Geologic Criteria for Western Kentucky Permanent CO_2 Storage

(Saline reservoir test)

Dave Williams and Rick Bowersox

Kentucky Geological Survey

KYCCS

House Bill 1

$5 million appropriated to research use and storage of CO_2 in Kentucky

"…the research shall include the drilling of deep wells in both coal fields (Illinois and Appalachian) in Kentucky, and performing the analysis necessary to estimate the potential for enhanced oil and gas recovery, enhanced coalbed methane recovery, or permanent storage of sequestration of carbon dioxide."

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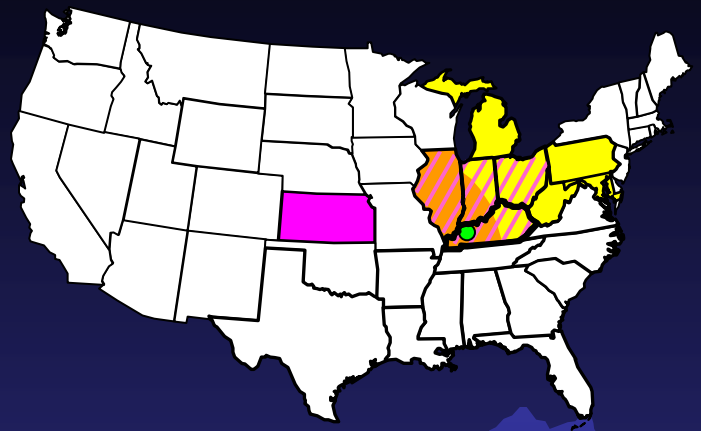
Storage (sequestration) research to build on



Past research

DOE-sponsored research in Kentucky

- **MIDCARB**
- **Phase 1- Midwest Regional Carbon Sequestration Partnership (MRCSP)**
- **Phase 1- Midwest (Illinois Basin) Geological Carbon Sequestration (MGCS) Consortium**

GOEP-sponsored research in Kentucky

- **Kentucky's FutureGen proposal**

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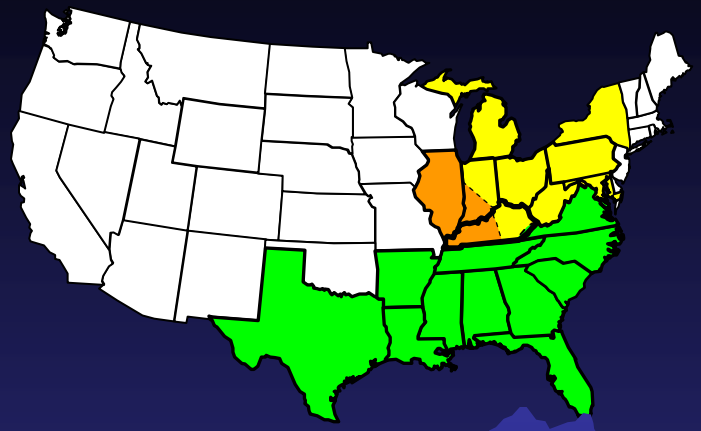
Storage (sequestration) research to build on



Current research

DOE-sponsored research in Kentucky

- **Phase 2- Midwest Regional Carbon Sequestration Partnership (MRCSP)**
- **Phase 2- Midwest (Illinois Basin) Geological Carbon Sequestration (MGCS) Consortium**
- **Phase 2- Southeast Regional Carbon Sequestration Partnership (SECARB)**

GOEP-sponsored research in Kentucky

- **Kentucky's industrial plant site bank**

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Storage (sequestration) research to build on

From this research we have gathered some geologic background to aid in planning a test for deep CO_2 storage in western Kentucky:

- **Minimum depths for miscible injection**
- **Principle reservoir targets and seals**
- **Other potentially limiting factors**
- **Wisdom from similar tests within the DOE-sponsored projects**

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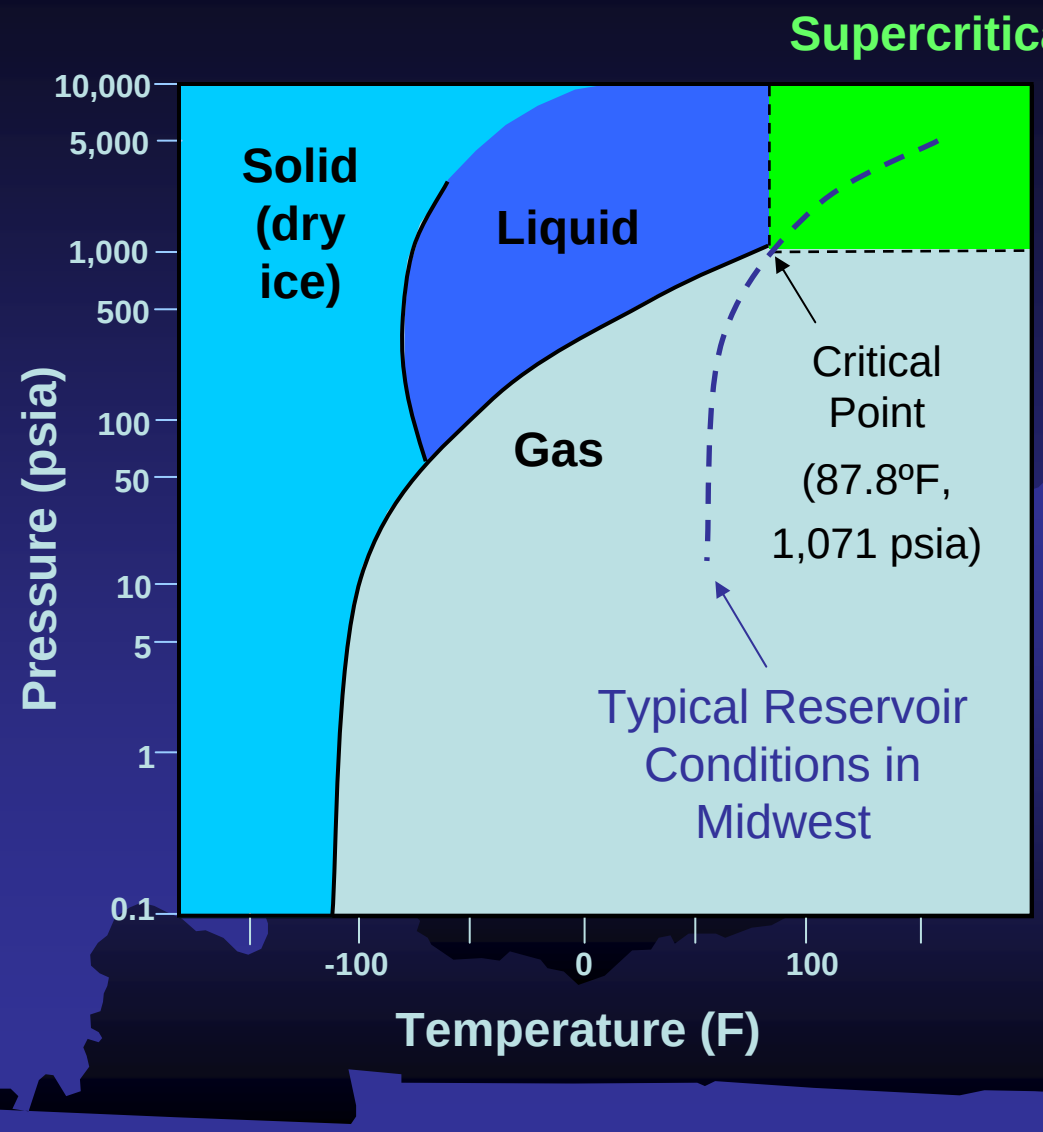
Minimum storage depths



The minimum depth for miscible CO_2 storage (sequestration) is determined by the properties of CO_2

Graph from MRCSP Phase 1 Final Report (Wickstrom and others, 2004)

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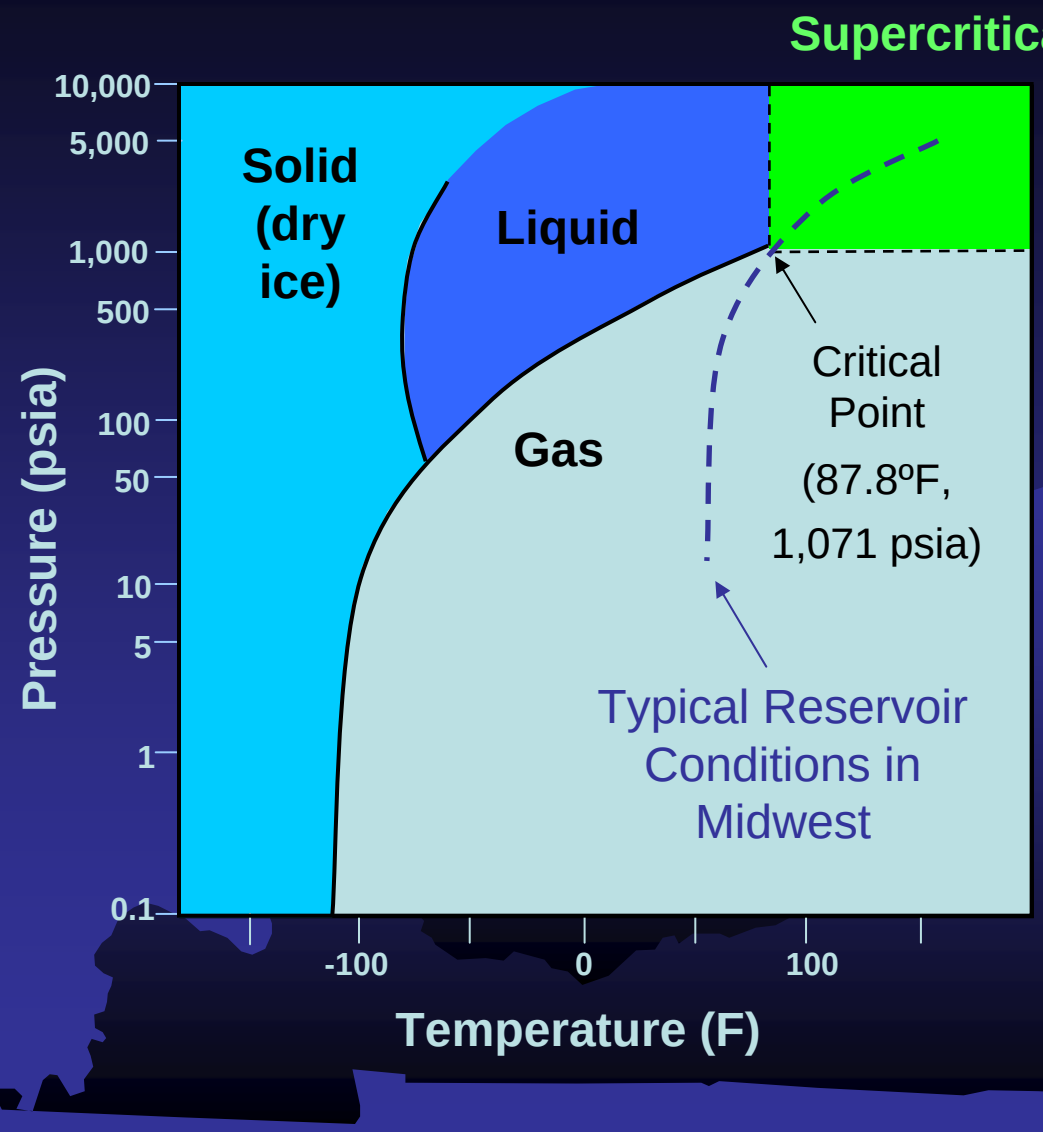
Minimum storage depths



At increased pressure and temperature, CO_2 behaves as a super-critical fluid (has properties of a liquid and gas) and is reduced in volume 250 times.

