Kentucky Consortium for Carbon Sequestration

Organization, Goals, and Future

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Acknowledgements

- Governor's Office of Energy Policy – Talina Mathews
  - Sponsor of today's meeting
  - Work to pass HB 1 and include carbon management in the bill
  - Funding of CO_2 projects at KGS
- Funding from DOE CO_2 Regional Partnerships: MRCSP, MGSC, and SECARB
- Discussions with industry representatives
- Colleagues in KGS Energy Section
  - Early recognition of the significance of CO_2 research to Kentucky

Outline

- HB 1 funding and directives
- Kentucky Consortium for Carbon Sequestration
- Project organization
- Structure of the industry partnerships
- Deep saline reservoir sequestration projects
- Enhanced oil and gas recovery projects

Why Are We Here?

- Kentucky HB 1 was passed in a 2007 special session and signed into law August 30.
- Provides financial incentives for coal gasification plants
- Provides $5 million for carbon sequestration research in Kentucky
- "The Kentucky Geological Survey is encouraged to use these funds to match available federal and private funds to the extent possible."

2007 HB 1 Directives

- Quantify the potential for:
  - Enhanced oil and gas recovery
  - Enhanced coalbed methane recovery
- Test the Devonian shale for CO_2 enhanced gas recovery and CO_2 sequestration potential
- Drilling of deep wells in the eastern and western coal fields to estimate sequestration potential

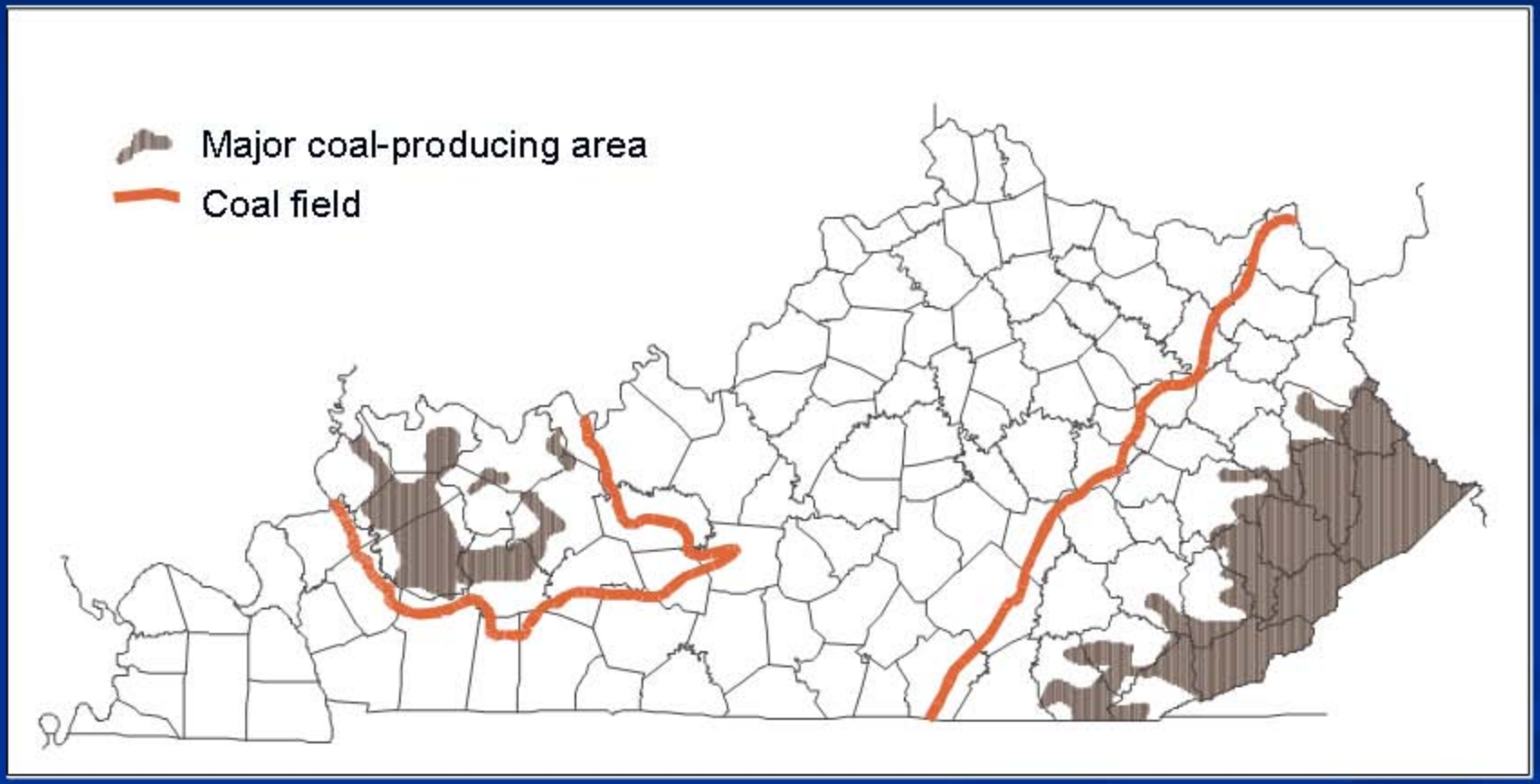
KYCCS

- KGS realizes that $5 million is not sufficient to accomplish all these goals
- Today we propose a joint industry-government consortium to carry out the directives in HB 1
- The **Kentucky Consortium for Carbon Sequestration** (KYCCS) will be administered by KGS at the University of Kentucky

KYCCS

- We hope utilities, energy companies, U.S. DOE, and service companies will share costs, provide in-kind services, and help guide the research
- KGS to select projects and sites, and allocate funds based on technical merit
- Project sites may be provided by consortium members or others (such as University land)
- Results to be non-proprietary to benefit the whole industry

Project Areas



Project Schedule

- Entire funding to be transferred by the end of the year
- Project to require 3 to 4 years for completion
- Project tasks to run concurrently
- Deep drilling to be first priority due to lead time required, identified partners, and costs
- Partners for EOR and EGR projects being sought

Project Organization

- Western Kentucky Deep Sequestration
  - Lead geologists: Rick Bowersox and Dave Williams
- Eastern Kentucky Deep Sequestration
  - Lead geologists: Steve Greb and Cortland Eble
- Enhanced Gas Recovery, Devonian shale (EGR)
  - Lead geologist: Brandon Nuttall
- Enhanced Oil Recovery (EOR)
  - Lead geologist: Marty Parris
- Public Education and Outreach
  - Mike Lynch

Proposed Program Budget

$5 million available for personnel, drilling, well testing, analyses, CO_2 purchases, etc.

State Funds	Industry Match	DOE & other federal	Total
$5 M	?	?	$15–20 M

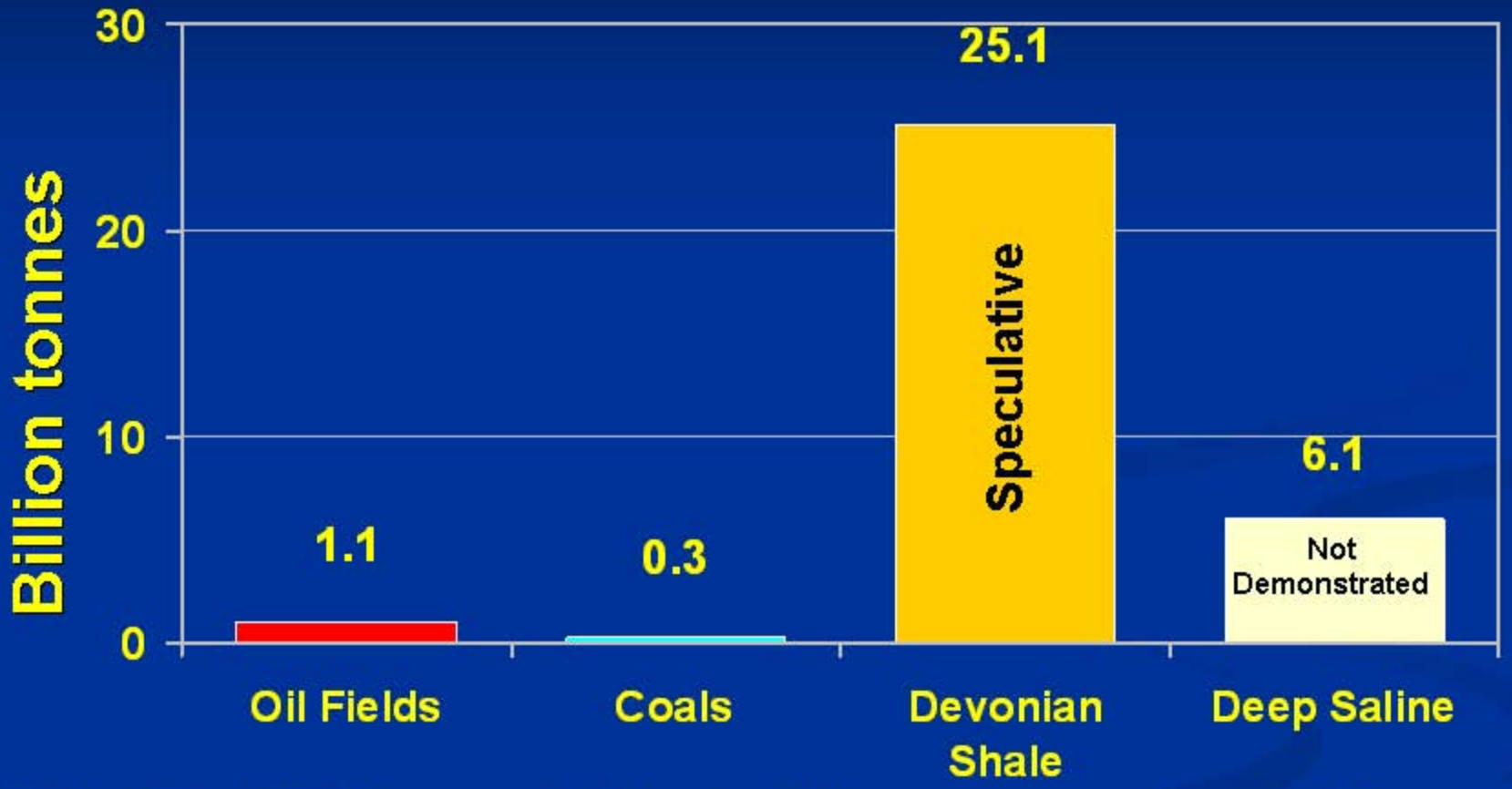
Well Costs are Significant

- Ohio Deep Sequestration well, Tuscarawas County, Ohio, 8,700 ft total depth
  - $2.3 million budget
- MGSC Phase III well, 7,500 ft total depth
  - $4 million budget for drilling, coring, and testing
- Recent Morgan County, Tennessee wildcat, 7,000-9,500 ft total depth
  - $3 million AFE reported by IHS

Well Design and Engineering

- KGS lacks in-house petroleum engineering expertise
- Outside consultants will be used for design of EOR projects, wells, injection tests, and operations oversight
- Will seek in-kind contributions from service companies

DOE Phase I CO_2 Storage Estimates



While CO_2 EOR potential is significant, deep saline or Devonian shale storage will be needed to handle expected volumes

Deep Saline Reservoir Projects

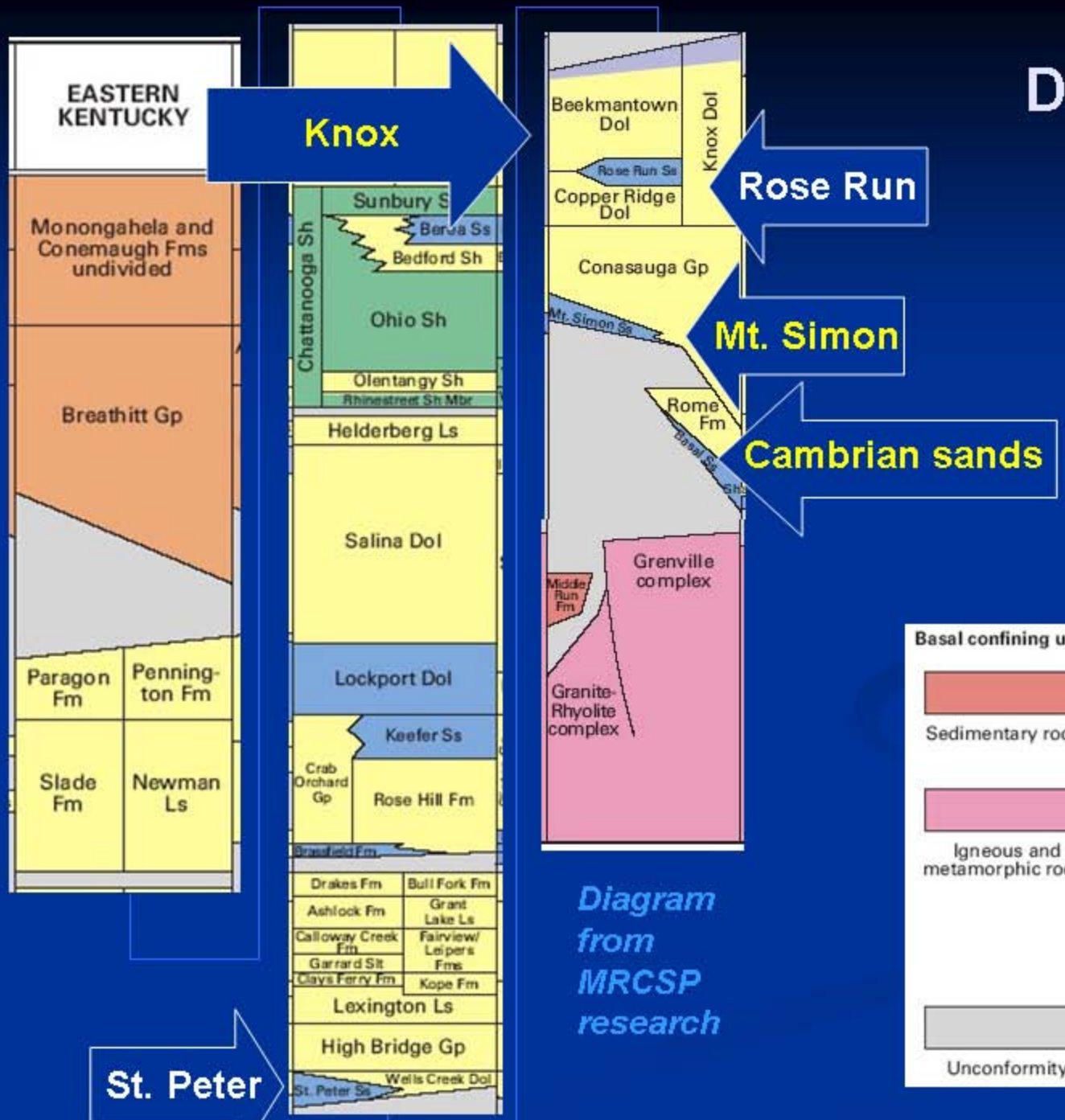
- Tests in eastern and western Kentucky
- Depths >2,500 ft; likely 5,000 to 9,000 ft range
- Injection tests with either water or CO_2
- Locations to be chosen to provide most data on multiple target zones
- No sites have been considered yet
- Agreement with mineral owner to buy back the well if hydrocarbons are encountered possible

