Geology and Petroleum Resources of Tennessee and the Use of Fracking as a Drilling Tool

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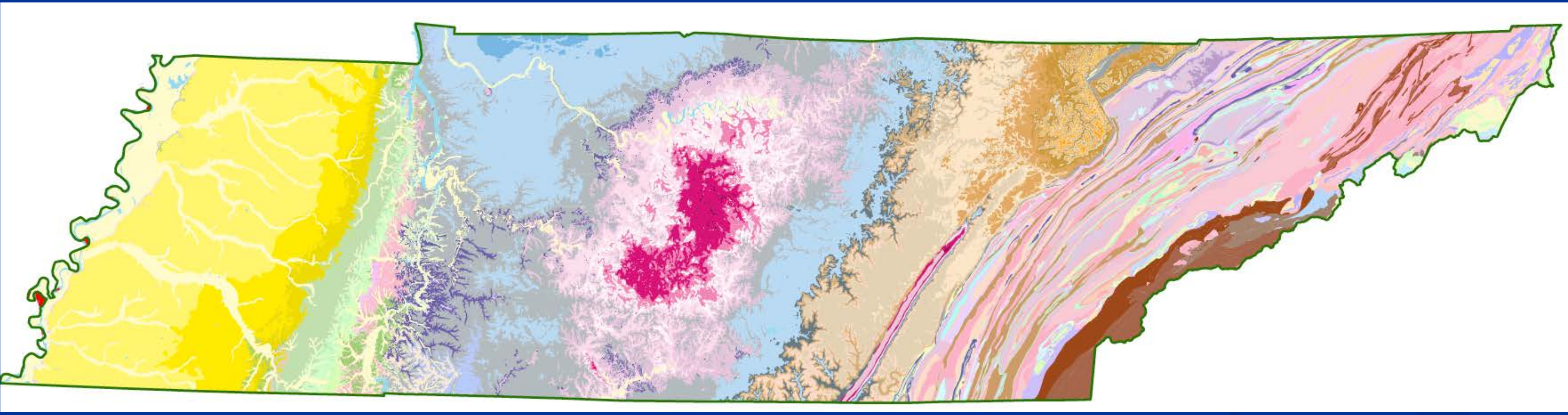
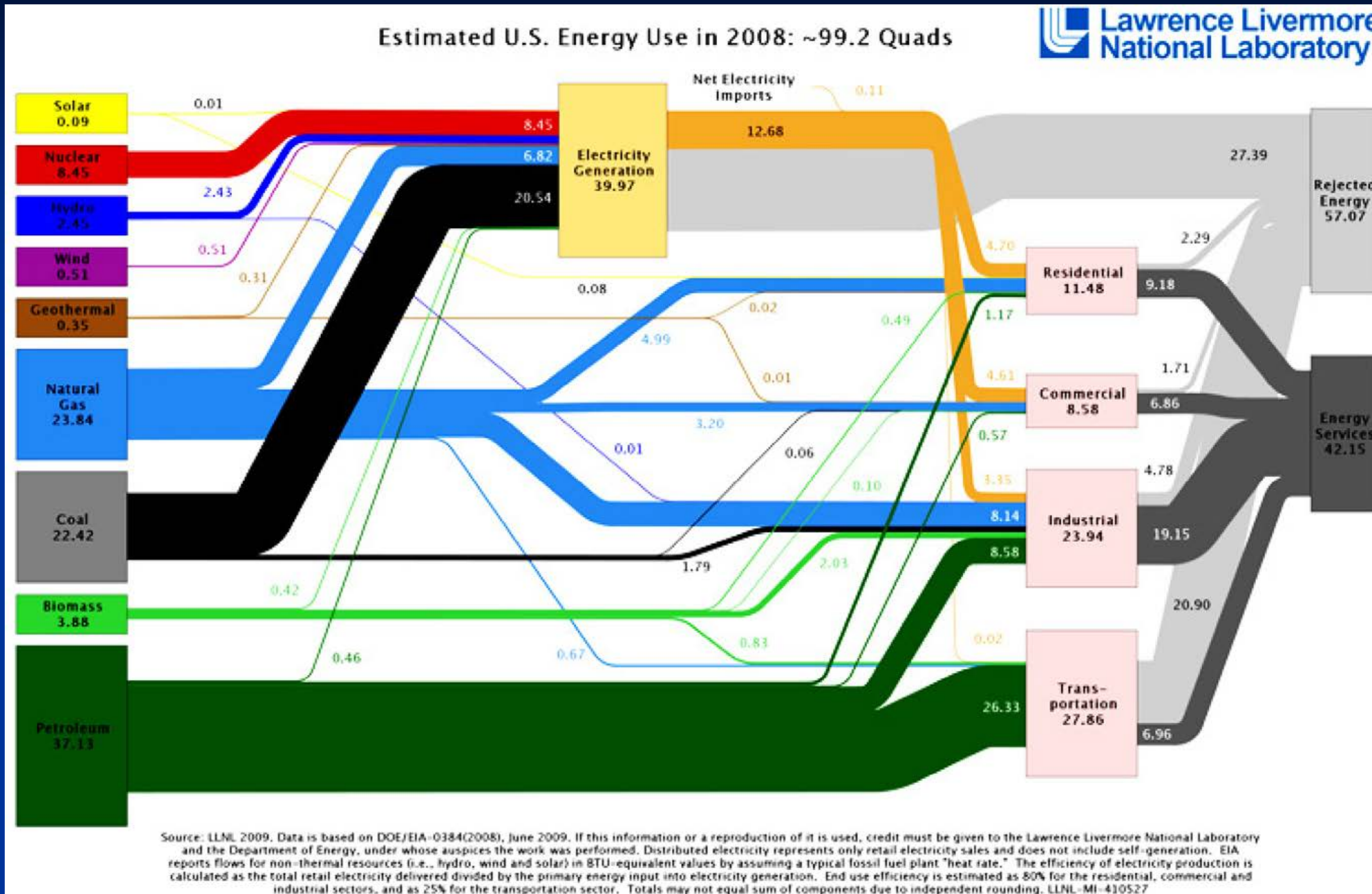


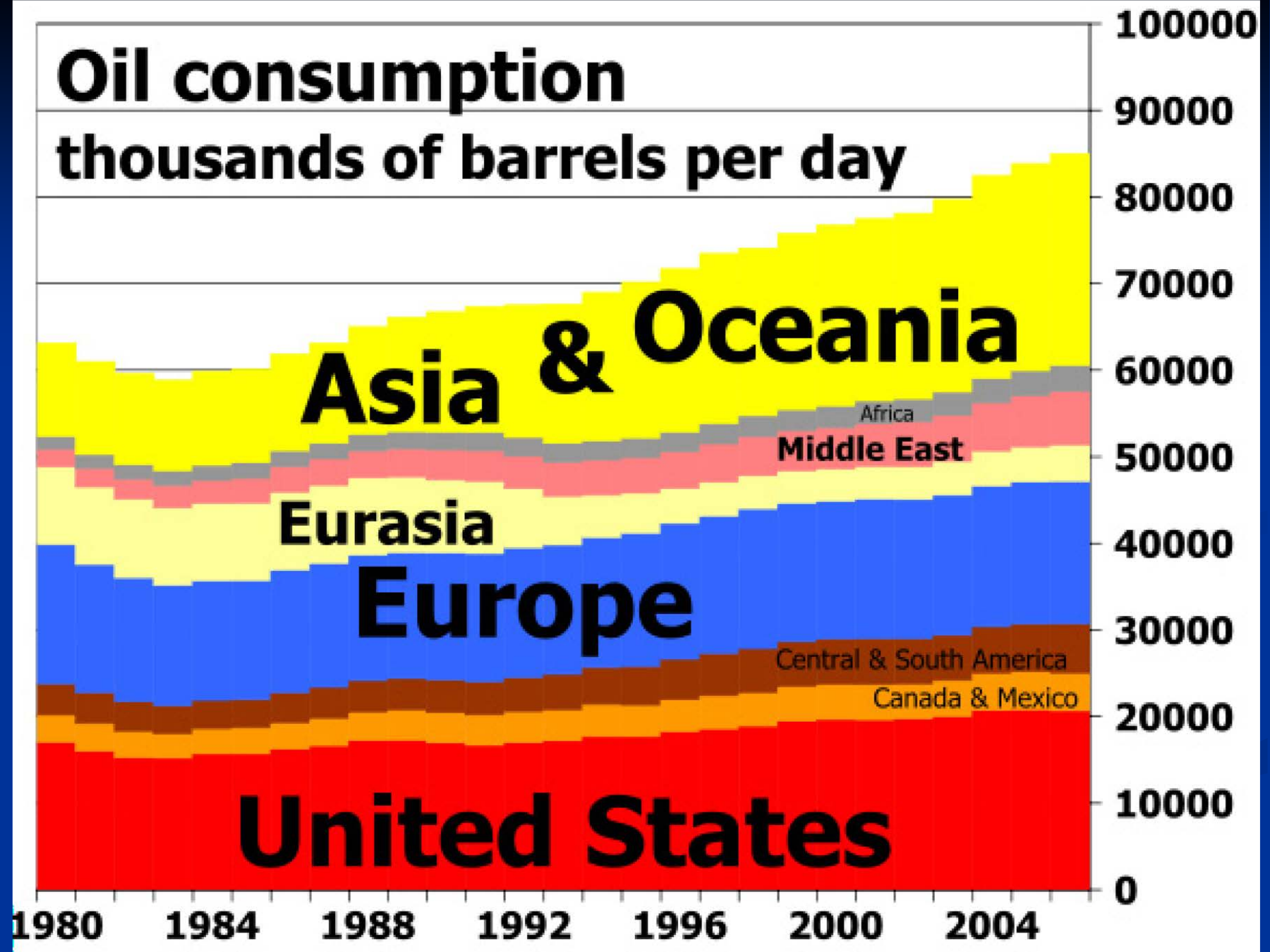
AICHE Monthly Mtg.
Knoxville, TN
April 18, 2013



Estimated U.S. Energy Use in 2008: ~99.2 Quads
Lawrence Livermore National Laboratory
Solar 0.09
Nuclear 8.45
Hydro 2.45
Wind 0.51
Geothermal 0.35
Natural Gas 23.84
Coal 22.42
Biomass 3.88
Petroleum 37.13
Electricity Generation 39.97
Net Electricity Imports
0.11
12.68
Residential 11.48
Commercial 8.58
Industrial 23.94
Trans-portation 27.86
Rejected Energy 57.07
Energy Services 42.15
27.39
2.29
9.18
1.71
6.86
4.78
19.15
20.90
6.96
0.01
8.45
2.43
6.82
20.54
0.51
0.31
0.08
0.02
4.99
0.01
3.20
0.01
0.06
1.79
0.42
0.46
0.67
0.83
2.03
0.10
0.49
1.17
0.57
4.70
4.61
3.35
8.14
8.58
0.02
26.33
Source: LLNL 2009. Data is based on DOE/EIA-0384(2008), June 2009. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

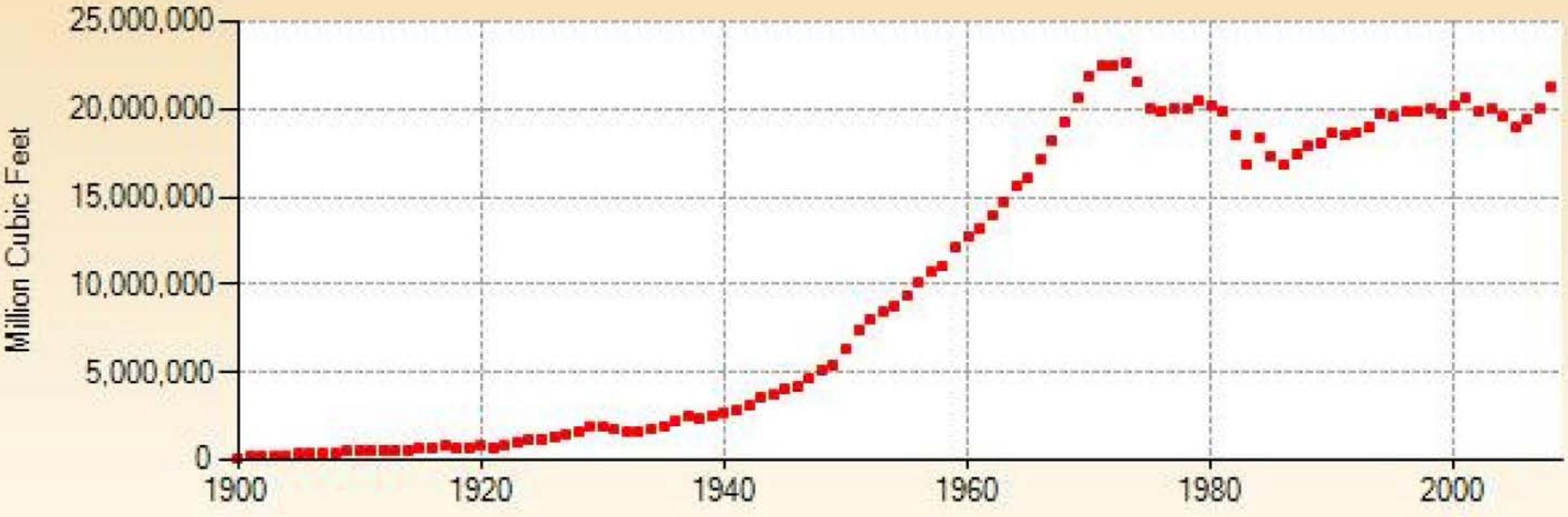
Fuel type	MJ/L	MJ/kg	BTU/imp gal	BTU/US gal	Research octane number (RON)
Regular gasoline/petrol	34.8	~47	150,100	125,000	Min. 91
Premium gasoline/petrol		~46			Min. 95
Autogas (LPG) (60% propane and 40% butane)	25.5–28.7	~51			108–110
Ethanol	23.5	31.1 [2]	101,600	84,600	129
Methanol	17.9	19.9	77,600	64,600	123
Gasohol (10% ethanol and 90% gasoline)	33.7	~45	145,200	121,000	93/94
E85 (85% ethanol and 15% gasoline)	33.1	44	108,878	90,660	100–105
Diesel	38.6	~48	166,600	138,700	N/A (see cetane)
BioDiesel	35.1	39.9	151,600	126,200	N/A (see cetane)
Vegetable oil (using 9.00 kcal/g)	34.3	37.7	147,894	123,143	
Aviation gasoline	33.5	46.8	144,400	120,200	80-145
Jet fuel, naphtha	35.5	46.6	153,100	127,500	N/A to turbine engines
Jet fuel, kerosene	37.6	~47	162,100	135,000	N/A to turbine engines
Liquefied natural gas	25.3	~55	109,000	90,800	
Liquid hydrogen	9.3	~130	40,467	33,696	

From Wikipedia

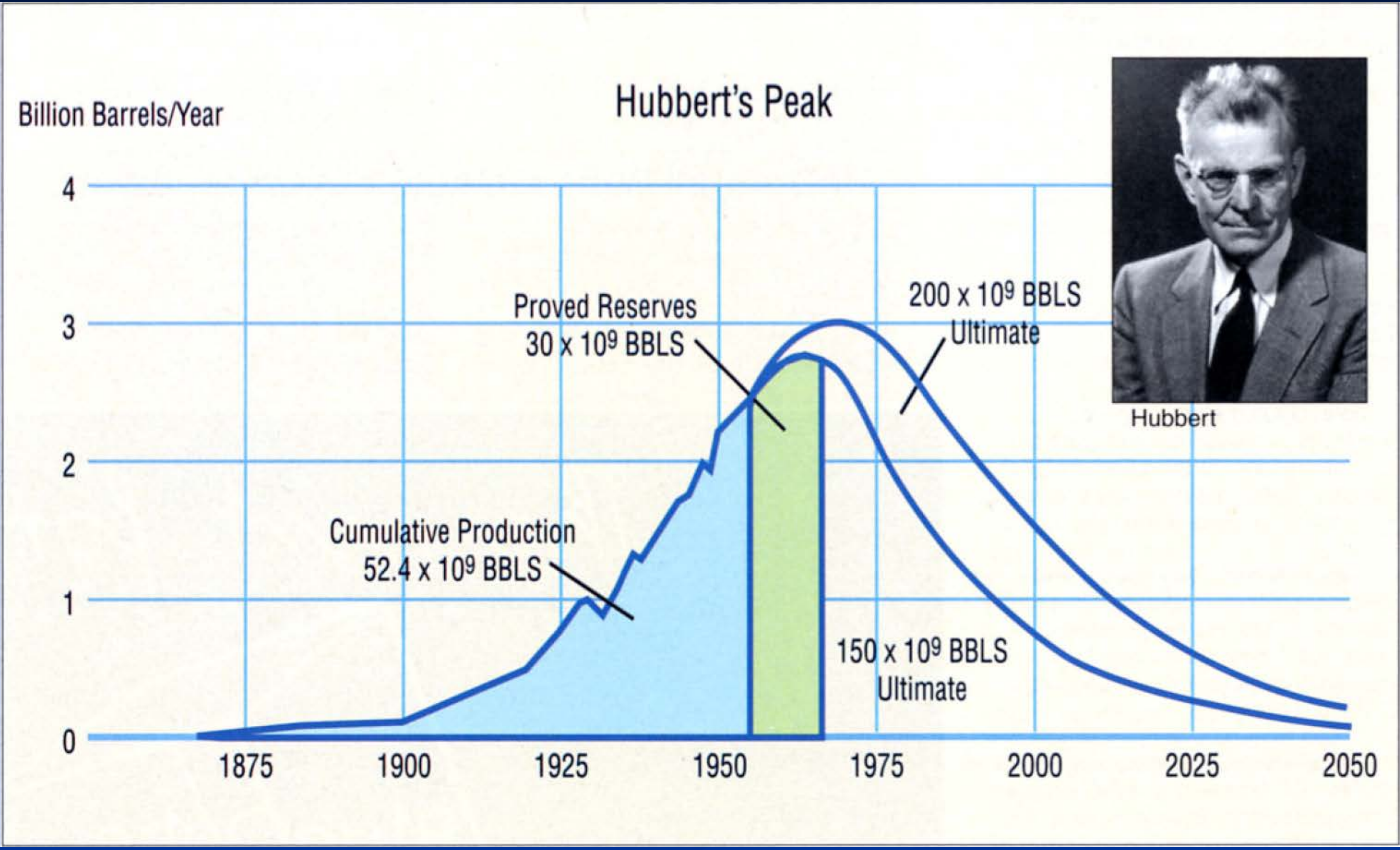

Oil consumption
thousands of barrels per day
Asia & Oceania
Africa
Middle East
Eurasia
Europe
Central & South America
Canada & Mexico
United States
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
1980
1984
1988
1992
1996
2000
2004

Annual U.S. Field Production of Crude Oil

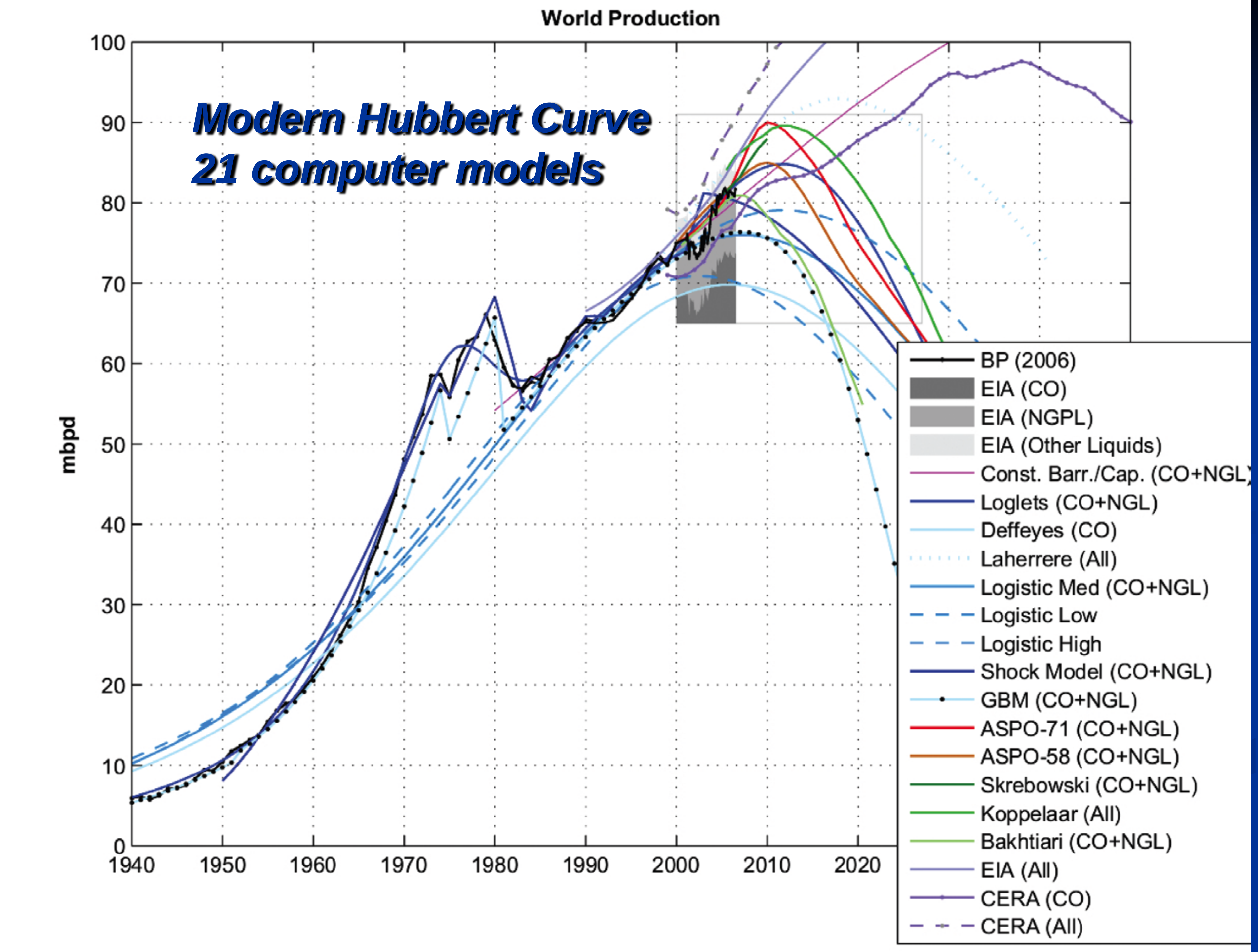
Annual U.S. Natural Gas Marketed Production



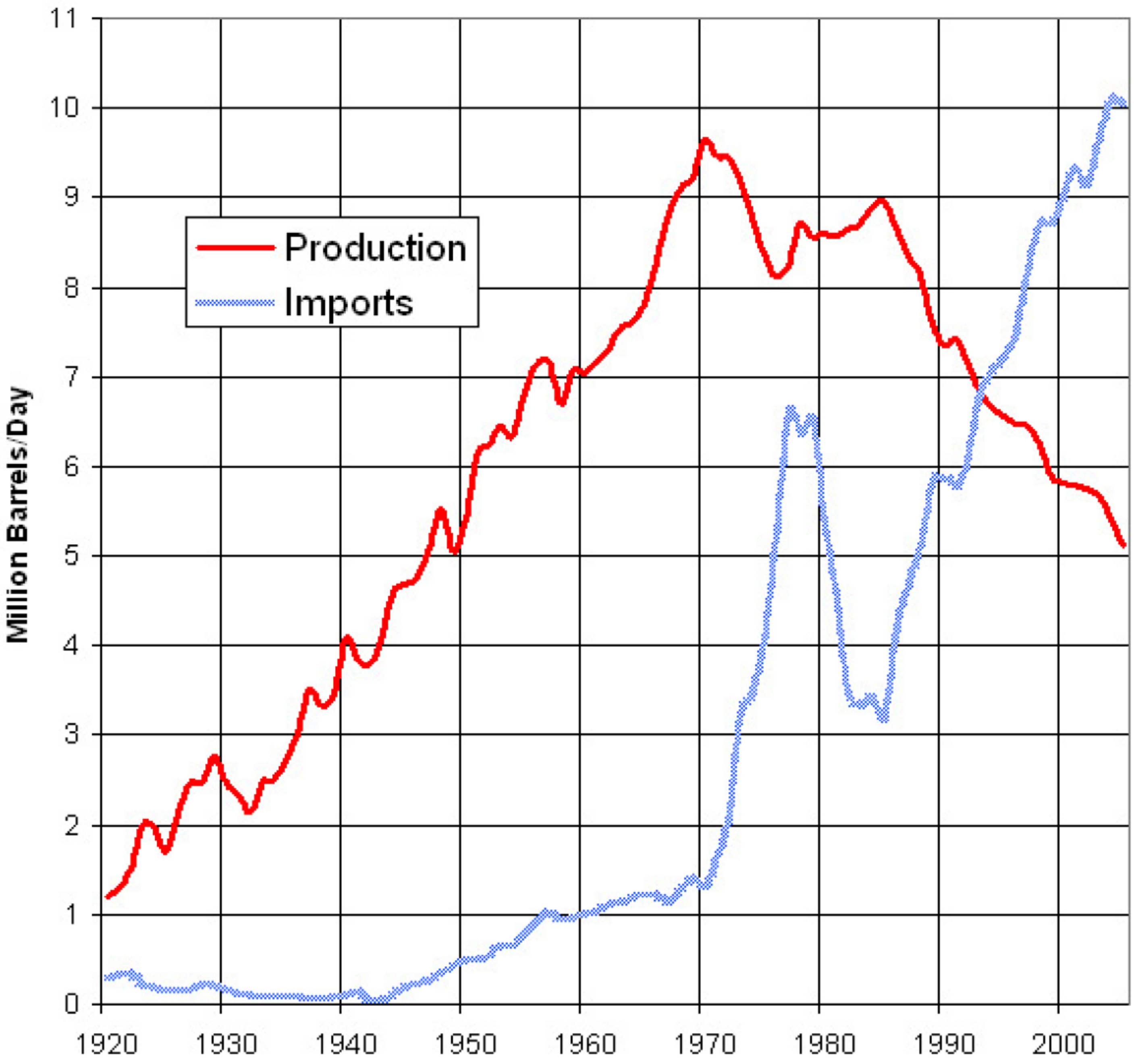
Source: U.S. Energy Information Administration

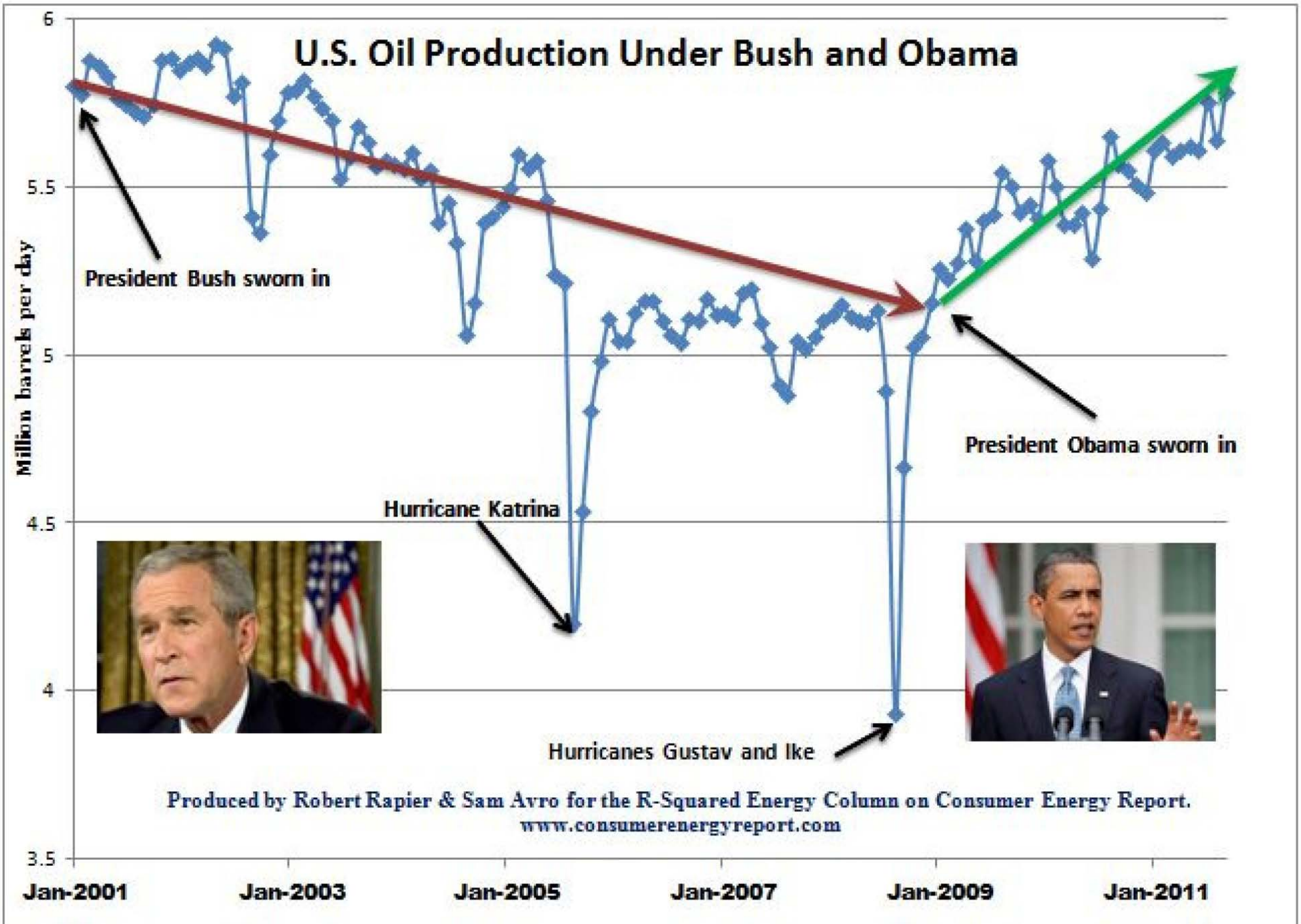


Hubbert's Peak
Billion Barrels/Year
4
3
2
1
0
1875
1900
1925
1950
1975
2000
2025
2050
Proved Reserves
30 x 10⁹ BBLS
Cumulative Production
52.4 x 10⁹ BBLS
200 x 10⁹ BBLS
Ultimate
150 x 10⁹ BBLS
Ultimate
Hubbert