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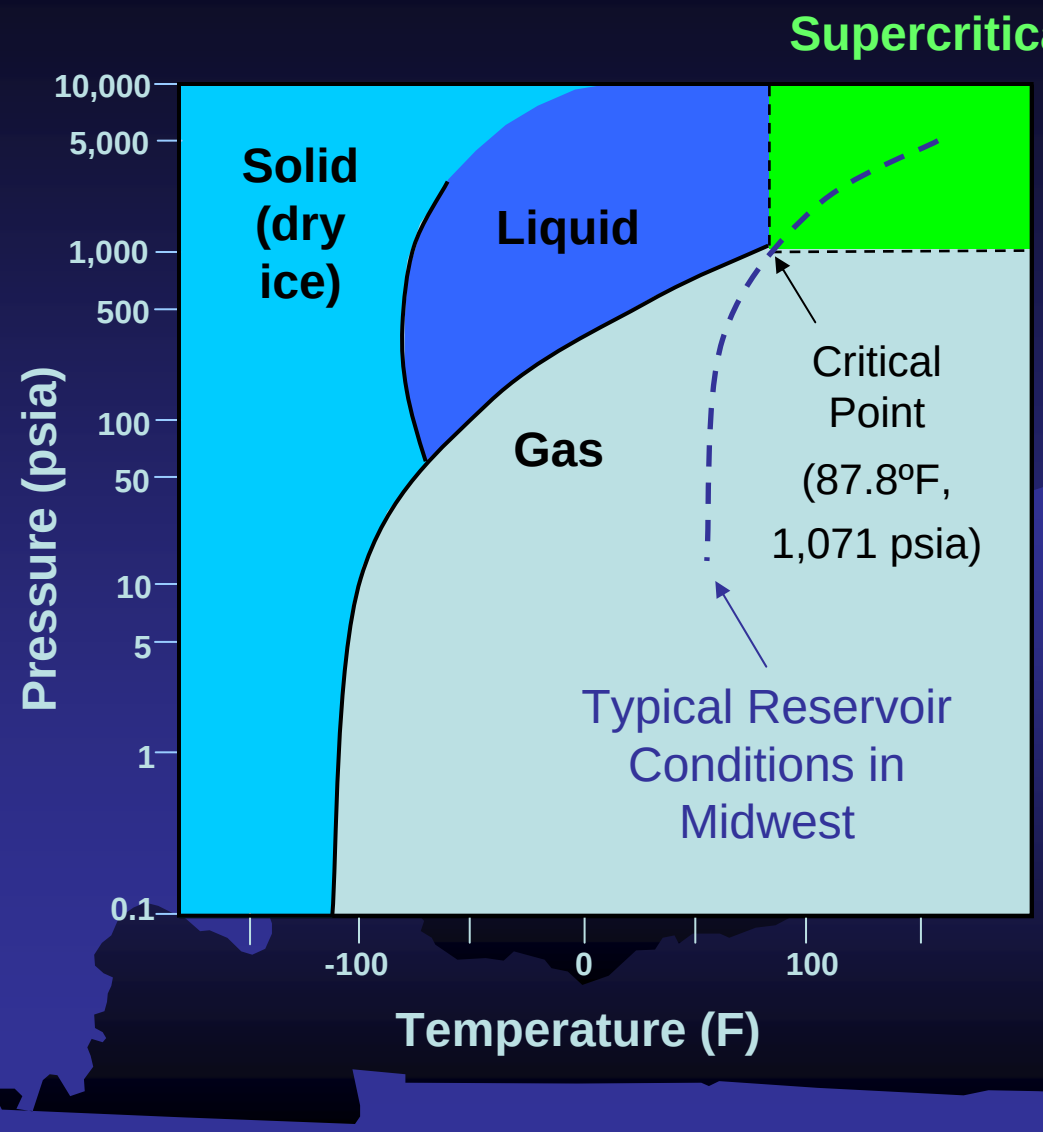
Minimum storage depths



Because future large-scale CO_2 storage will need supercritical conditions, our deep well needs to test reservoirs at depths where any injected CO_2 would be at supercritical conditions

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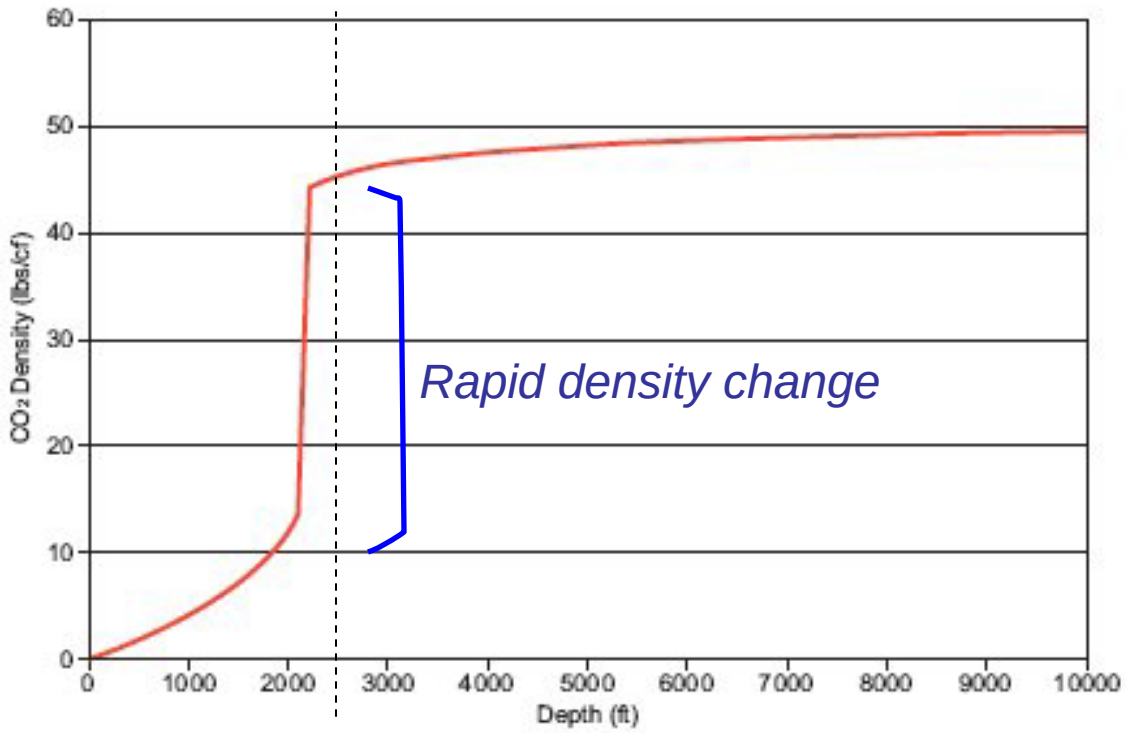
Minimum storage depths



From MRCSP Phase 1 Final Report (Wickstrom and others, 2004)

Figure 23.—Diagram showing CO_2 density with depth for a typical pressure gradient, surface temperature, and geothermal gradient in the MRCSP area. CO_2 density data is from Lemmon and others (2003).

Research by the MRCSP and MGCS indicate that the critical point for CO_2 in the Midwest and Kentucky should occur at a depth of ~2,500 ft

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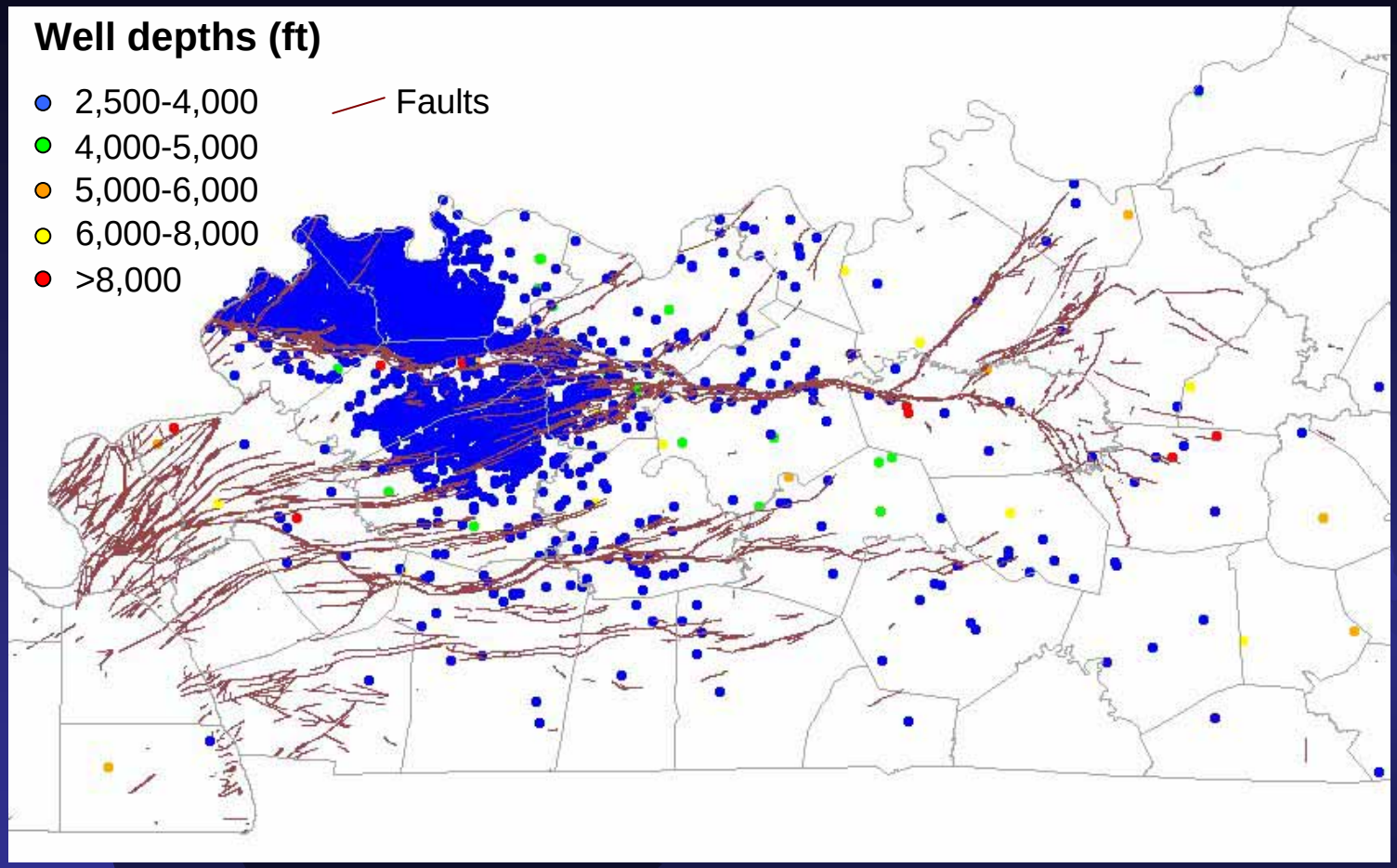
Kentucky data at minimum storage depths