Deep Wells

- Site characterization by KGS and consortium members
  - Subsurface mapping
  - Purchase existing seismic data; acquire new seismic
  - Evaluation of well logs, cores, and well samples
  - Characterize seals
  - Design monitoring plan (subsurface and surface)
  - Permit wells according to regulations for oil & gas wells or EPA-regulated injection wells.
- Well design and engineering
  - Outside consultants and consortium members

Technical Work: Deep Wells

- Obtain whole core and side-wall cores in reservoir and seal intervals
- Run and interpret extensive suite of well logs
- Collect brine samples from target zones for geochemistry
- Analyze core samples for porosity, permeability, mineralogy, mechanical strength, and other physical properties
- Conduct injection tests using fluid, air or CO_2
- Public education and outreach
- Reporting and technology transfer



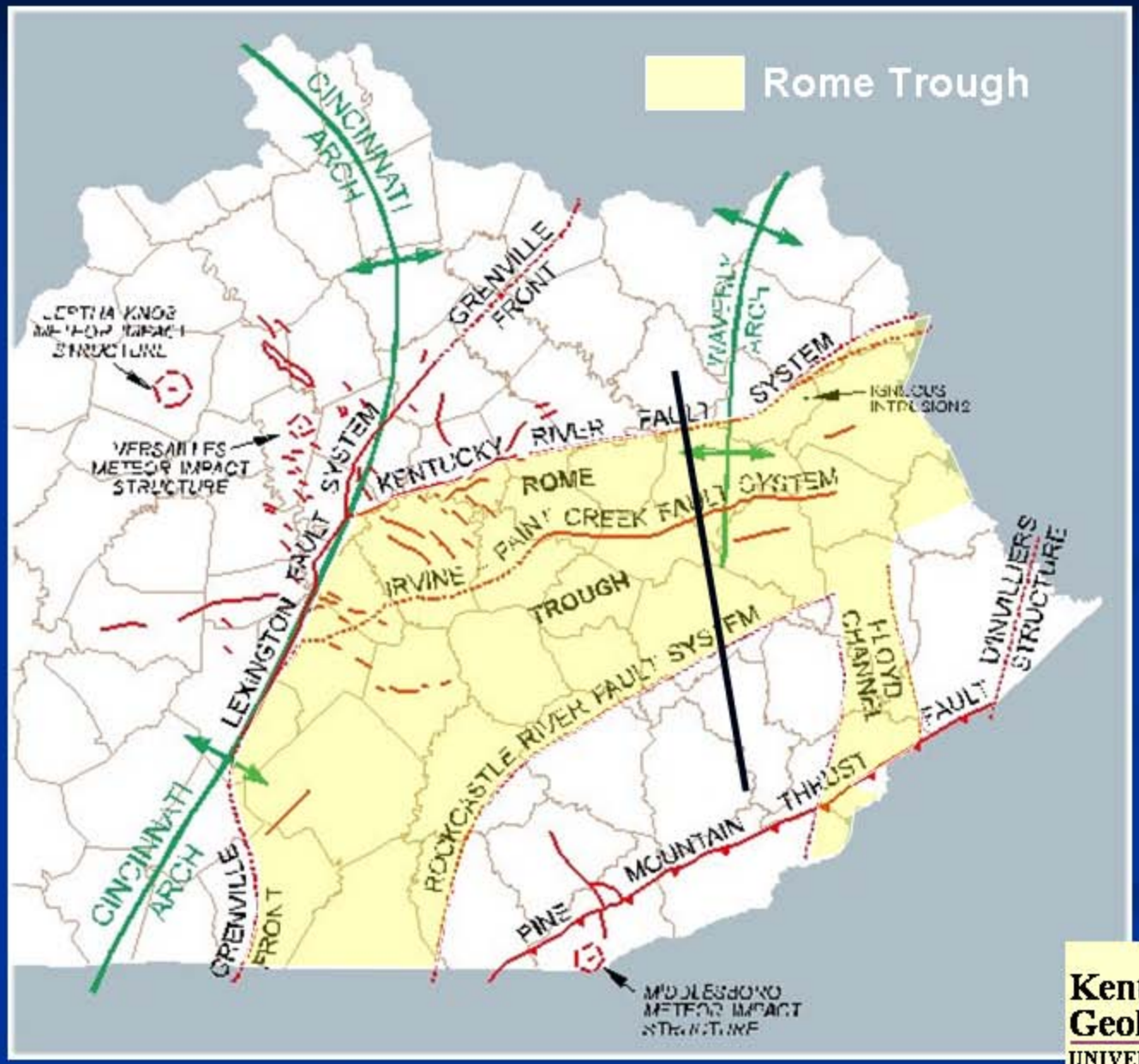
Deep Saline Targets

- Strata vary in characteristics
- Some are known reservoirs
- Some are potential reservoirs
- Some are seals
- Deep saline reservoirs shown with arrows

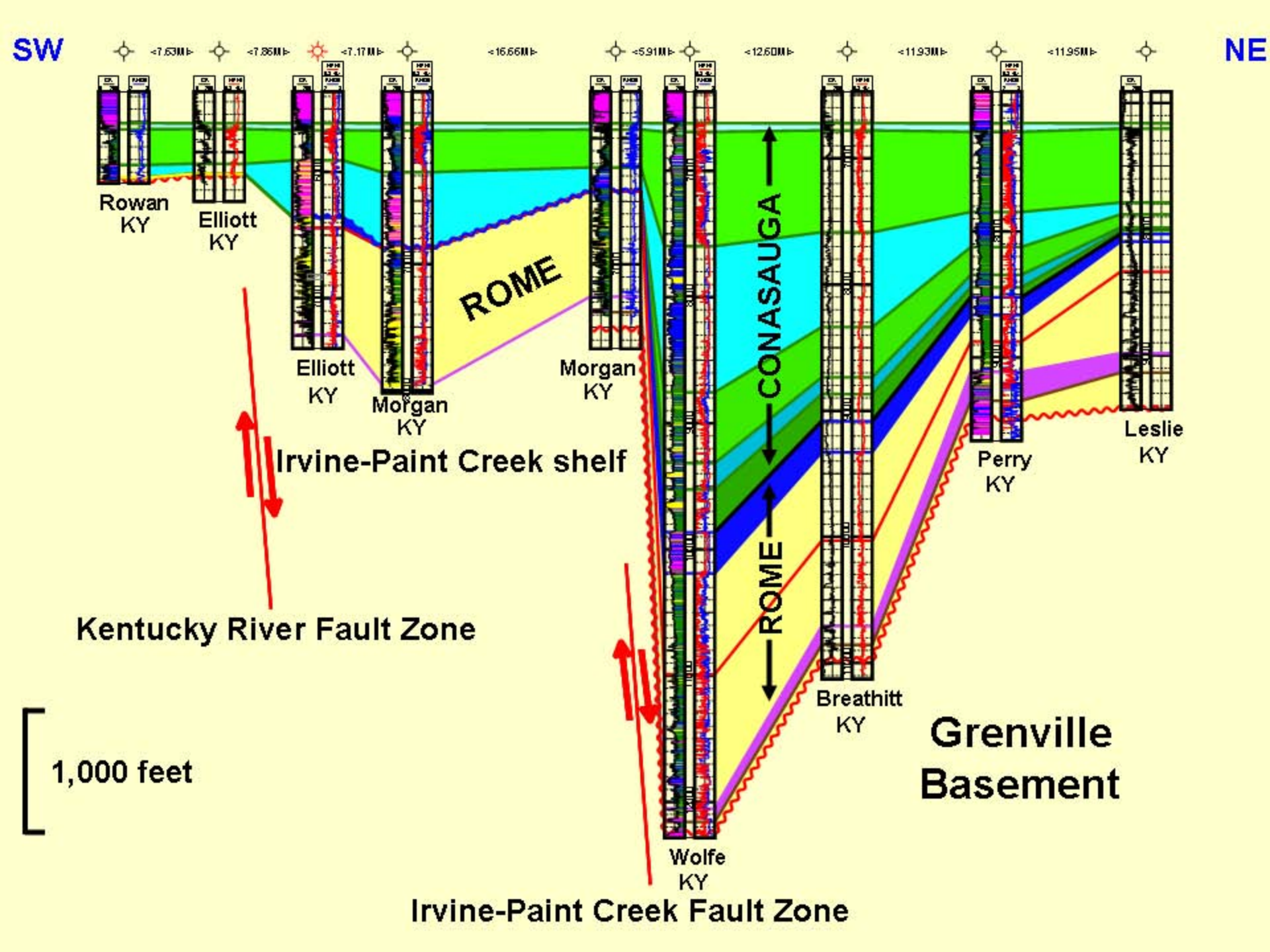
Cambrian Sandstones (rift)

- Sandstones deposited in fault-bounded basins
  - Rome Trough – eastern
  - Rough Creek Graben – western
- Confined to grabens
- Faults create trapping mechanisms
- Good porosity in eastern Ky., poor in west (to date)

Rome Trough, Eastern Kentucky



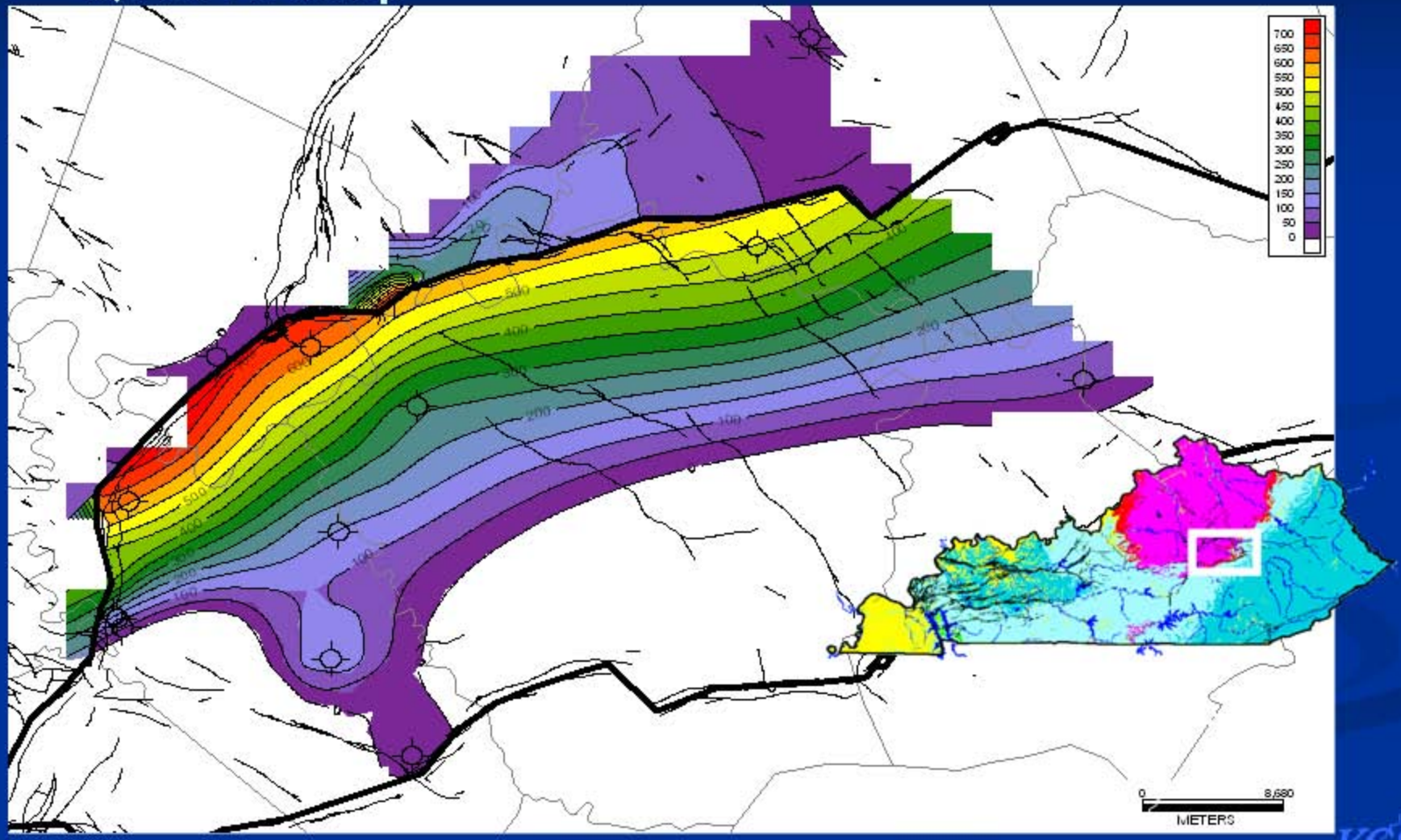
Kentucky Geological Survey
UNIVERSITY OF KENTUCKY


SW
NE
Rowan KY
Elliott KY
Elliott KY
Morgan KY
Morgan KY
ROME
CONASAUGA
ROME
Irvine-Paint Creek shelf
Kentucky River Fault Zone
Wolfe KY
Breathitt KY
Perry KY
Leslie KY
Grenville Basement
1,000 feet
Irvine-Paint Creek Fault Zone