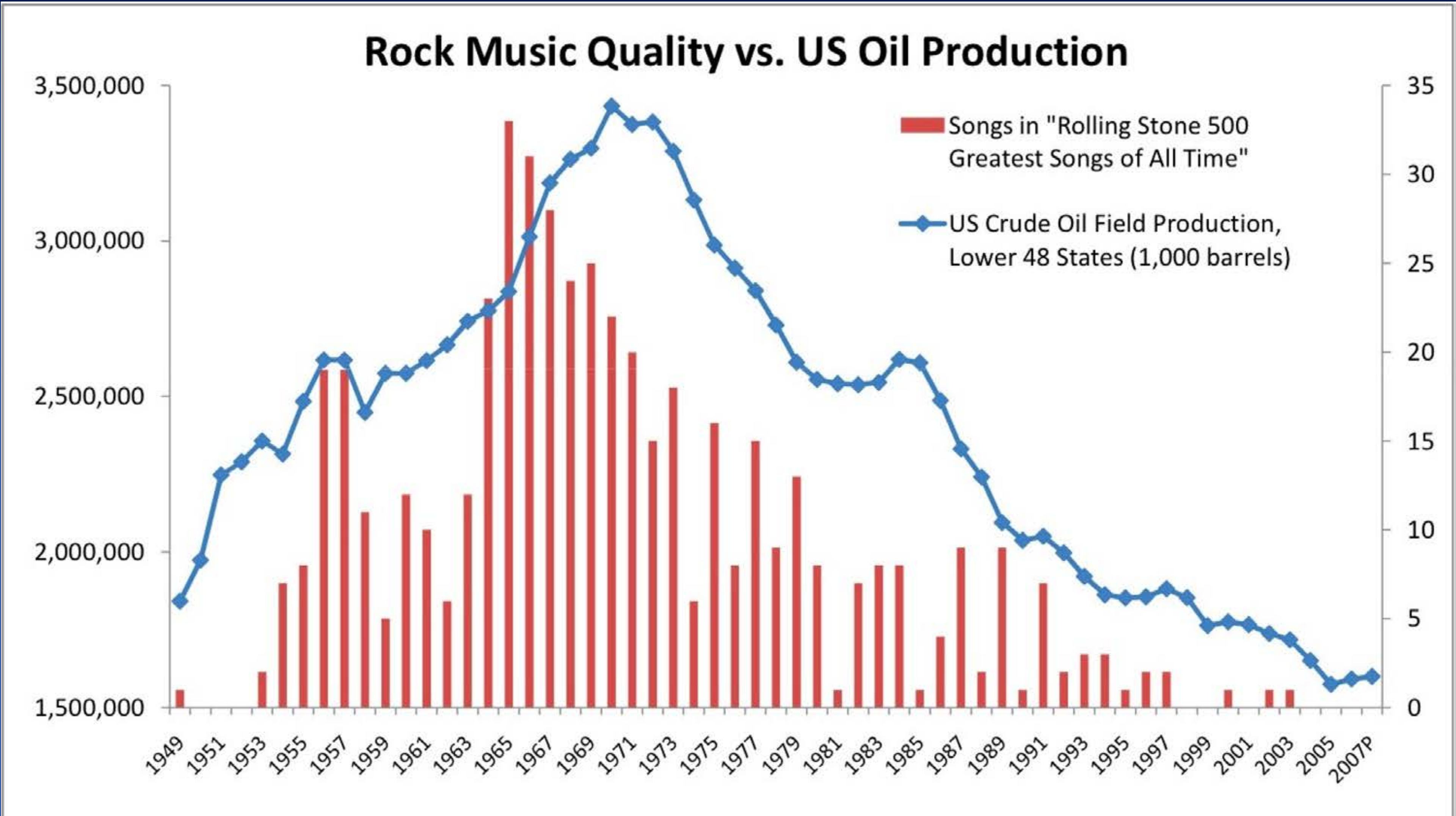

World Production
Modern Hubbert Curve
21 computer models
mbpd
100
90
80
70
60
50
40
30
20
10
0
1940
1950
1960
1970
1980
1990
2000
2010
2020
BP (2006)
EIA (CO)
EIA (NGPL)
EIA (Other Liquids)
Const. Barr./Cap. (CO+NGL)
Loglets (CO+NGL)
Deffeyes (CO)
Laherrere (All)
Logistic Med (CO+NGL)
Logistic Low
Logistic High
Shock Model (CO+NGL)
GBM (CO+NGL)
ASPO-71 (CO+NGL)
ASPO-58 (CO+NGL)
Skrebowski (CO+NGL)
Koppelaar (All)
Bakhtiari (CO+NGL)
EIA (All)
CERA (CO)
CERA (All)

US Oil Production and Imports



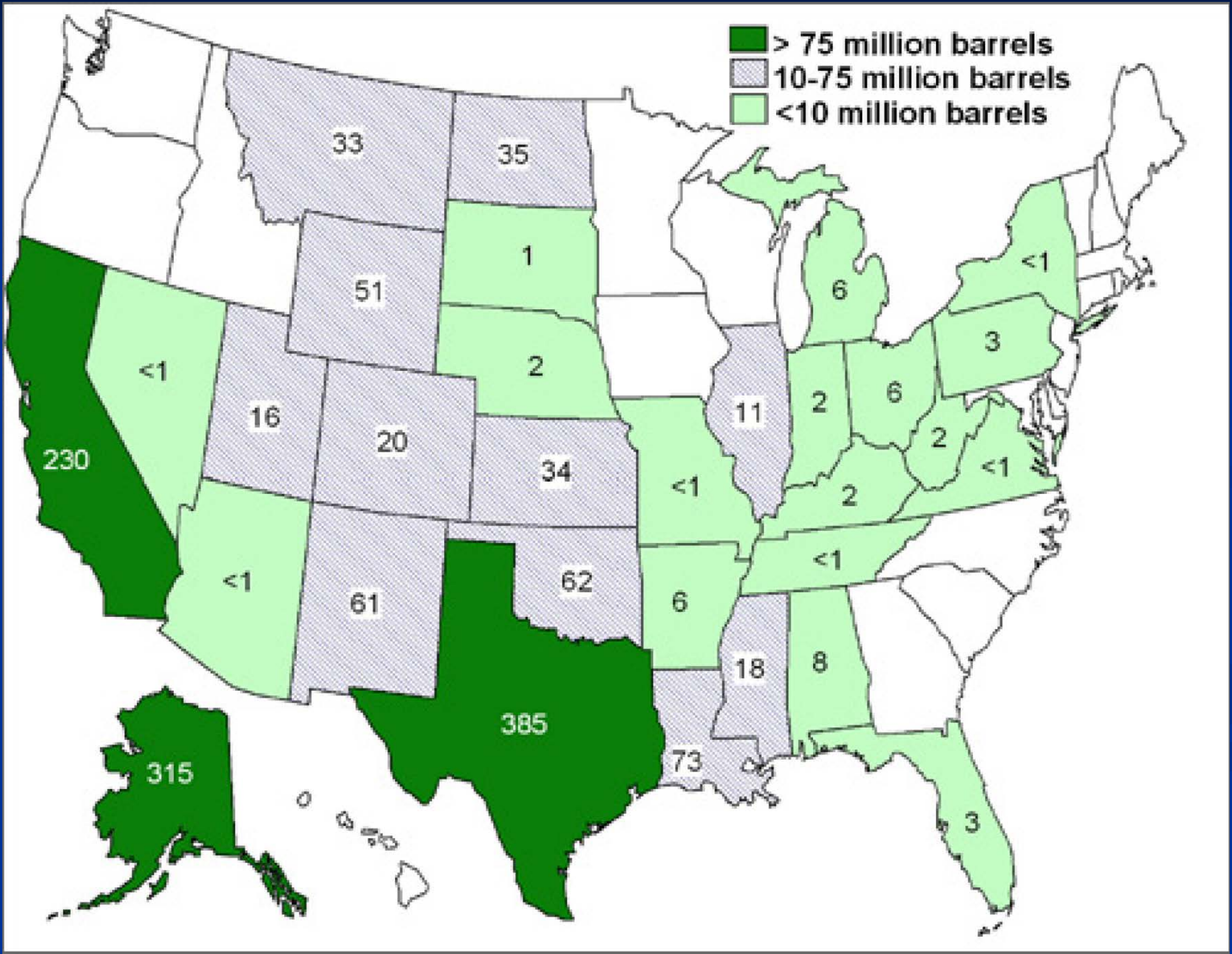


U.S. Oil Production Under Bush and Obama
Million barrels per day
6
5.5
5
4.5
4
3.5
President Bush sworn in
President Obama sworn in
Hurricane Katrina
Hurricanes Gustav and Ike
Produced by Robert Rapier & Sam Avro for the R-Squared Energy Column on Consumer Energy Report.
www.consumerenergyreport.com
Jan-2001
Jan-2003
Jan-2005
Jan-2007
Jan-2009
Jan-2011



Rock Music Quality vs. US Oil Production
Songs in "Rolling Stone 500 Greatest Songs of All Time"
US Crude Oil Field Production, Lower 48 States (1,000 barrels)
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
35
30
25
20
15
10
5
0
1949
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007P

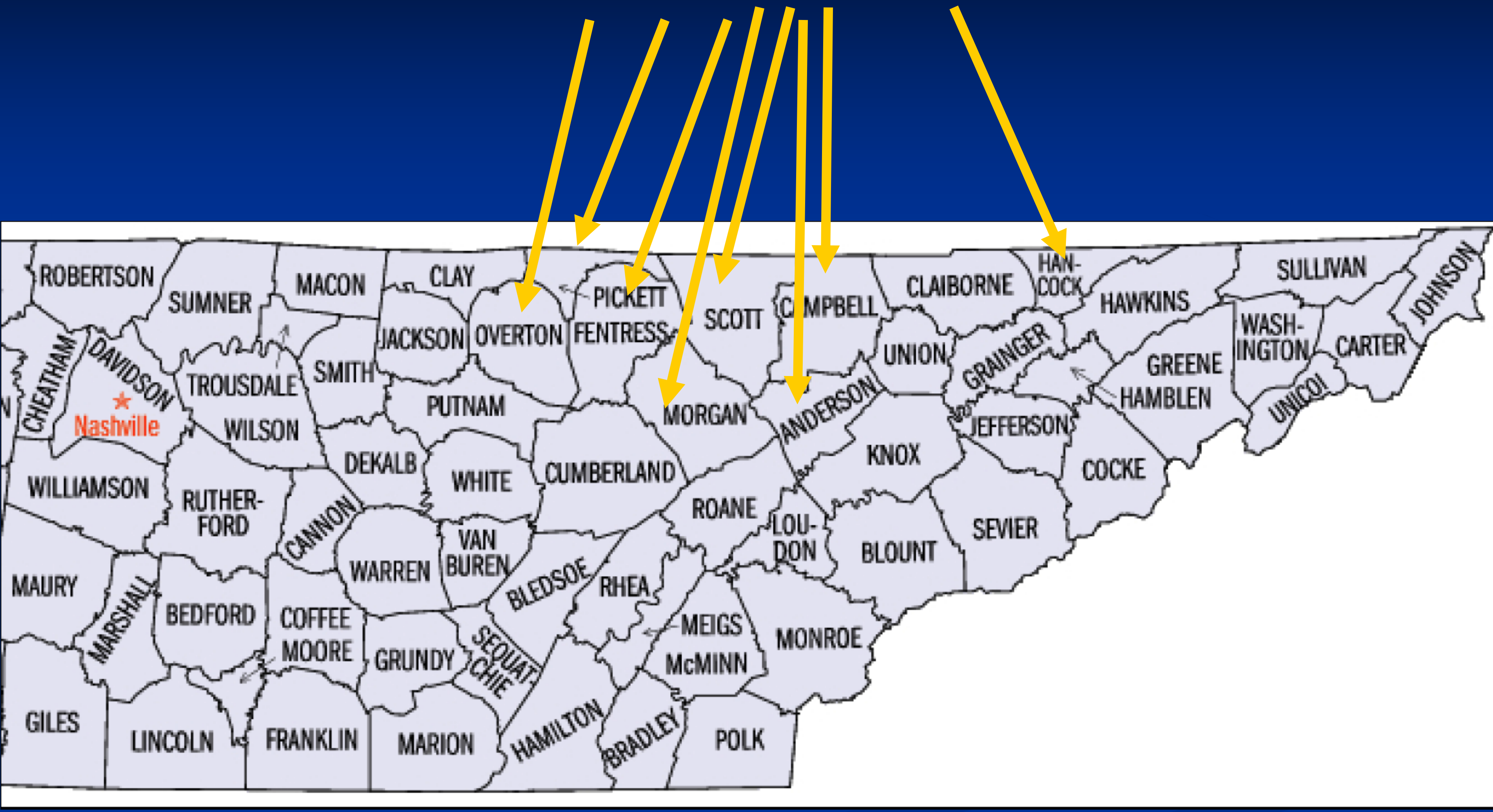
Annual Oil Production



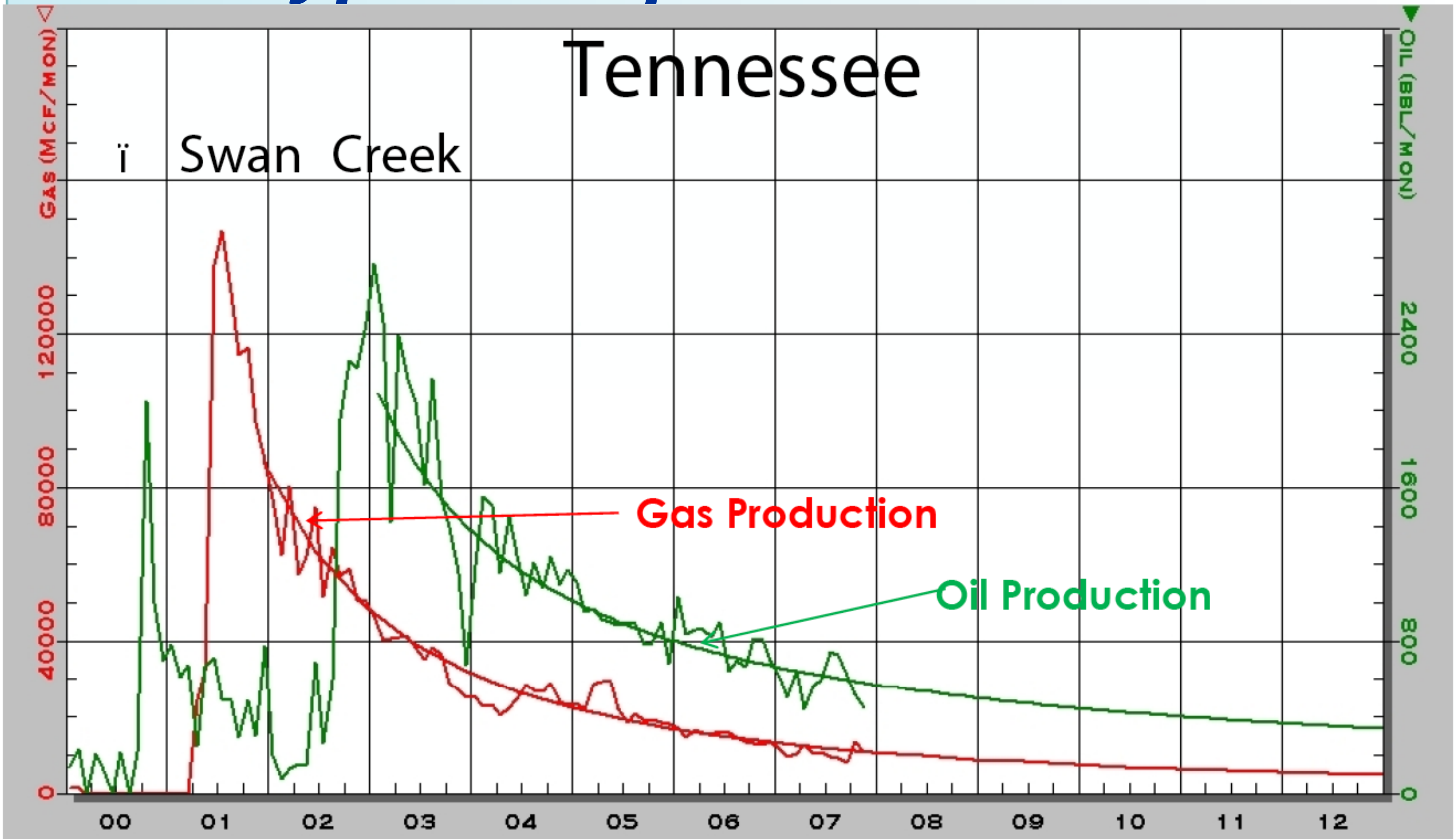
Production of one of these rigs has to be >40,000 bbl/day to be economic

A very good well in TN or KY would produce 50-100 bbl/day & the owner makes a very good profit

Producing Counties in TN



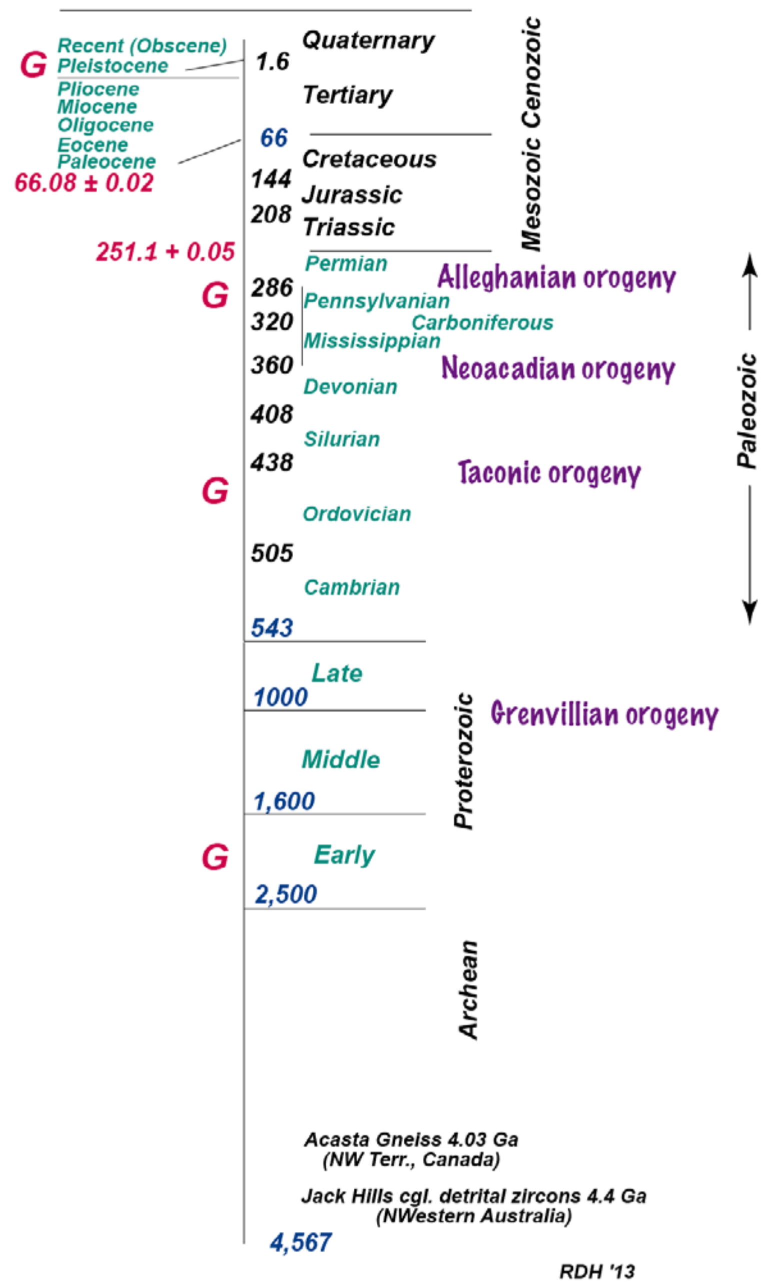
Typical Depletion Curves

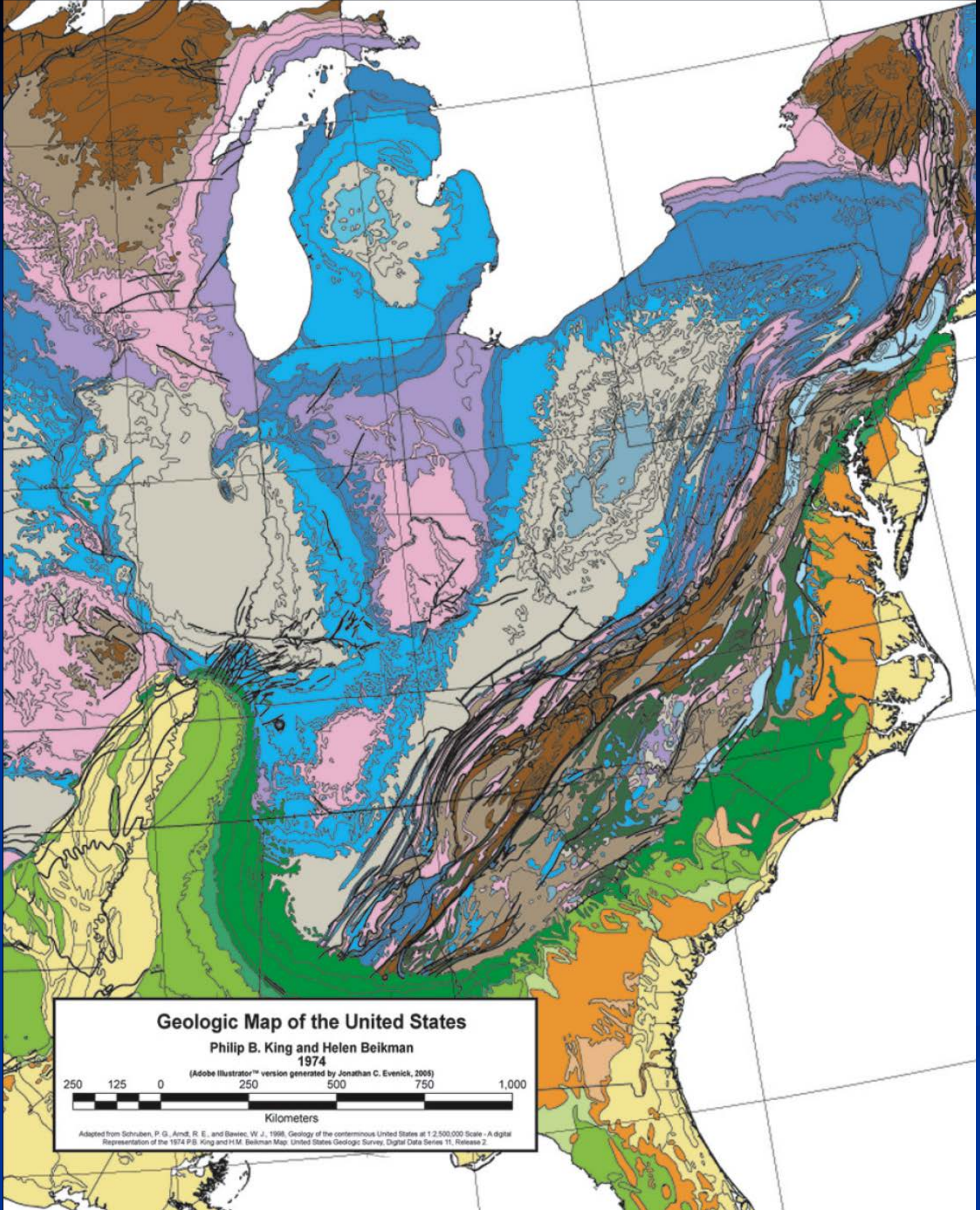


3 BCF Produced from current development, 1 BCF Remaining
OIL: Produced about 150,000+ barrels with 90,000 remaining

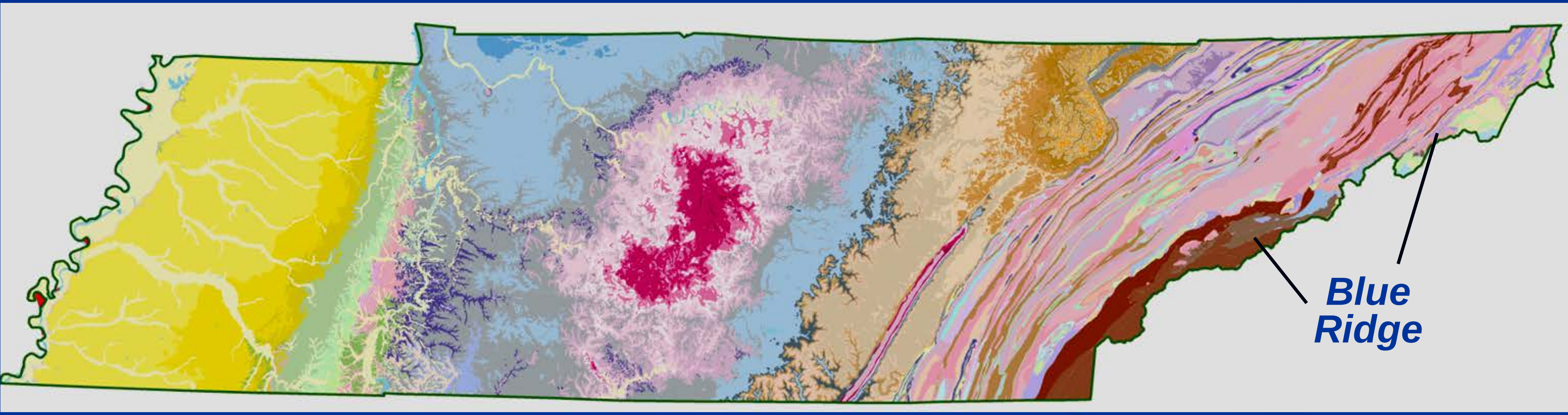
Courtesy of Jeff Bailey, Tengasco

Geologic Time Scale



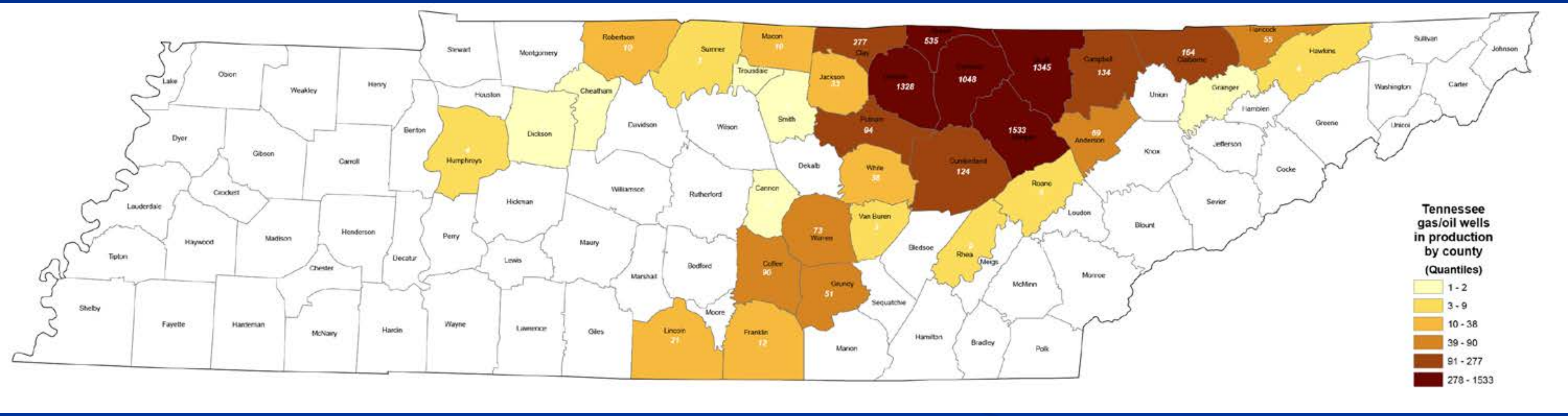

Geologic Map of the United States
Philip B. King and Helen Beikman
1974
(Adobe Illustrator™ version generated by Jonathan C. Evenick, 2005)
250
125
0
250
500
750
1,000
Kilometers
Adapted from Schruben, P. G., Arndt, R. E., and Bawiec, W. J., 1998, Geology of the conterminous United States at 1:2,500,000 Scale - A digital Representation of the 1974 P.B. King and H.M. Beikman Map: United States Geologic Survey, Digital Data Series 11, Release 2.