Existing well data in western Kentucky at depths greater than 2,500 ft

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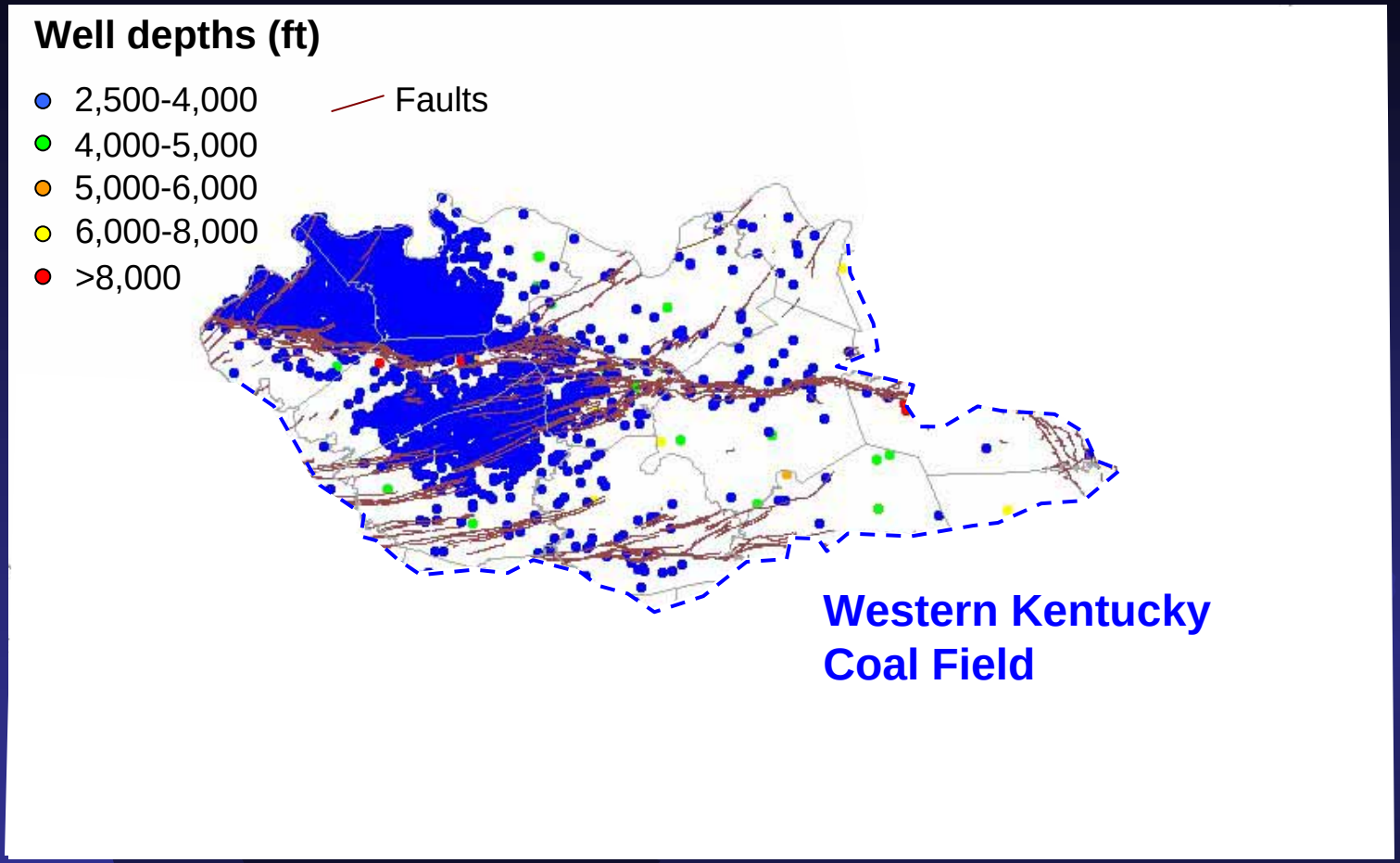
Kentucky data at minimum storage depths



Western Kentucky Coal Field and the existing well data at depths greater than 2,500 ft

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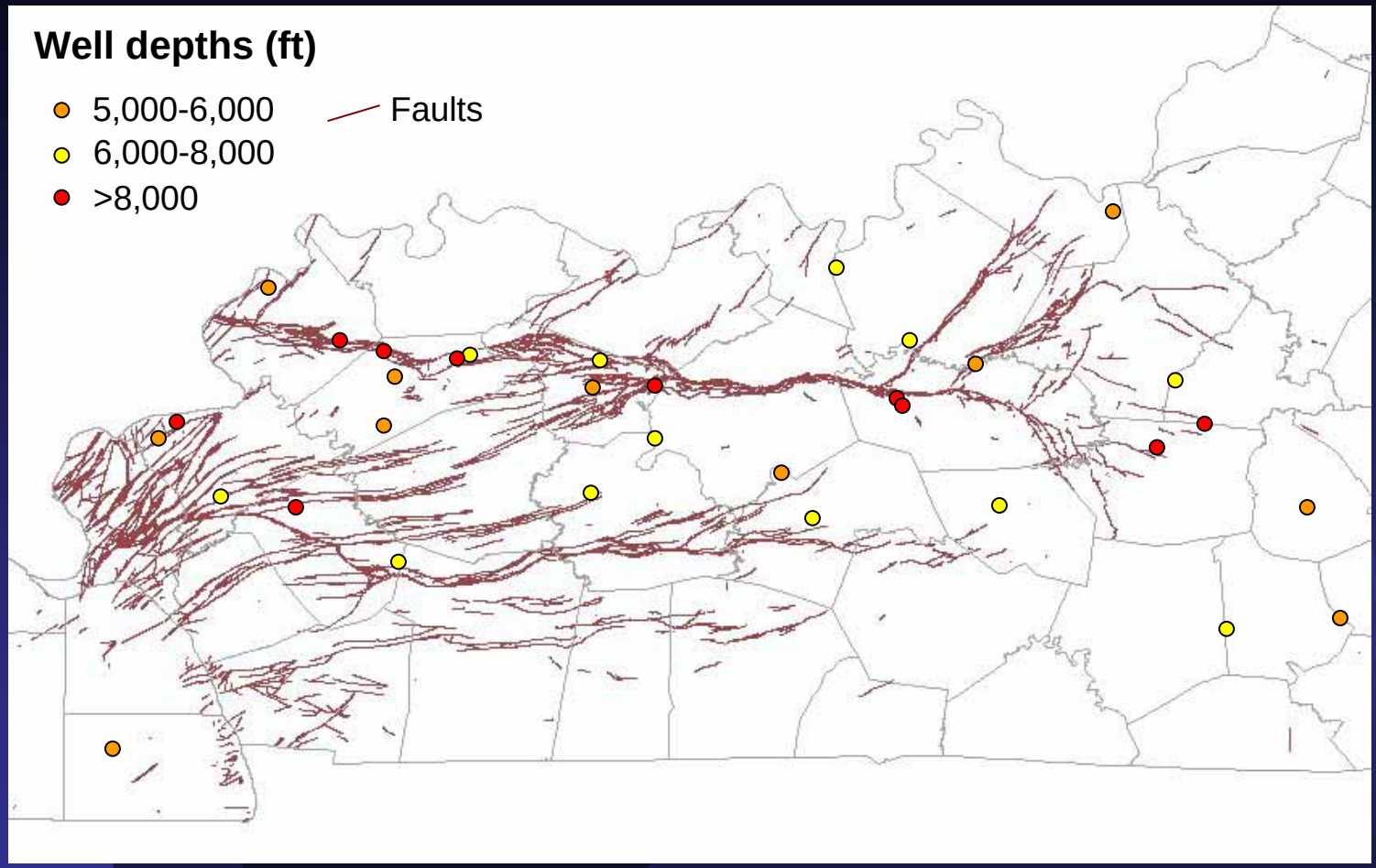
Kentucky data below minimum storage depths



Well data decreases at depths > 5,000 ft

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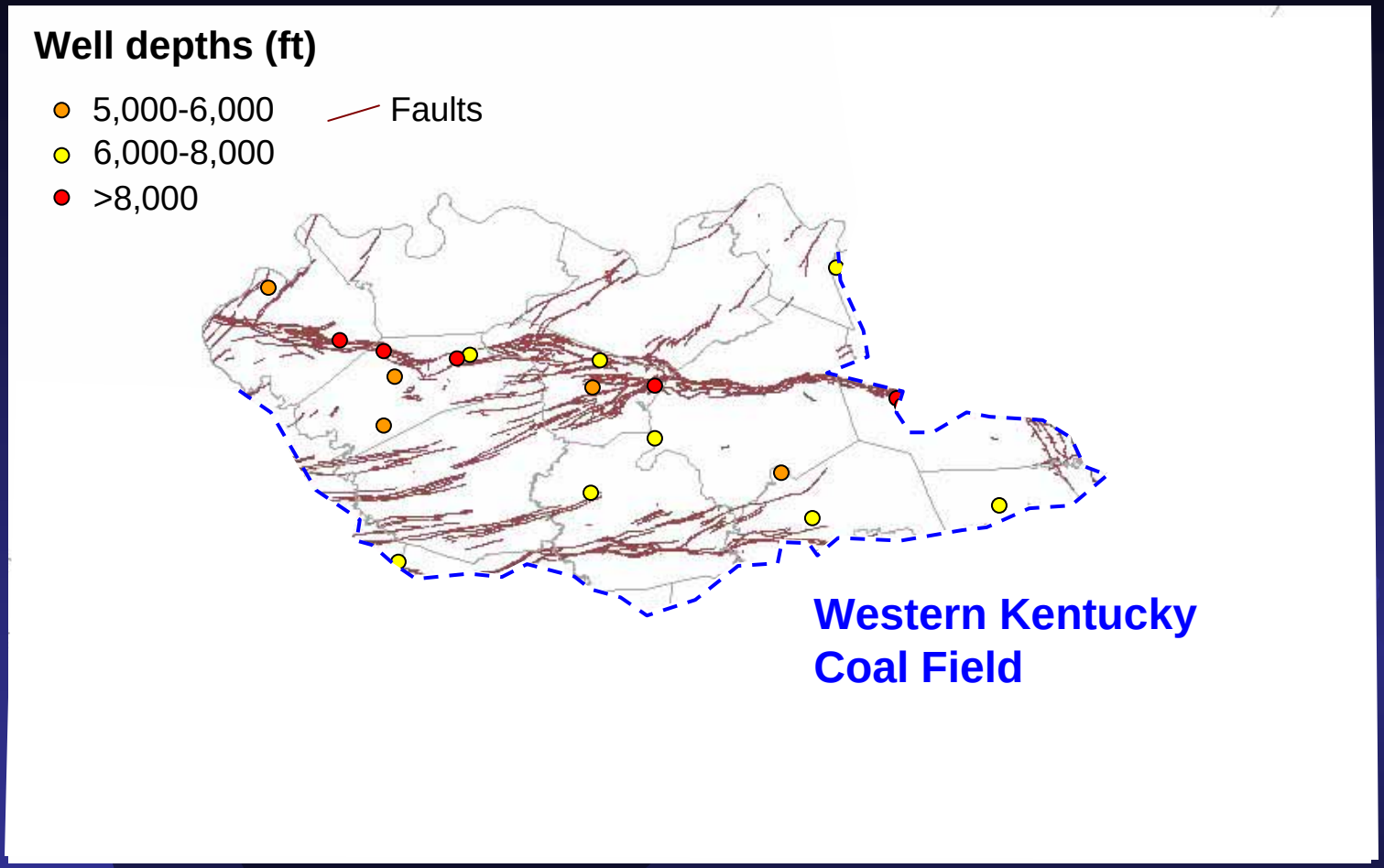
Kentucky data below minimum storage depths