Kentucky potential deep saline reservoirs

Thick Rome Sandstone Wedge (up to 700' thick)

4 – 5,000 ft. deep

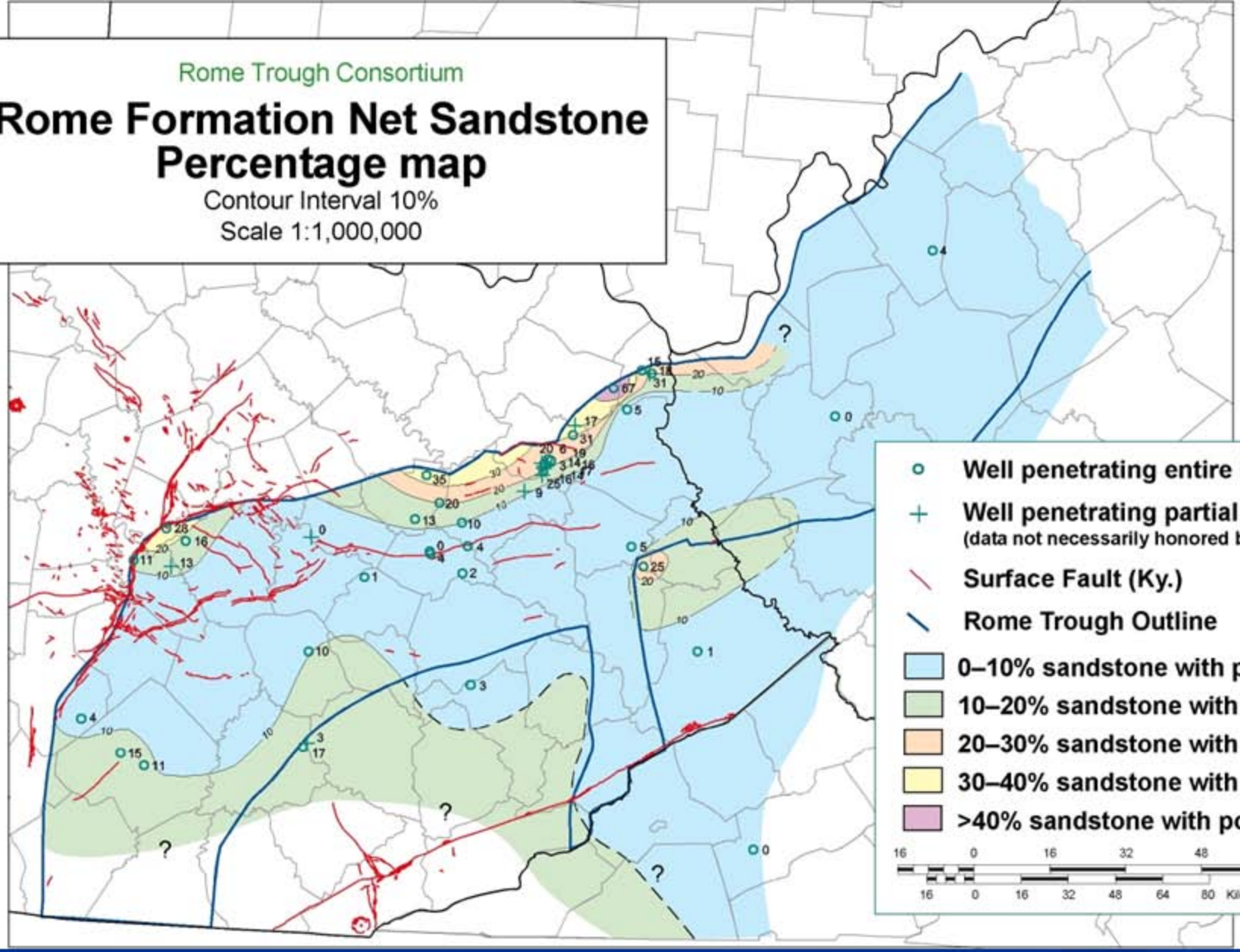


Rome Trough Consortium

Rome Formation Net Sandstone Percentage map

Contour Interval 10%

Scale 1:1,000,000



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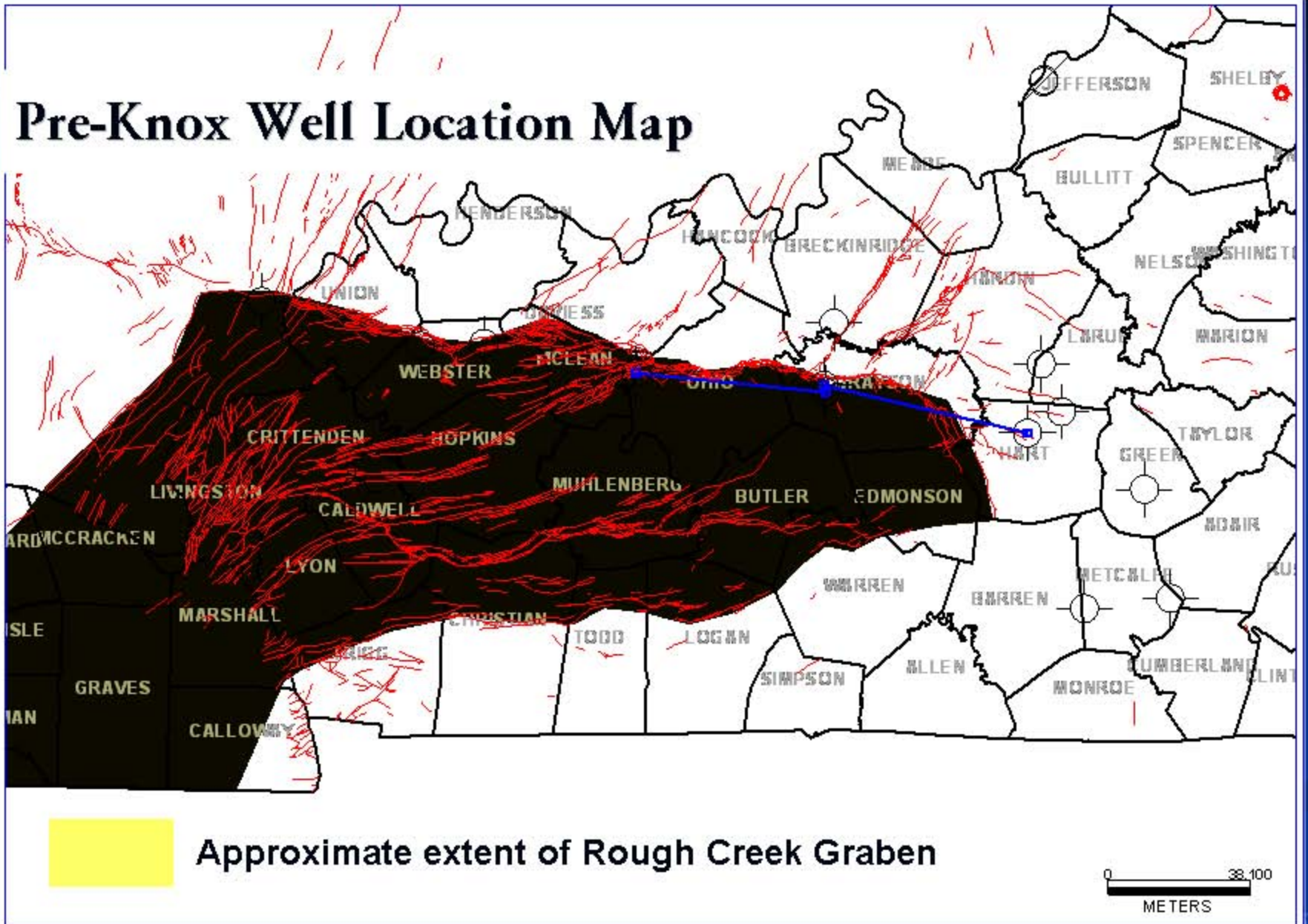

Pre-Knox Well Location Map
JEFFERSON
SHELBY
SPENCER
BULLITT
MEADE
HENDERSON
HANCOCK
BRECKINRIDGE
NELSON
UNION
WEBSTER
MCLEAN
OHIO
MARION
CRITTENDEN
HOPKINS
GREEN
TAYLOR
LIVINGSTON
MUHLENBERG
BUTLER
EDMONSON
CALDWELL
MCCRACKEN
LYON
ADAIR
WARREN
BARREN
MARSHALL
CHRISTIAN
TODD
LOGAN
SIMPSON
ALLEN
MONROE
CUMBERLAND
GRAVES
CALLOWAY
Approximate extent of Rough Creek Graben
0
38,100
METERS

N-S Grayson Co. Cross Section

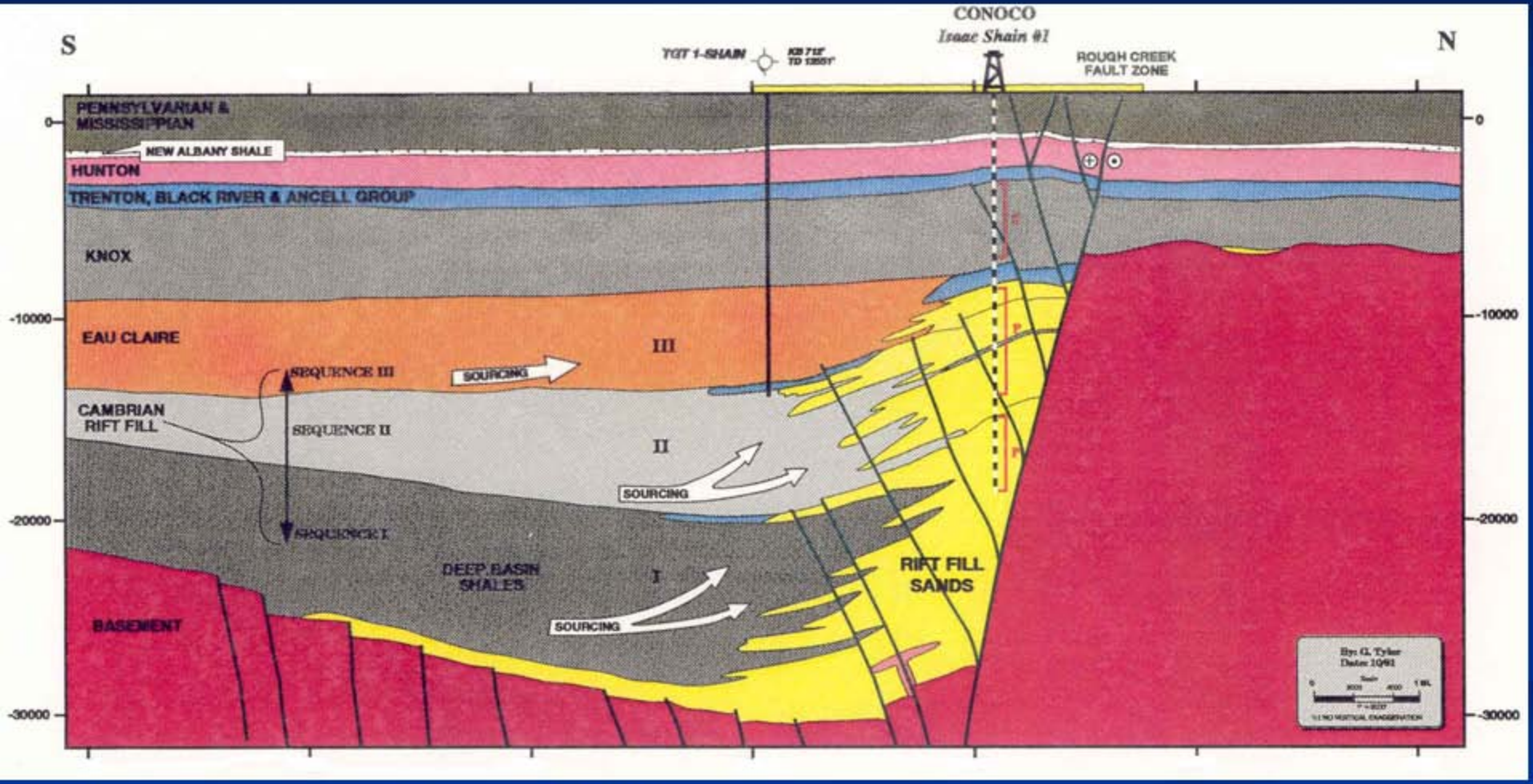
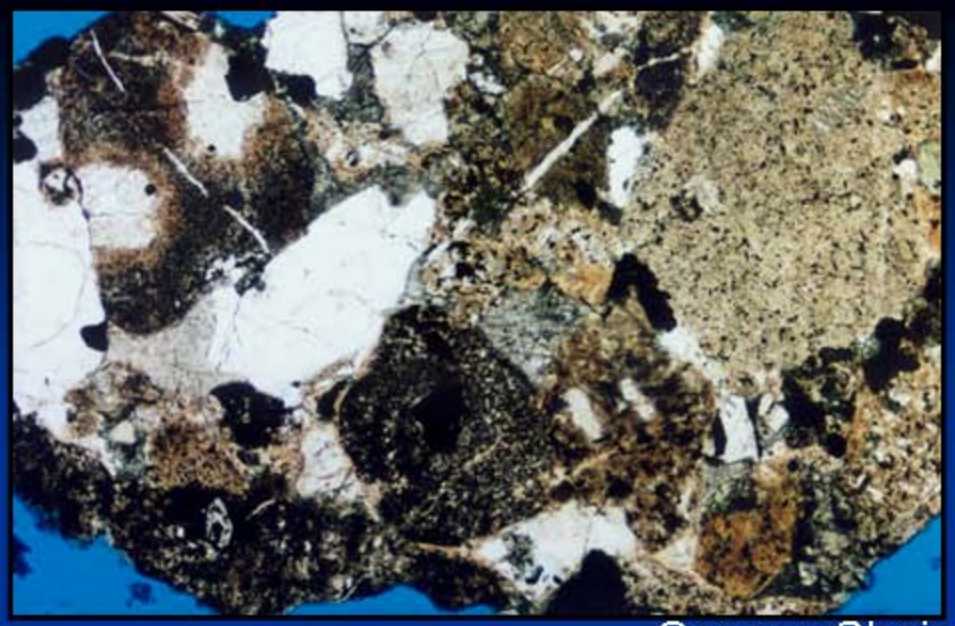
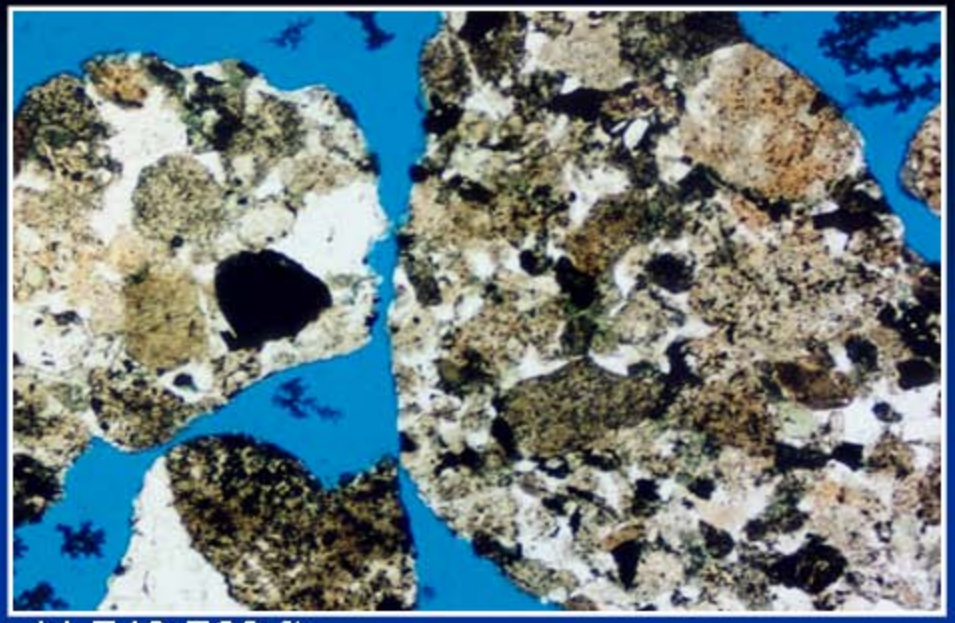
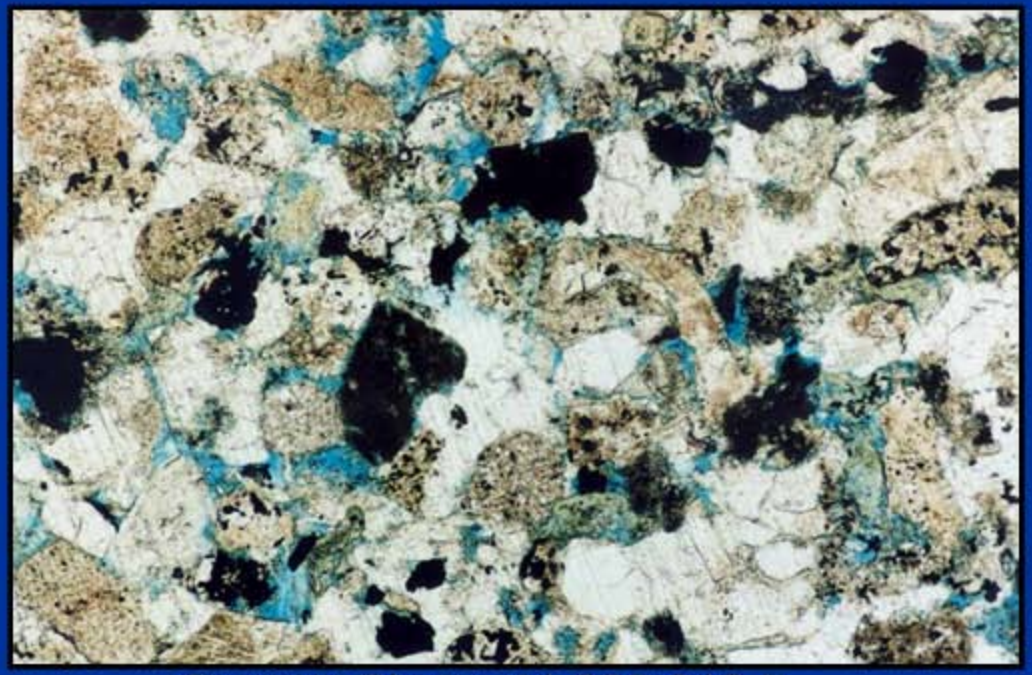


