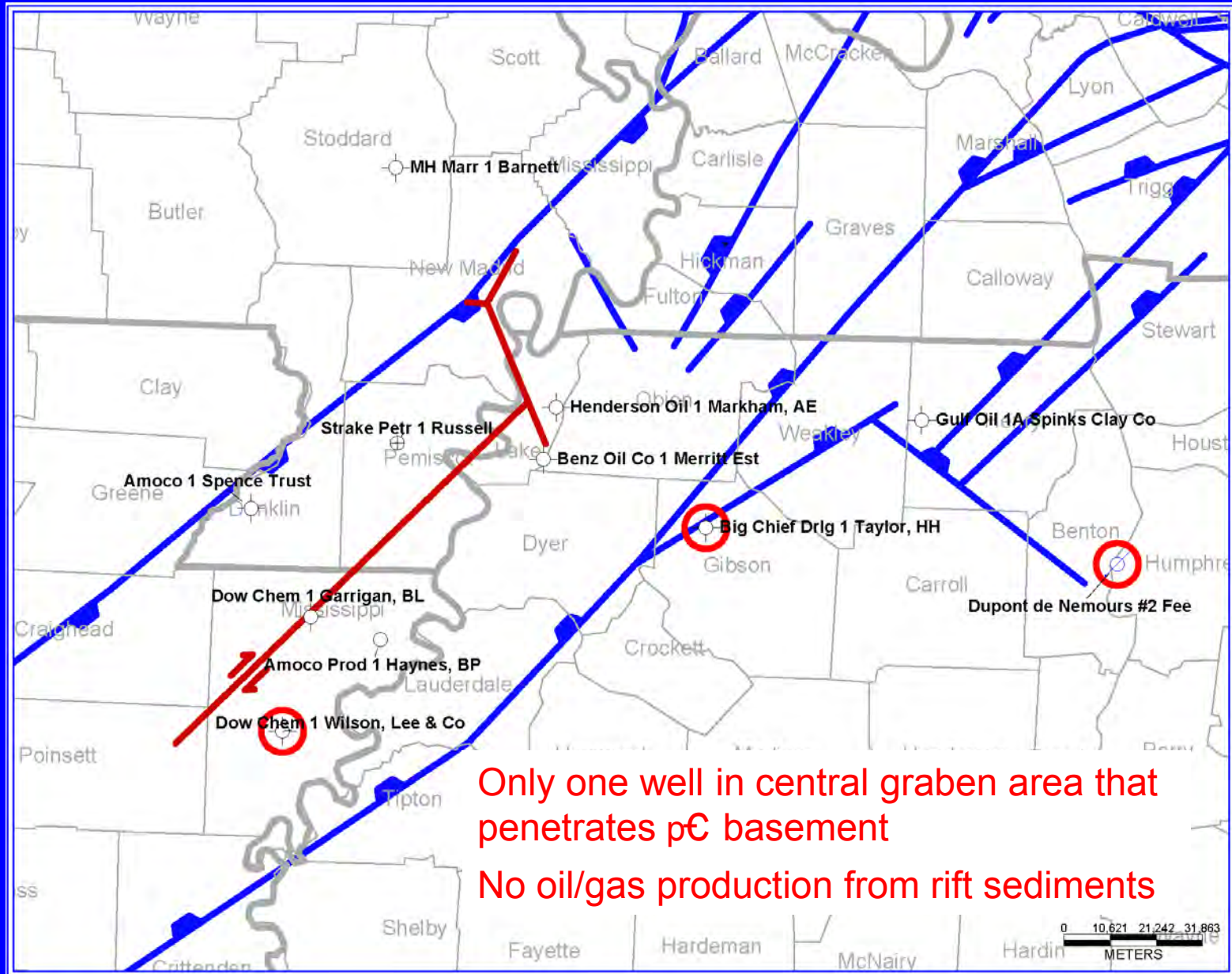
Mississippi Valley Graben



Mississippi Valley Graben

- MVG is 45 mi wide, 185 mi long rift graben
- Filled with Cambrian strata
- Connects to RCG-RT system; Similar deposition and organic preservation?
- No production from rift sediments, but 9 of 22 wells drilled reported oil or gas shows

Northern Mississippi Valley Graben



Only one well in central graben area that penetrates pC basement

No oil/gas production from rift sediments

MVG Interpretation Issues

- Few deep wells that penetrate Cambrian rocks
- Limited availability of quality well logs
- Resolution of seismic images hampered by impedance level of Paleozoic-Cretaceous boundary, and pervasive faulting within graben interior