Western Kentucky Coal Field and deep wells

- **Also, few core or rock samples at depth**

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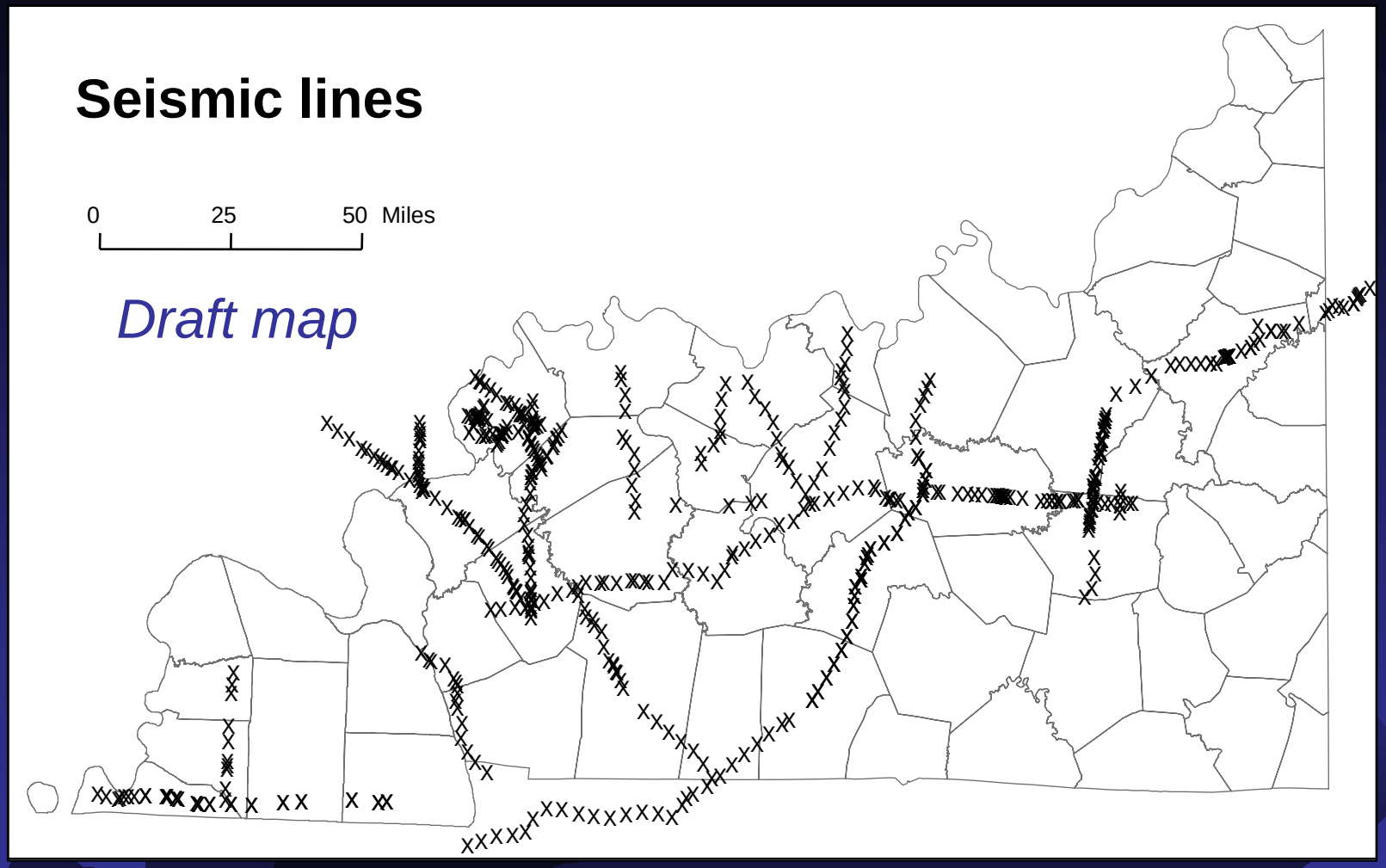
Kentucky data below minimum storage depths



KGS also has access to seismic data to aid in interpretation of the deep subsurface

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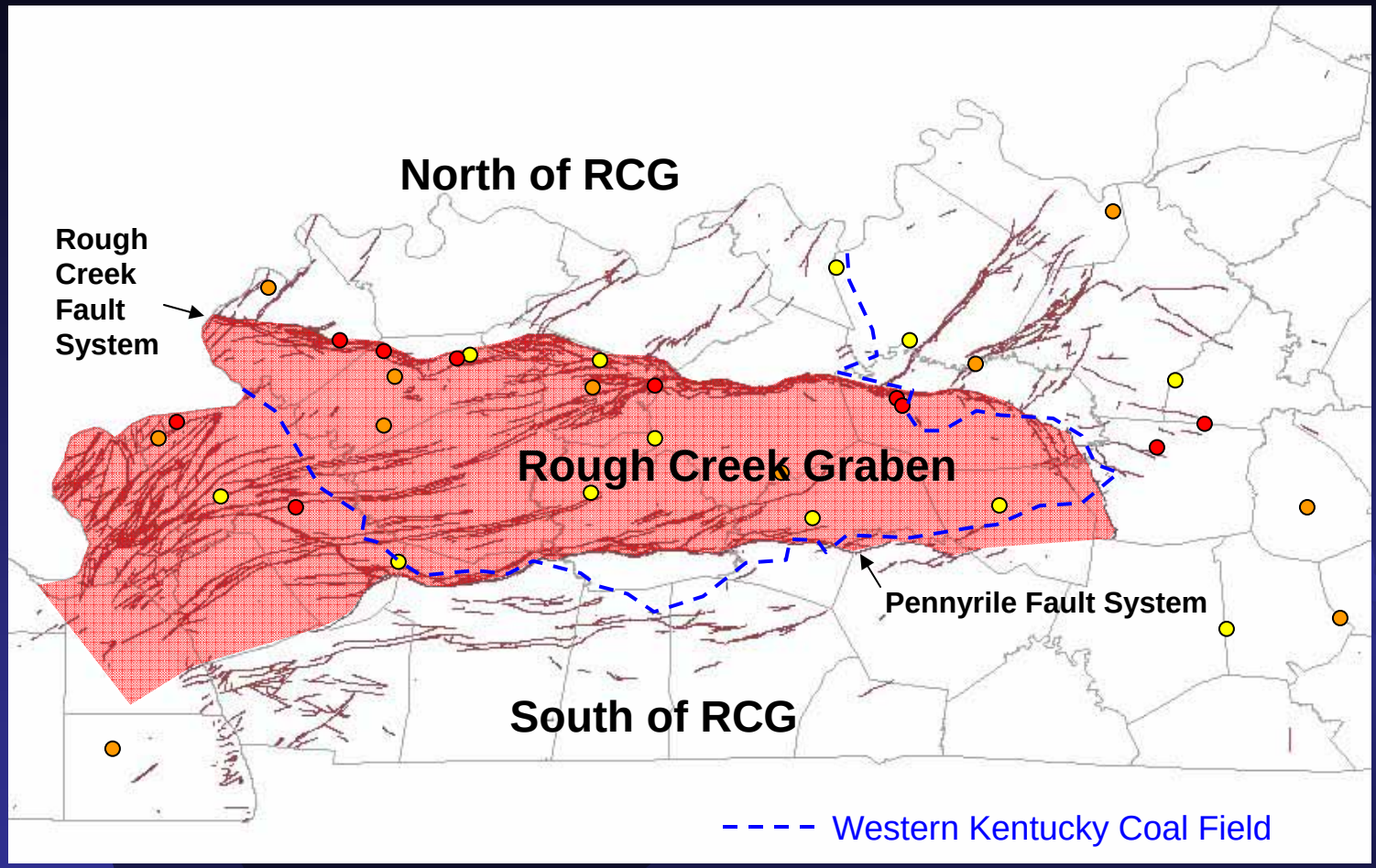
Western Kentucky structure



Our site evaluation needs to consider that there are at least three distinct geologic areas in the Western Kentucky Coal Field: the Rough Creek Graben, and north or south of the graben

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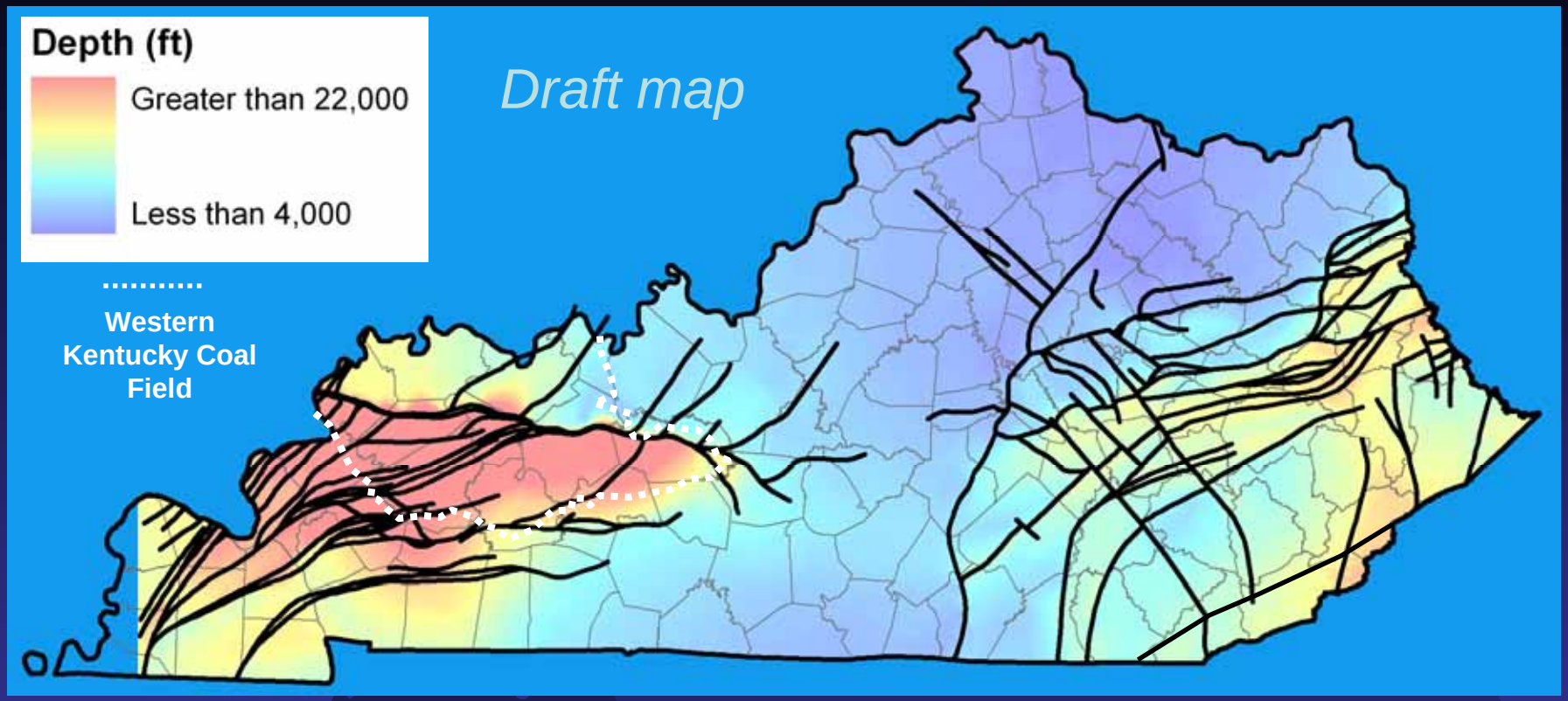
Western Kentucky structure