Figure courtesy of ConocoPhillips





Conoco Shain: 11,740-760 ft



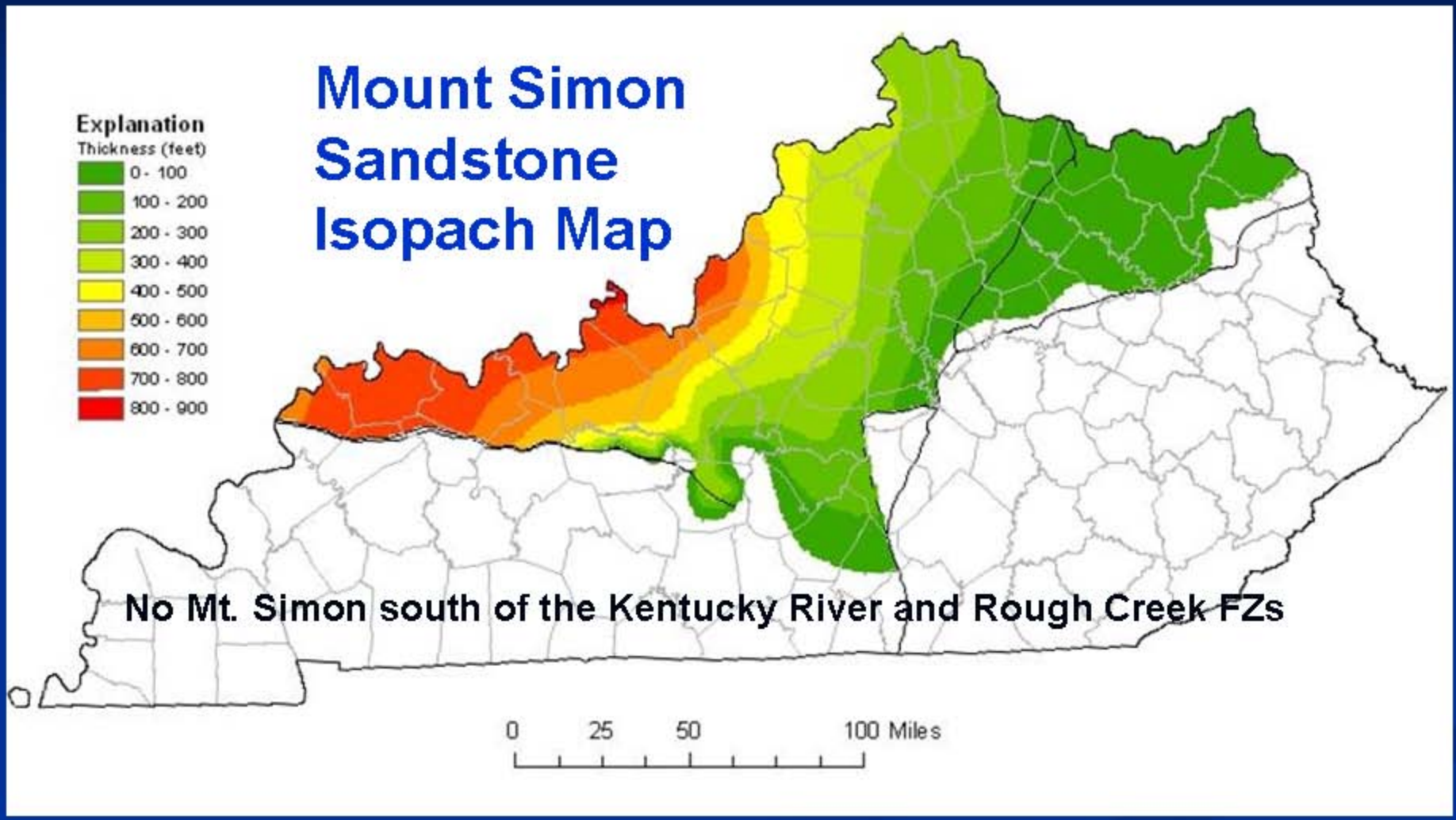
Conoco Shain: 11,000-010 ft

- Thick immature lithic sandstones dominate in the Conoco Turner and Shain wells
- Minor porosity observed

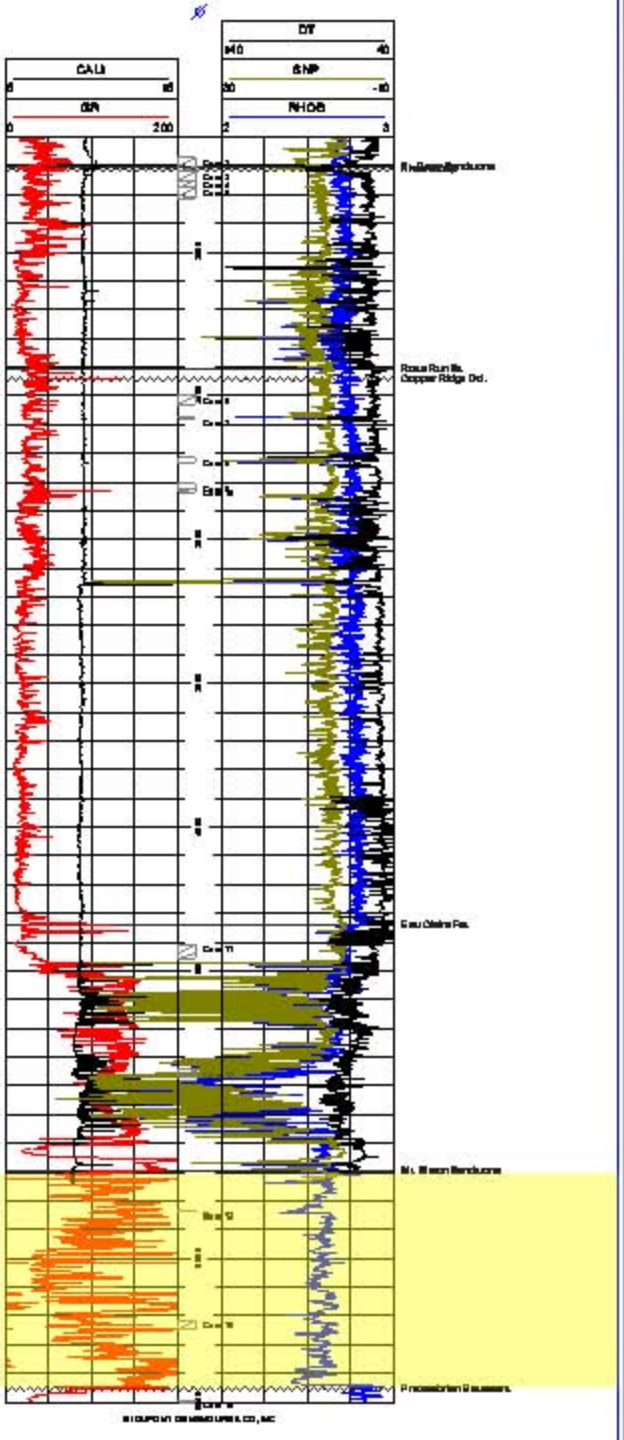
Mt. Simon Sandstone

- Important saline reservoir in Illinois and the Midwest
- Only deposited north of rift basins in Kentucky
- Thickens and deepens to west, but porosity decreases
- Tested Mt. Simon injection in Louisville, but tight
- MRCSP sequestration demo well into Mt. Simon in Boone County in 2008
- Should we test the Mt. Simon elsewhere in Ky.?