Geologic Map of Tennessee



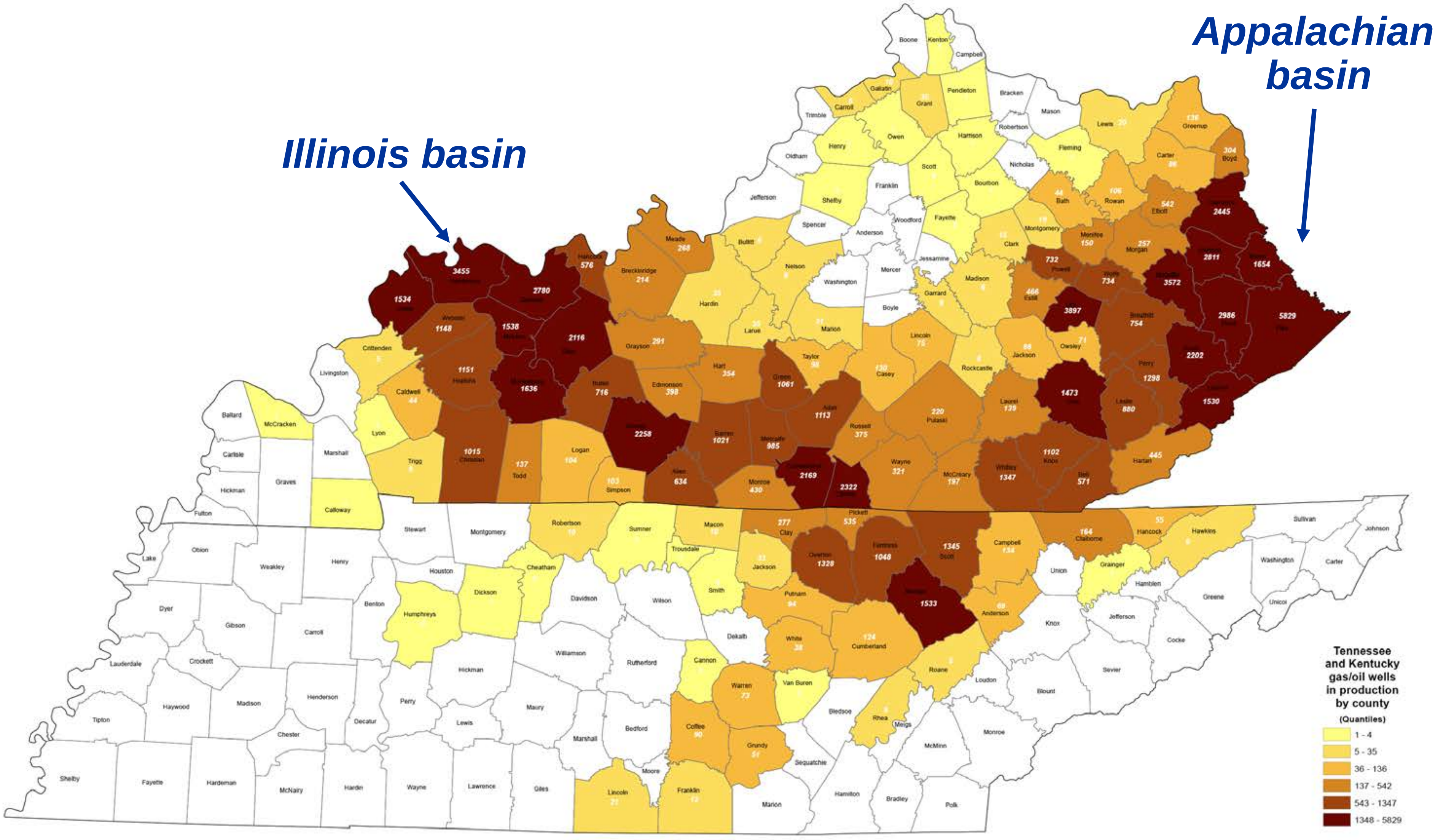
Hardeman, 1966
ArcView version
by USGS
modified by
Andrew L Wunderlich

Producing Wells in Tennessee



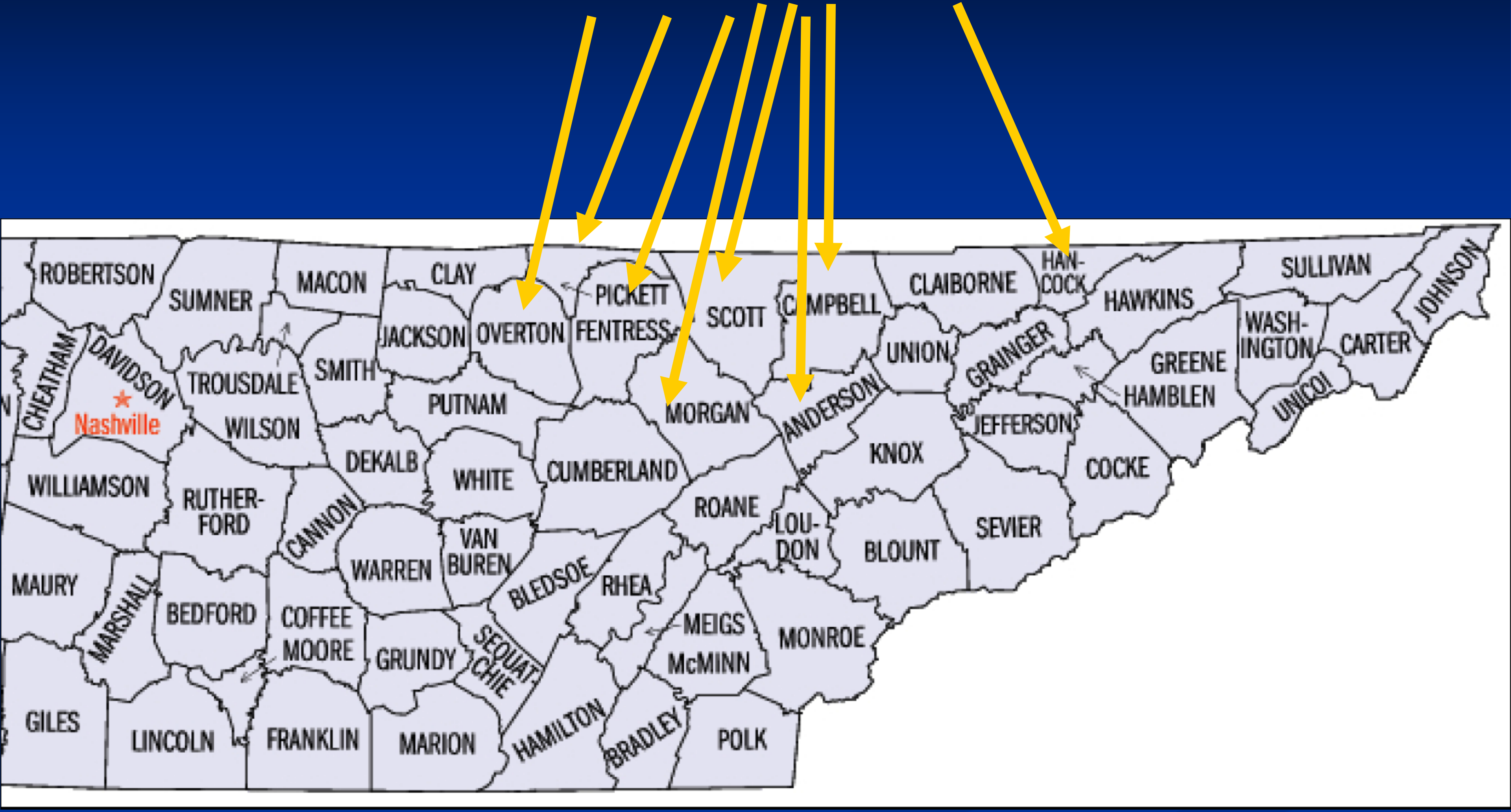
Data from TDG

Kentucky-Tennessee Producing Wells

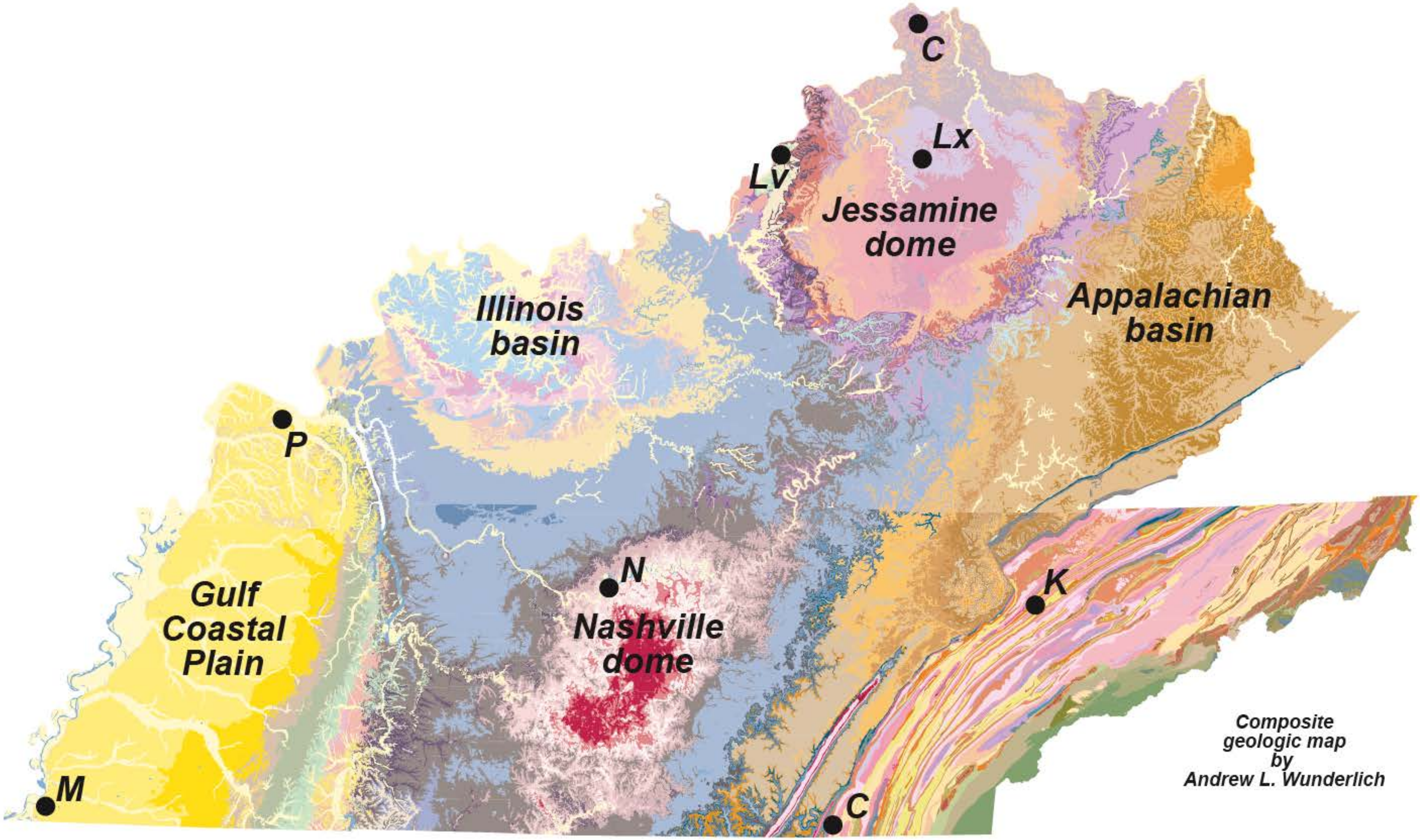


Could Tennessee increase production? How?

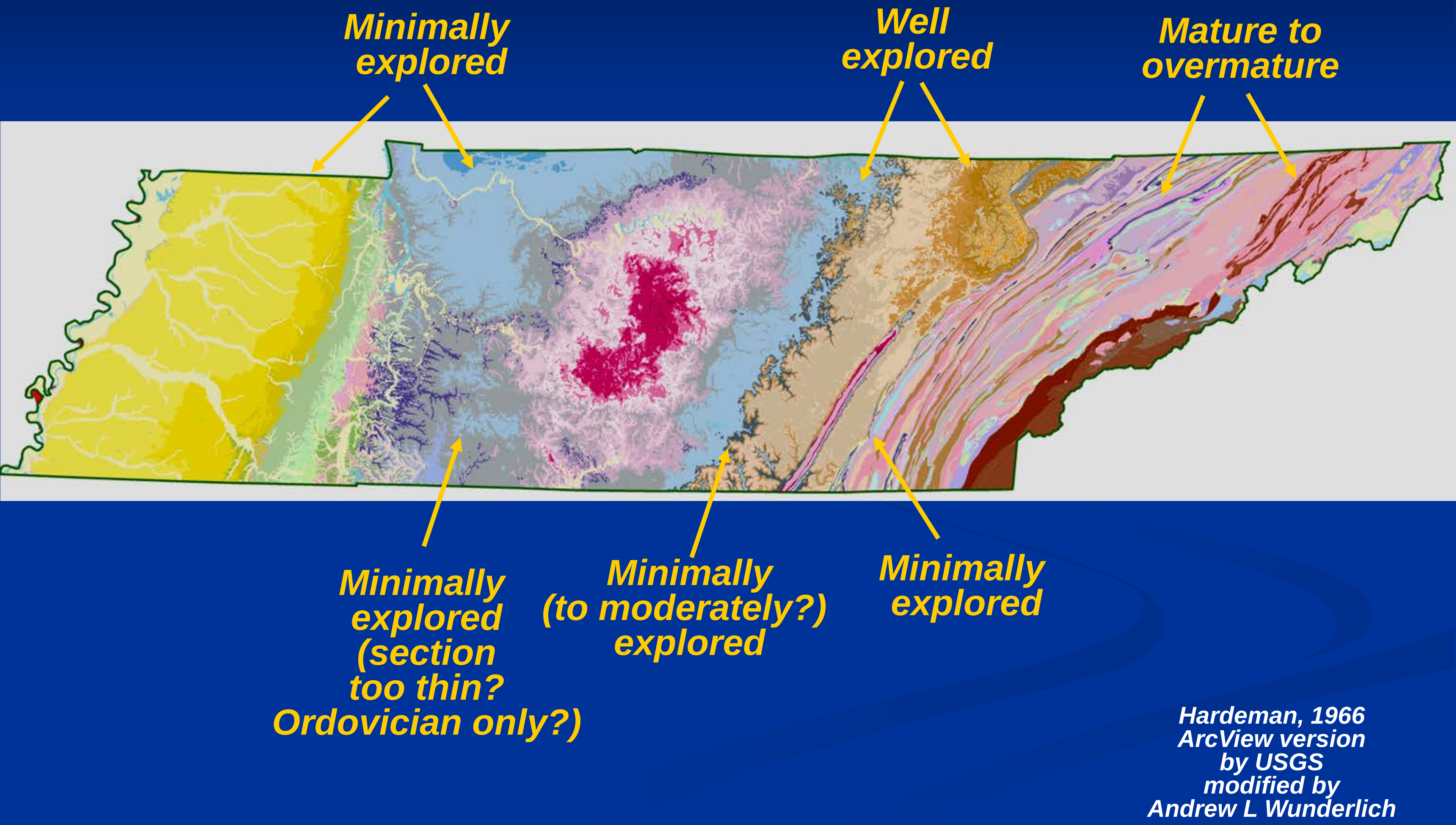
Producing Counties in TN



Kentucky–Tennessee Composite Geologic Map



Should Kentucky geology be part of a Tennessee exploration strategy?


Minimally explored
Well explored
Mature to overmature
Minimally explored (section too thin? Ordovician only?)
Minimally (to moderately?) explored
Minimally explored
Hardeman, 1966
ArcView version by USGS
modified by Andrew L Wunderlich

Petroleum Systems

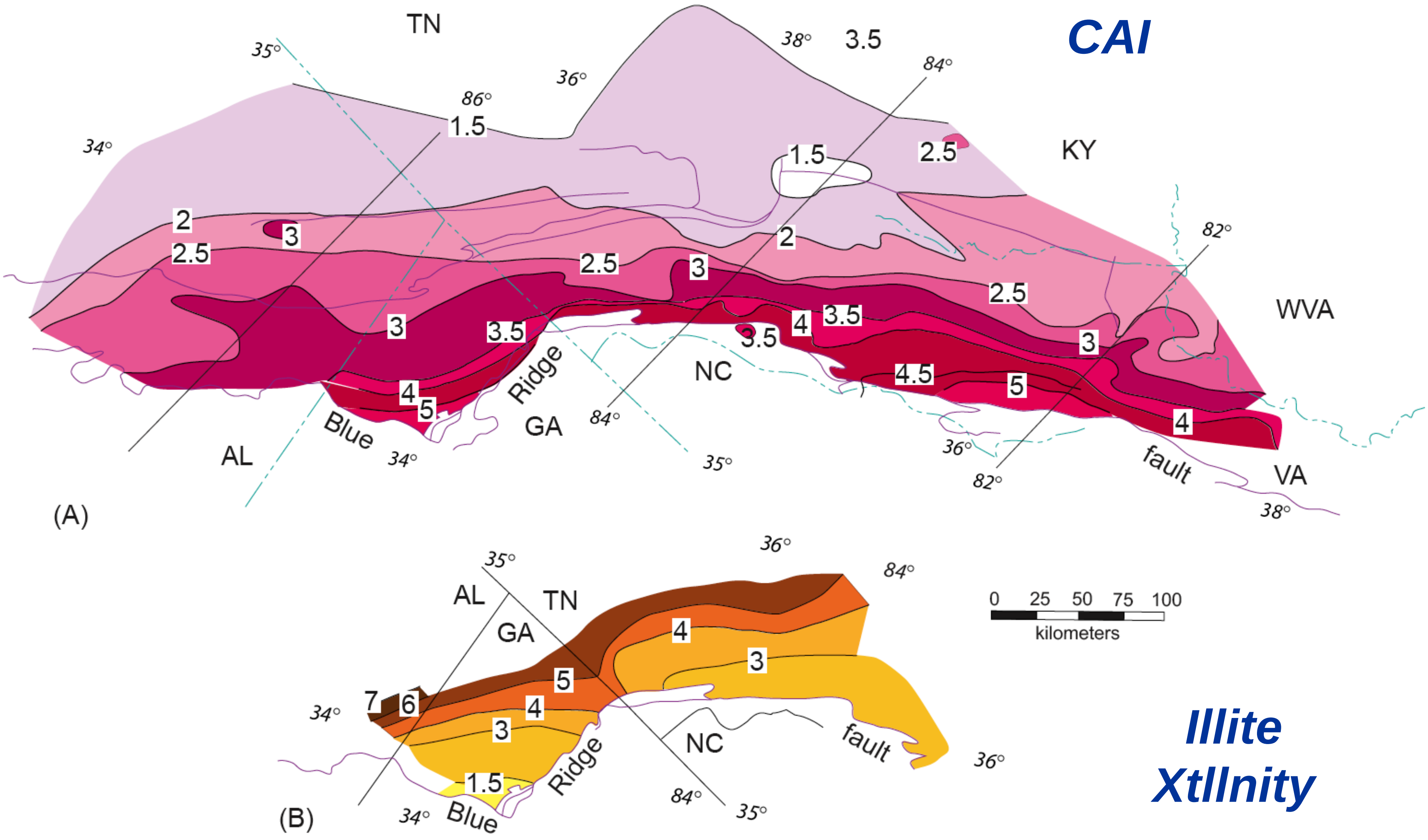
Rock mass in which hydrocarbons accumulate, migrate, and are trapped.

Paraphrased from definition by Magoon & Dow, 1994, AAPG Memoir 60

Requirements for Hydrocarbon Formation & Survival

- ***Marine plants (diatoms?)—accumulation in an anoxic environment.***
- ***Rapid burial so the organic matter is not oxidized.***
- ***Conversion to hydrocarbons requires heat (the "kitchen").***
- ***Oil has to be trapped once it moves so it remains anoxic.***
- ***Trap cannot be breached through time—requires an efficient seal.***

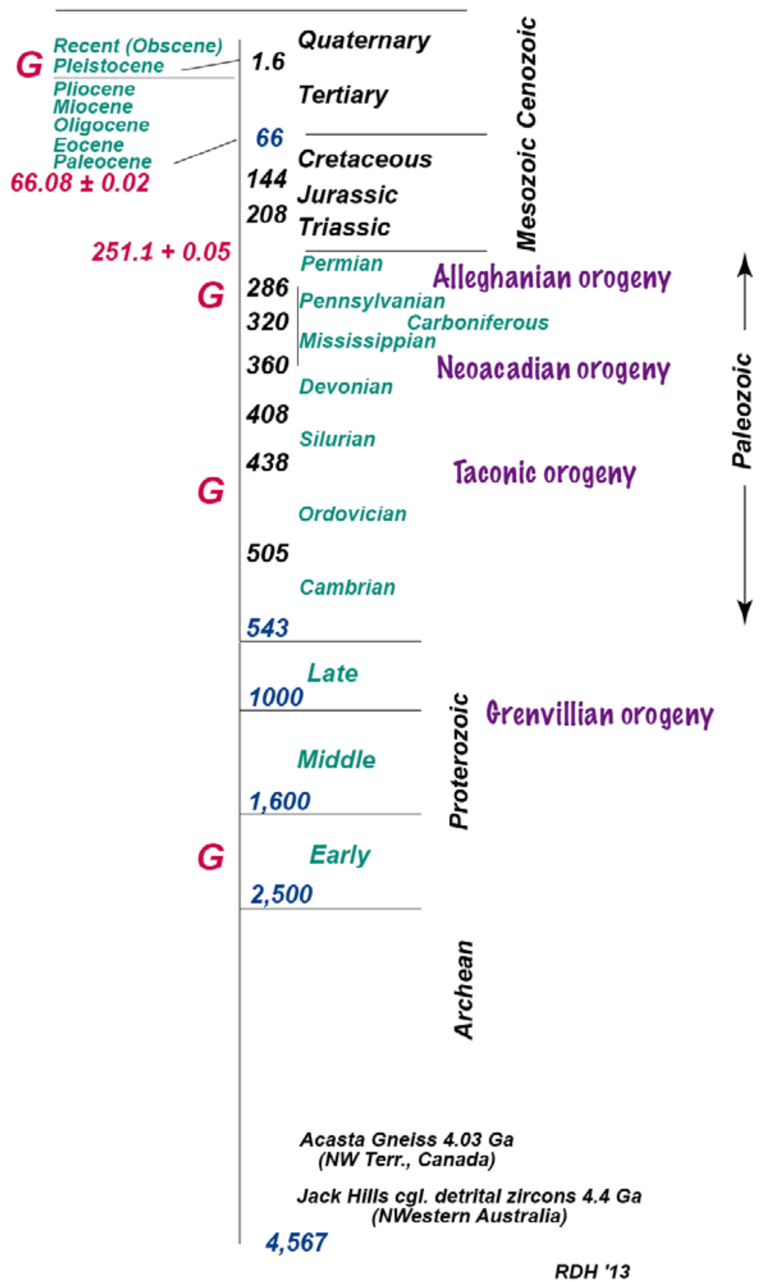
Indicators of Thermal Maturity



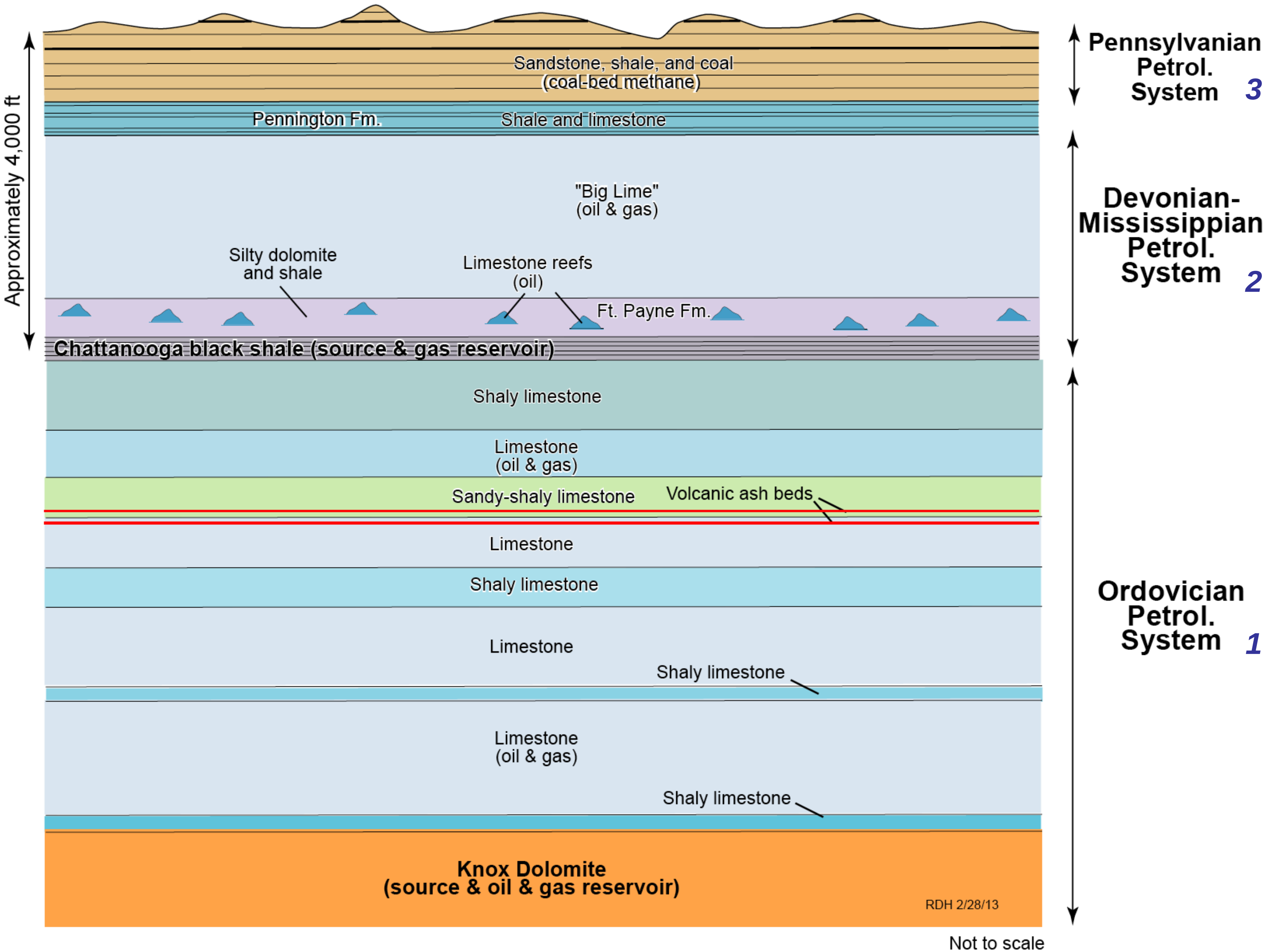
Conodont Alteration Index

CAI	Naturally altered conodonts from field samples (Rheinisches Schiefergebirge and Montagne Noire)	Temperature range
1		<50°-80°
2		60°-140°
3		110°-200°
4		190°-300°
5		300° - 480°
6		360° - 550°