Depth to the Precambrian basement

There are major differences in depths to potential target horizons in and out of Kentucky's grabens

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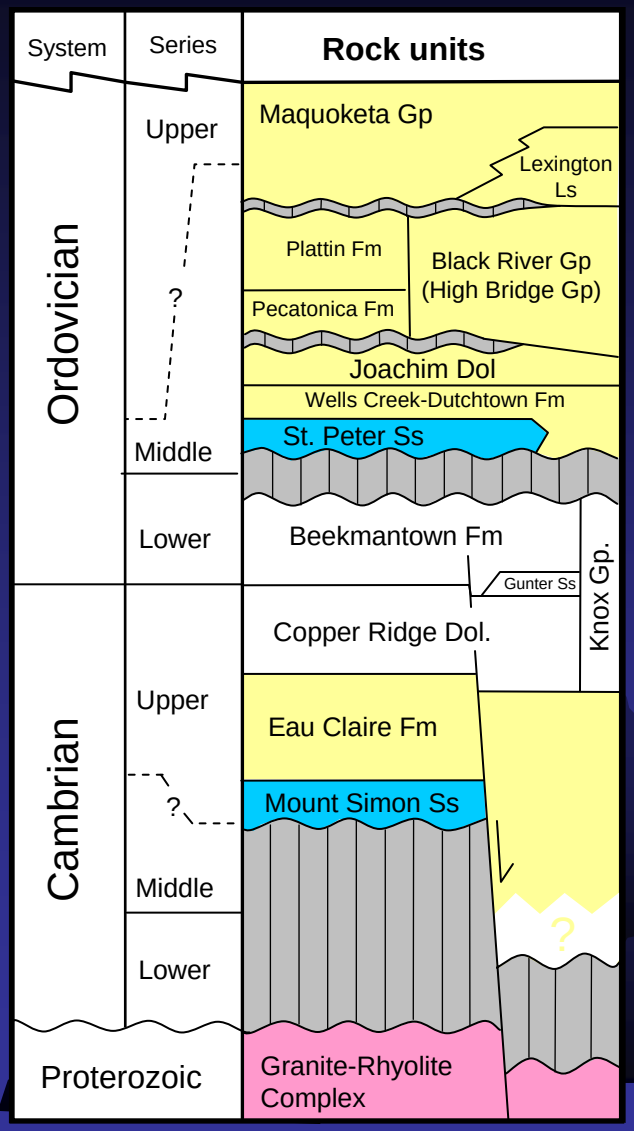
Deep rock units in western Kentucky



Previous research has established which rock units in the deep subsurface are possible saline reservoirs and which are possible sealing or containment intervals

- **Potential CO_2 sinks/ reservoirs**
- **Caprock-containment interval**
- **Unconformity**
- **Sink or seal (*depends on location*)**
- **Metamorphic and igneous rocks (*mostly seal*)**

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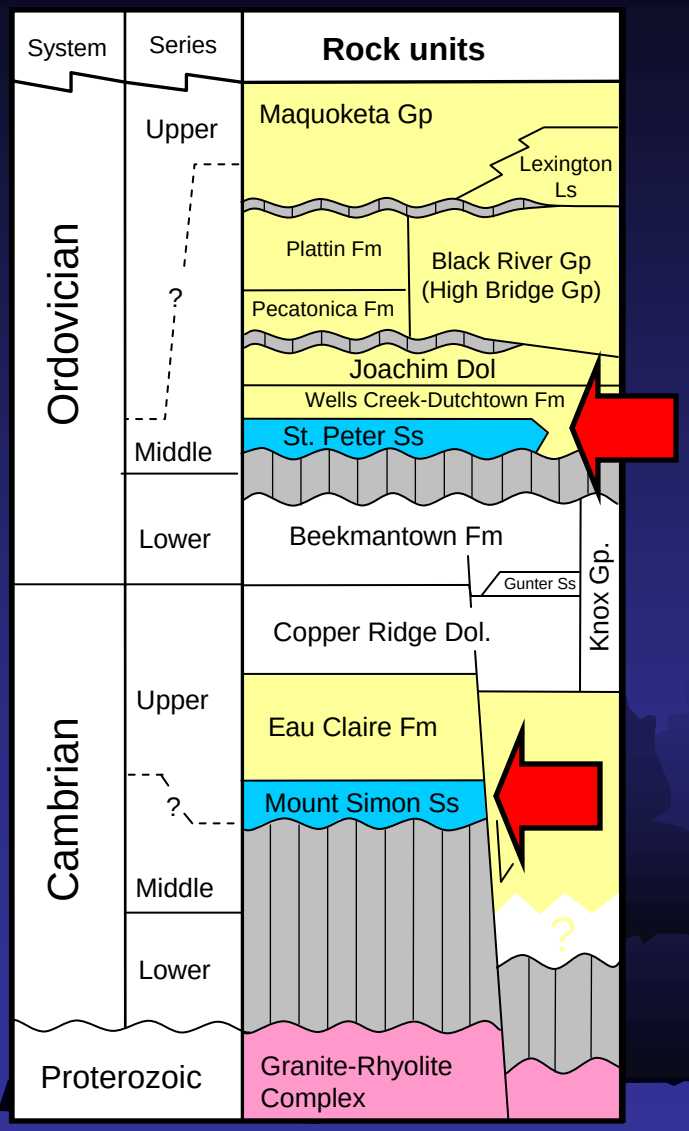
Deep rock units in western Kentucky



Known "regional" saline reservoirs at depth are:

- **Mount Simon Sandstone**
- **St. Peter Sandstone**

Potential CO_2 sinks/ reservoirs

Caprock-containment interval

Unconformity

Sink or seal (*depends on location*)

Metamorphic and igneous rocks (*mostly seal*)

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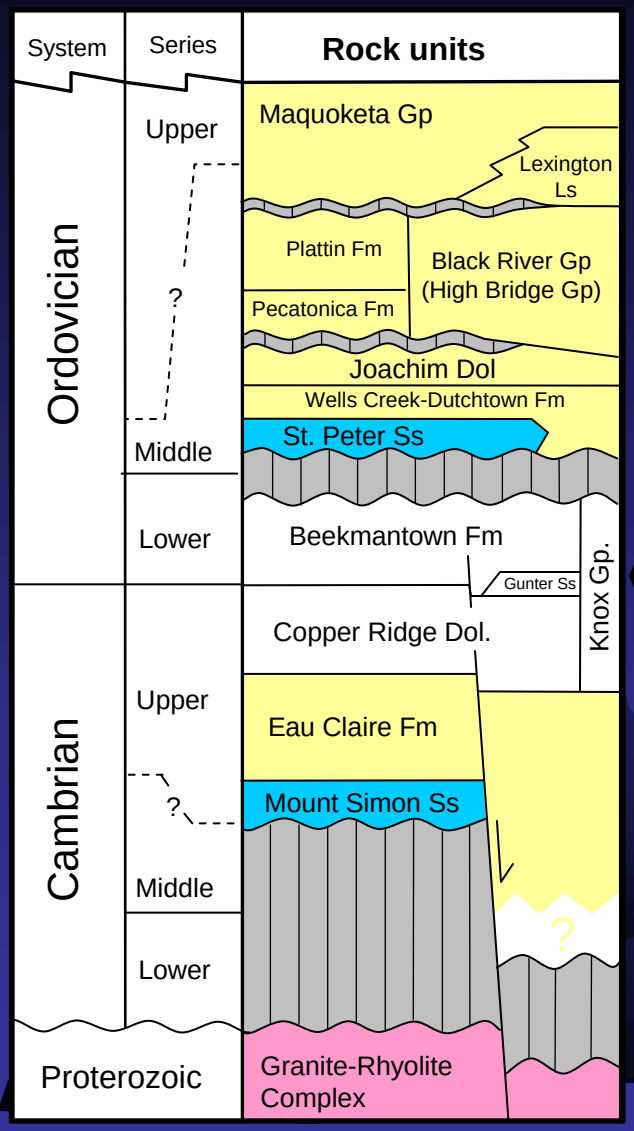
Deep rock units in western Kentucky



Also, some units may contain both sealing intervals and saline reservoirs:

- **Knox Group**

Potential CO_2 sinks/ reservoirs

Caprock-containment interval

Unconformity

Sink or seal (*depends on location*)

Metamorphic and igneous rocks (*mostly seal*)

Other local reservoirs may also occur and may need to be evaluated

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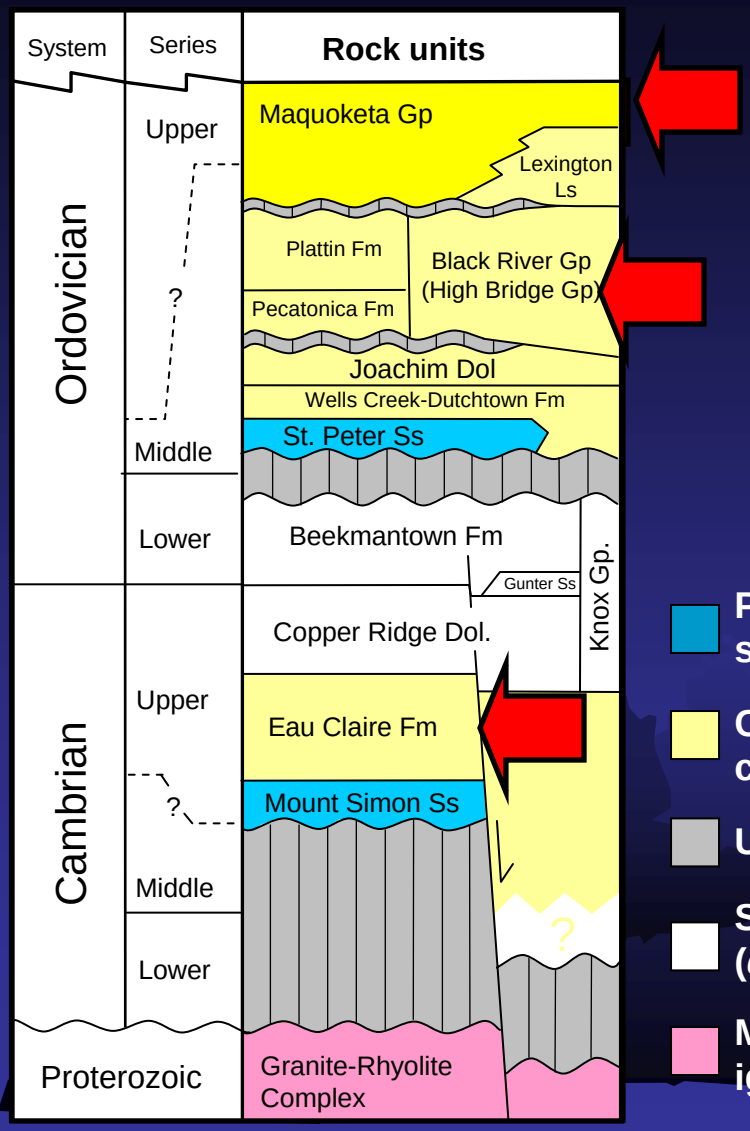
Deep rock units in western Kentucky