Kentucky potential deep saline reservoirs



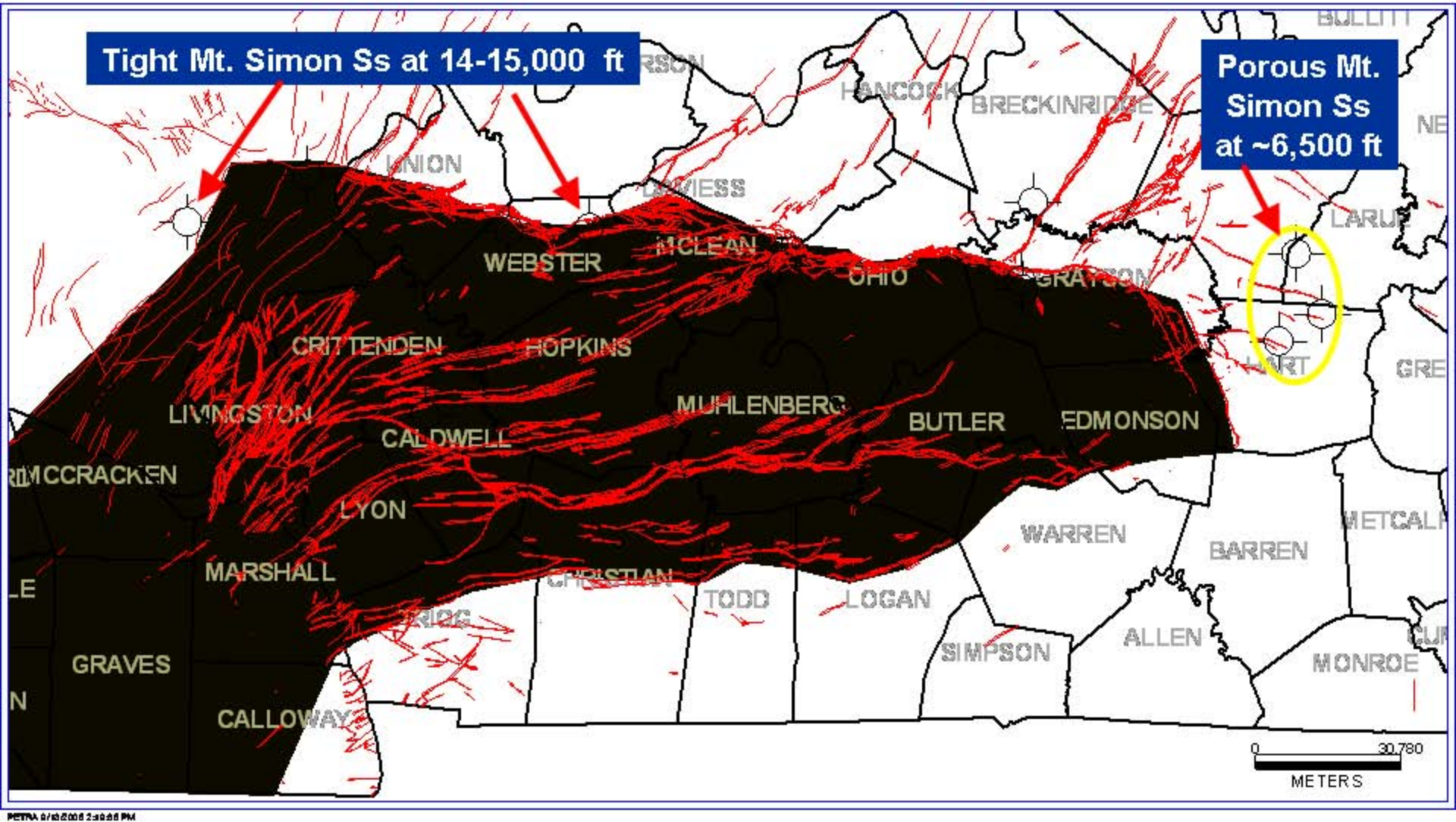
- Based on ~20 wells

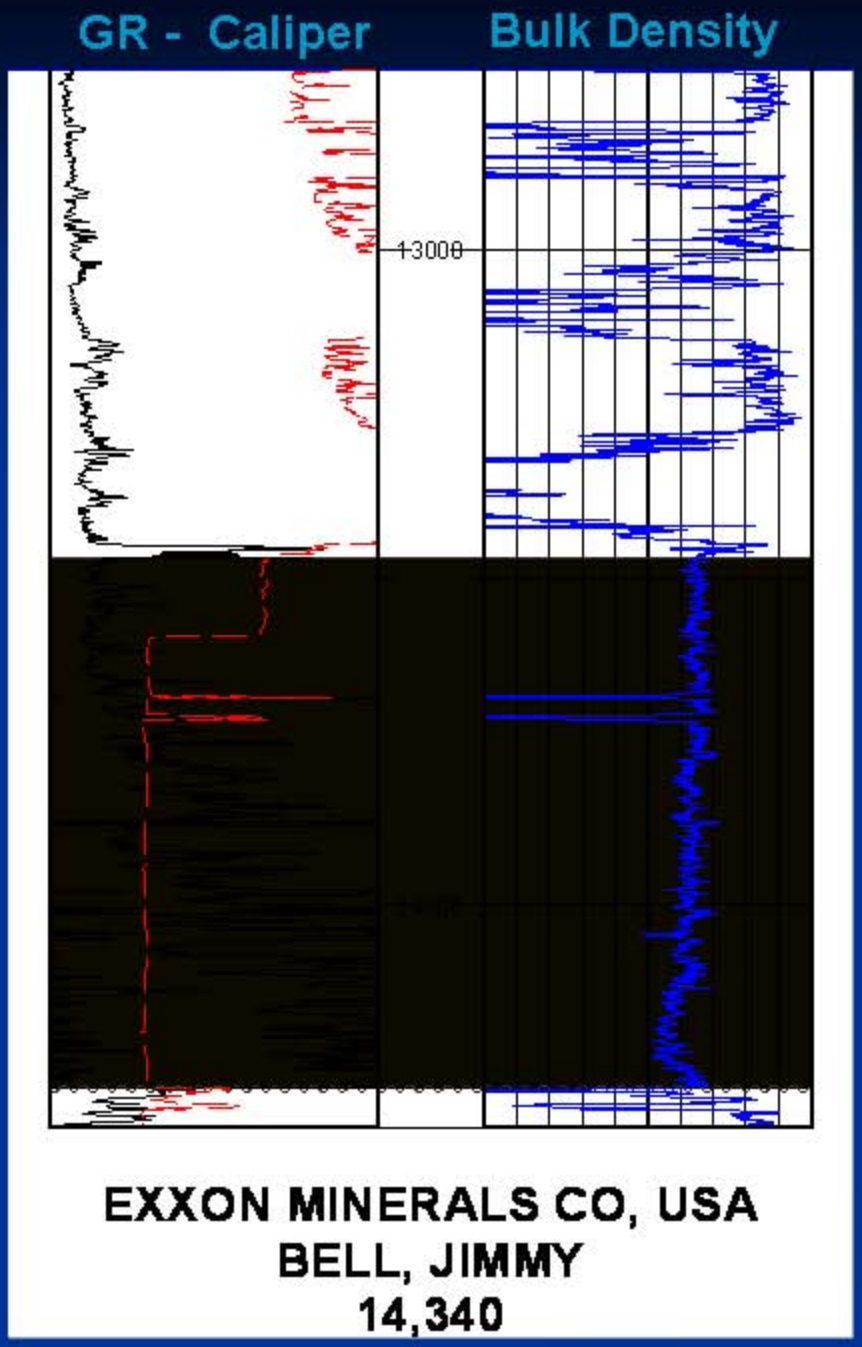


Mt. Simon Ss., Louisville, Ky.

- Dupont waste disposal site
- Mt. Simon ~750 ft. thick
- Depth: ~5,500 ft.
- Poor reservoir quality
- Injected into Knox

Mt. Simon may have better properties to east

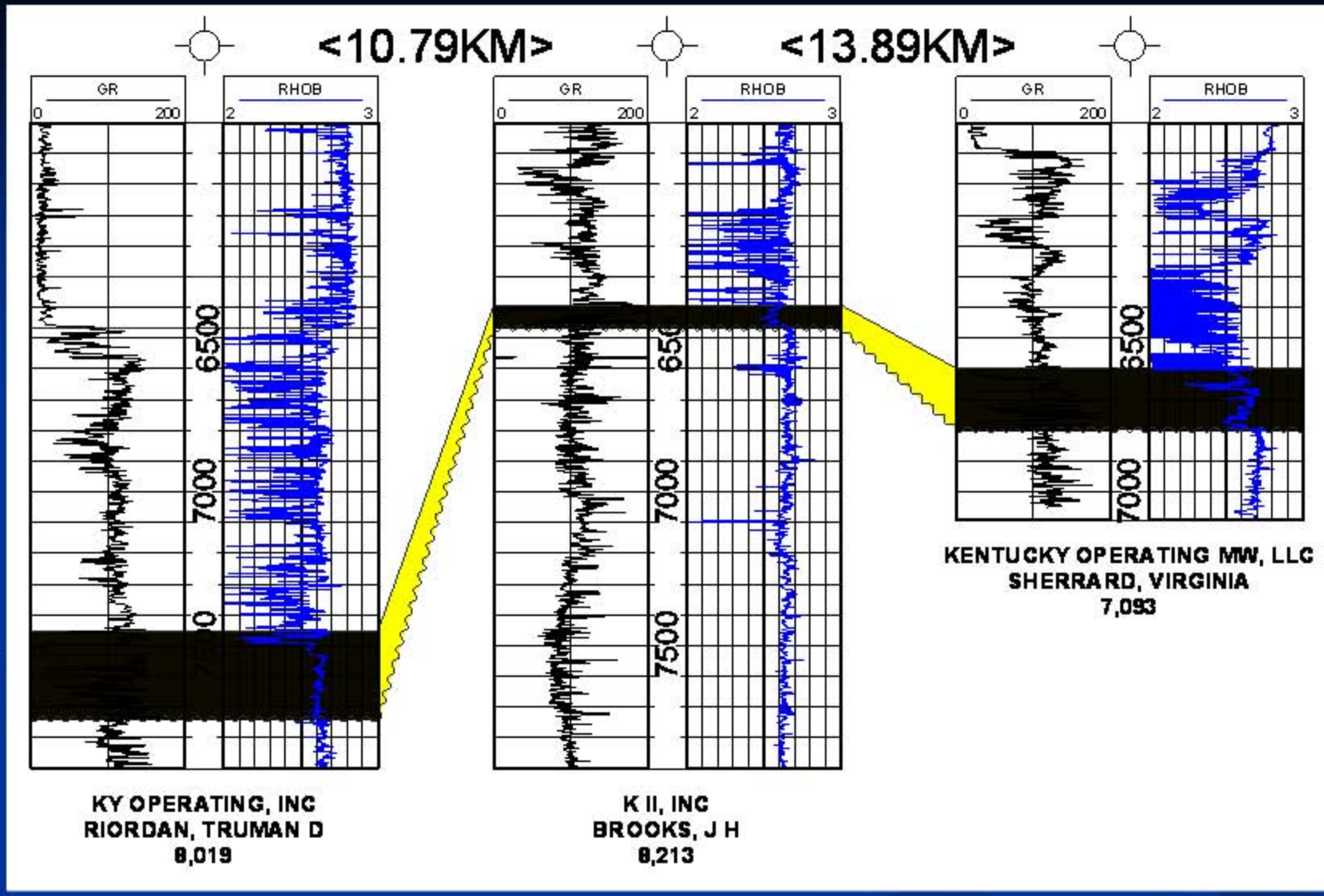




Mt. Simon Ss., Webster County, Ky.

- Near Rough Creek Fault Zone
- About 750 ft thick at 14,000 ft
- Poor reservoir quality

Mt. Simon Sandstone



Porous Mt. Simon Ss east of the Rough Creek Graben, Hart and Larue Counties, Ky.

Mt. Simon Depth-Porosity Plot
Illinois Basin

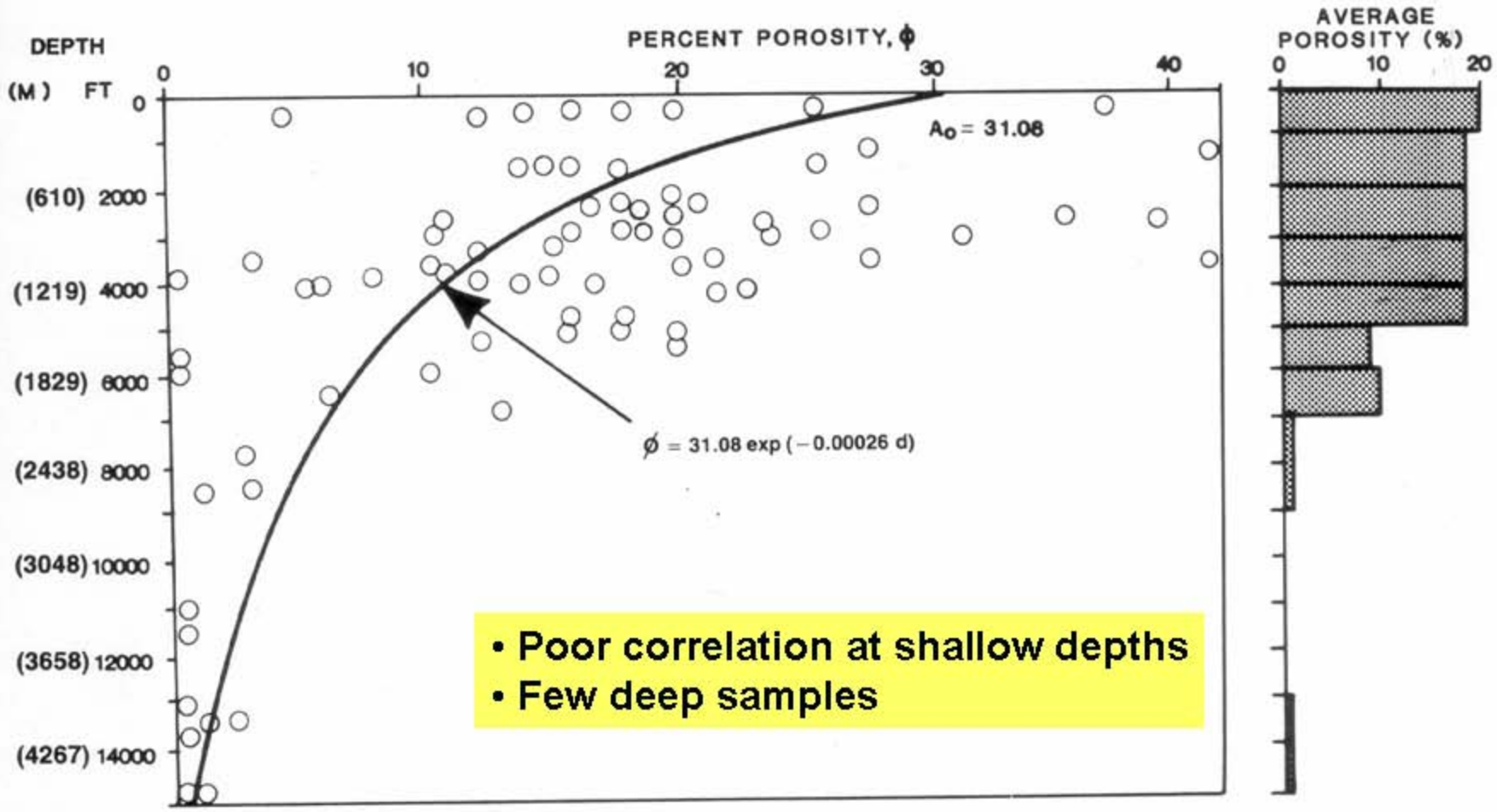
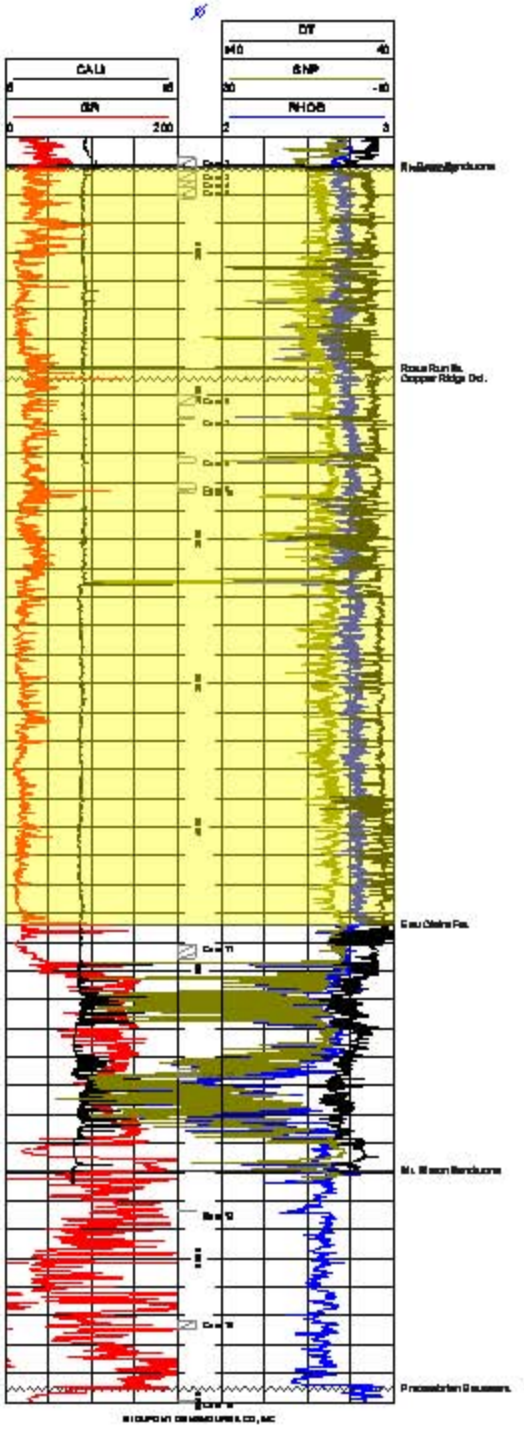


Figure 11—Porosity-depth relationships for 89 samples of Upper Cambrian Mount Simon Sandstone. Open circle = secondary porosity dominant.