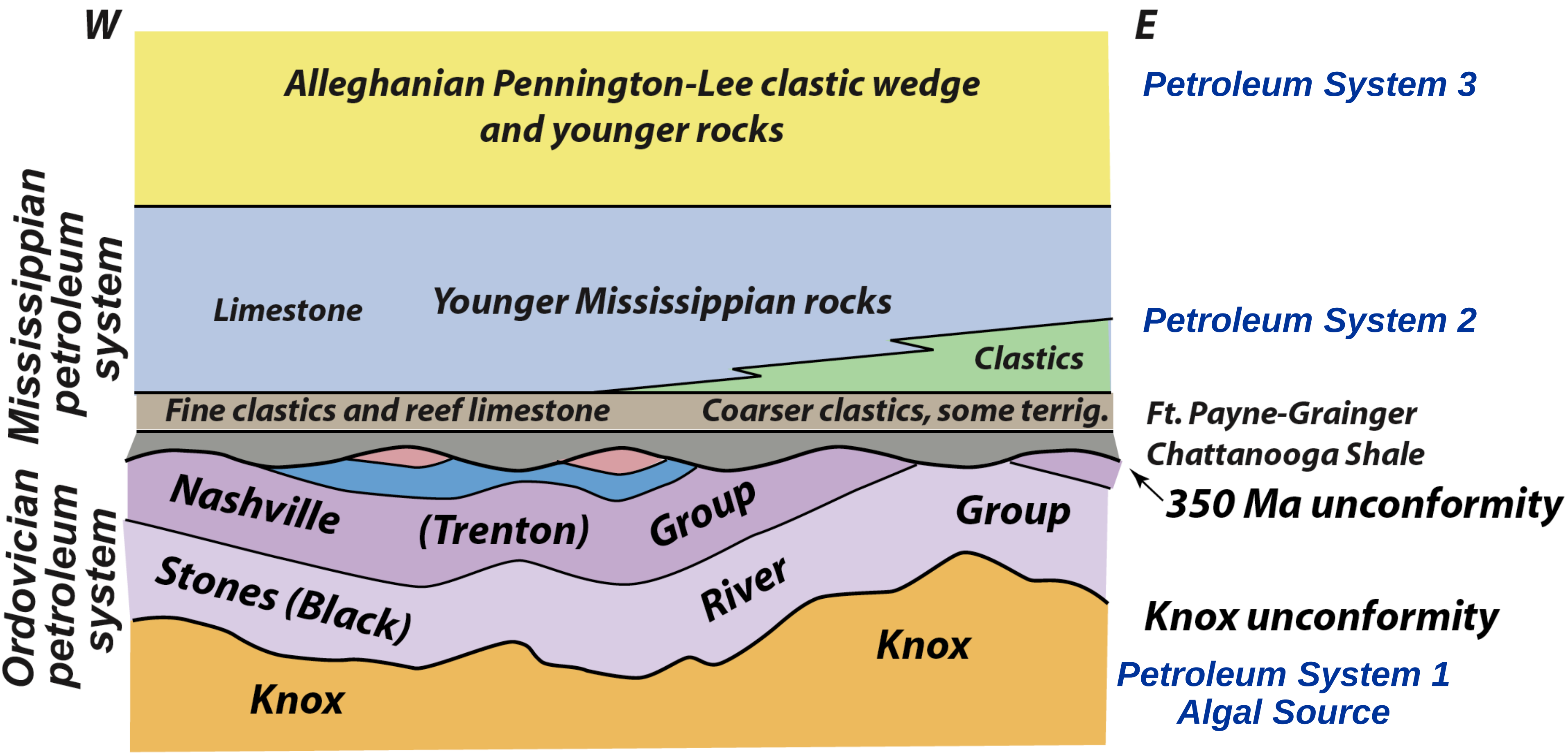
Geologic Time Scale



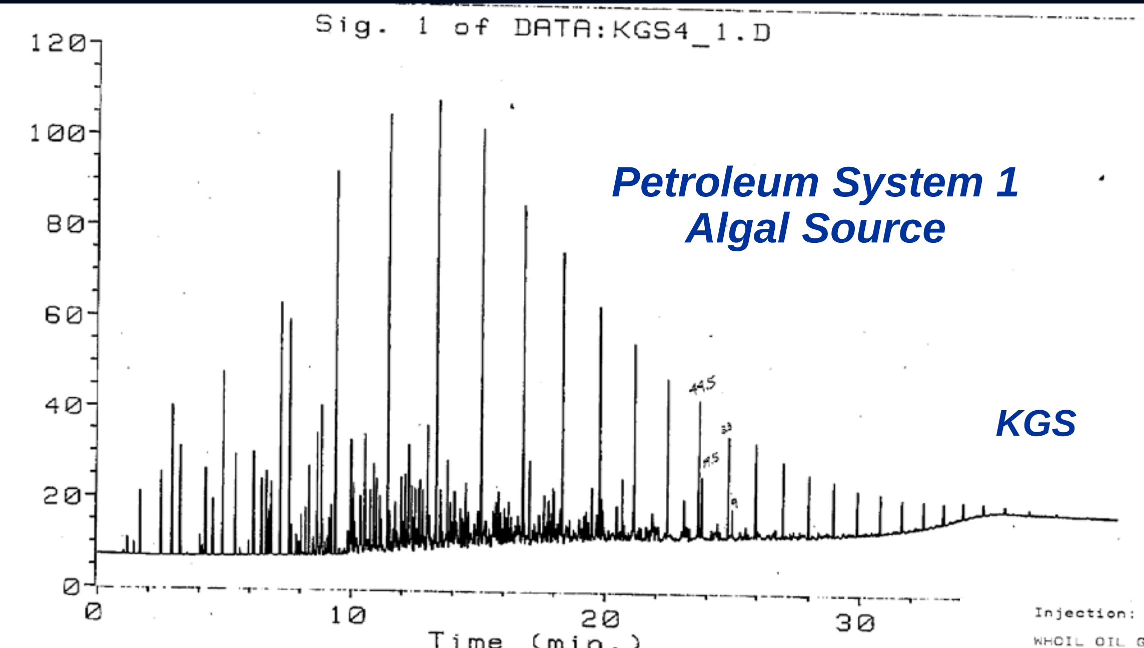
Petroleum Systems in Tennessee

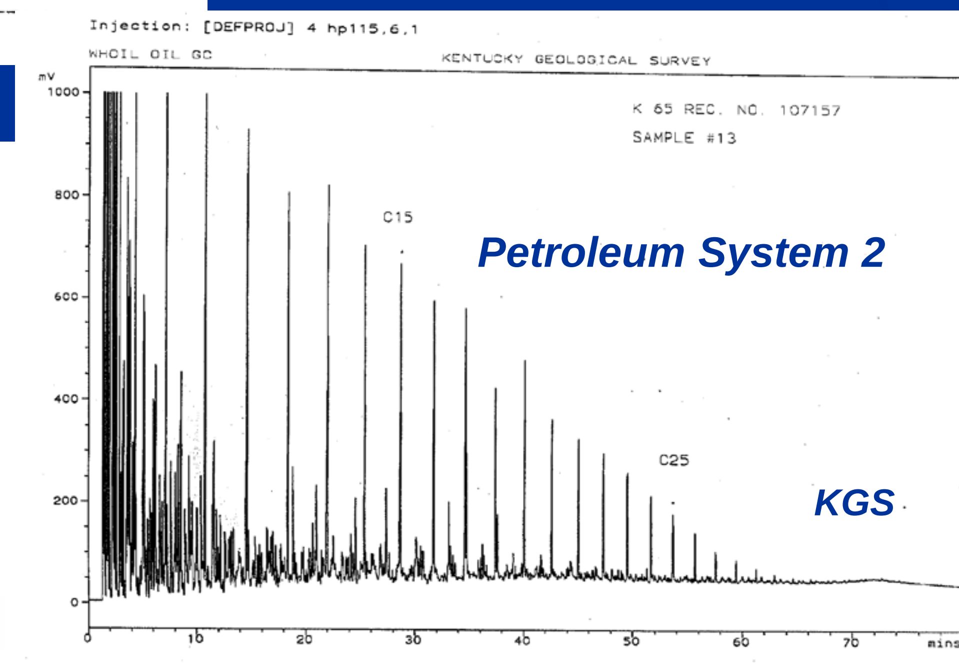


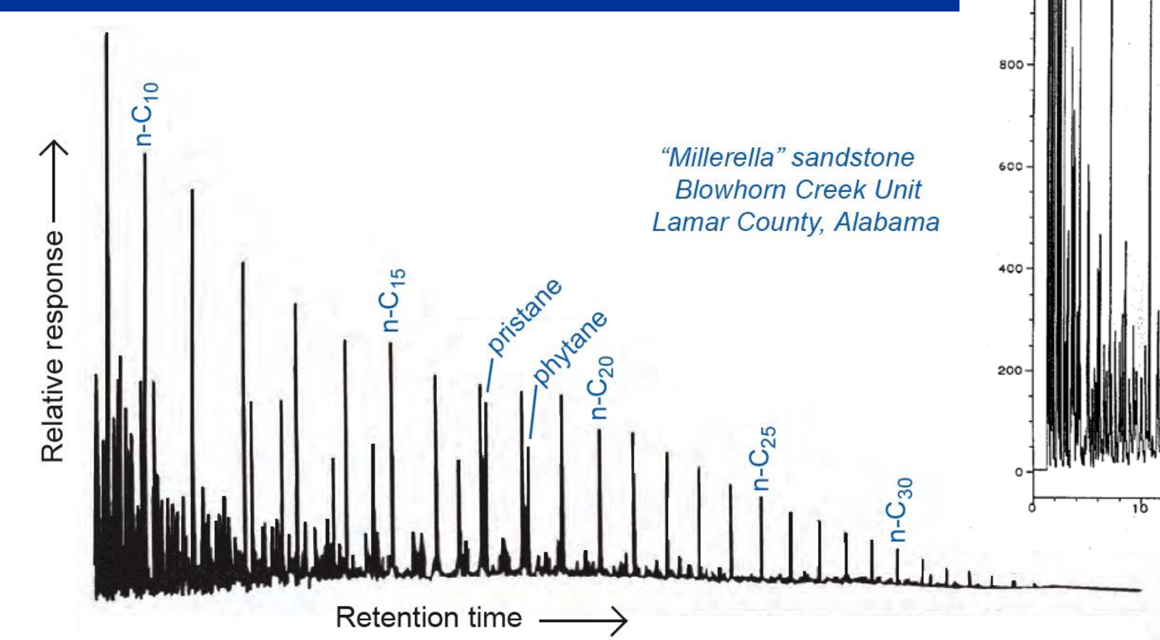
Tennessee Petroleum Systems



Gas Chomatograph Patterns & Biomarkers







Source for Ordovician Hydrocarbons

Copper Ridge Dolomite
U.S. 25E

Chattanooga-Maury-Ft. Payne Contacts

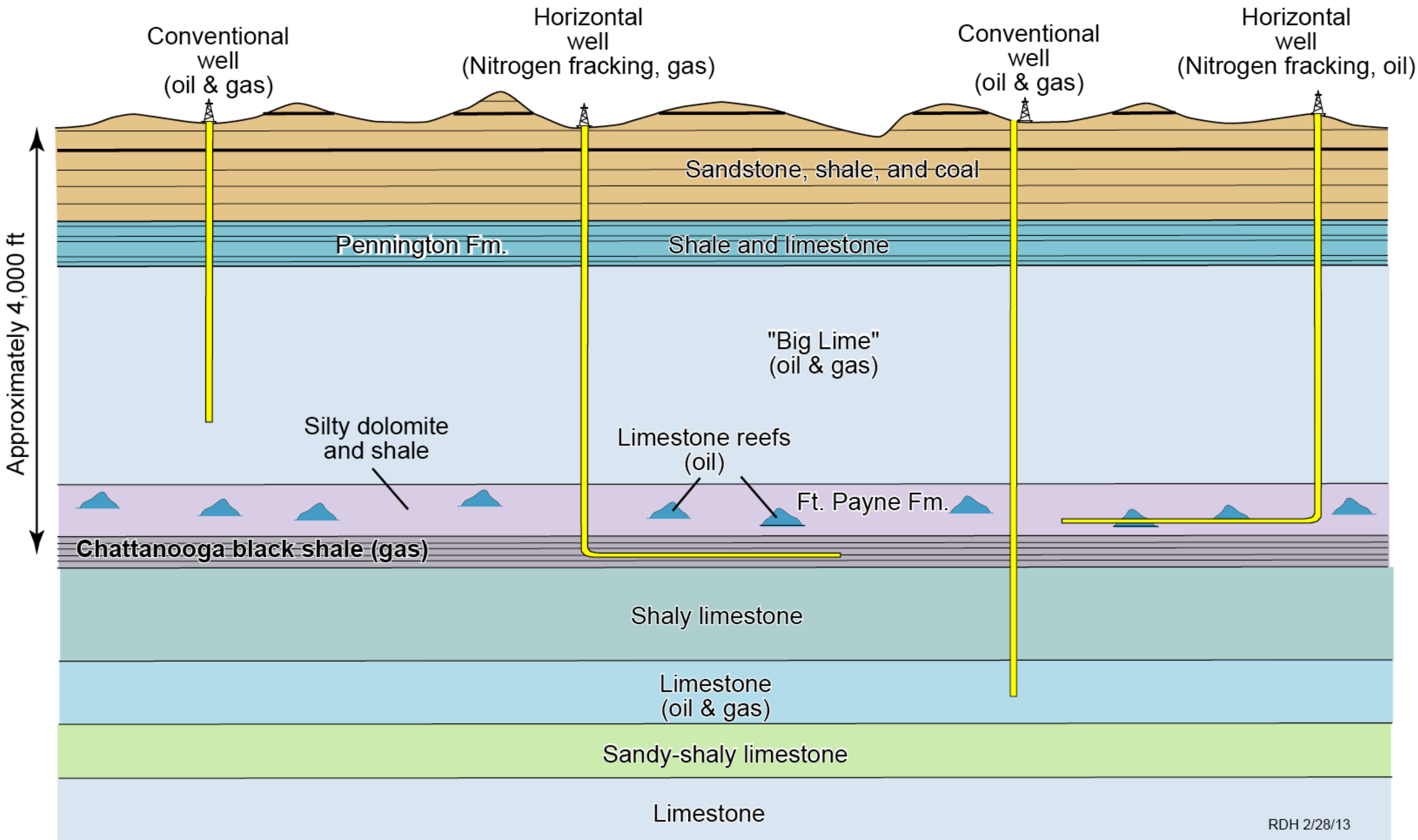
Pasminco core hole near Carthage, TN

RDH '03

Leipers-Chattanooga Contact

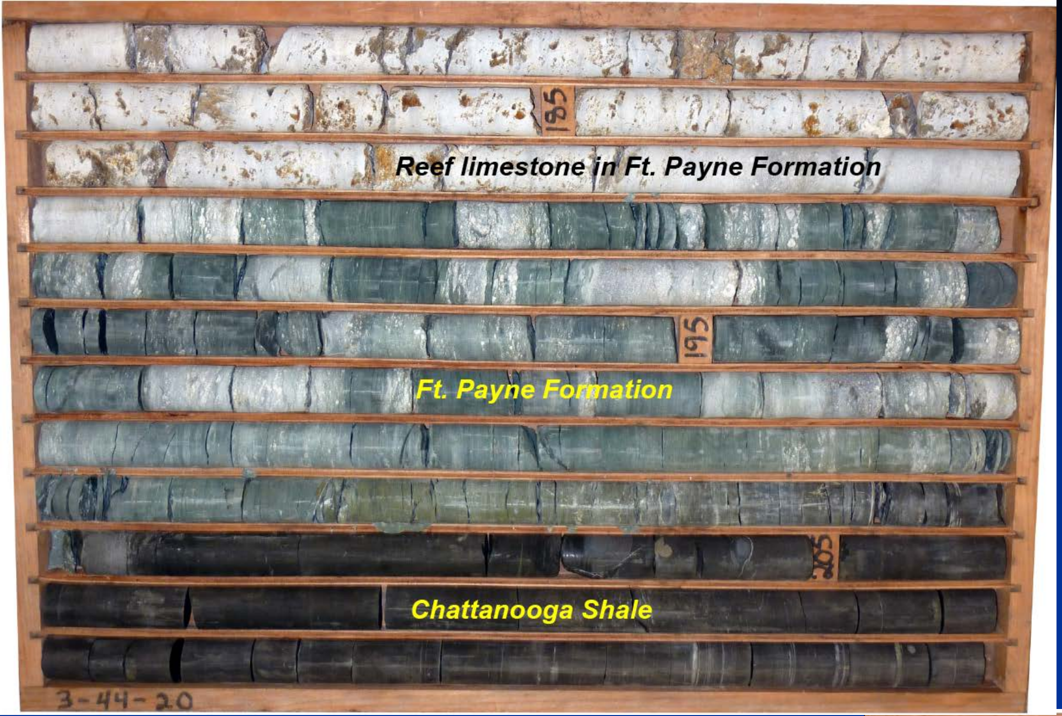
Pasminco core hole near Carthage, TN

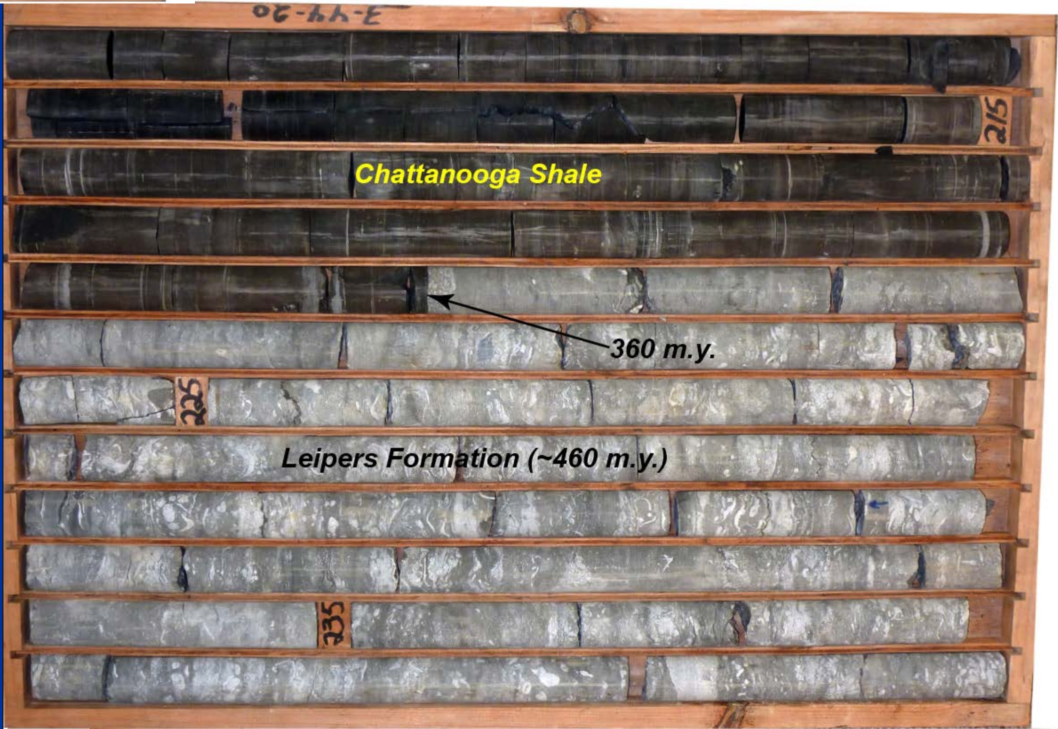
Oil and Gas Exploration Options in the Cumberland Plateau & Highland Rim in Tennessee



Not to scale

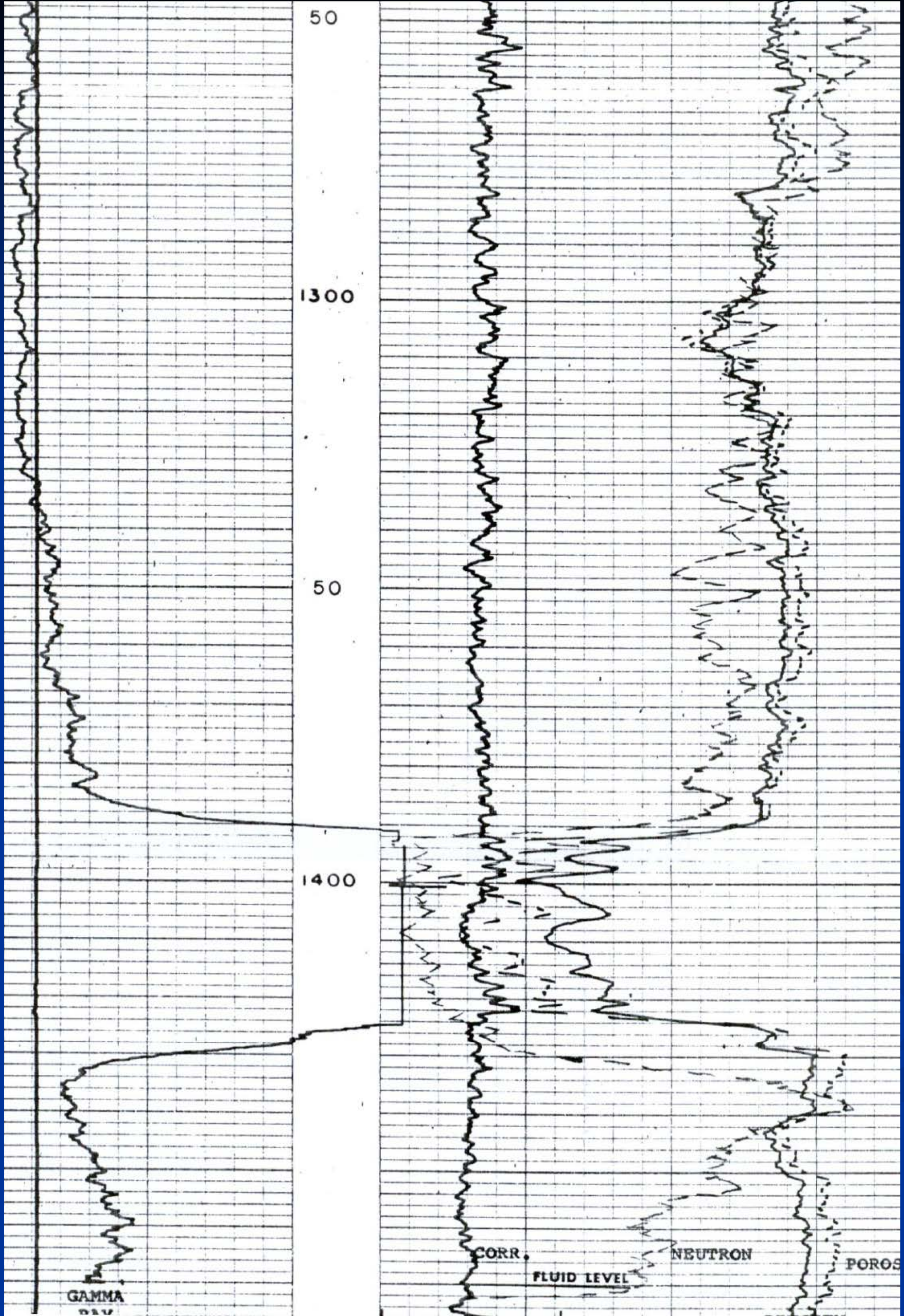
Savage mining company core through the Chattanooga Shale (from near Carthage, TN)





1970s or Older Geophysical Log

Chattanooga Shale



Potential & Known Reservoirs

- Primary porosity
  - Incompletely cemented carbonate rocks
  - Ft. Payne Walsortian reefs (Mississippian)
  - Oolite shoals (Mississippian)
- Secondary porosity
  - Dolomitization in carbonates (Ord., Miss.)
  - Hydrothermal alteration
  - Fractures & faults

Appalachian Compressed-Air Rig

Worn-out Rig Swan Creek Field, TN

Flared gas well
Hancock Co., TN

Turner Valley, Alberta, Rig

What is fracking?

- ***Creating artificial fractures in rocks for one of several purposes.***

- Economic reasons—enhancement of gas recovery.

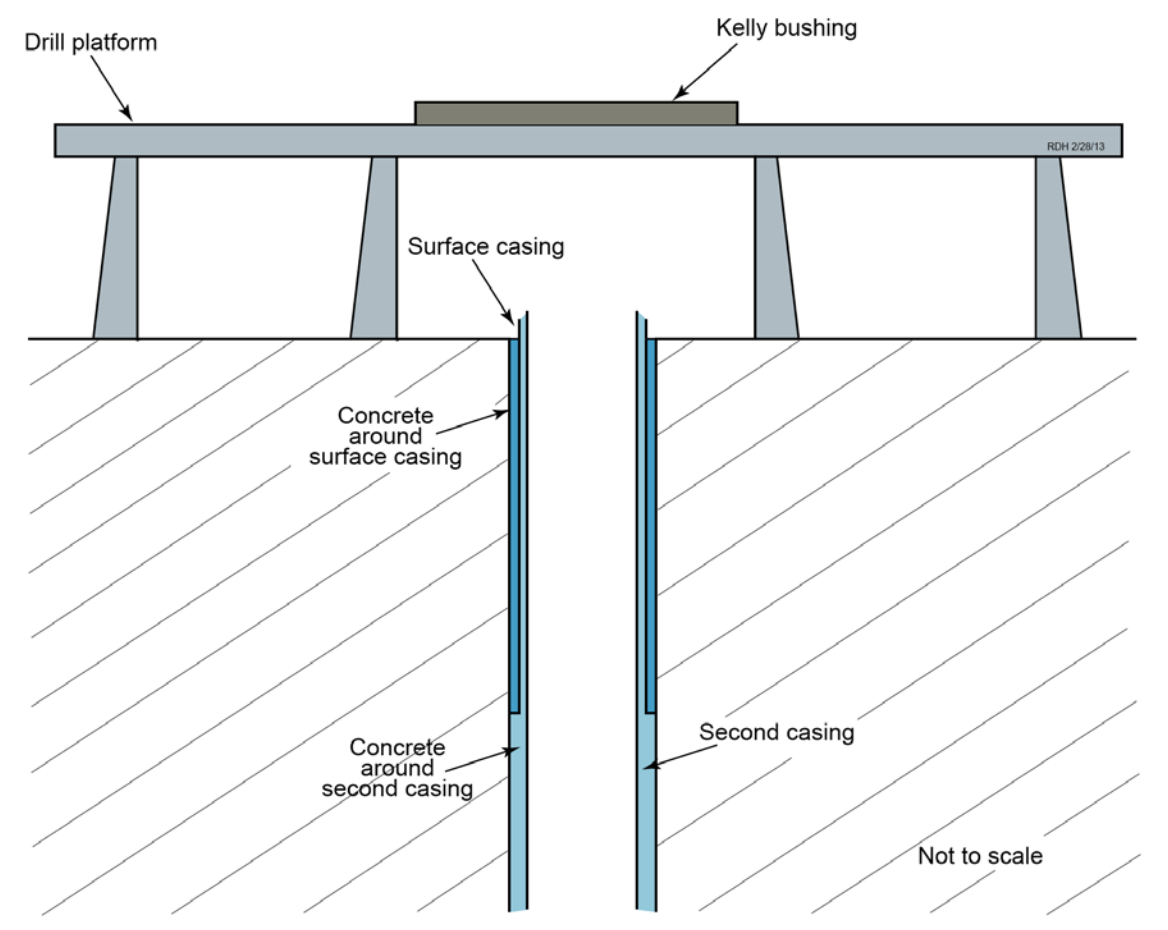
- To measure stress in the Earth.

- ***Goal in gas production is to fracture only the rock unit that contains gas (otherwise gas is lost).***

Where do groundwater problems originate with fracking?

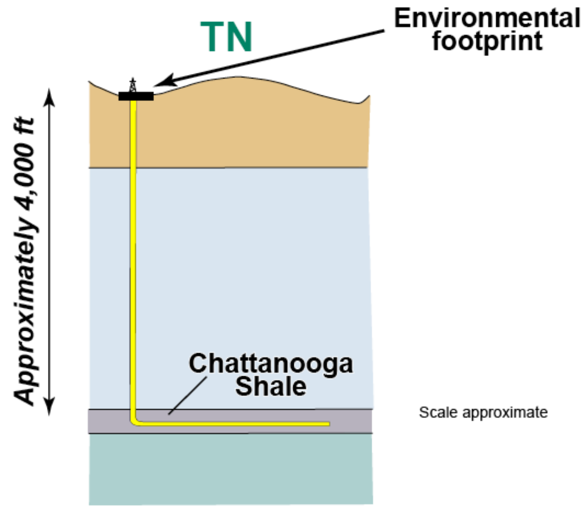
- *Improper handling of fluids on the surface.*

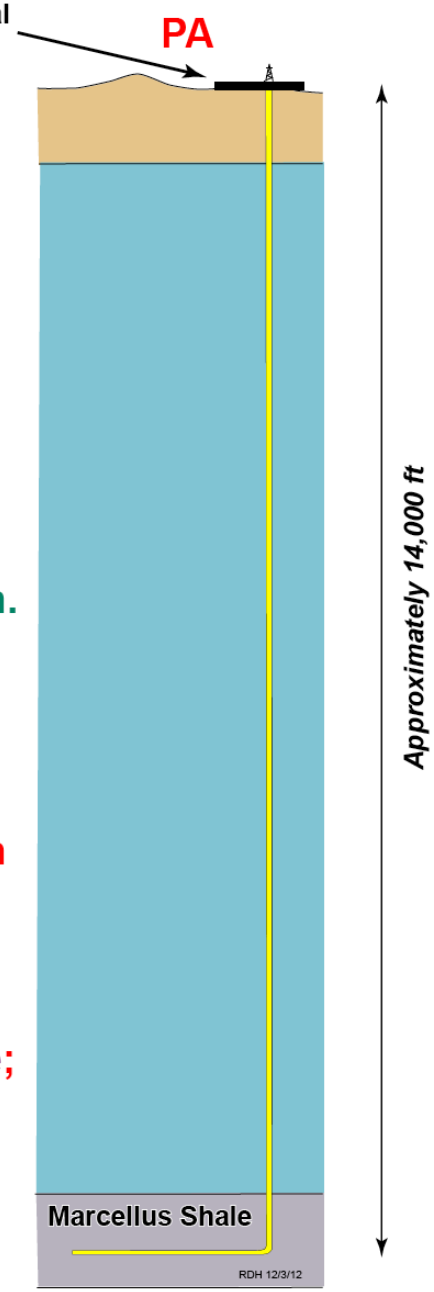
- *Poor cementing of casings, leaving voids or cracks.*



These are the natural fractures along which sand and other chemicals are pumped:

Comparison of Horizontal Gas Drilling with Fracking in Tennessee and Pennsylvania





Tennessee: Shallow depth.
Fracking with nitrogen.
Small environmental impact; minimal fluid disposal problems.

Pennsylvania: Great depth.
Requires fracking with liquids.
Large environmental impact on ground and surface water with mishandled fluids on the surface; large fluid disposal problems.