Potential CO_2 sinks/ reservoirs

Caprock-containment interval

Unconformity

Sink or seal (*depends on location*)

Metamorphic and igneous rocks (*mostly seal*)

Just as important in an injection project are the containing (sealing) units:

- **Eau Claire Fm**
- **Wells Creek and High Bridge carbonates**
- **Maquoketa Shale (primary seal)**
- **Devonian Shale (ultimate seal)**

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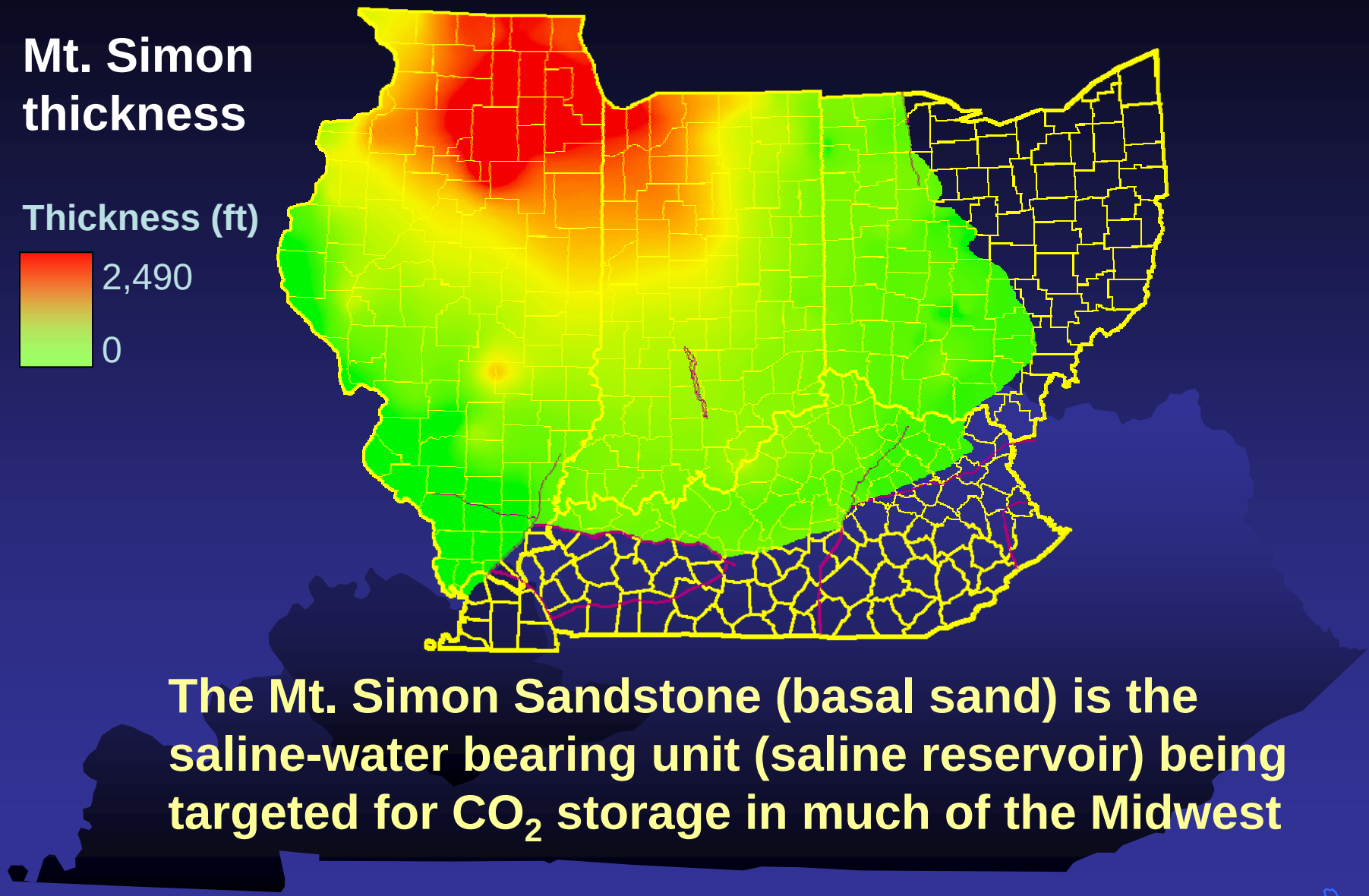
Potential reservoirs at depth: Mount Simon



The Mt. Simon Sandstone (basal sand) is the saline-water bearing unit (saline reservoir) being targeted for CO_2 storage in much of the Midwest

Map from MGCS data

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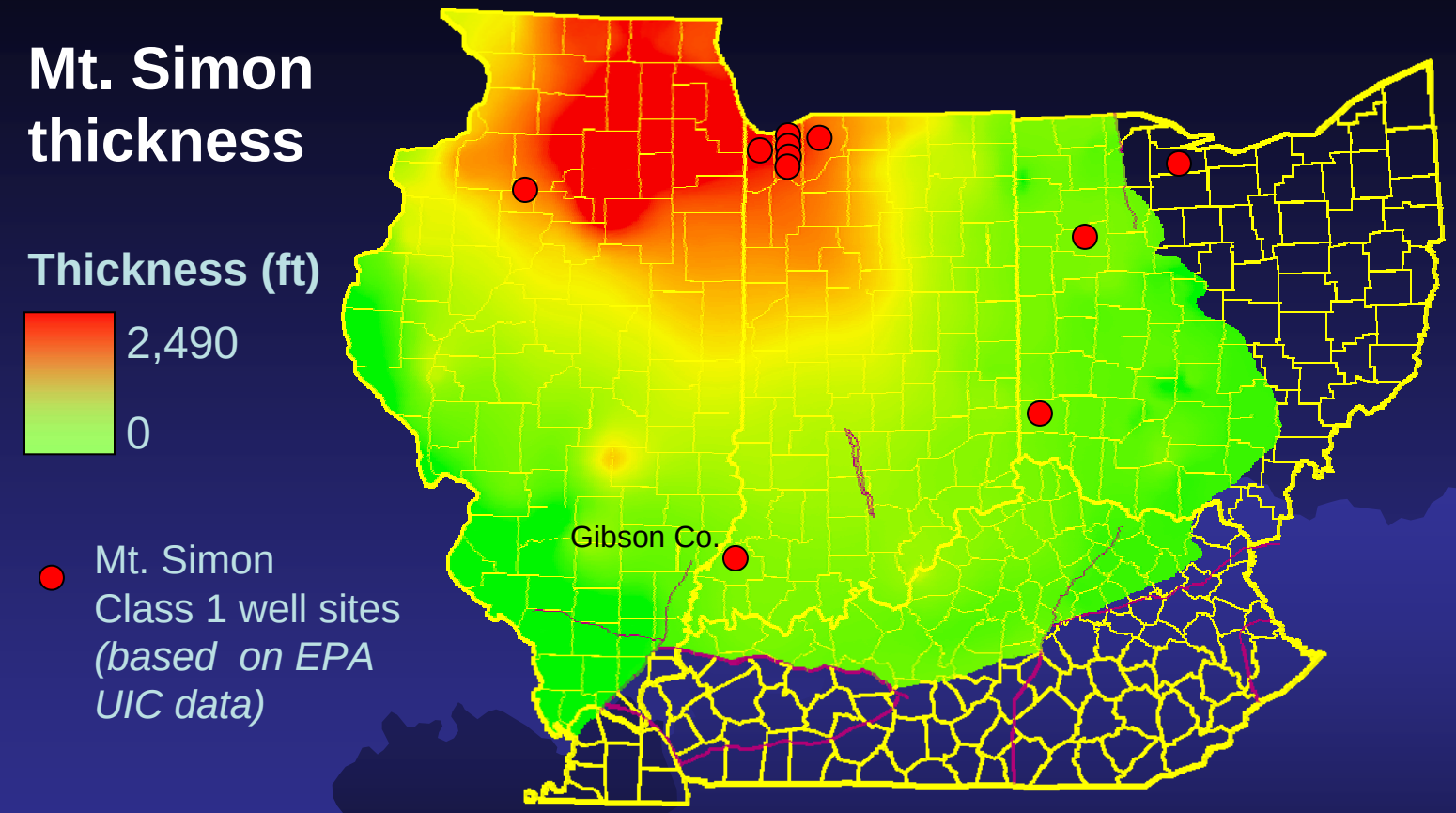
Potential reservoirs at depth: Mount Simon