Hoholick and others, 1984, AAPG Bulletin

Knox dolomite

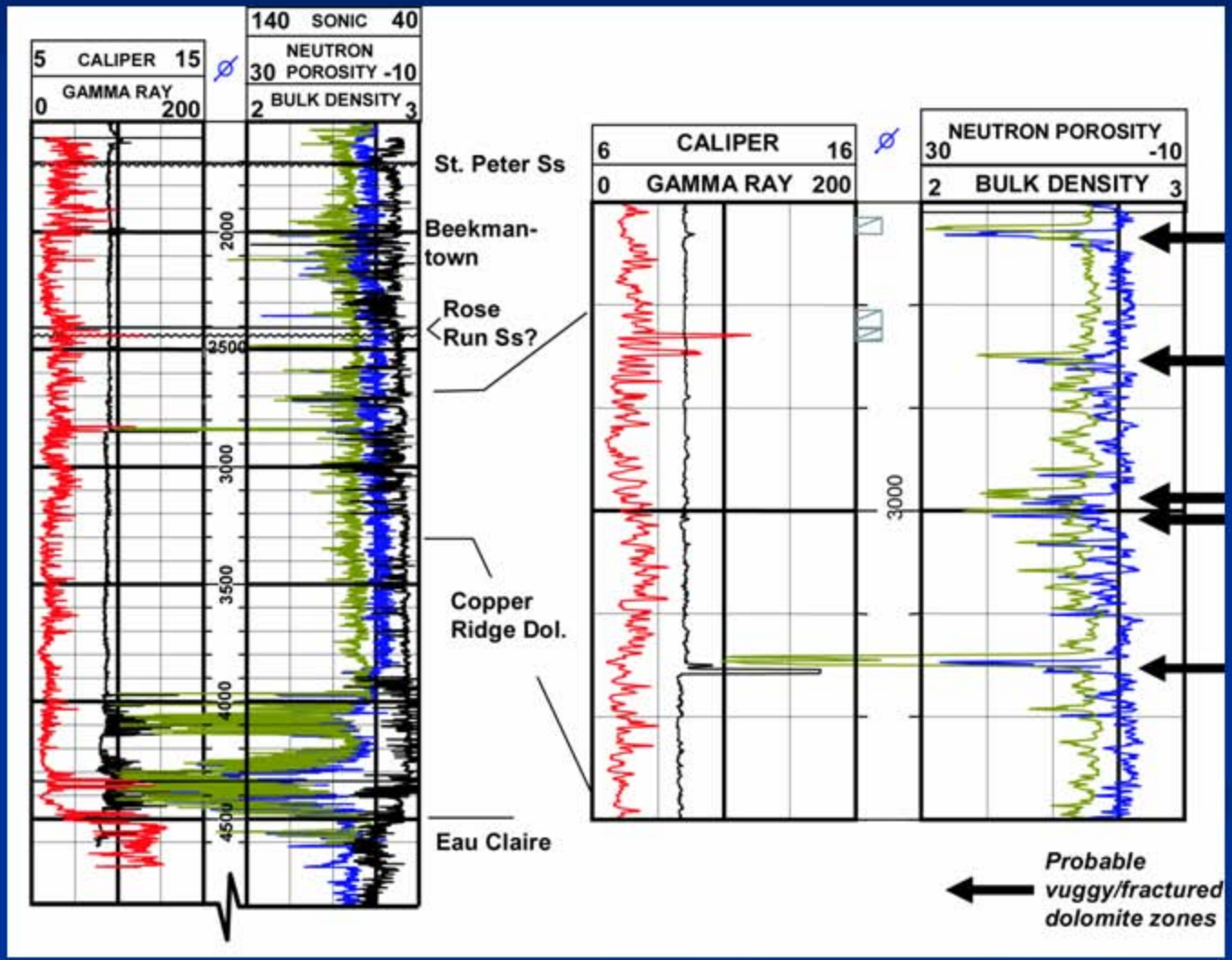
- Formation underlies the entire state
- Includes thick non-porous confining intervals with thinner vuggy porosity zones
- Two waste disposal sites and several gas storage fields have used the Knox
- Dolomite lithology will be more reactive with CO_2-saturated brines
- Porosity is erratic, commonly fracture-related: modeling will be challenging



Knox Dolomite, Louisville, Ky.

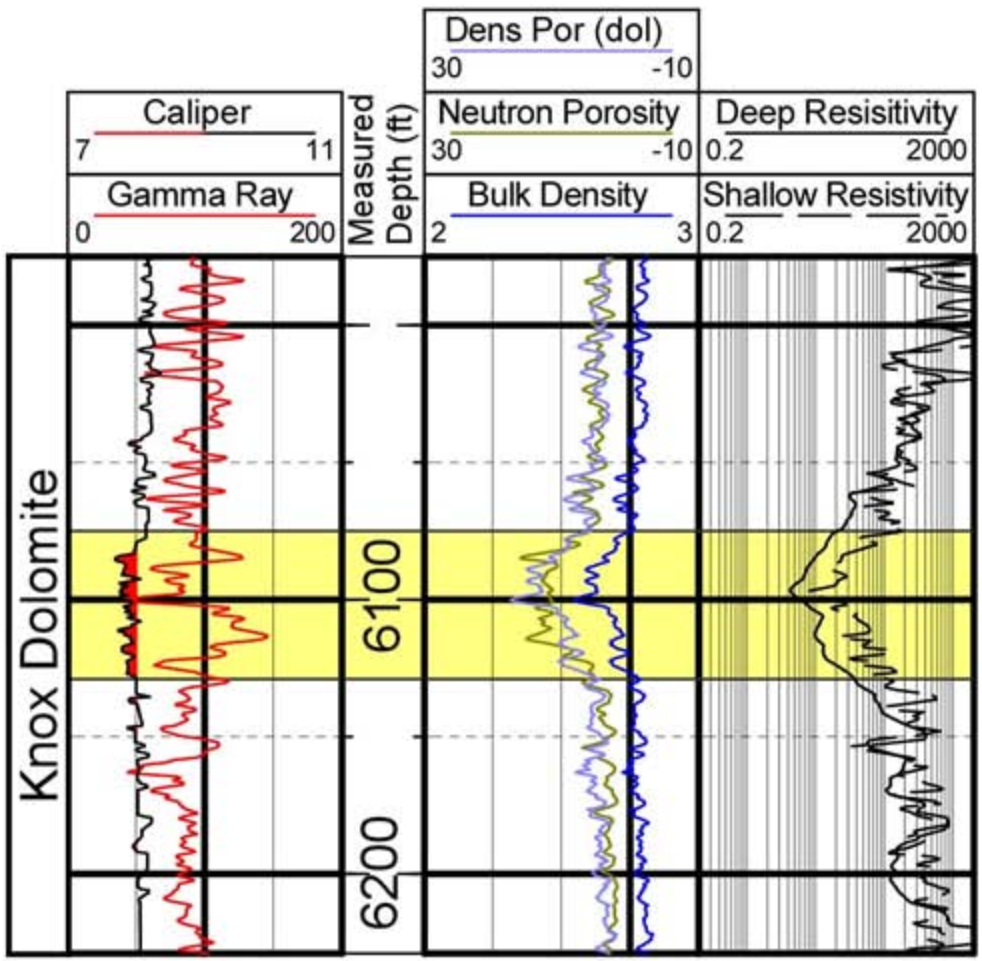
- Dupont waste disposal site
- Knox ~2,600 ft. thick
- Depth: ~1,700 – 4,300 ft.
- Injection into vuggy, cavernous dolomite

Dupont WAD1 Fee well, Louisville
Knox Injection Zone



Injection rate of 150 gallons per minute at 175 psi (5,100 bf/d)

Potential Knox zone, McLean Co.



Texas Gas 1A Kerrick: Knox Zone

54 ft. zone (>4% porosity)
Porosity range 4-17%
Maximum Porosity 17.4%
Mean Porosity 9.3%
Assumed Perm.: 60 md
Injection pressure: 4,800 psi

Modeled injectivity, matrix porosity only:
5 million cf CO_2 per day
274 metric tonnes CO_2 per day
100,000 metric tonnes CO_2/year

FutureGen would require 10 wells

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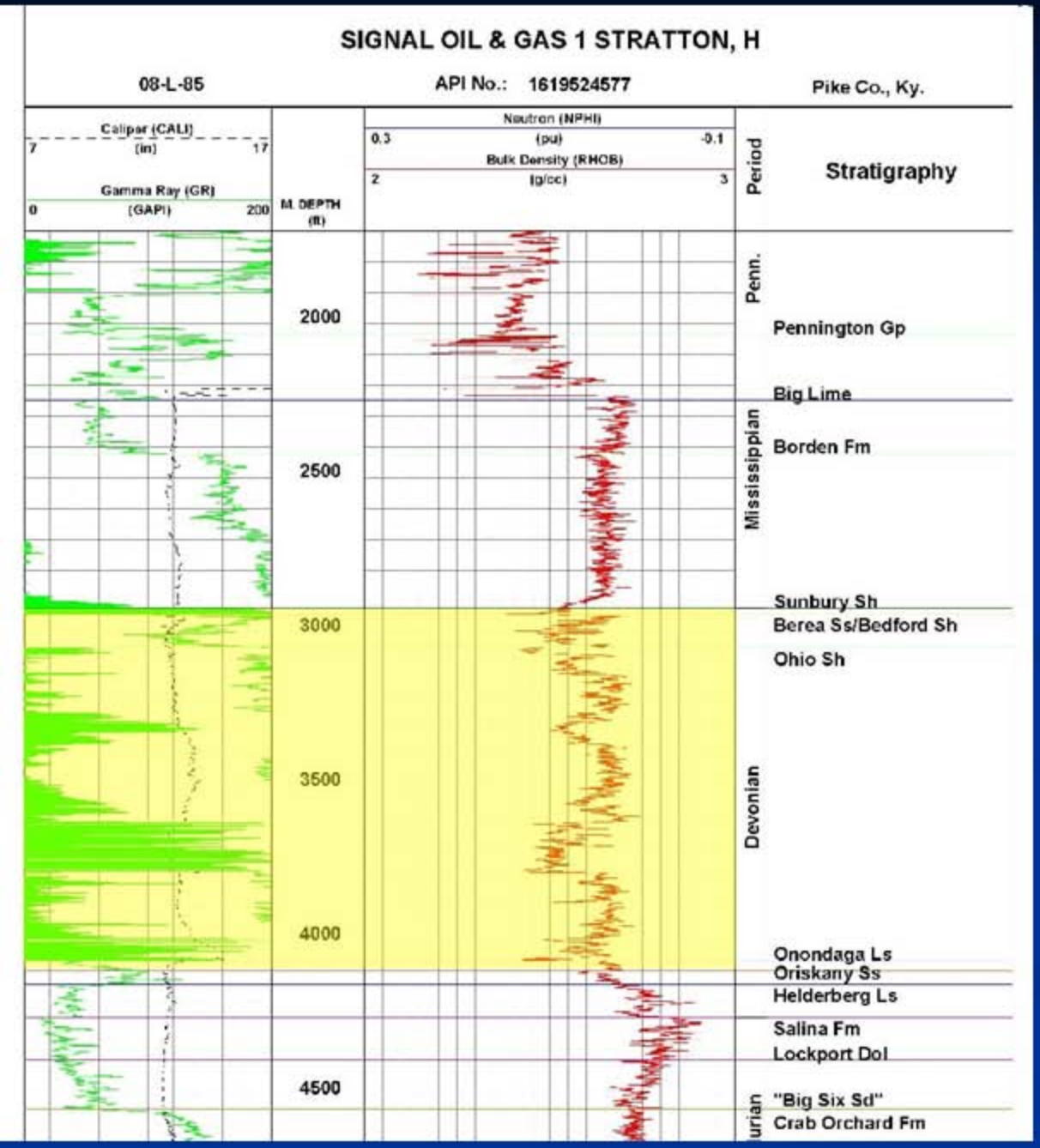
Deep Saline Summary

- Numerous potential deep saline targets
- All need verification by injection testing
- Where we drill will determine what targets are evaluated
- Plan to include 2-3 zones in each well

CO_2 Enhanced Gas Recovery Project



- Focus on Devonian shale
- Unconventional gas reservoir
- Methane adsorbed onto organic matrix
- CO_2 behaves similarly