Prepared by:
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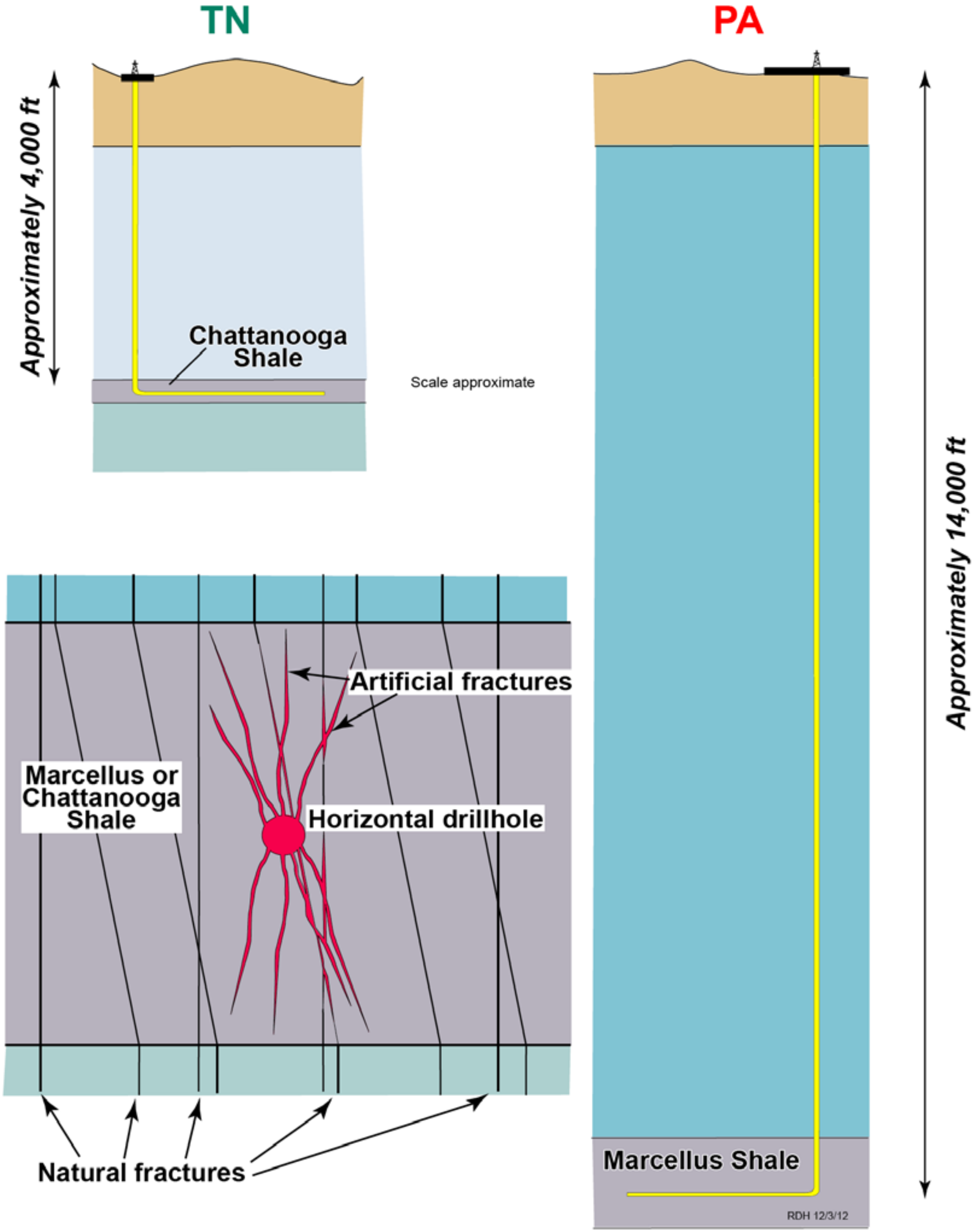
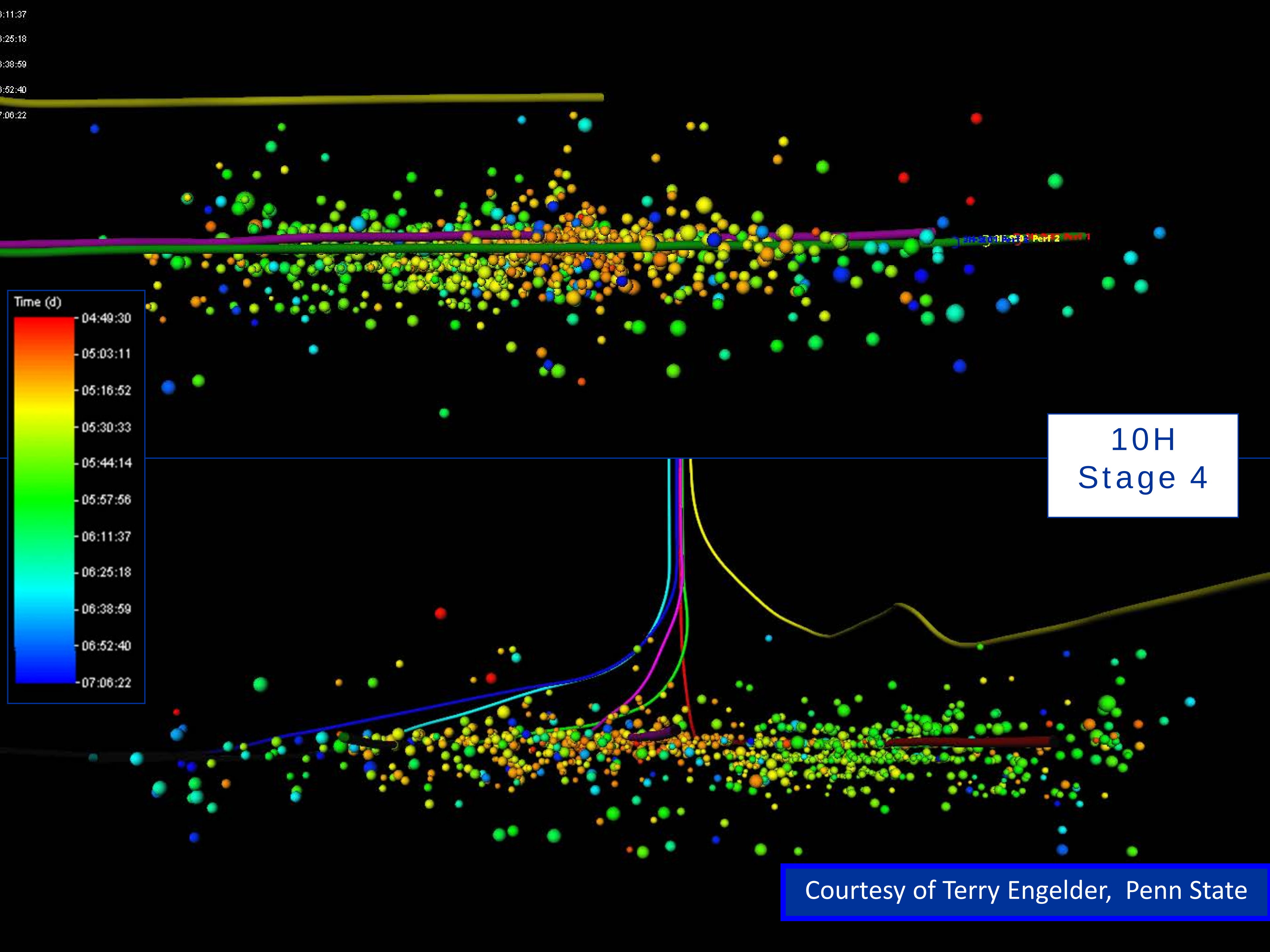
UT Distinguished Scientist
Department of Earth & Planetary Sciences
University of Tennessee
Knoxville, TN 37996

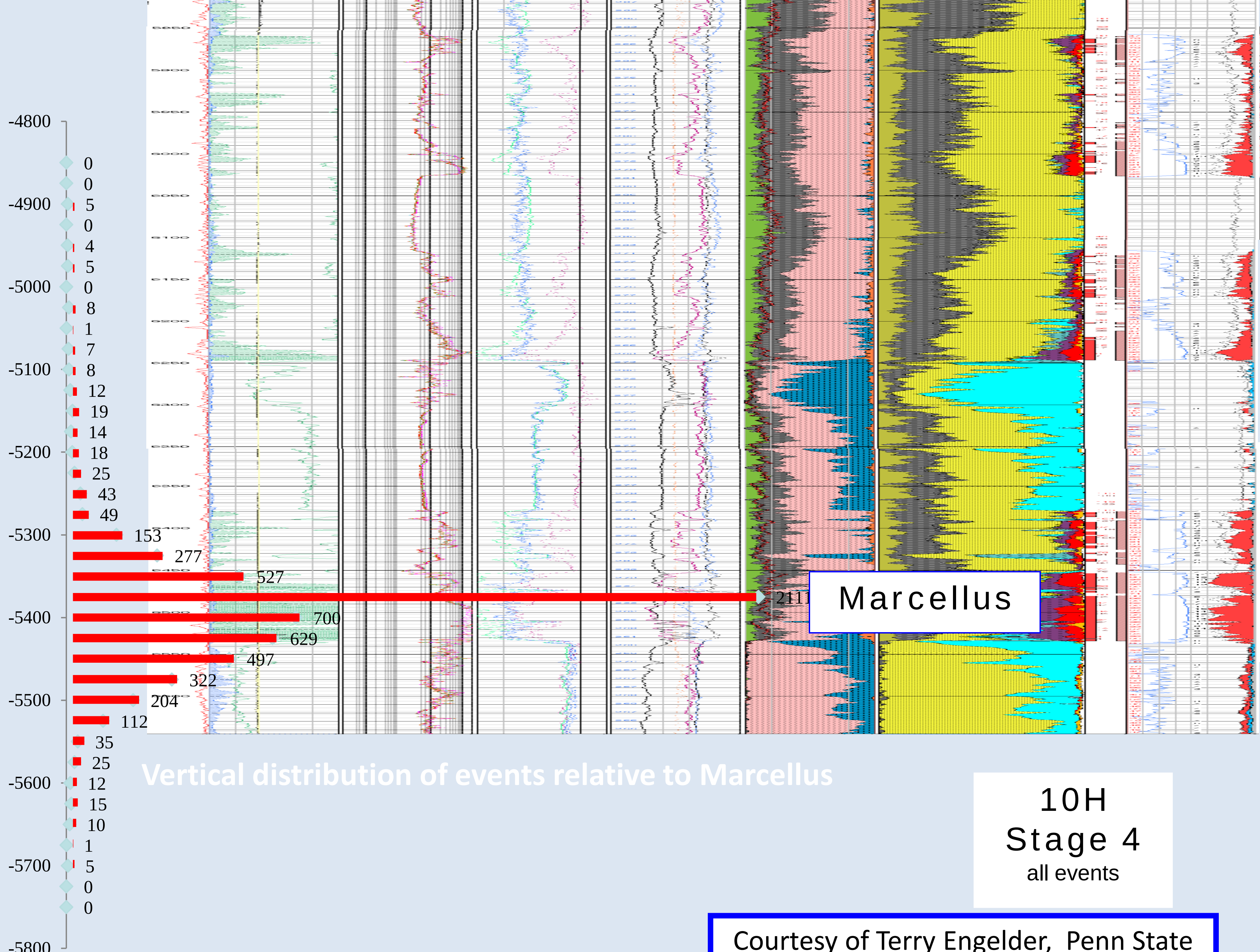
How do artificial fractures appear?



Natural fracture

Calcite filled natural fractures


Time (d)
04:49:30
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
10H
Stage 4
Courtesy of Terry Engelder, Penn State

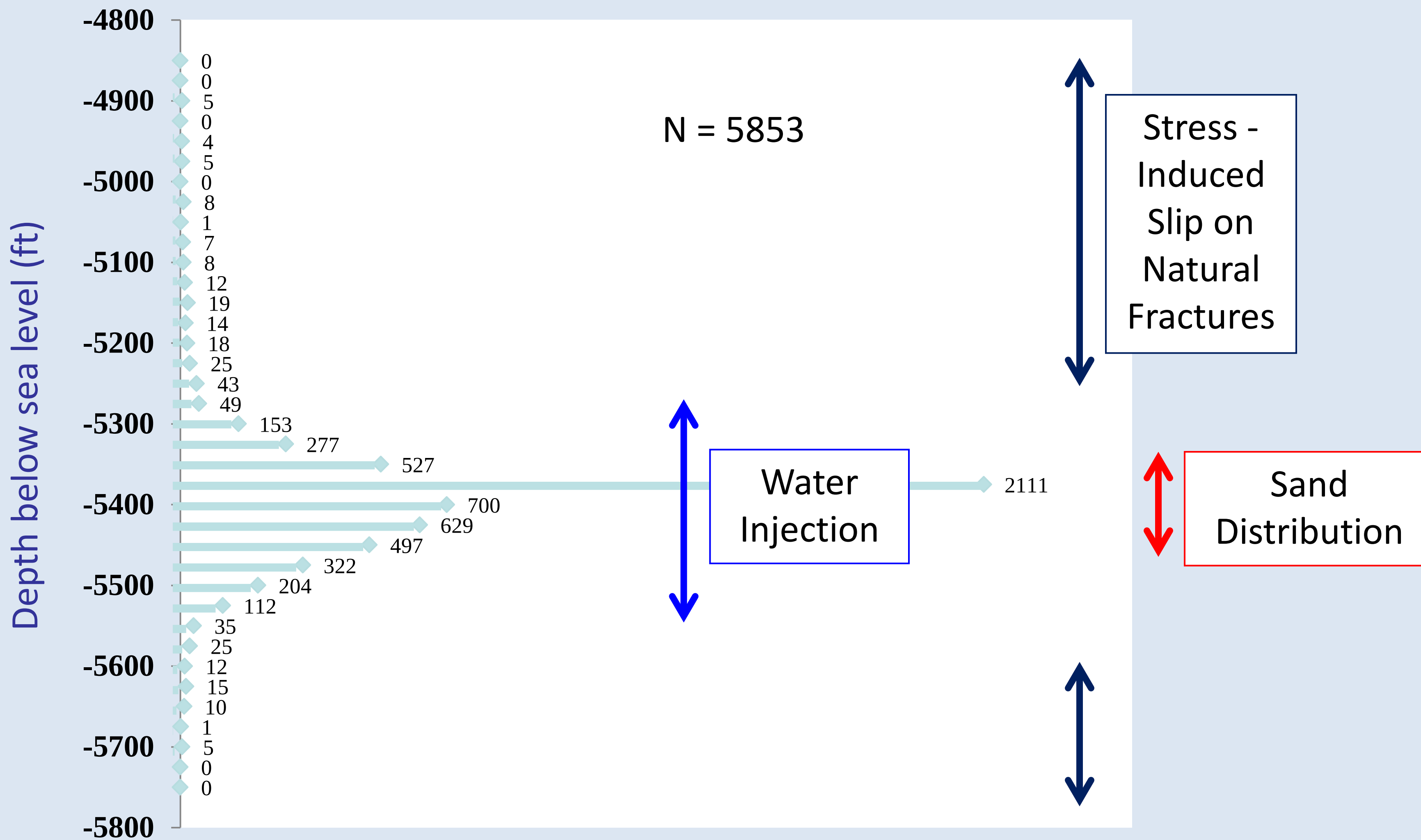


Vertical distribution of events relative to Marcellus

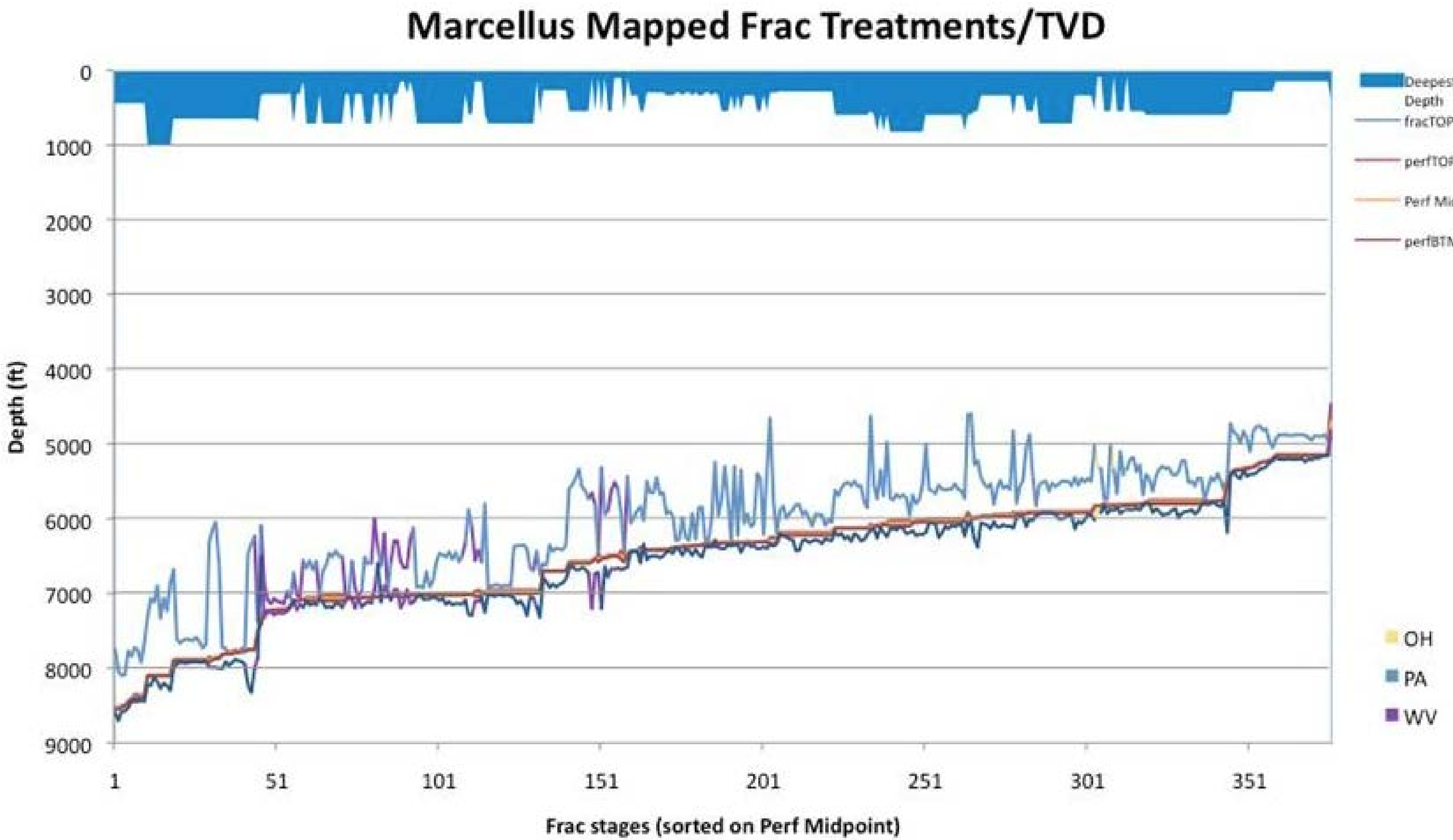
10H
Stage 4
all events

Courtesy of Terry Engelder, Penn State

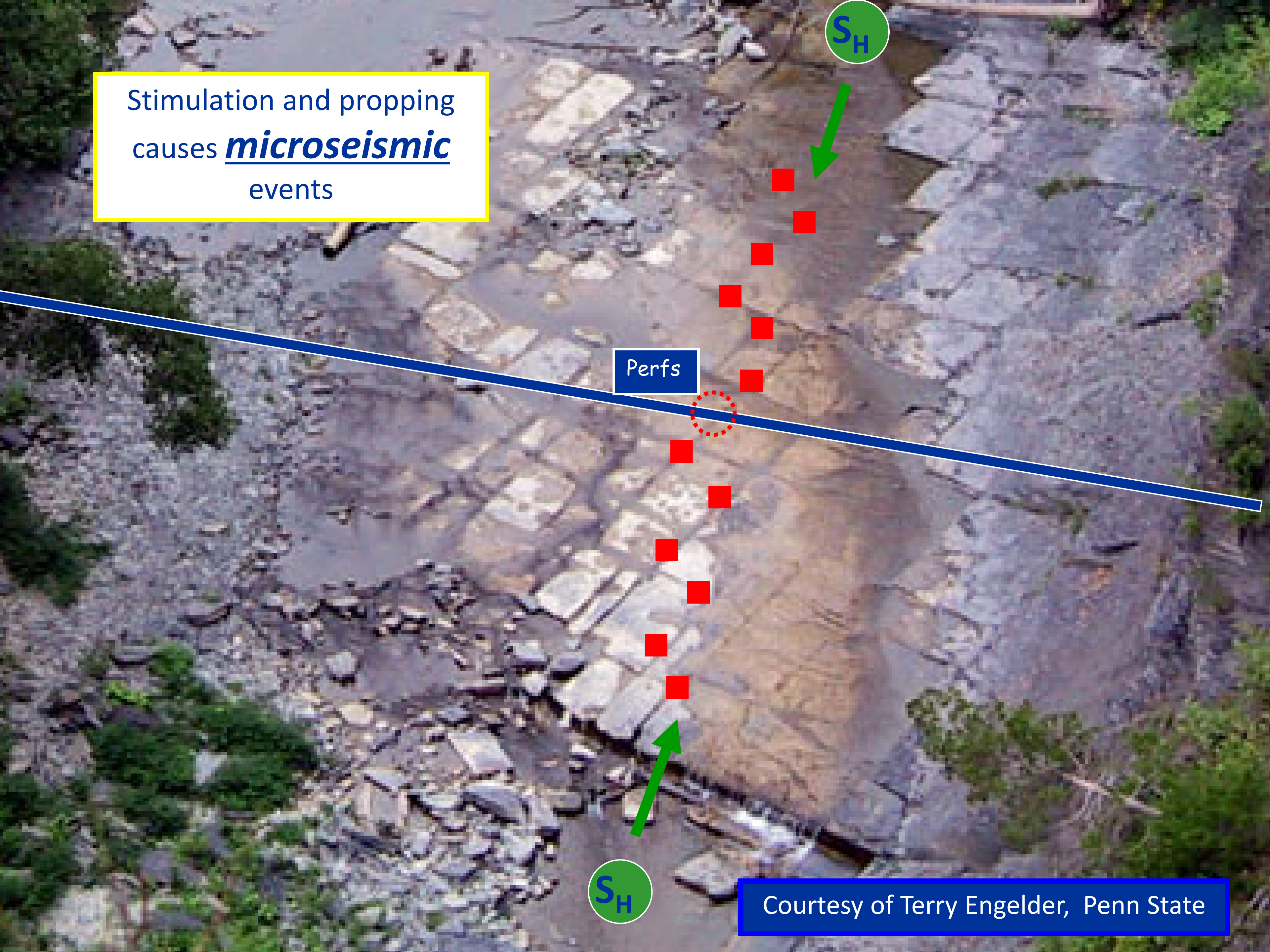
Depth distribution of microseismic events (10H)



Courtesy of Terry Engelder, Penn State



Fisher & Warpinski, 2012, SPE


Stimulation and propping causes ***microseismic*** events
S_H
Perfs
S_H
Courtesy of Terry Engelder, Penn State

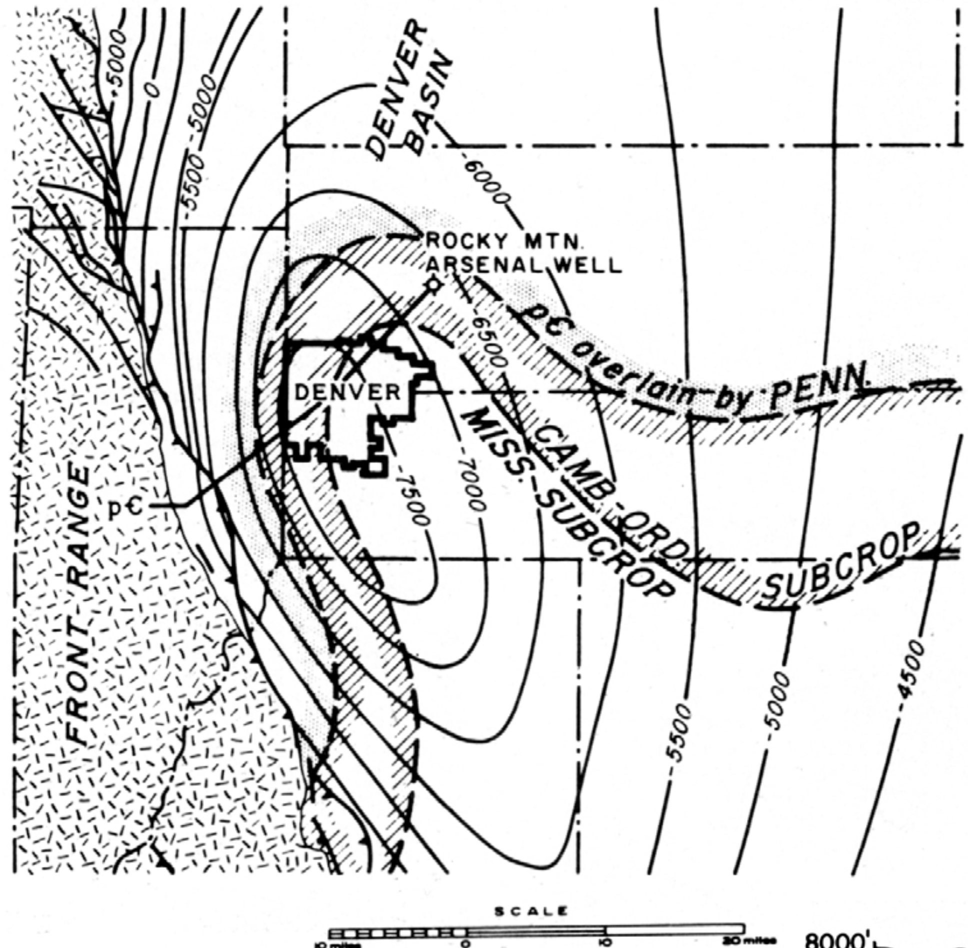
Can fracking cause earthquakes?