South

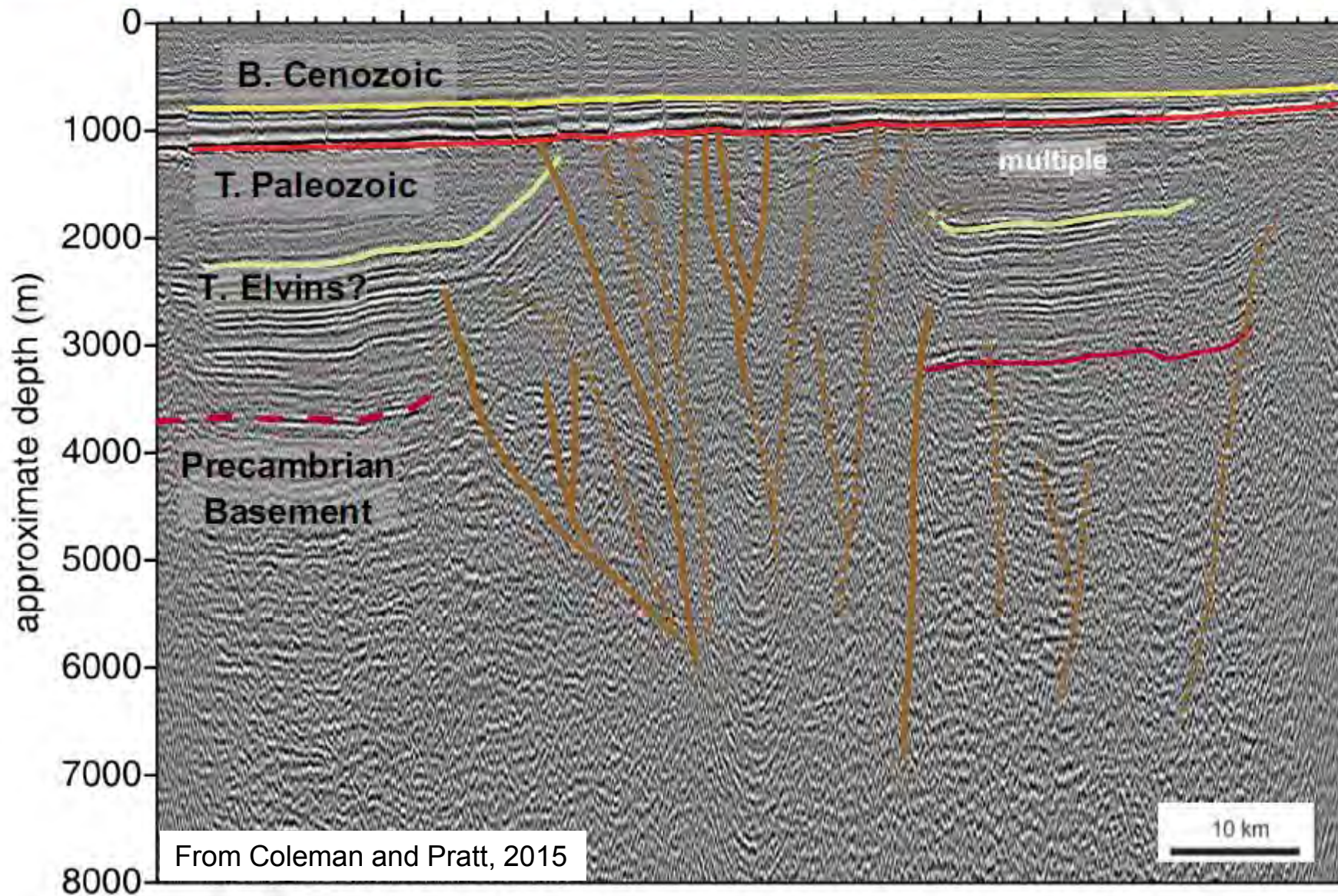
NMSZ / Blytheville Arch

North

Wilson #1



Garrigan #1



From Coleman and Pratt, 2015

10 km

Conclusions

- Viable petroleum system exists in Rome Trough. Rogersville Shale (Conasauga Group) is primary source interval.
- Source rock quality in Rogersville is variable— not a uniformly rich source. Controls on TOC distribution not well understood.
- Rogersville unconventional play should be possible in higher TOC areas, but need to consider depth and economics.

Conclusions (cont.)

- Similar organic-rich horizons may exist within the Eau Claire Fm of the Rough Creek or Mississippi Valley Grabens (but have not been identified to date).
- Because of complex history of faulting, structure data (seismic, gravity, magnetics) will be a key tool in developing rift-related Cambrian shale plays.

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Kentucky Geological Survey

September 25-28, 2016



<http://esaapgmtg.org/>