The Mt. Simon is already used for industrial waste injection in other states

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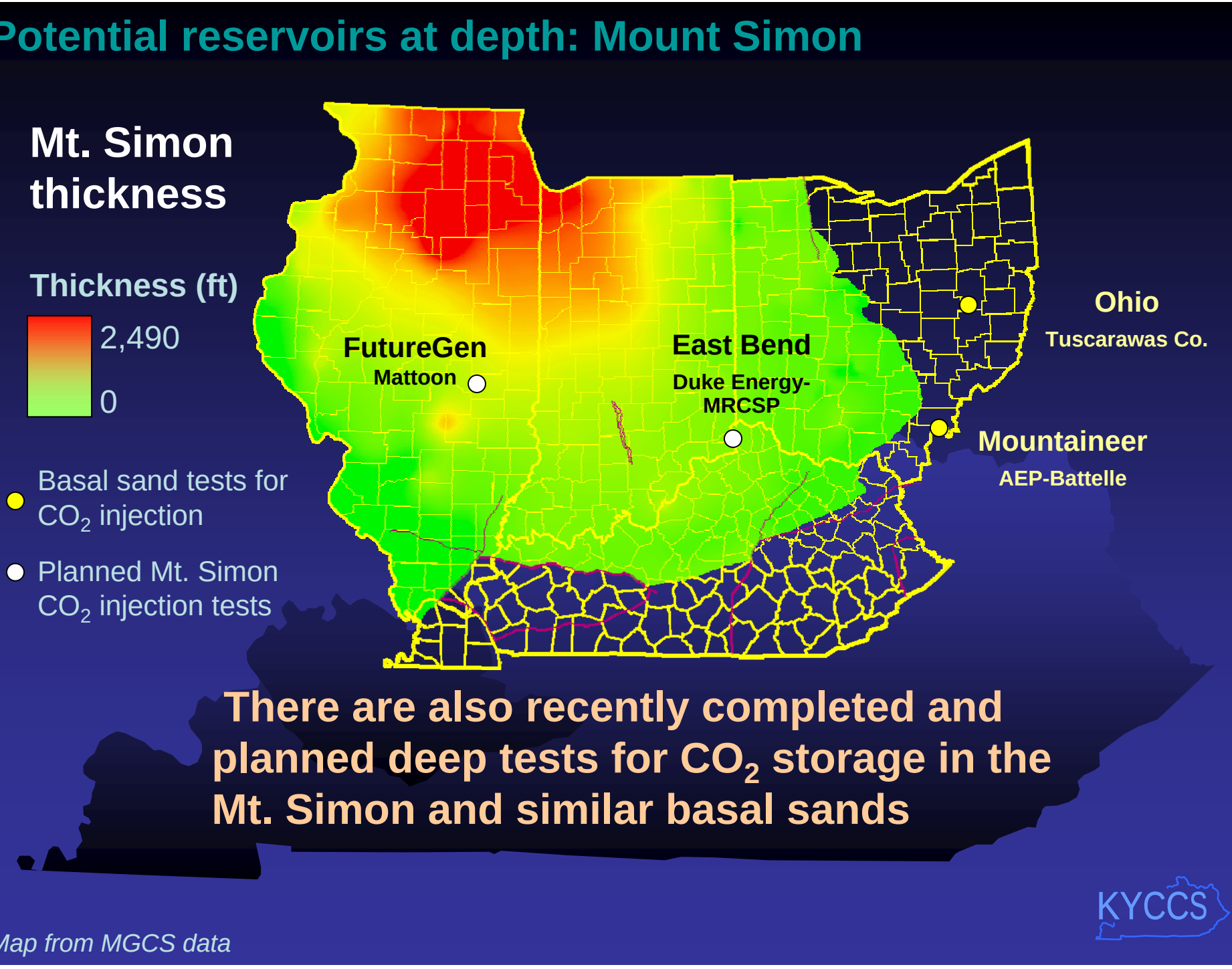
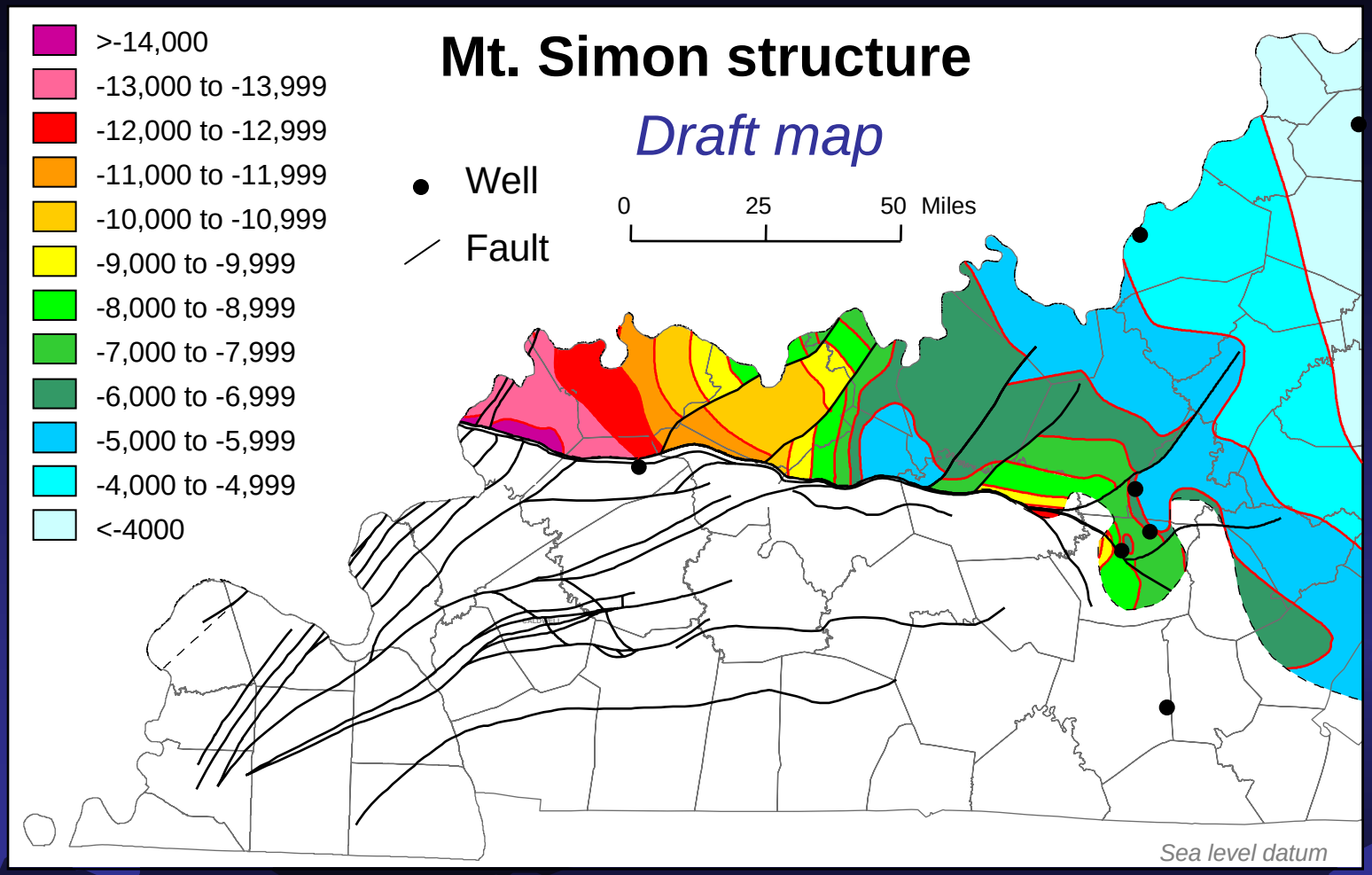
Map from MGCS data

Potential reservoirs at depth: Mount Simon



Potential reservoirs at depth: Mount Simon



- At depths of 14,500 to 6,000 in western Kentucky
- Few well data. Mostly inferred from seismic data

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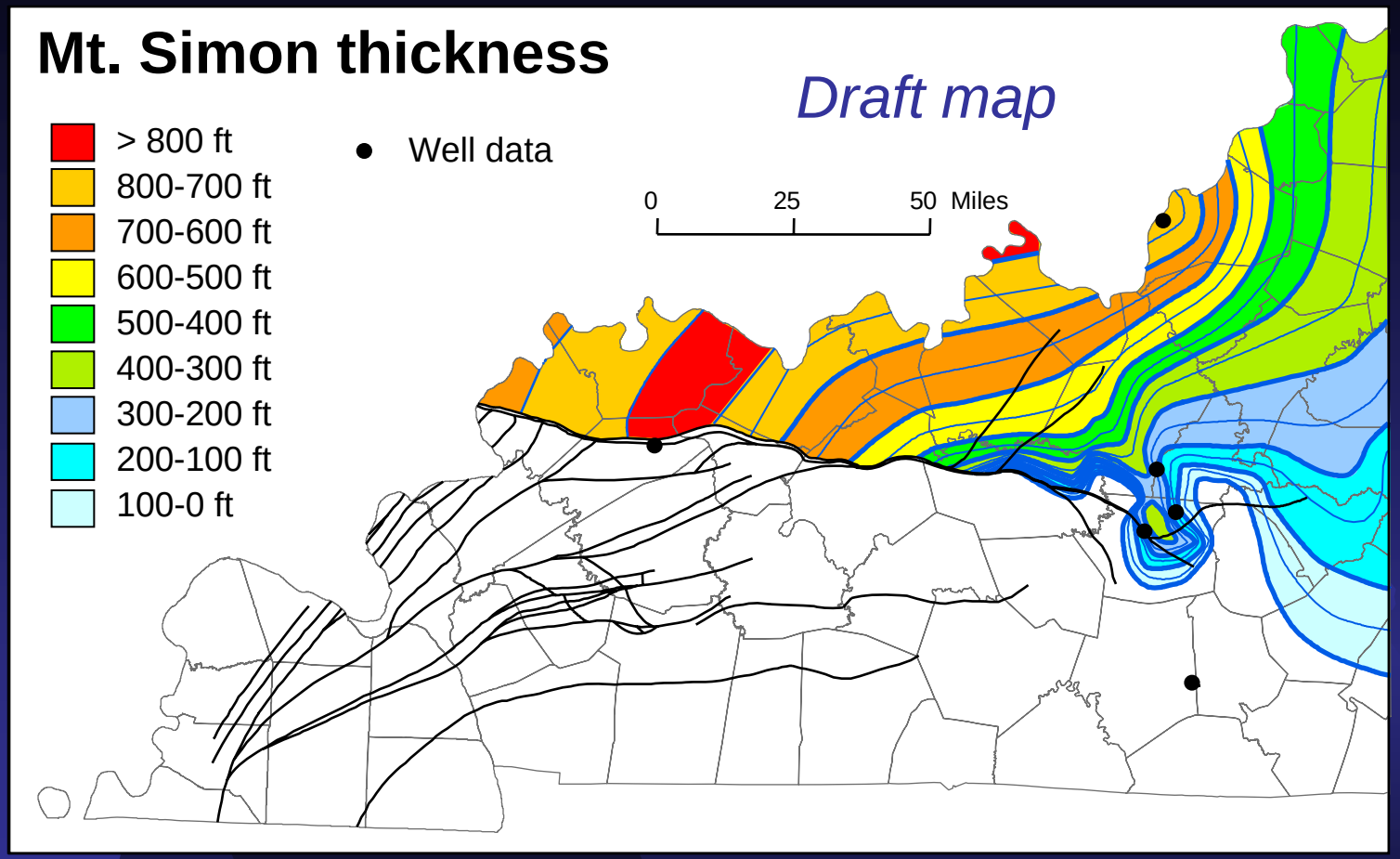
Potential reservoirs at depth: Mount Simon