Yes

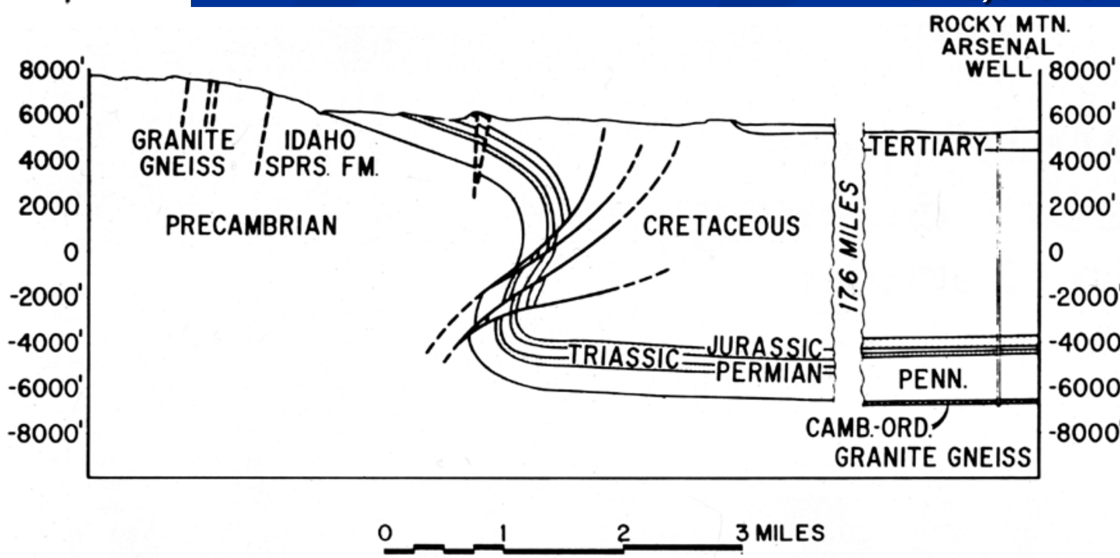
Ohio 2012 M 4.0
Oklahoma 2012 & earlier
Texas 2012 & earlier

Known for many years

Rocky Mtn. Arsenal Toxic Liquids Injections Location

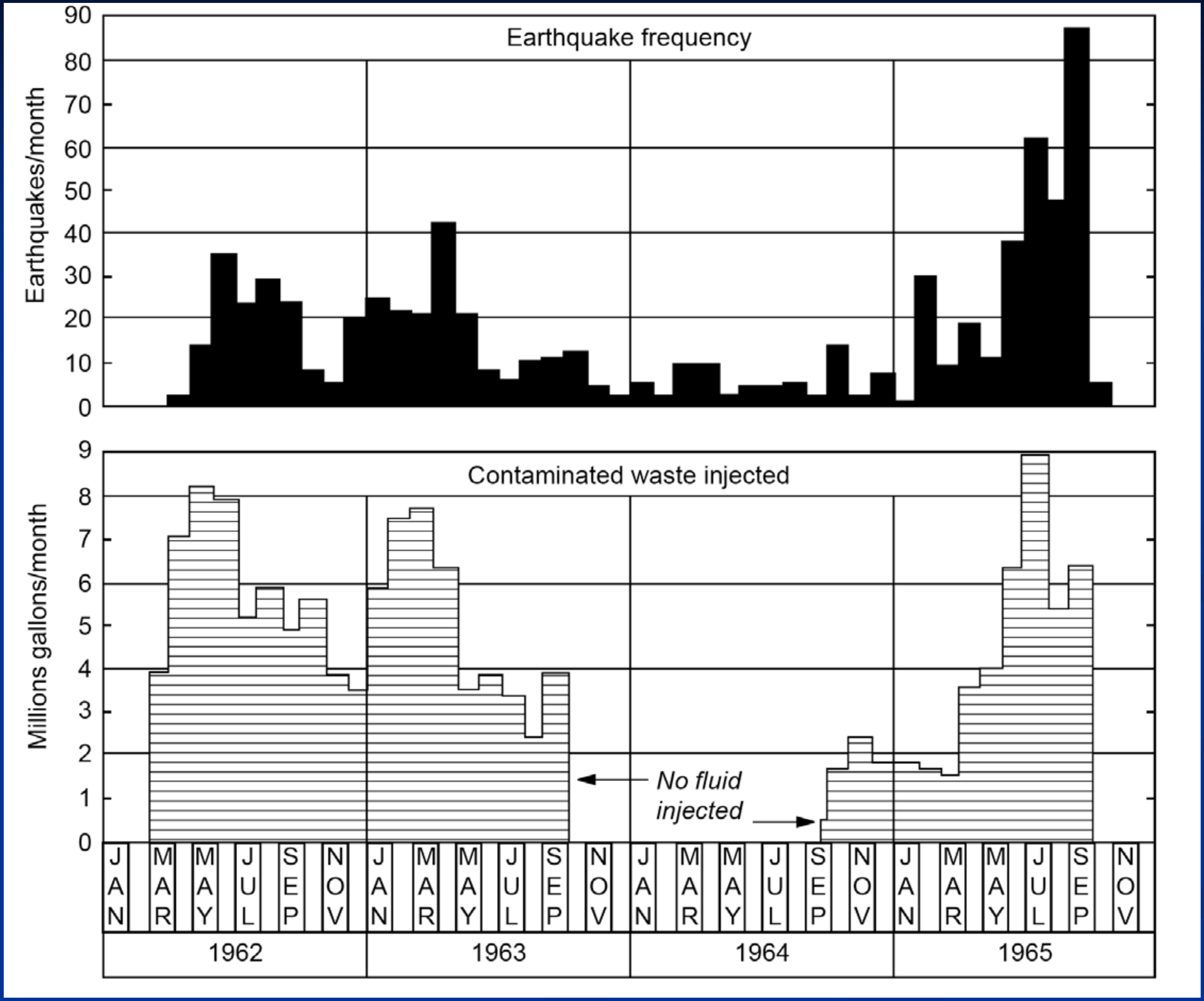


TD 12,045 ft



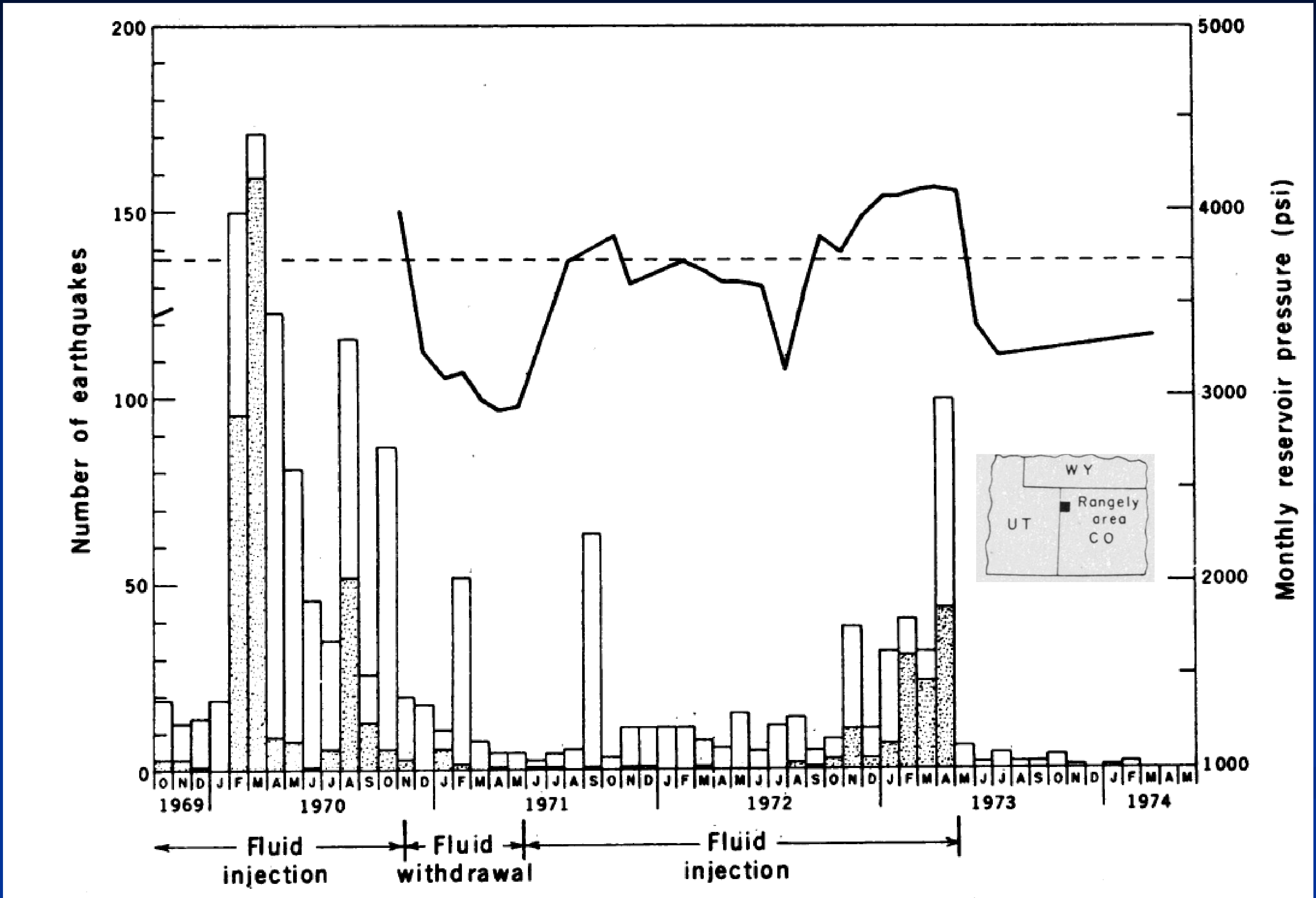
From Evans, 1966, GEOTIMES

Rocky Mtn. Arsenal Toxic Liquids Injections & Earthquakes



From Evans, 1966, GEOTIMES

Attempts to Control Earthquakes using Deep-Well Injection



From Raleigh, Healy, & Bredehoeft, 1976, Science

"In no case have we made a definitive determination that the fr
process has caused chemicals to enter ground water."

Lisa Jackson, outgoing EPA Administrator

The Editorial Page

NEW HAMPSHIRE UNION LEADER

Friday, March 15, 2013 • Page A8

Being against fracking is the latest cause for silly people

John Stossel

CELEBRITIES are now upset about fracking, the injection of chemicals into the ground to crack rocks to release oil and gas. With everyone saying they want alternatives to foreign oil, I'd think celebrities would love fracking.

I'd be wrong. Lady Gaga, Yoko Ono and their group, Artists Against Fracking, don't feel the love. Yoko sang, "Don't frack me!" on TV.

Stopping fracking is the latest cause of the silly people. They succeeded in getting scientifically ignorant politicians to ban fracking in New York, Maryland and Vermont.

Hollywood gave an Oscar to "Gasland," a documentary that suggests fracking will shove gas into some people's drinking water, so the water will burn. It's true that some water contains so much natural gas that you can light it.

But another documentary, "FrackNation," shows that gas got into plumbing long before fracking came. There's gas in the earth. That's why it's called "natural gas." Some gets into well water. Environmental officials investigated the flames shown in "Gasland" and concluded that the pollution had nothing to do with fracking.

"FrackNation" director Phelim McAleer tried to confront "Gasland" director Josh Fox about this, but Fox wouldn't answer his questions. Instead, he demanded to know whom McAleer works for. He also turned down my invitations to publicly debate fracking. Many activists don't like to answer questions that don't fit their narrative.

Even some homeowners who filed a lawsuit claiming that their water was poisoned by fracking weren't happy to learn that their water is safe. I'd think they would be delighted, but "FrackNation" shows a couple reacting with outrage when environmental officials test their water and find it clean.

The real story on fracking, say scientists, is that the risks are small and the rewards immense. Fracking lowered the price of natural gas so much that Americans heat our homes for less, and manufacturing that once left America has returned. For those concerned about global warming, burning gas instead of oil or coal reduces CO2 emissions.

"Skeptical Environmentalist" author Bjorn Lomborg points out that "green" Europe promised to reduce emissions, but "only managed to cut half of what you guys accidentally happened to do when you stumbled on fracking."

Still, the process sounds dangerous. It requires chemicals and explosions. So fracking is now scapegoated for the usual litany of things that peasants feared when threatened with curses centuries ago: livestock dying, bad crop yields, children born with deformities.

None of it is backed by scientific evidence. Even environmentalists who usually are too cautious (by my standards) see little danger. President Obama's first EPA administrator, Lisa Jackson, told Congress that the EPA cannot show "that the fracking process has caused chemicals to enter groundwater."

One of the more outlandish fears is that fracking will cause earthquakes. Silly people at MSNBC say fracking creates "a skyrocketing number of earthquakes." Yes, cracking rocks does cause vibrations. But then, so does construction with dynamite or jackhammers — not to mention trucks on the highway.

Time and again, as humans make a good-faith effort to find new, cleaner ways to produce the energy a growing population needs, environmentalists find a reason — often very small or non-existent — that makes the new method unacceptable.

They say coal is dirty and normal oil production might overheat the planet. Hydroelectric dams kill fish. Nuclear plants could suffer meltdowns. Windmills kill birds.

Some won't be happy unless we go back to what we did *before* industrialization: burn lots of trees and die young.

Nothing is completely risk-free. Companies make mistakes. Chemical spills happen.

But those risks are manageable. They are also far preferable to the risk of paying more for energy — thereby killing opportunities for the poor.

So far, most regulators outside New York, Maryland and Vermont have ignored the silly people. So thanks to fracking, Americans pay less for heat (and everything else), the economy is helped, new jobs get created, we create less greenhouse gas, and for the first time since the 19th century, America may become a net exporter of energy.

Good things happen if the silly people can't convince *all* politicians to ban progress.

◆

John Stossel is host of "Stossel" on the Fox Business Network. He's the author of "No They Can't: Why Government Fails, but Individuals Succeed."

Conclusions about Fracking:

- *Fracking, in concert with horizontal drilling, is an effective tool to increase oil or gas production.*

- *Fracking should not produce ground water pollution.*

- *Most claims of ground water pollution by fracking, when studied by rigorous scientific techniques, have proven false.*


Existing Keystone pipeline
Proposed Keystone XL expansion
CANADA
Fort McMurray
Tar sands
Manitoba
Alberta
Edmonton
British Columbia
Saskatchewan
Hardisty
Saskatch.
Vancouver
Regina
Winnipeg
Ontario
Seattle
Missouri
N.D.
Montana
Billings
S.D.
Mississippi
U.S.
Sand Hills
Neb.
Omaha
Illinois
0
400
MILES
Patoka
Denver
Steele City
Kansas
St. Louis
Missouri
Cushing
Arkansas
Okla.
Ogallala Aquifer
Dallas
Texas
Pacific Ocean
Houston
Port Arthur
Gulf of Mexico
MEXICO


NORTHWEST TERRITORIES
Athabasca
Oil Sands
Fort McMurray
Peace River
Oil Sands
SASKATCHEWAN
Grande Prairie
ALBERTA
Cold Lake
Oil Sands
Edmonton
Lloydminster
BRITISH
COLUMBIA
Red Deer
Calgary
Canada
Medicine Hat
Lethbridge
United States
NORTH
MONTANA
0 50 100 200
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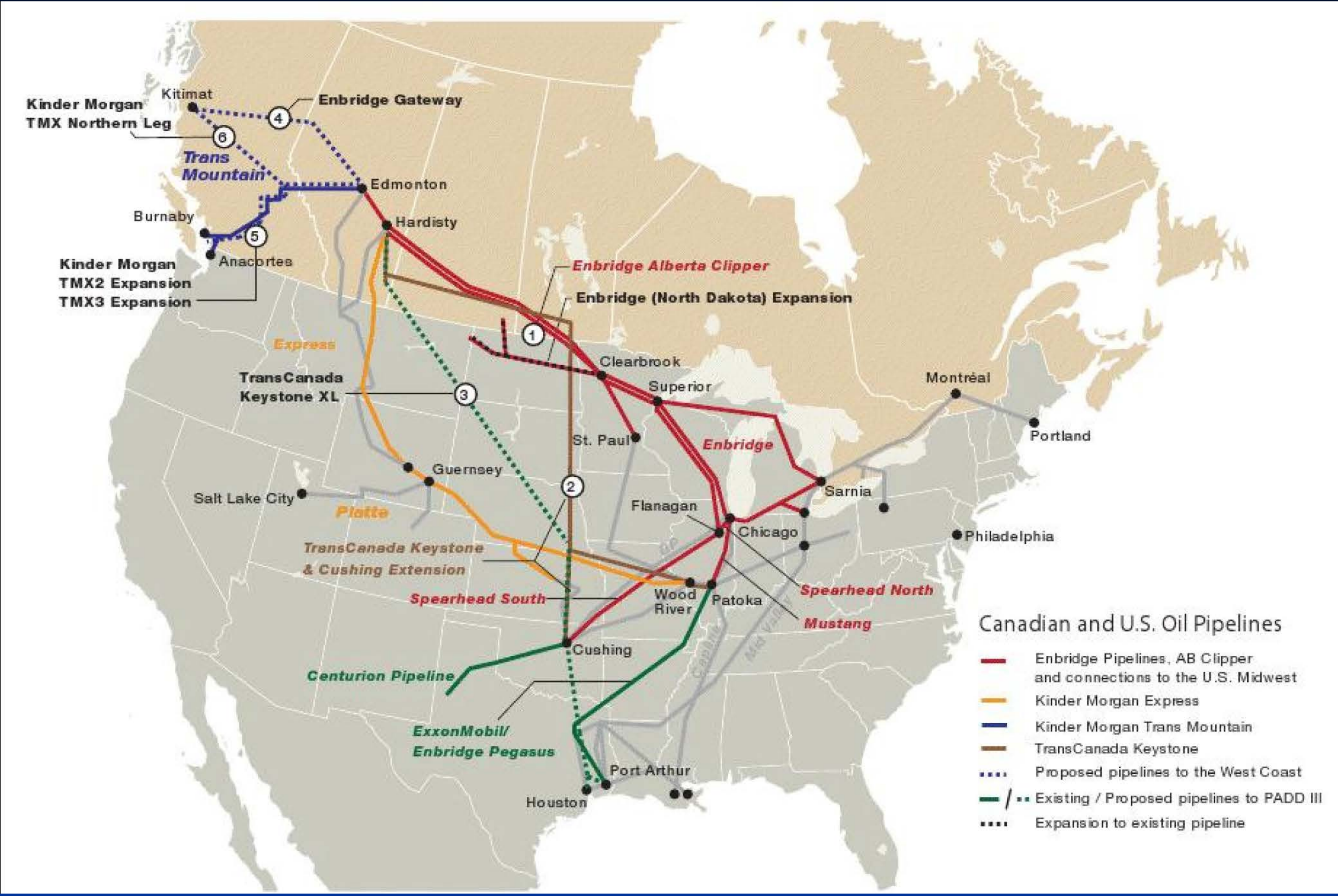
MILDRED LAKE, ALTA.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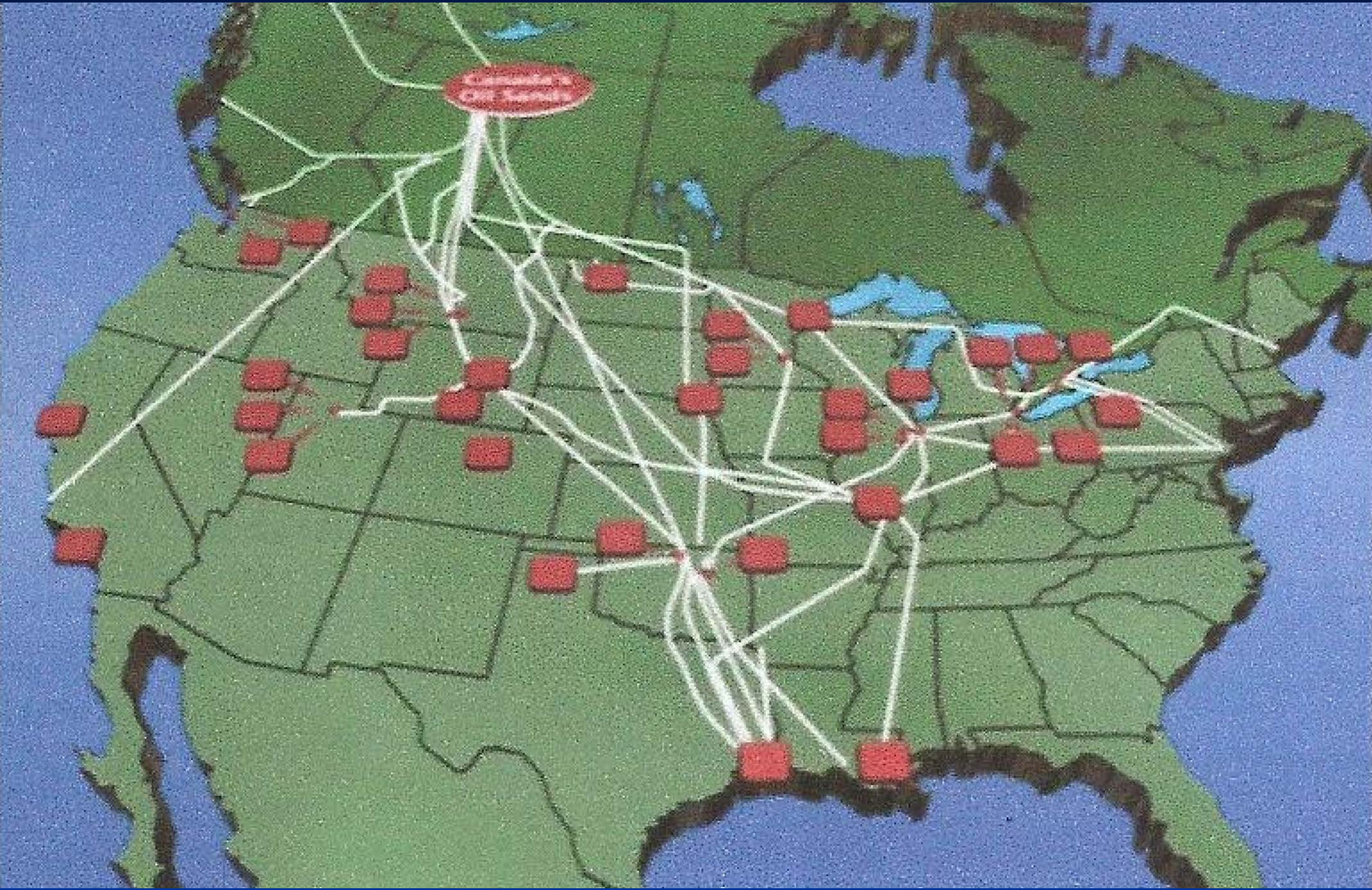
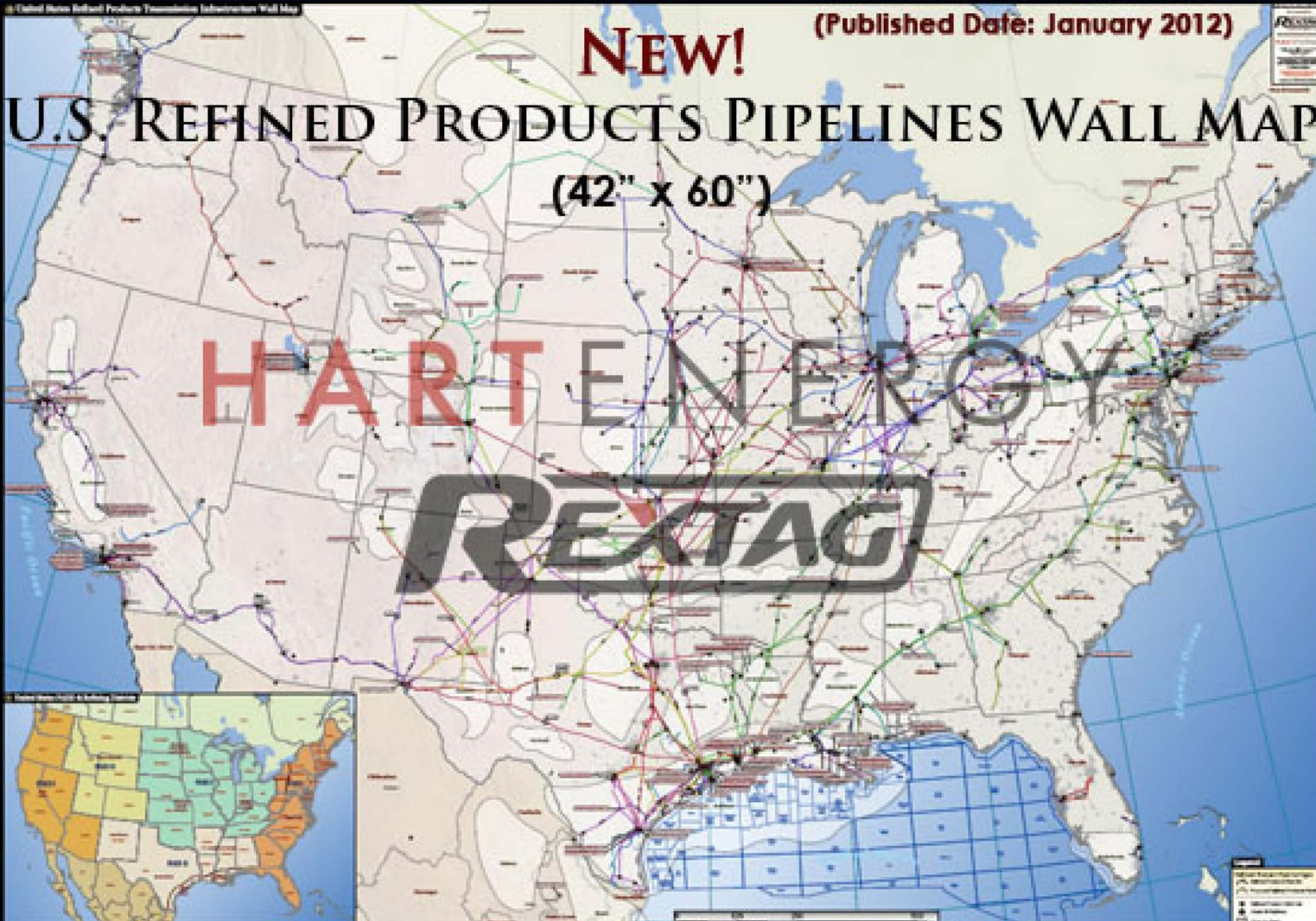
Kinder Morgan
TMX Northern Leg
Enbridge Gateway
Trans
Mountain
Edmonton
Burnaby
Hardisty
Anacortes
Kinder Morgan
TMX2 Expansion
TMX3 Expansion
Enbridge Alberta Clipper
Enbridge (North Dakota) Expansion
Express
Clearbrook
TransCanada
Keystone XL
Superior
Montréal
Portland
St. Paul
Enbridge
Guernsey
Sarnia
Salt Lake City
Flanagan
Platte
Chicago
Philadelphia
TransCanada Keystone
& Cushing Extension
Spearhead North
Spearhead South
Wood
River
Patoka
Mustang
Cushing
Centurion Pipeline
ExxonMobil/
Enbridge Pegasus
Port Arthur
Houston
Capline
Mid Valley
Canadian and U.S. Oil Pipelines
Enbridge Pipelines, AB Clipper
and connections to the U.S. Midwest
Kinder Morgan Express
Kinder Morgan Trans Mountain
TransCanada Keystone
Proposed pipelines to the West Coast
Existing / Proposed pipelines to PADD III
Expansion to existing pipeline



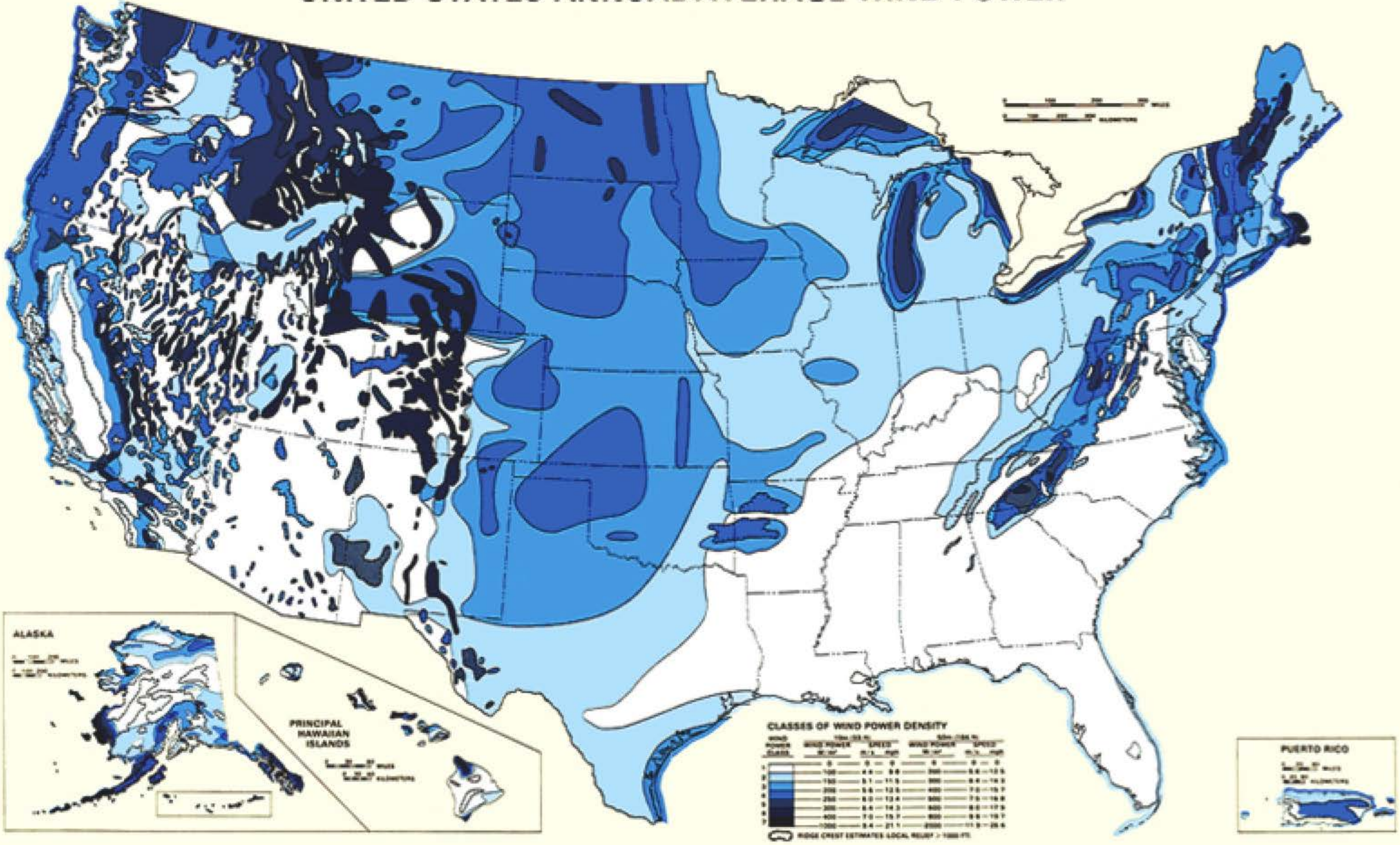


(Published Date: January 2012)
NEW!
U.S. REFINED PRODUCTS PIPELINES WALL MAP
(42" x 60")
HART ENERGY
REXTAG

Alternative Energy Sources

Wind Power

UNITED STATES ANNUAL AVERAGE WIND POWER



TVA Wind Farm near Oak Ridge

Wind Farm (where?)

"One big rig in the Gulf produces more energy in one day than ALL of the wind farms in the US!"

Shell VP, April, 2011, AAPG Meeting, Houston

"For every Btu put into oil/gas exploration -production, 20,000 Btu are returned."

"Ratio is currently 1 : 1.25 Btu (possibly 1:1.6 Btu) for switchgrass.