Devonian Shale in Kentucky

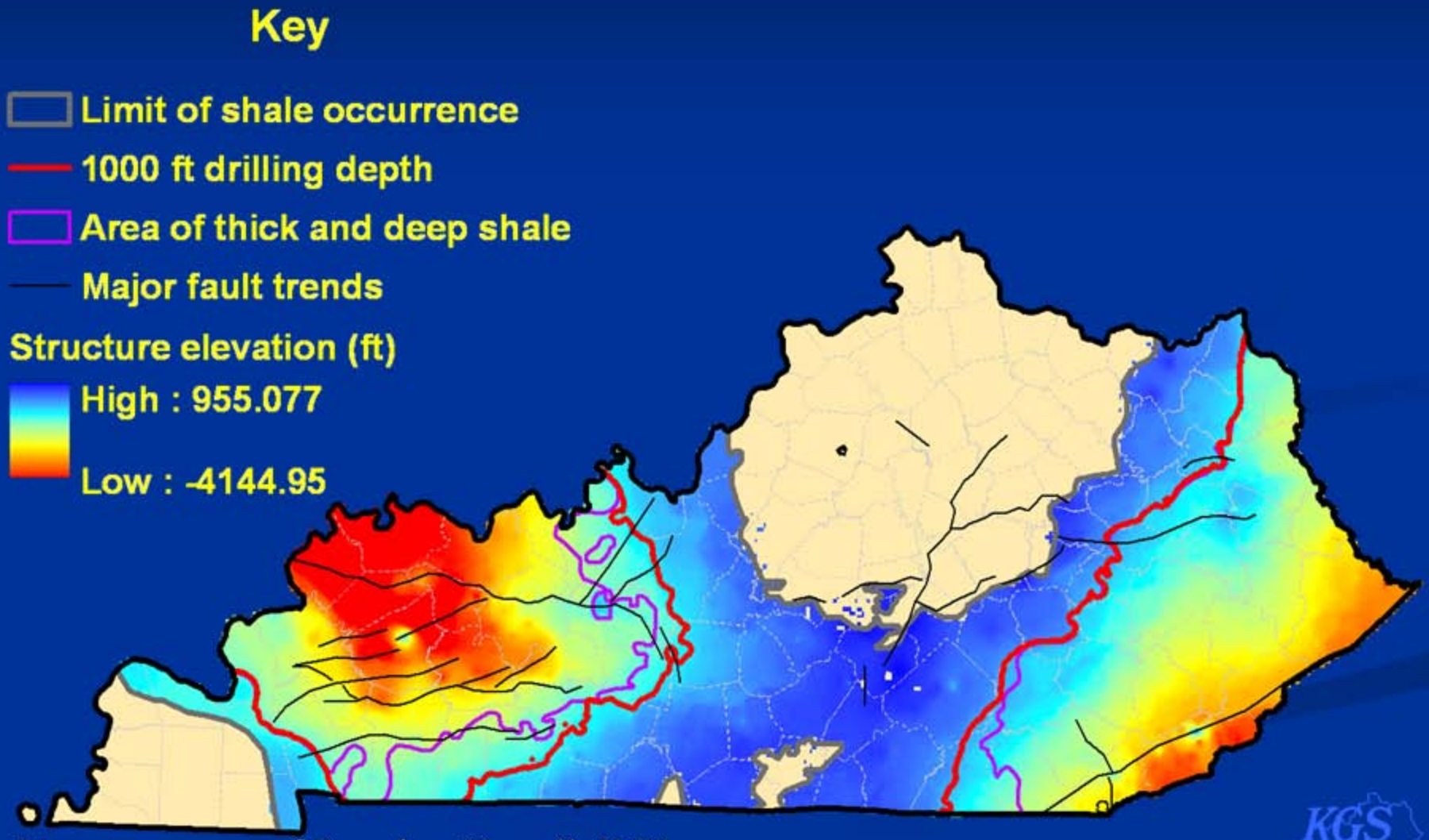
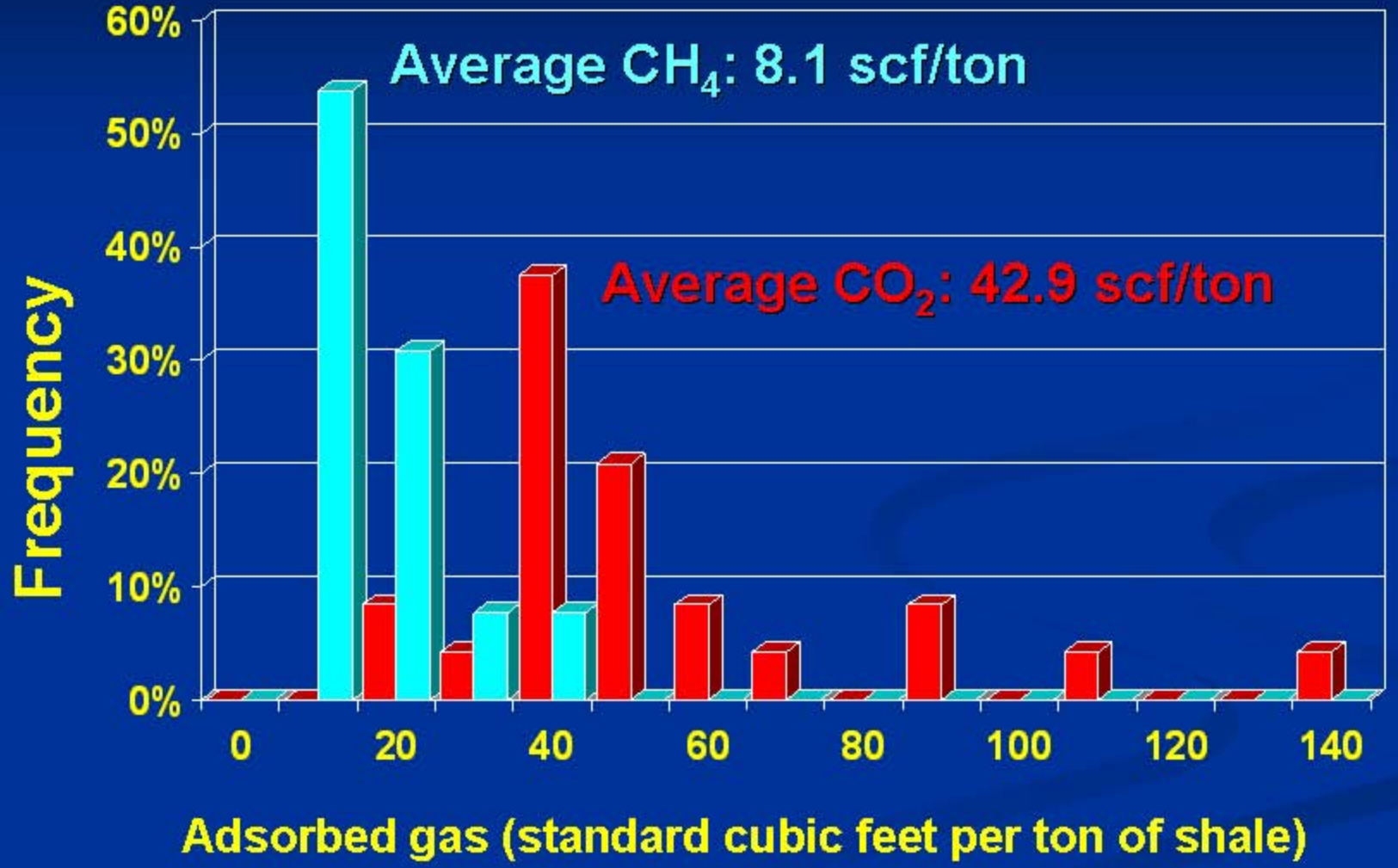


Figure courtesy of Brandon Nuttall, KGS

Adsorption at 400 PSIA



$CO_2 = 5.3 \times CH_4$

Data from B. Nuttall

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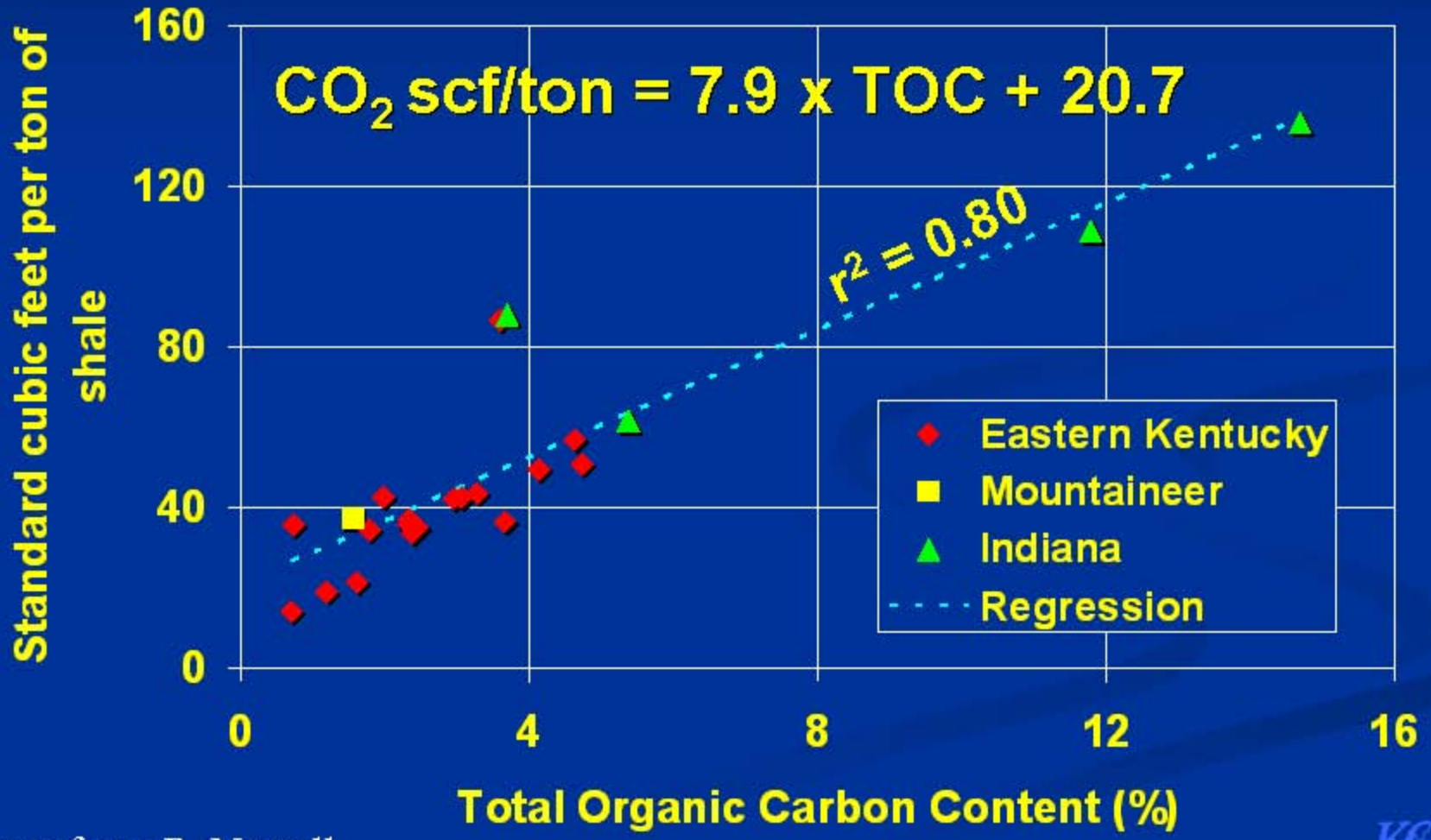
CO_2 Adsorption at 400 PSIA



Data from B. Nuttall

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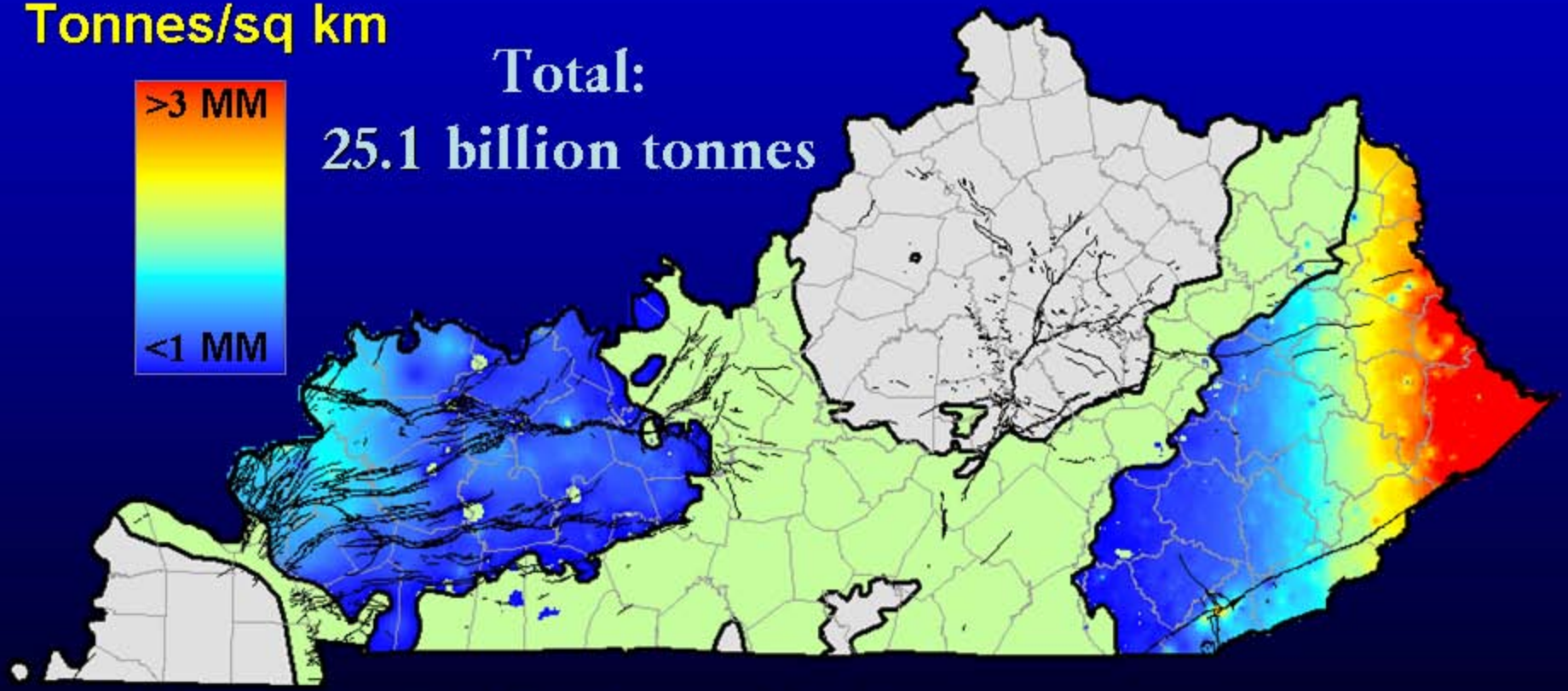
Devonian Black Shale Sequestration Potential