Jeff Bailey, President, CEO Tengasco 1/12/12

Biofuels

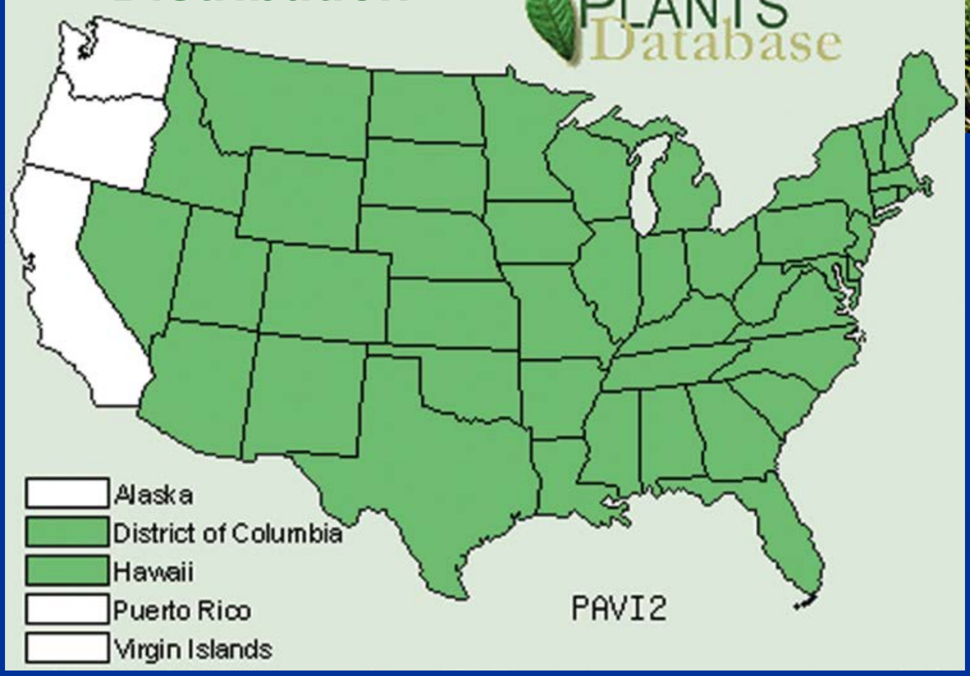
—Panacea?

Future Solutions?

Panacea?

Native switch grass (Panicum virgatum)

Distribution



Seeds

Conversion of Carbohydrates to Ethanol

Sucrose (= disaccharide of glucose–fructose) → C_2H_5OH

Not too difficult w/ yeast enzyme (accomplishes oxidation)

Corn starch (= poly$C_6H_{10}O_5$ = polyglucose) → C_2H_5OH

More difficult, but can be made easier by using corn syrup—high in glucose–fructose (easily broken down) and starch.

Cellulose (= poly$C_6H_{10}O_5$ = polyglucose) → C_2H_5OH

More difficult, because there are places on the polymer chain that are difficult for the enzyme to access.

Learn from Moonshiners: sprout the corn, take it to a mill to be ground, let the paste ferment (add sugar to boost yeast production), add a little chicken manure for a source of both uric acid and bacteria, and distill after suitable aging.

Thanks to Dr. Dave Baker, UTK Chemistry Dept., and local farmer

Too Good To Be True?

How do we maintain high corn yields year after year?

What is 20–10–10? What is its source, and future source(s)?

How is NH_4NO_3 made? What is the Haber–Bosch process?

Pass H_2 and N_2 over Fe, Mo, or $FeFe_2O_4$ [catalyst] at 500° C and 0.5 kb P $\longrightarrow$ NH_3

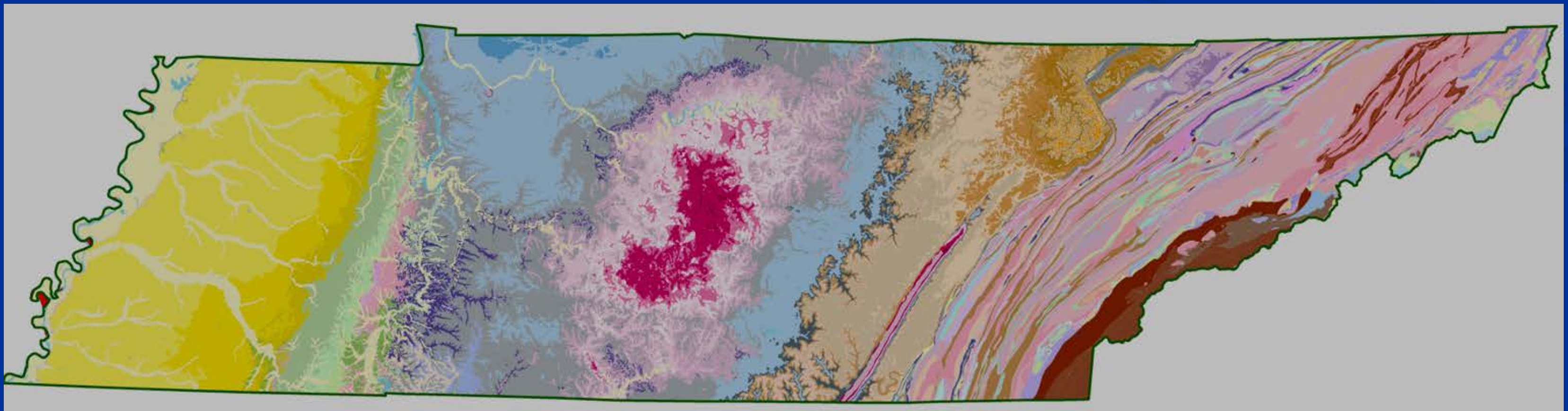
Convert to NH_4NO_3

No Problem?

Why is NH_4NO_3 no longer made in the U.S. (since ~2003)?

Conclusions

- Tennessee has greater petroleum potential than has been developed—large parts of Tennessee remain unexplored.
- Greatest current potential is in oil, because is much more valuable than gas.
- Fracking can and is being done with nitrogen, which minimizes the potential environmental impact of gas development.
- Become better informed on issues like this.



Sleeper or Howler?

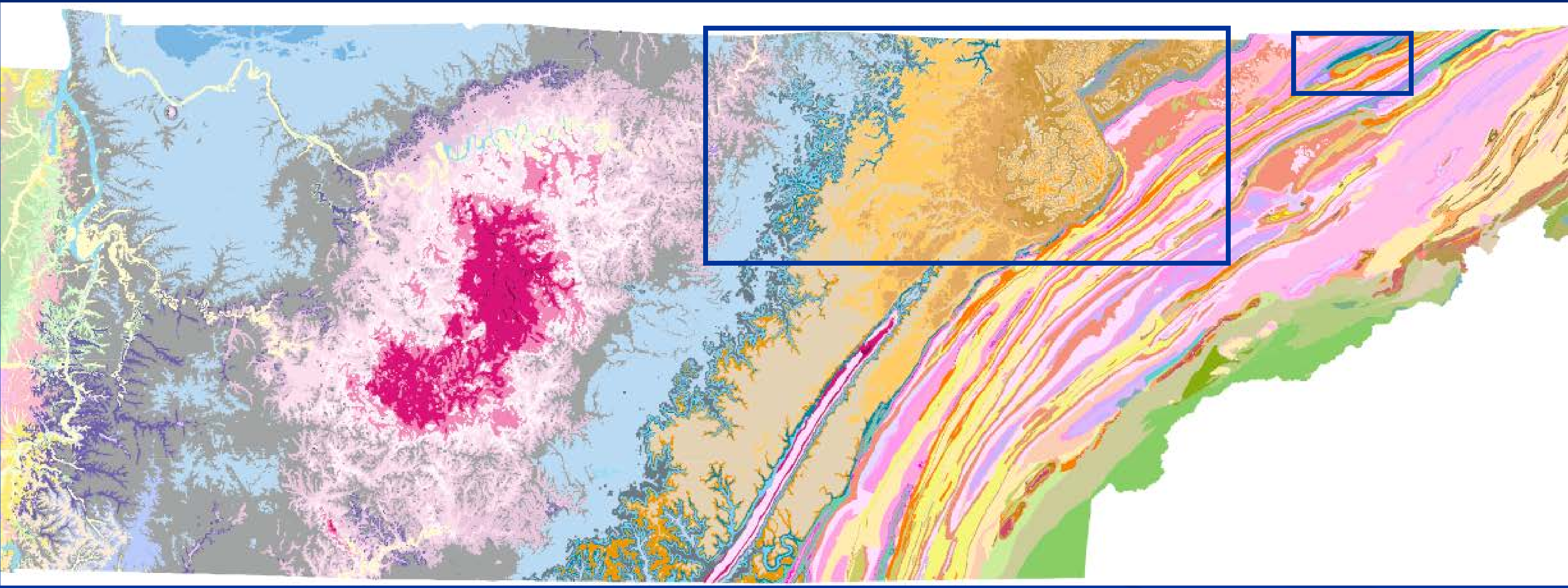
Bob's Most Attentive Audience

I might have said less if I had had more time.

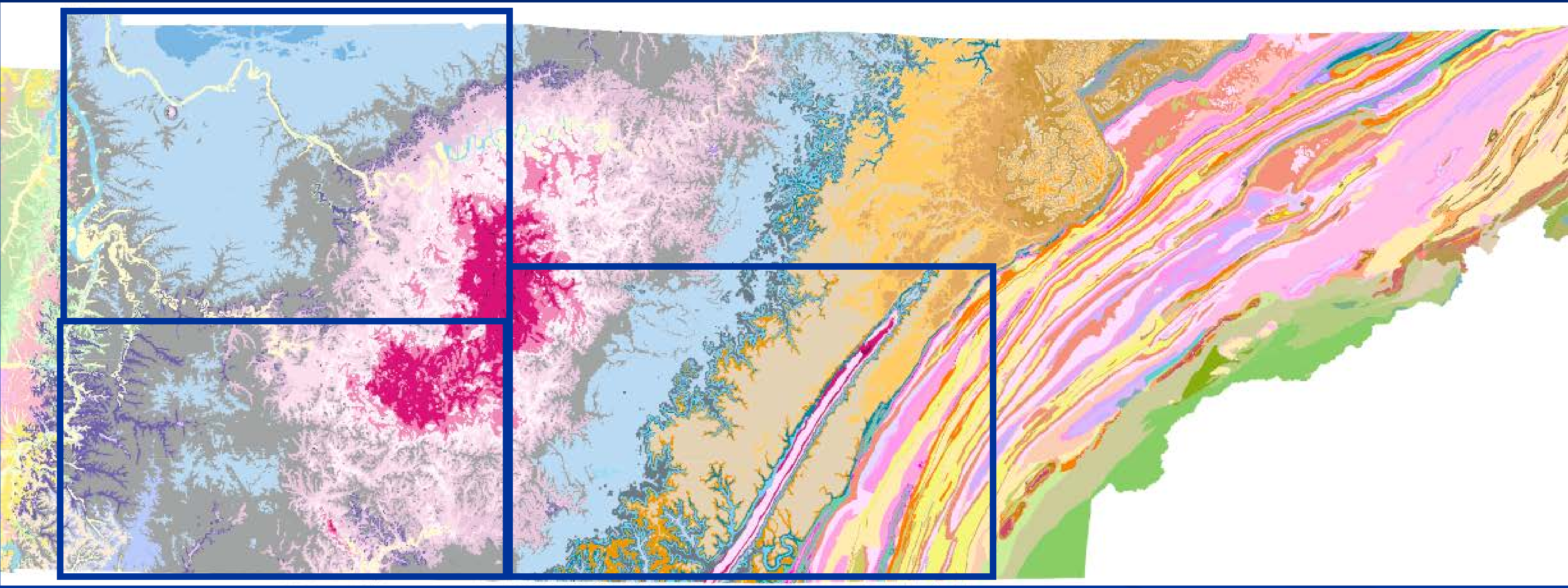
With apologies to Blaise Pascal.

FIN

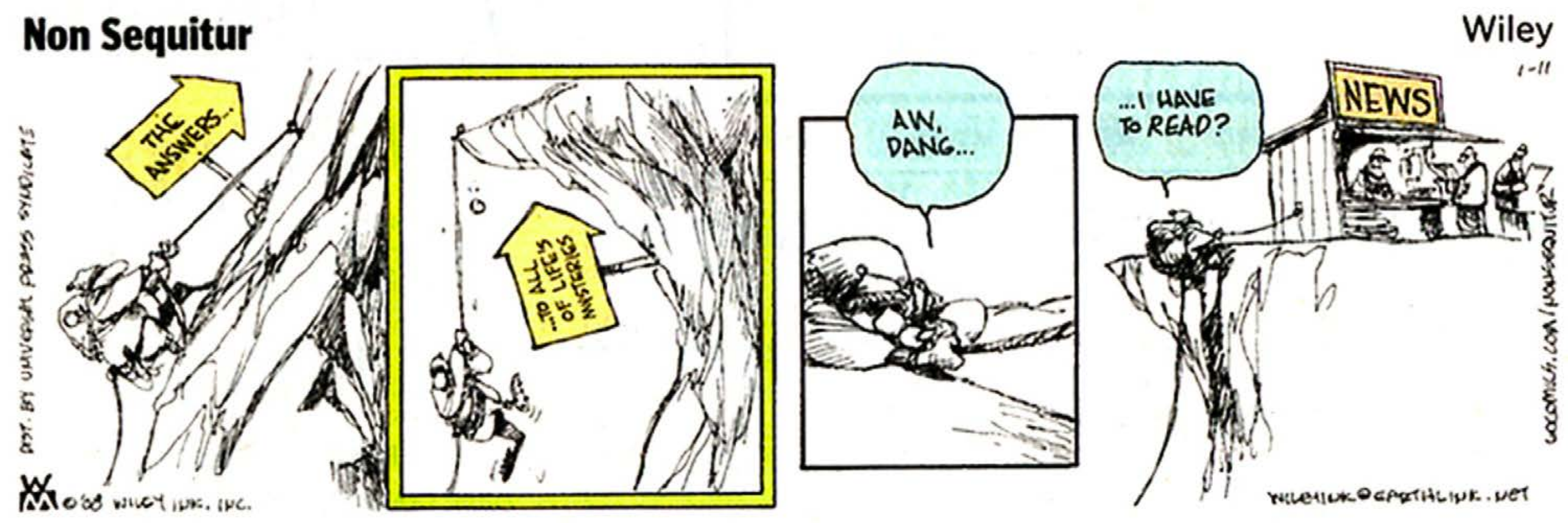
Exploration/Production in Tennessee



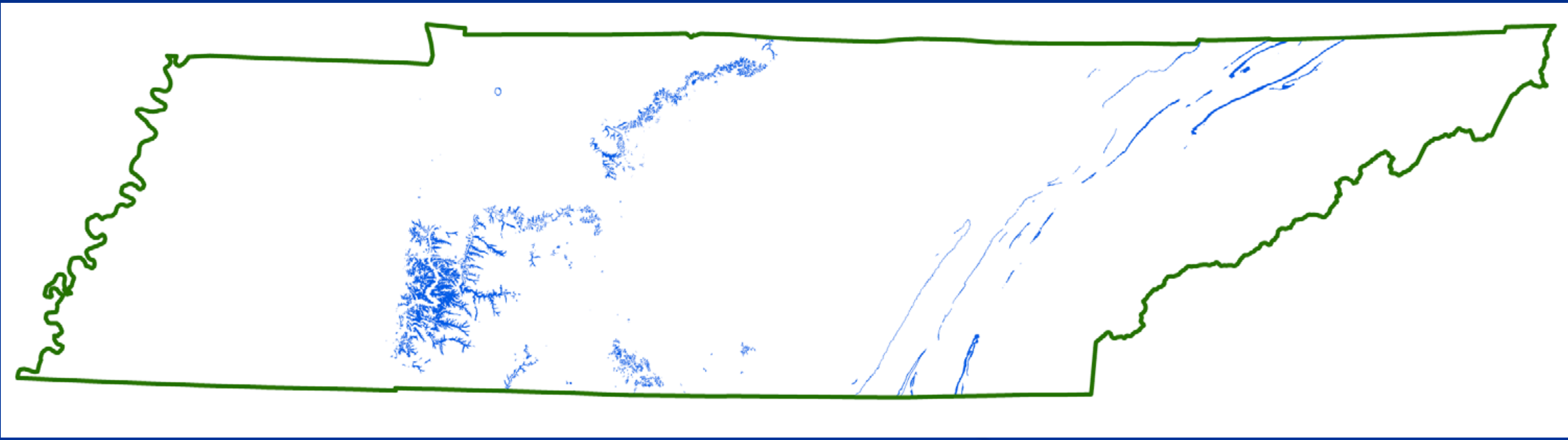
Additional Exploration Opportunities in Tennessee



So, where do u want to get your information?

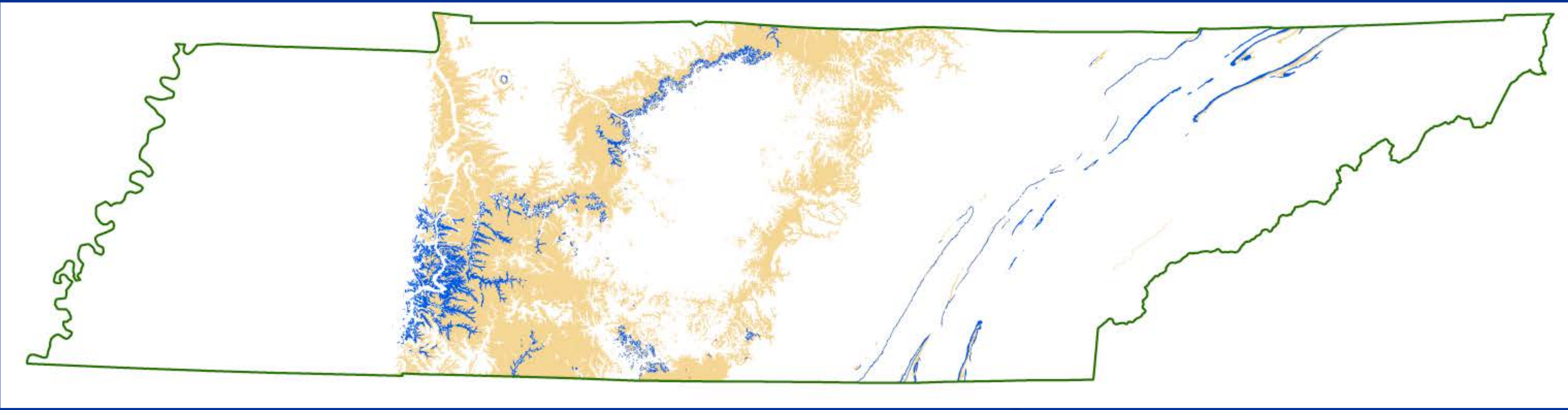


Exposed Silurian Rocks in TN



From Hardeman, 1966, TDG

Exposed Silurian & Mississippian Rocks in TN



Message

- Ordovician Petroleum System: Ordovician rocks (Nashville & Stones River Groups) still have great potential for oil exploration in Tennessee.

- Mississippian Petroleum System: Mississippian potential is also very good, and and shallower, but difficult to pinpoint new prospects.

- The structure of the rocks below the Chattanooga Shale contrasts with that above the Chattanooga, adding a degree of complexity to exploration.

- Large parts of Tennessee remain underexplored.

Oil Sources in Two Petroleum Systems

- ***Ordovician***

  Moderate migration in Middle Ordovician carbonate rocks

  Vertical migration from Copper Ridge Dolomite (Cambrian)

  Out-of-basin migration from Sevier Shale (E TN)?

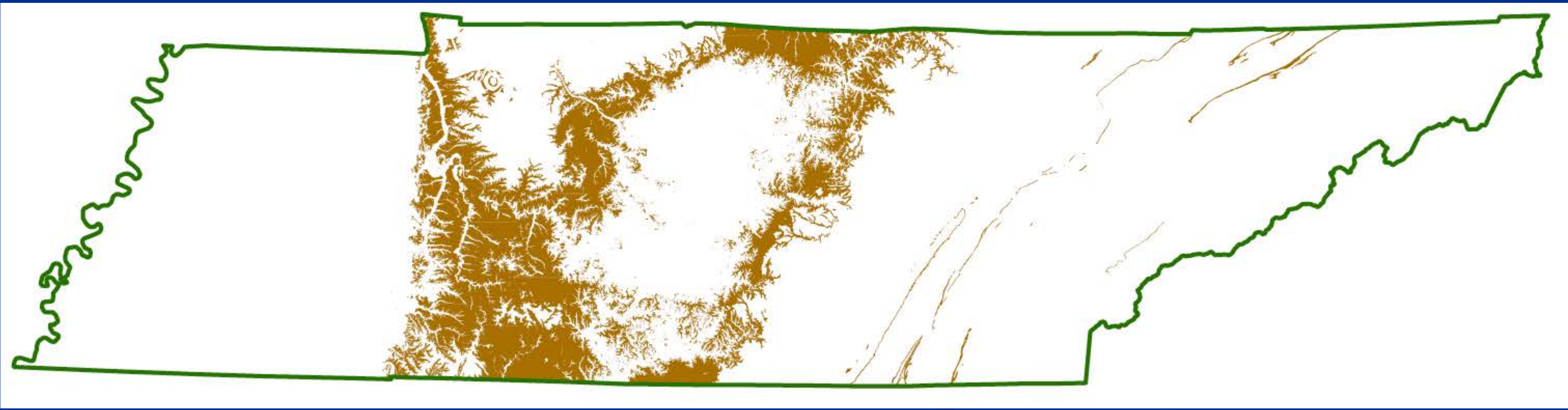
  (Conasauga in TN unlikely to be source or reservoir)

  [Exception: Dolomite facies like Copper Ridge in NE TN]

- ***Mississippian***

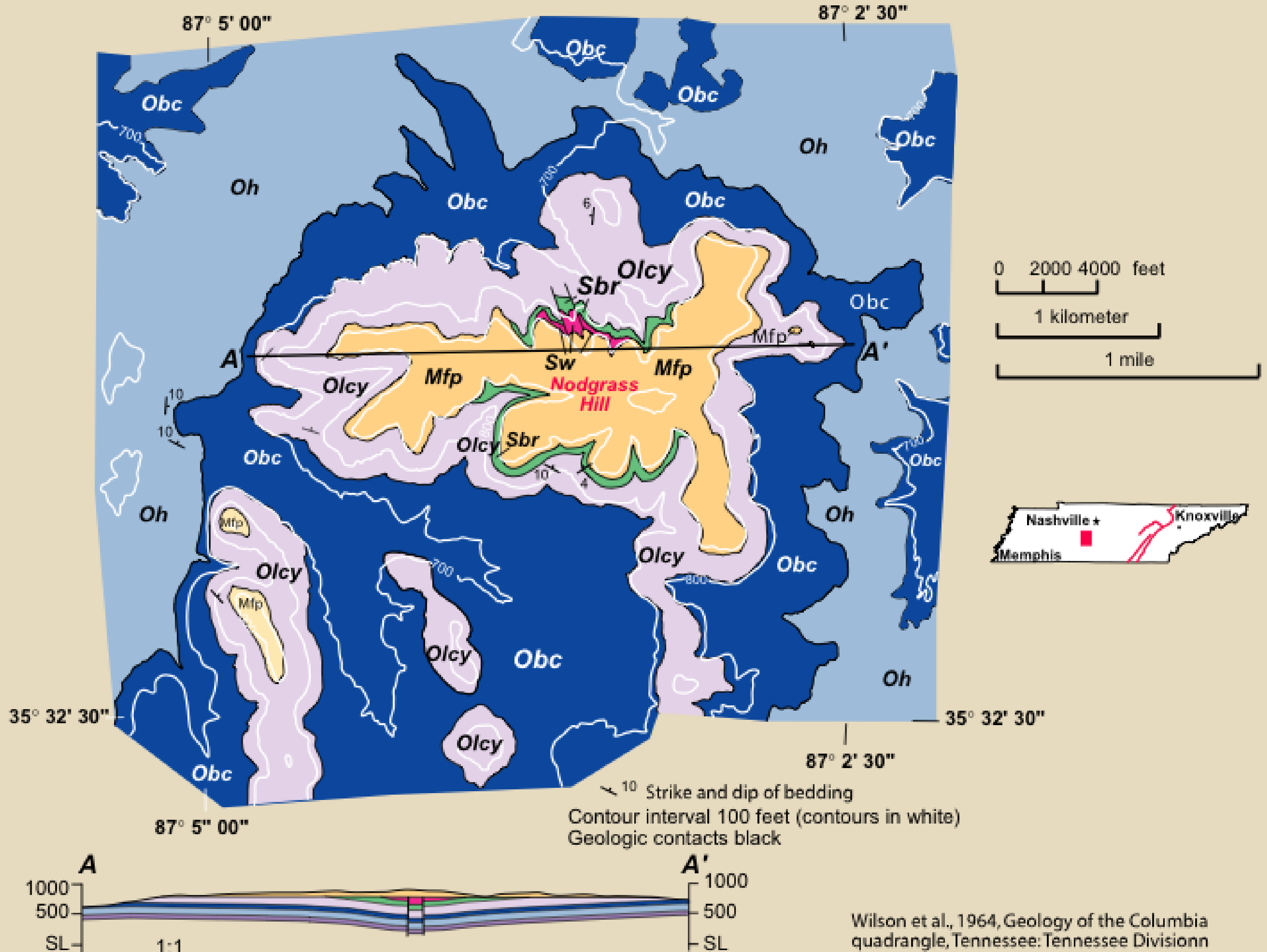
  Chattanooga Shale

Exposed Mississippian Rocks in TN

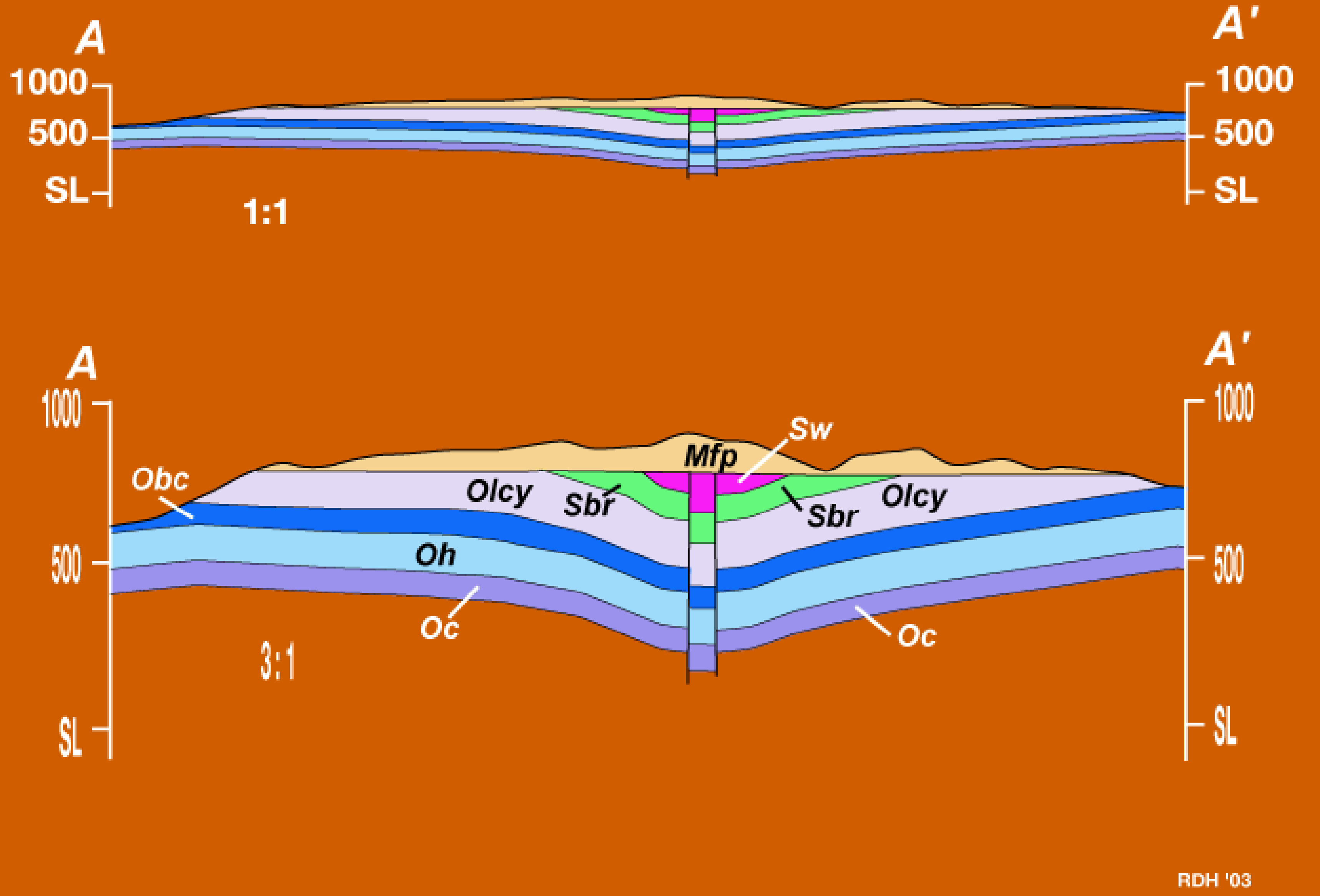


From Hardeman, 1966, TDG

Part of Columbia, TN, Quad



Wilson et al., 1964, Geology of the Columbia quadrangle, Tennessee: Tennessee Divisionn of Geology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RDH '03

Exploration Program for the Mississippian Petroleum System

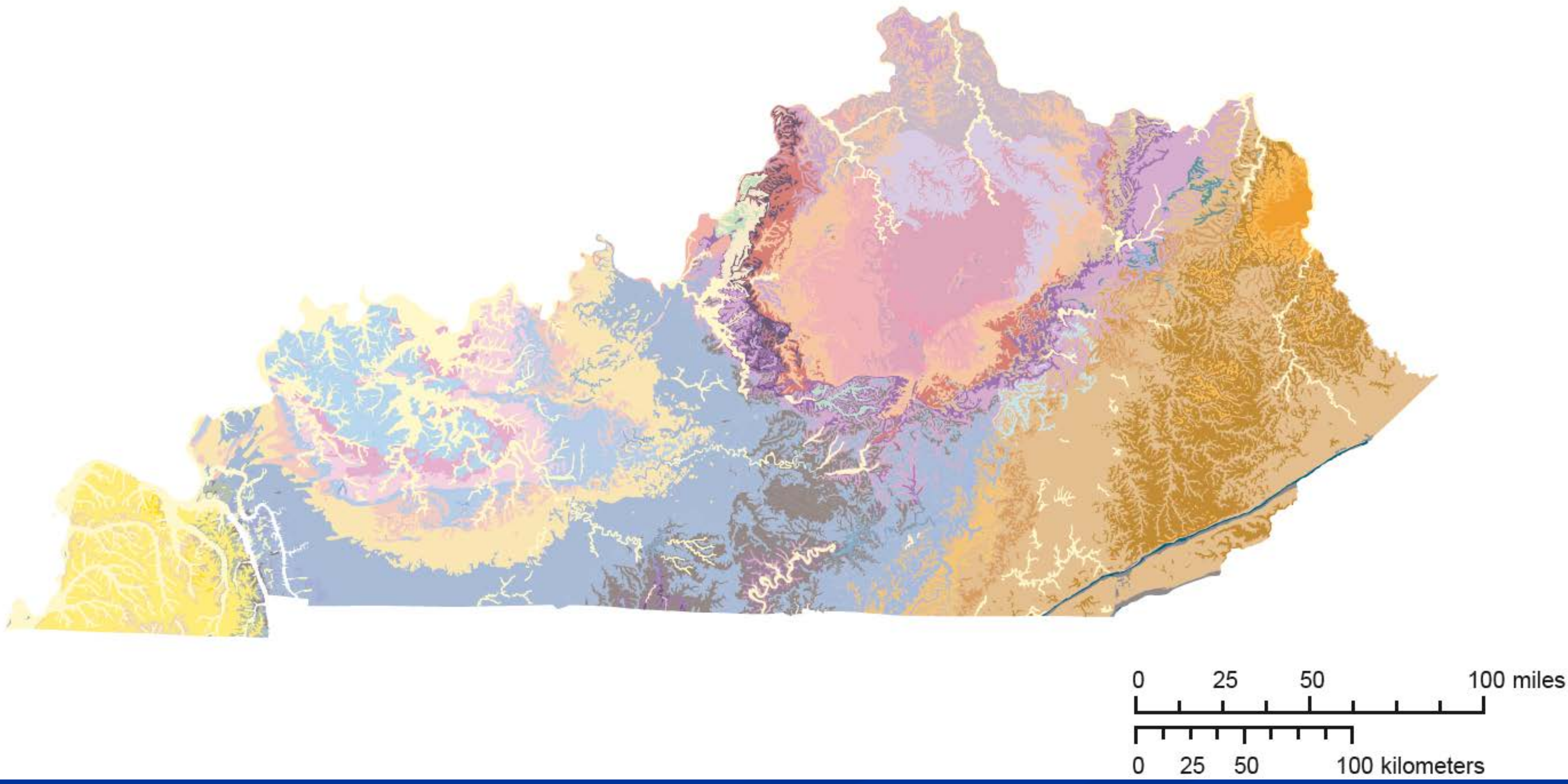
- ***Structure contours on Chattanooga Shale.***
- ***Map oolite shoals in the Monteagle (Big Lime).***
- ***Map Ft. Payne reefs.***
- ***Map faults, fracture systems.***
- ***Risk assessment and economics.***

Additional Data Needed

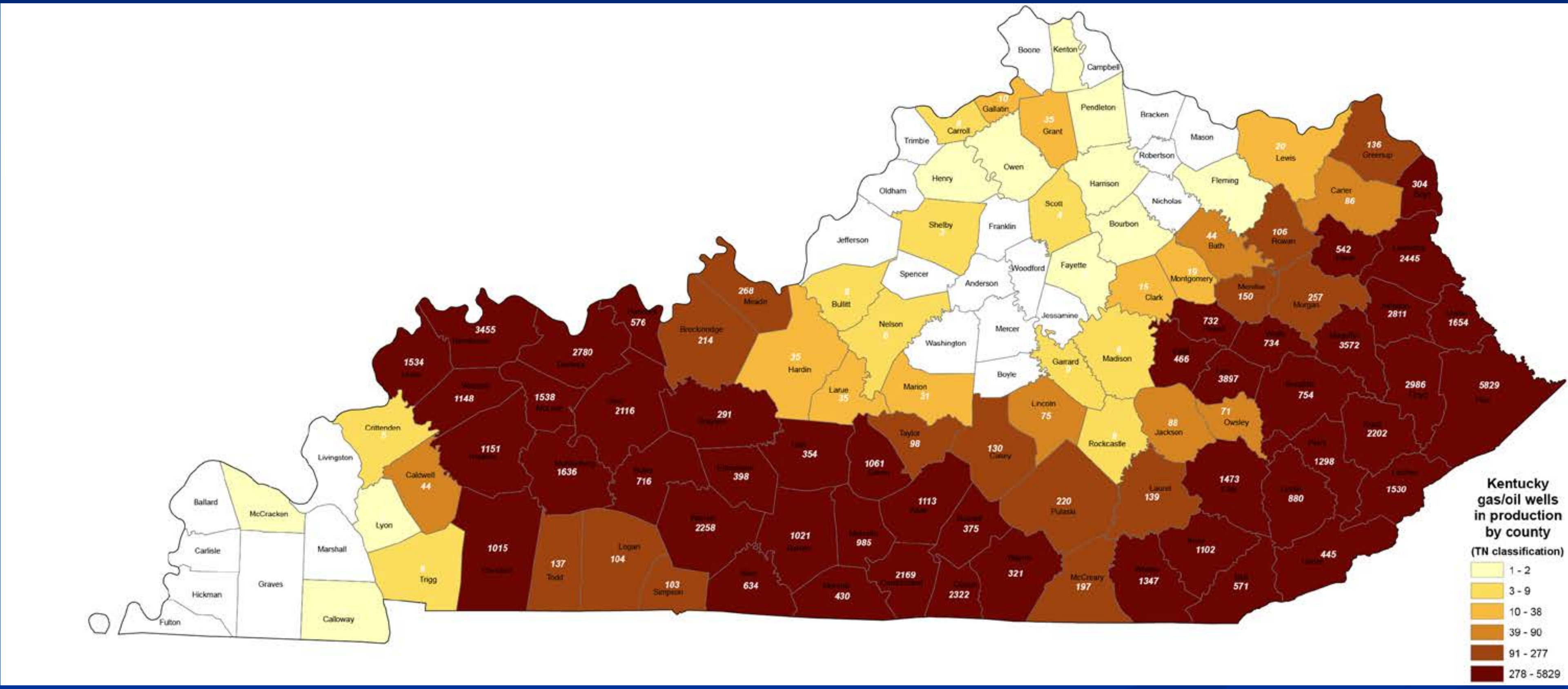
- *2D seismic reflection lines.*

- *Form consortia to share expense.*

Kentucky Geologic Map



Producing Wells in Kentucky



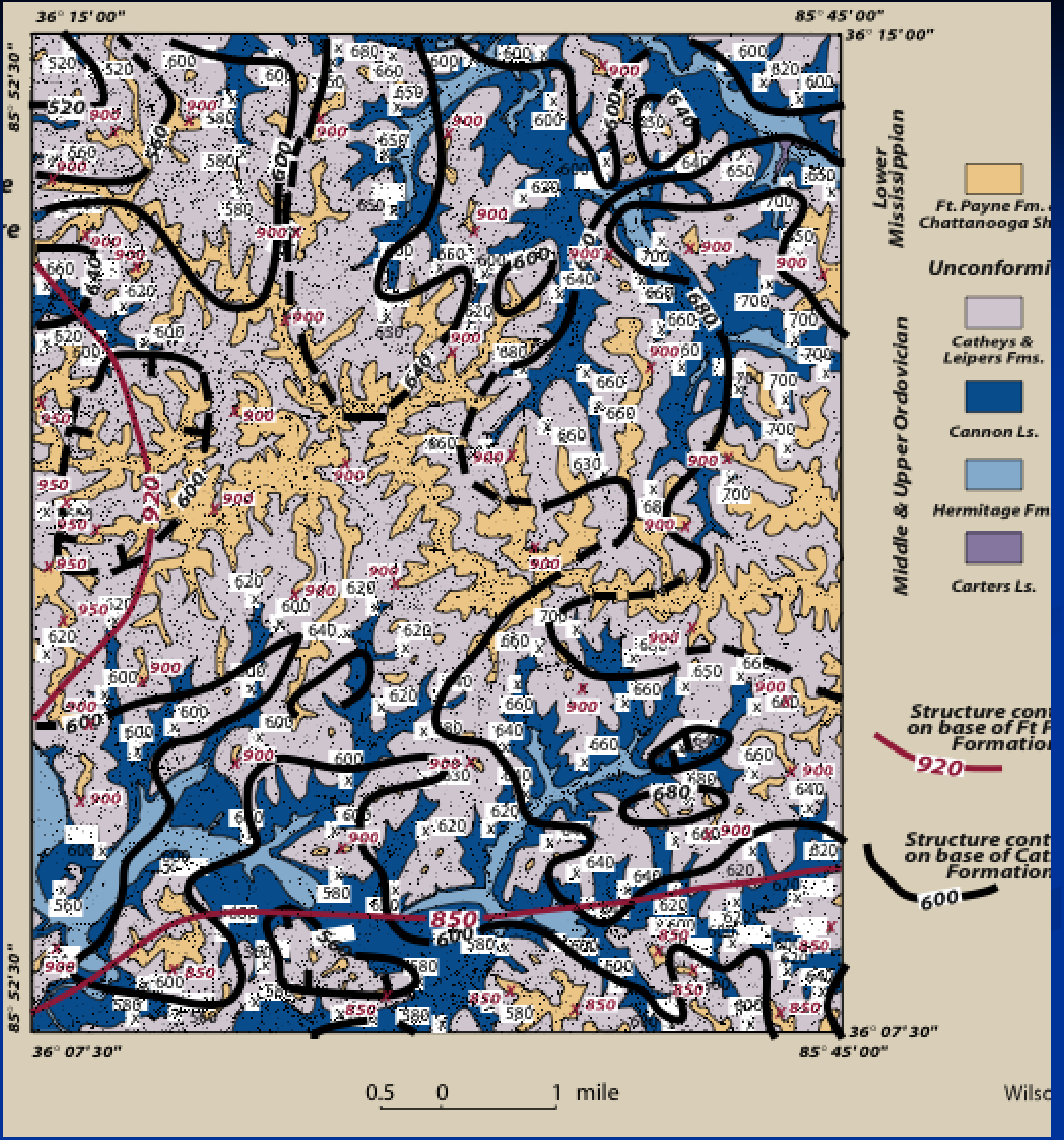
Data from KGS

Exploration Program for the Ordovician (Pre-Chatt.) Petroleum System

- *Structure contour maps of top of Hermitage from existing surface and subsurface data.*
- *Identify and map folds (and faults).*
- *Isopach pay zones in Cannon (Sunnybrook) and Murfreesboro (Stones River) from subsurface data.*
- *Identify local faults and other fracture systems.*
- *Risk assessment and economics.*

Buffalo Valley Quad, TN

C.W. Wilson, Jr.
TN Div. Geology (1971)



Petroleum Systems

Natural system that encompasses a mass of active source rock & all related O & G. Includes all geologic elements and processes essential for a hydrocarbon system to survive.

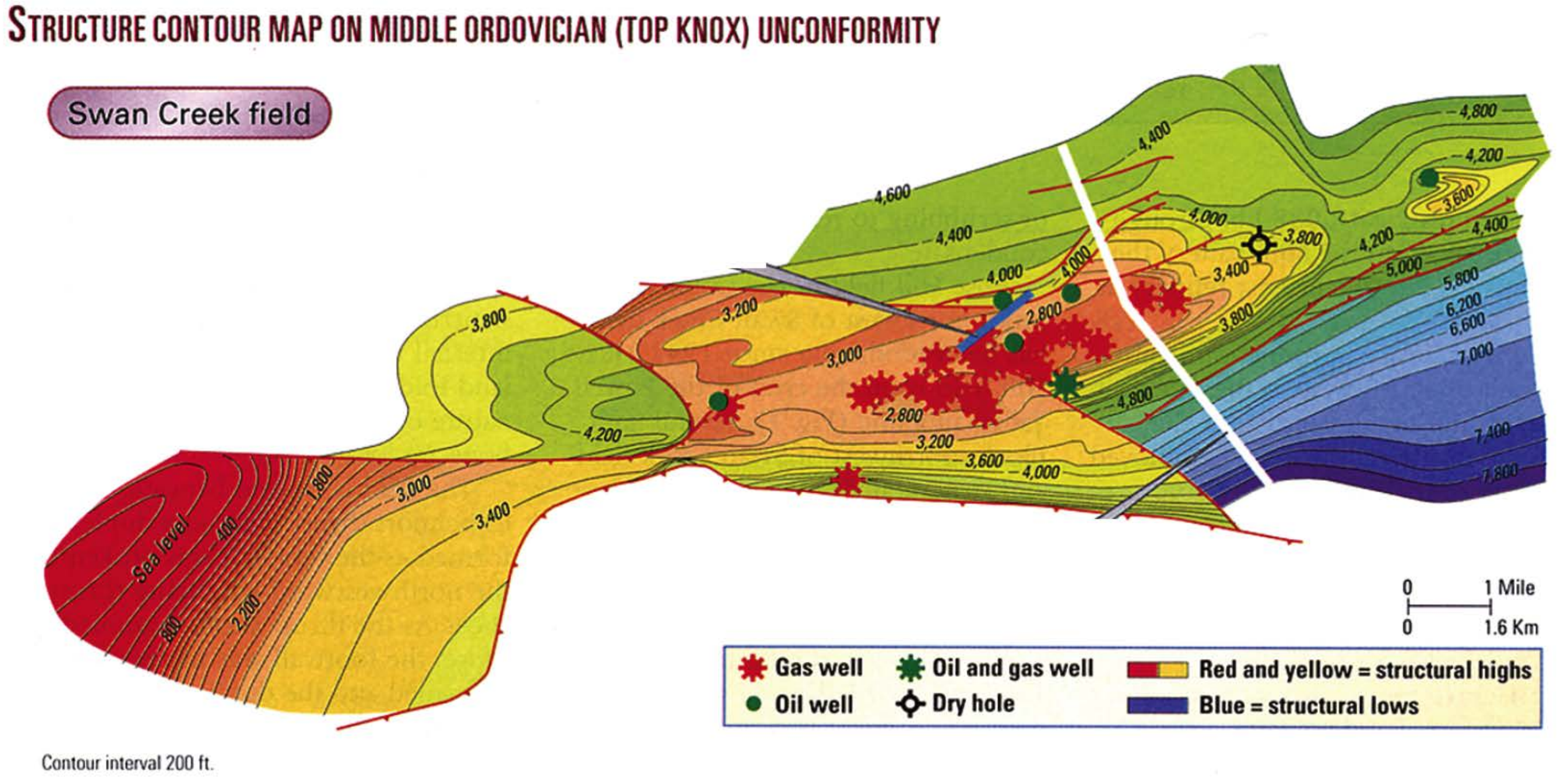
Essential Elements of Petroleum Systems

- ***Source rock.***
- ***Reservoir rock.***
- ***Seal rock.***
- ***Overburden rock.***

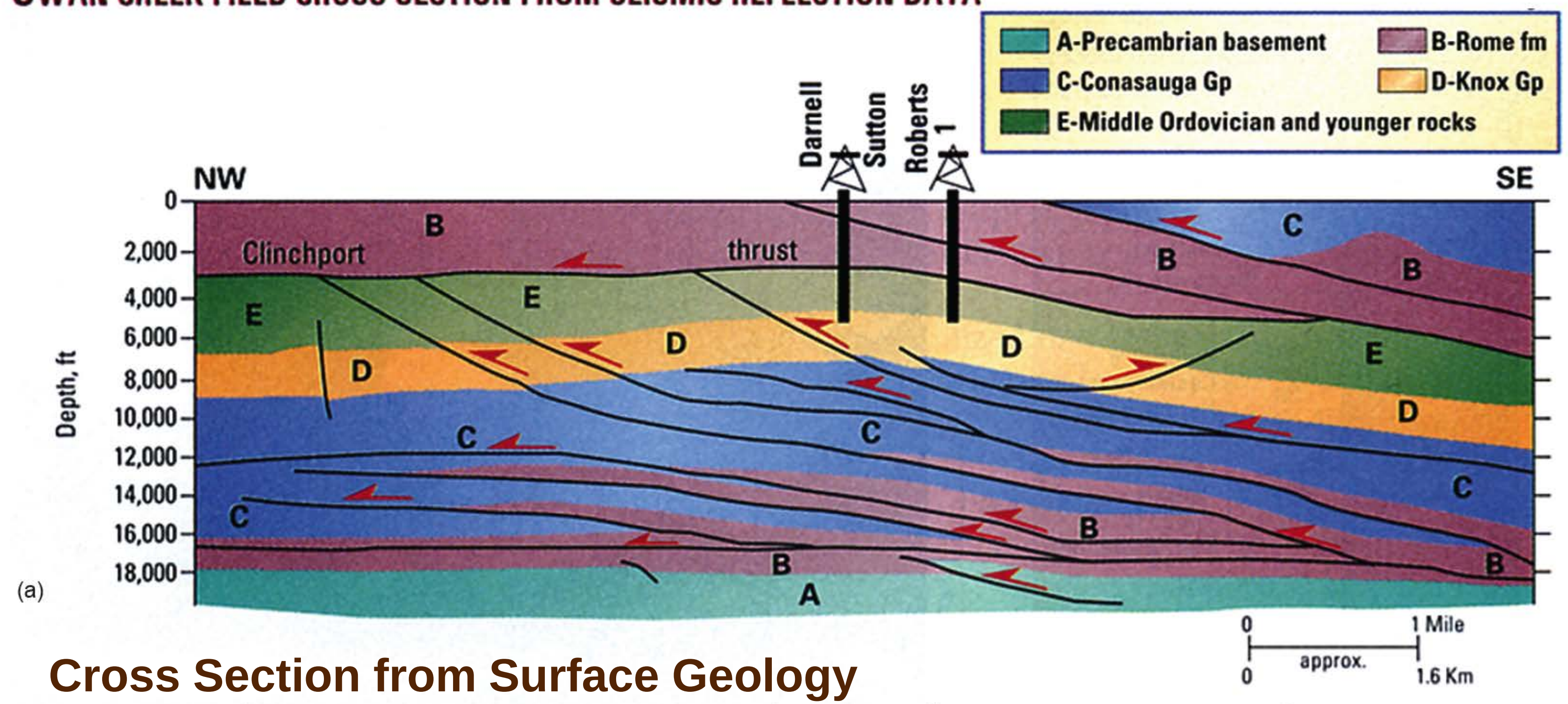
Processes Enabling Petroleum Systems

- ***Trap formation.***
- ***Generation, migration, & accumulation of O & G.***

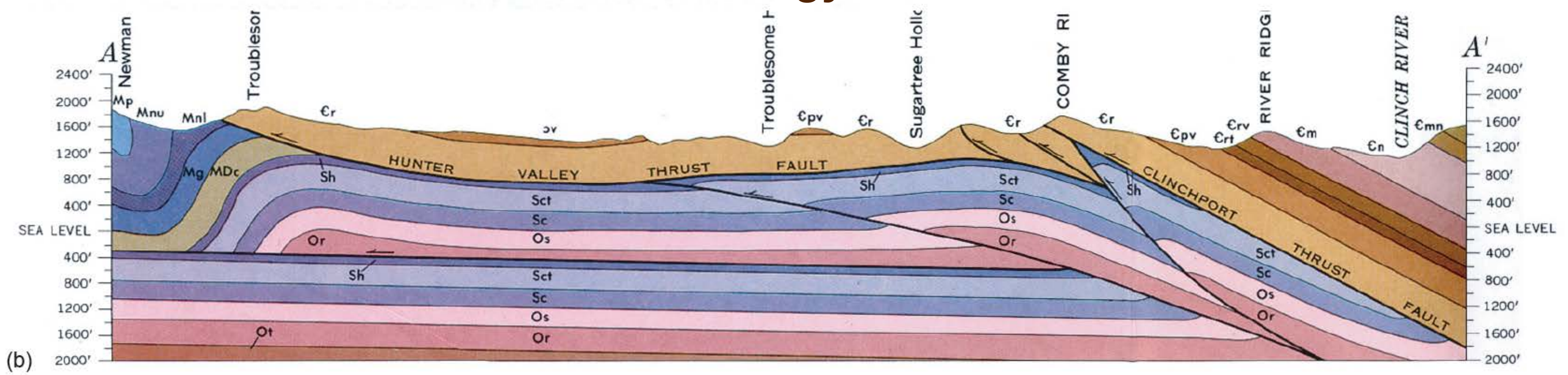
Swan Creek Closure Problem



Swan Creek Field Cross Section from Seismic Reflection Data

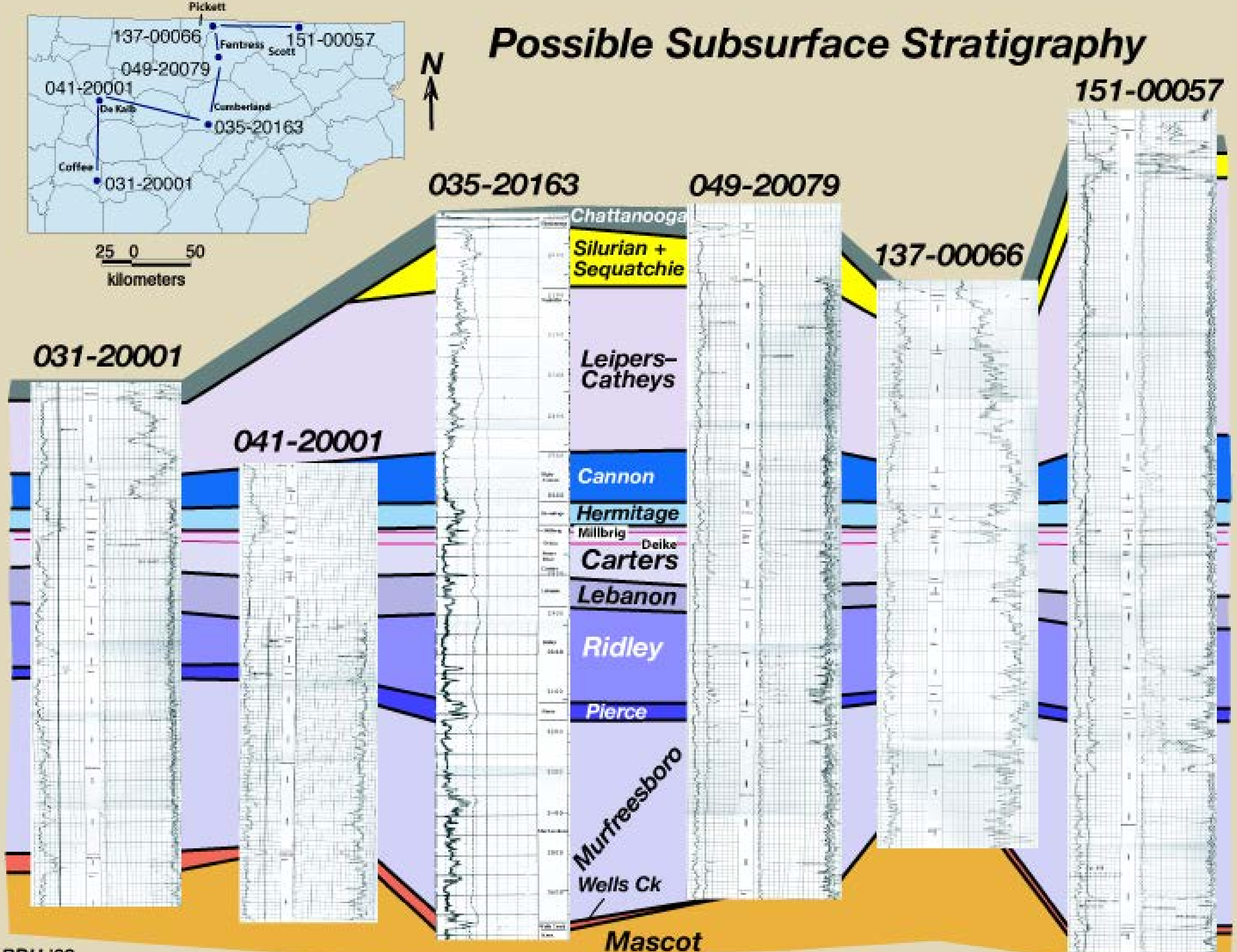


Cross Section from Surface Geology



From Mixon & Harris, 1971, USGS

TOGA–2012


Possible Subsurface Stratigraphy
Pickett
137-00066
Fentress
Scott
151-00057
049-20079
041-20001
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Chattanooga
Silurian + Sequatchie
Leipers–Catheys
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Hermitage
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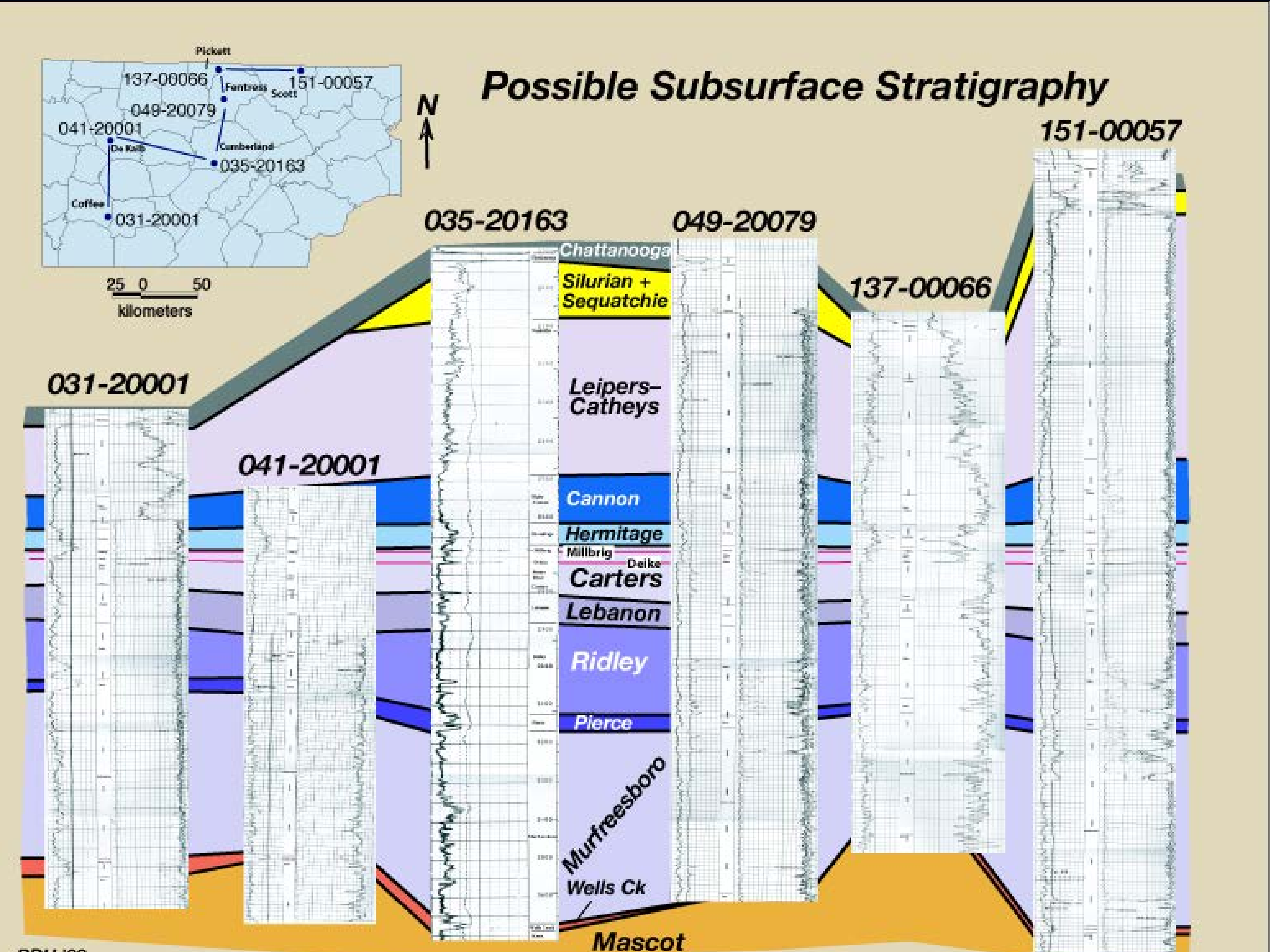
Carters
Lebanon
Ridley
Pierce
Murfreesboro
Wells Ck
Mascot



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