(speculative)



1.2 m^3/tonne (40 scf/ton) thickness weighted average

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CO_2 EOR Project

- CO_2 injection has been used to enhance oil recovery for over 30 years in other areas
- Limited use of CO_2 in Kentucky to date despite very good results
- Problems:
  - CO_2 sources, cost, and pipeline infrastructure
  - Nature of our oil reservoirs
    - Size, depth, temperature, degree of fracturing

New Sources of CO_2 in Kentucky

- Proposed coal gasification plants could provide a CO_2 source closer to our producing areas
- "Waste" CO_2 has value, and could improve production in Kentucky oil and gas fields
- KGS is currently characterizing oil fields for CO_2 EOR suitability

CO_2 for Enhanced Oil Recovery

- CO_2 floods proven to recover 7-25% additional oil
- Permanent sequestration of some CO_2 in the reservoir
- Produced CO_2 can be captured and recycled
- **Miscible** CO_2 flood:
  - depths > 2,500 ft
  - 10 – 15% additional recovery
- **Immiscible** CO_2 flood:
  - depths < 2,500 ft
  - 6 – 7% additional recovery, but can be higher

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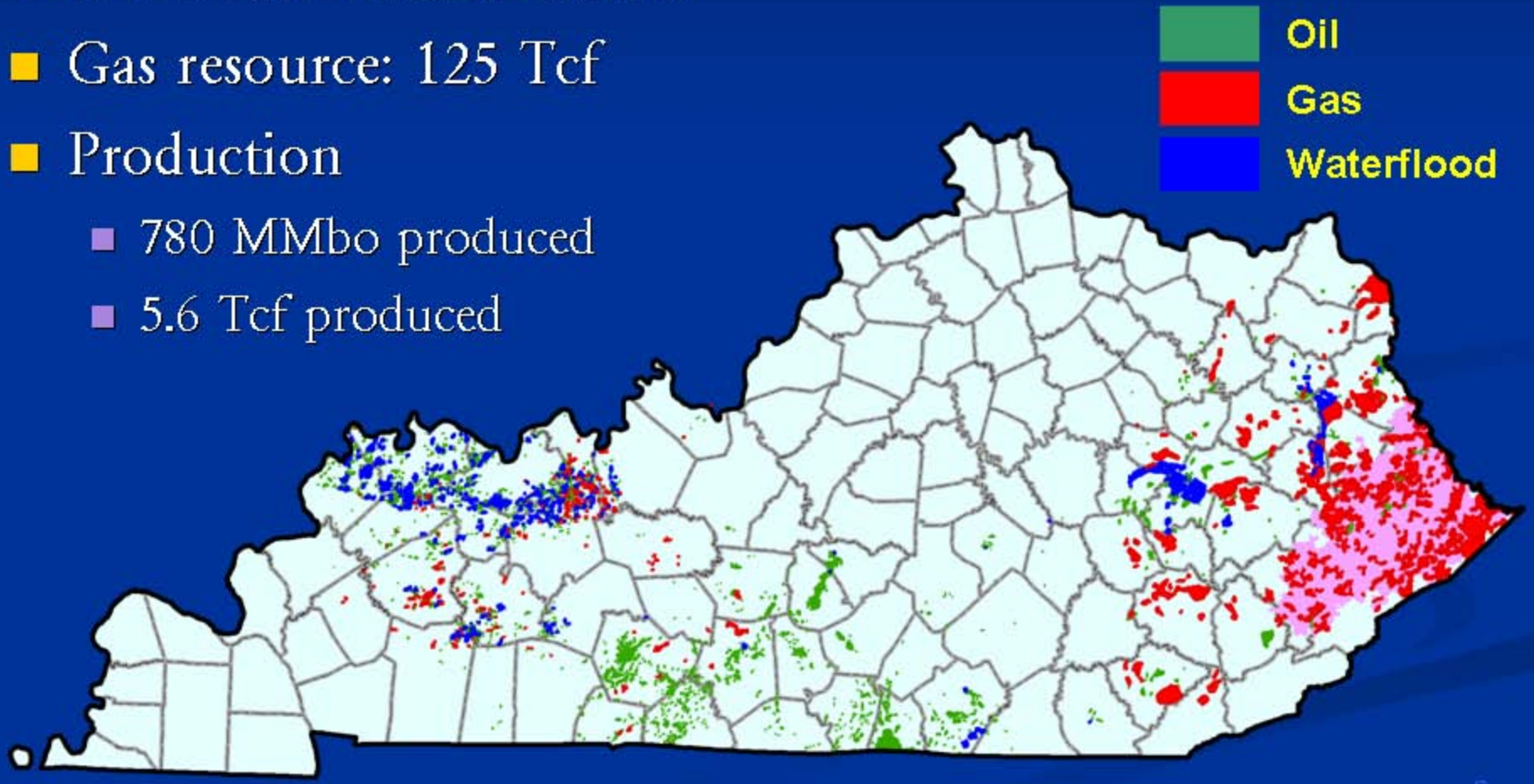
Oil and Gas Fields of Kentucky

- OOIP: 2.4 billion barrels*
- Gas resource: 125 Tcf
- Production
  - 780 MMbo produced
  - 5.6 Tcf produced



** Does not include 3.4 billion barrels tar sand/heavy oil in W. Ky.*

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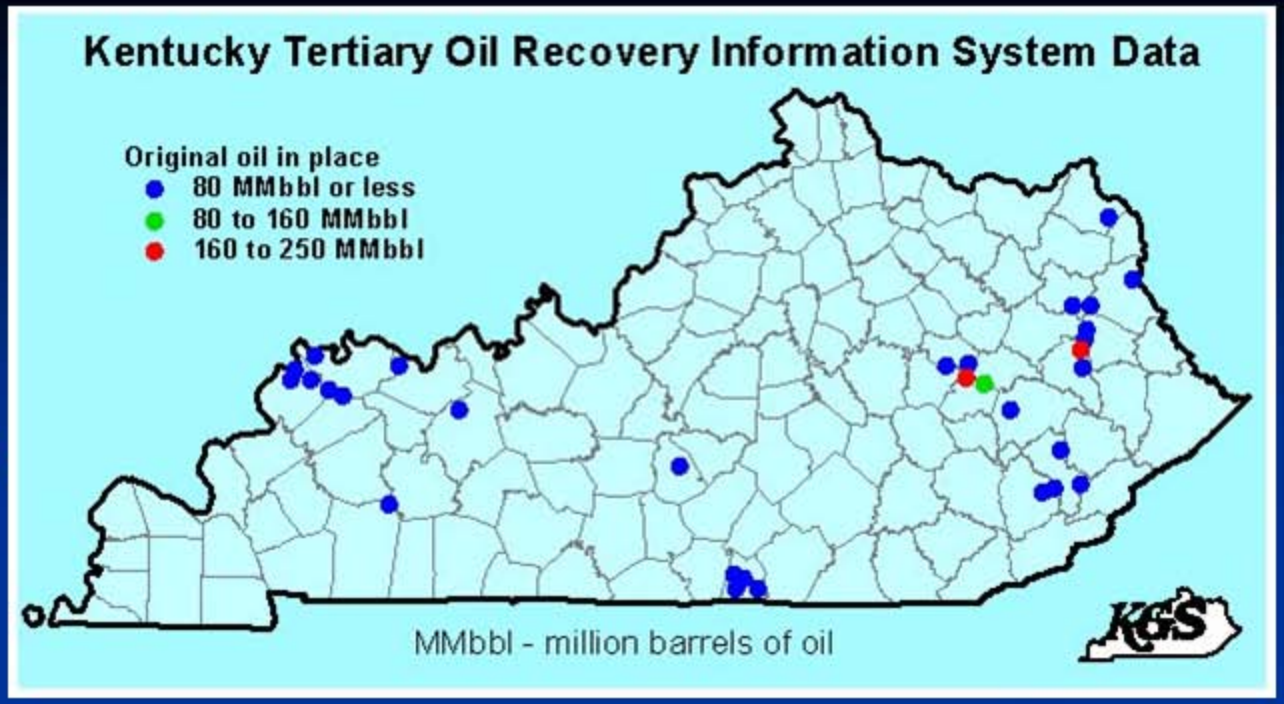
TORIS Database



- Not all reservoirs suitable for CO_2 EOR
  - Good reservoir characterization required
- TORIS has detailed oil reservoir data for 46 reservoirs in 36 fields
- Original oil: 1.7 billion bbl
- Remaining oil: 1.3 billion bbl (~75%)

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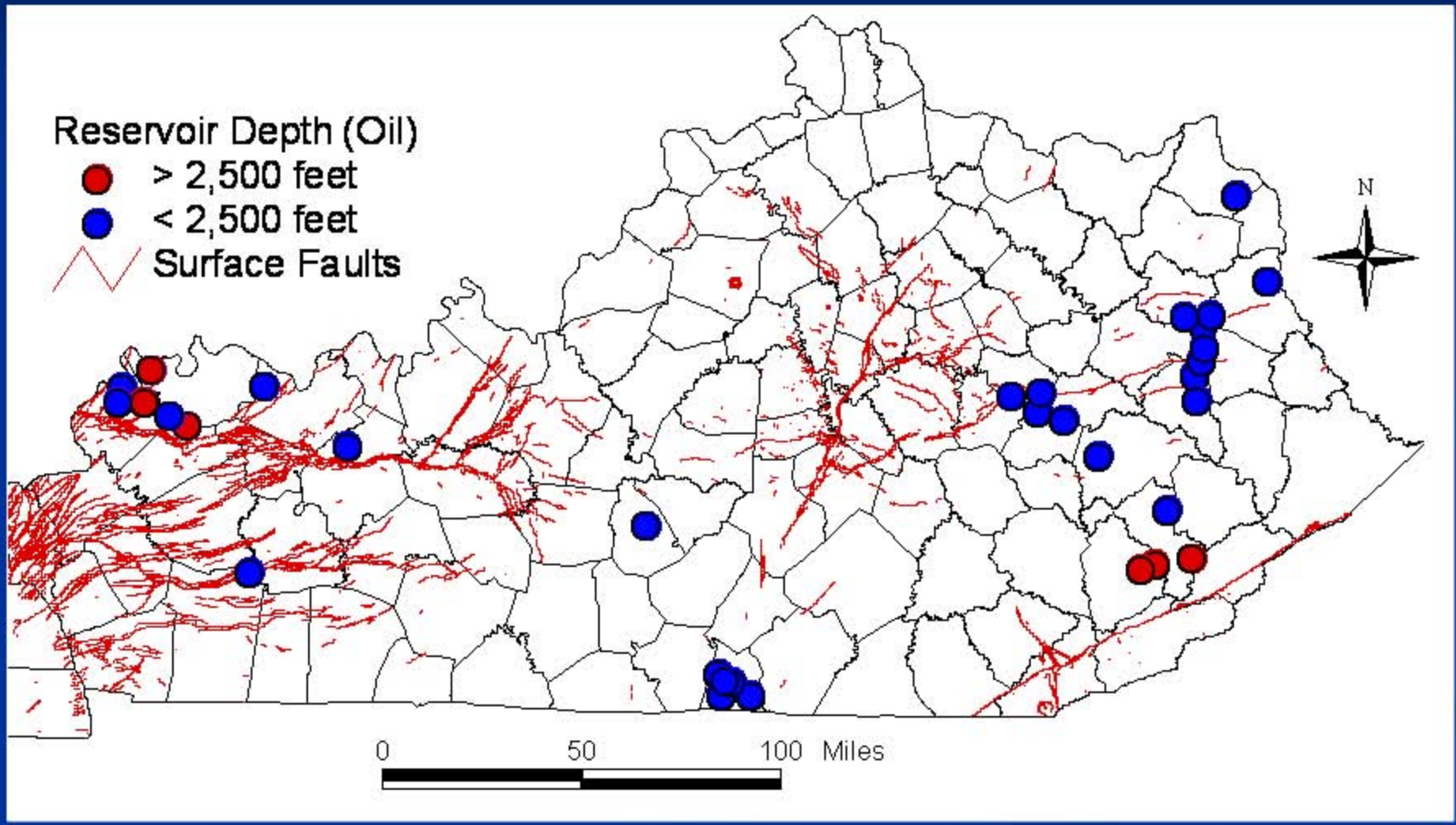
TORIS Fields by Depth



EOR Summary

- Effectiveness of CO_2 EOR will vary: screening is important
- Immiscible CO_2 floods will be important in Kentucky
- Economics in smaller fields will have to be evaluated
- Problems:
  - Fracturing and other heterogeneities
  - Improperly abandoned wells
- At least one EOR demonstration will be conducted
- Seeking partner(s) to work with

What's Next?

- Participation decisions requested by Jan. 15
  - Consortium will remain open after that date
- We expect the level of industry funding will vary
- In-kind participation is welcomed
- A company's participation and funding level cannot be held confidential
- Project results to be released immediately

Impact of Results

- Kentucky geology is not a homogenous "layer cake"
- Research sites will be as representative as possible, however:
  - A successful project will not prove sequestration is possible everywhere, and an unsuccessful project will not condemn the entire state
- This research will be a major step along the path toward carbon management, not the final chapter

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