- Restricted to area north of Rough Creek faults
- Thins to southeast

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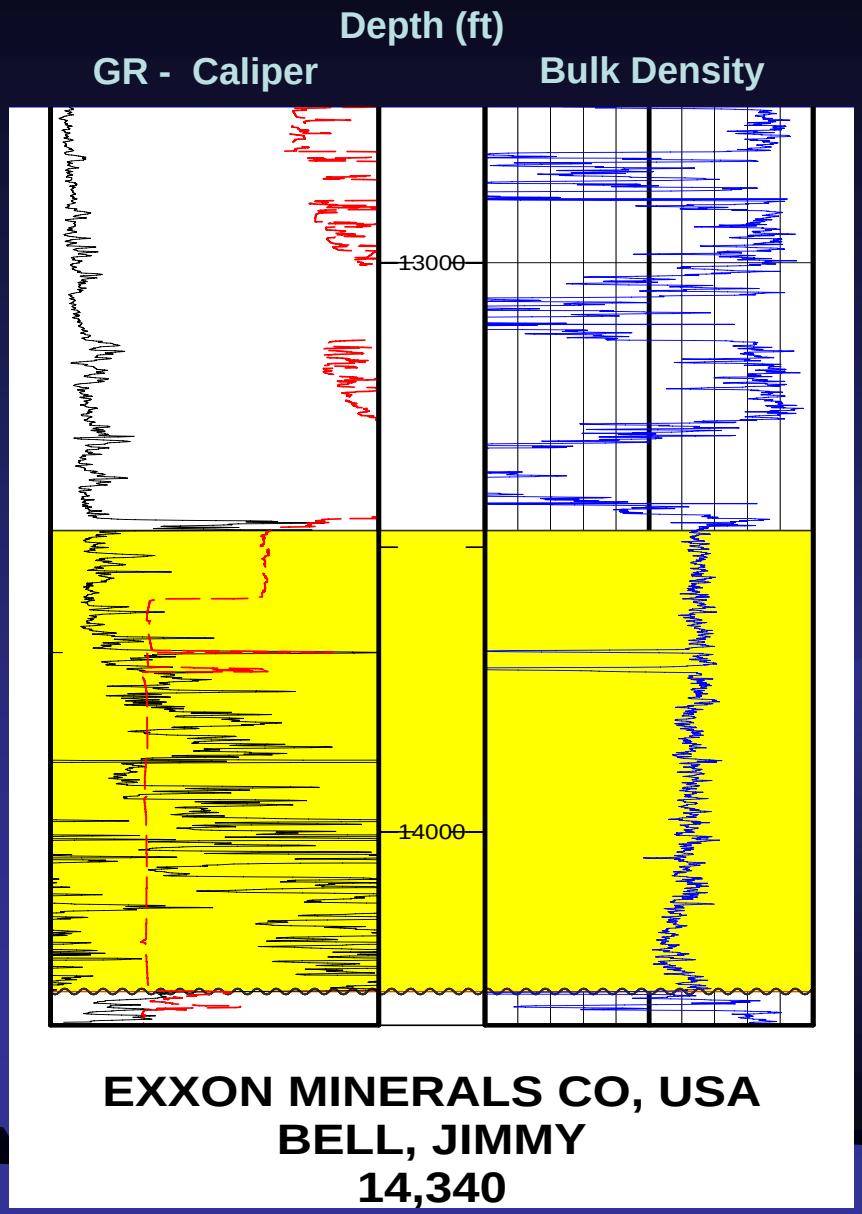
Potential reservoirs at depth: Mount Simon

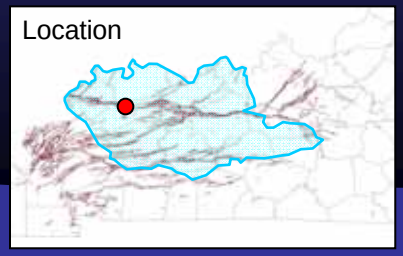


KY deep well example:

Mt. Simon,

Exxon-Bell Well,
Webster County, Ky.

- **Thickness: 750 ft**
- **Depth: 13,490 ft**
- **Poor reservoir quality**
- **Eau Claire faulted out?**



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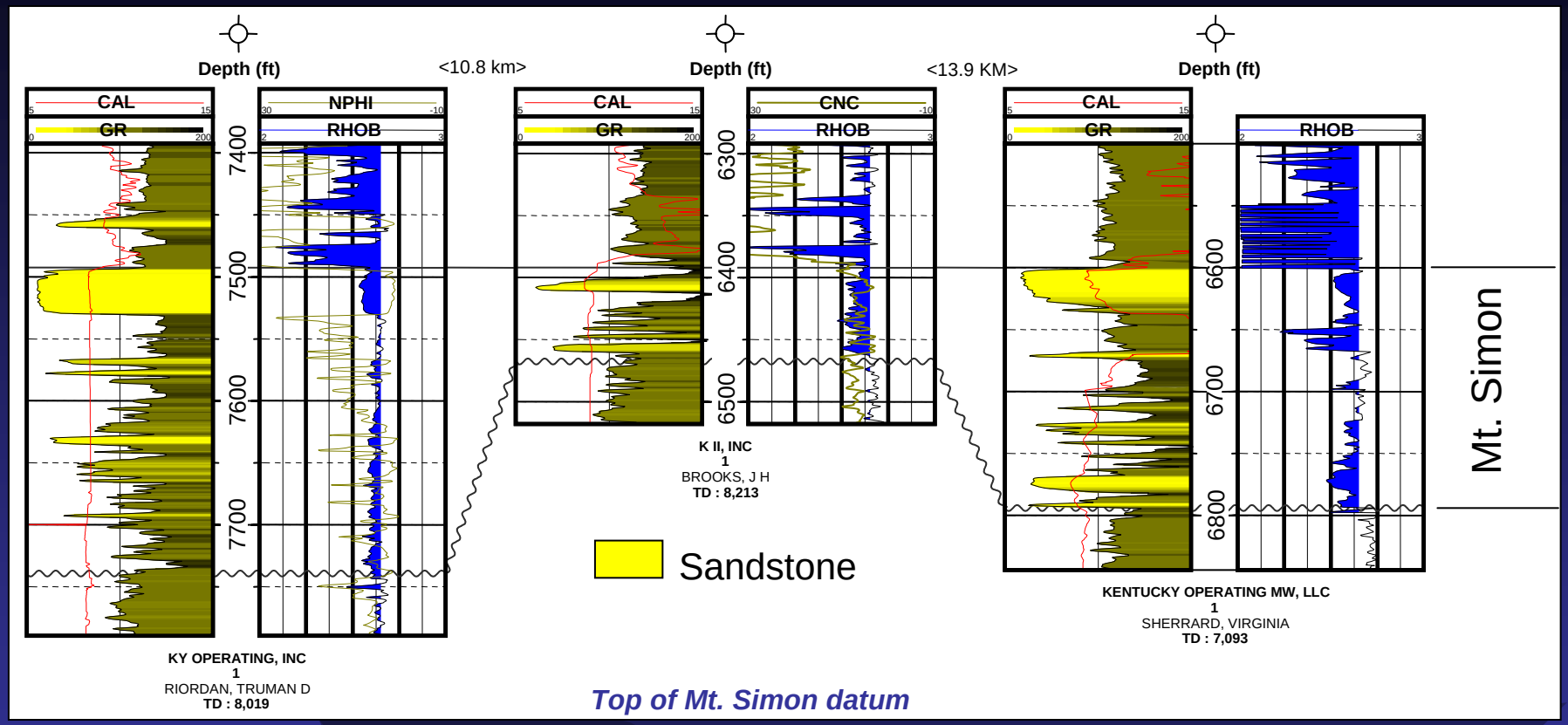
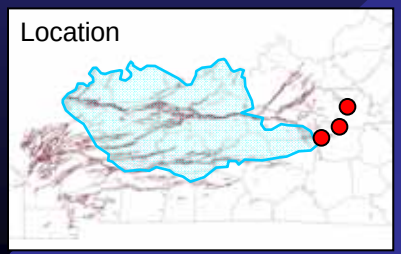
Potential reservoirs at depth: Mount Simon

KY examples at shallower depths:



Three tests of Mt. Simon just east of the coal field at shallower depths



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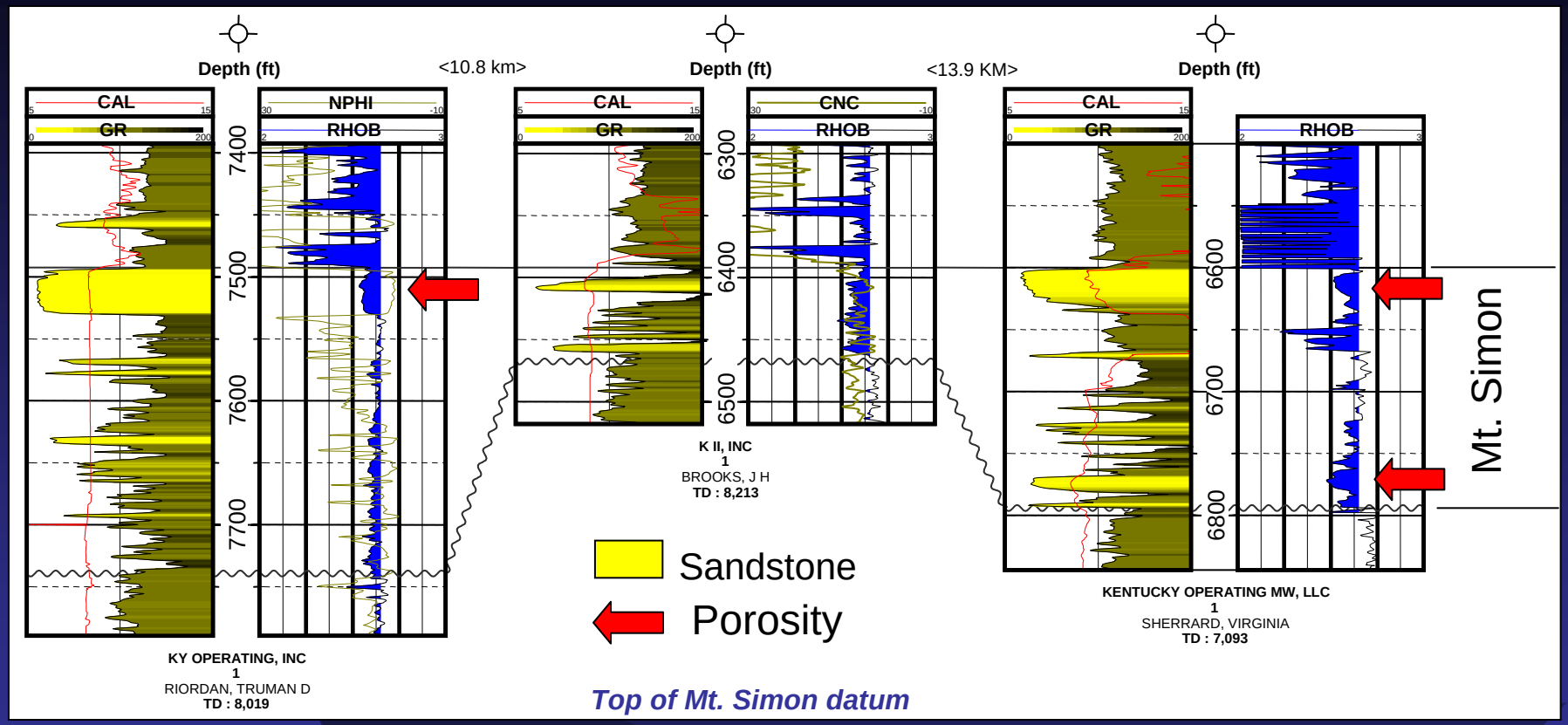
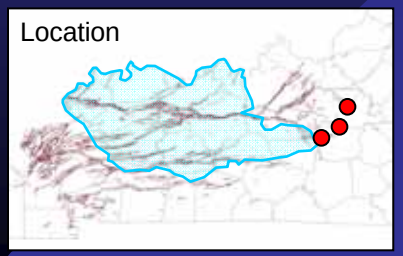
Potential reservoirs at depth: Mount Simon

KY examples at shallower depths:



There is some porosity in these wells



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Potential reservoirs at depth: Mount Simon

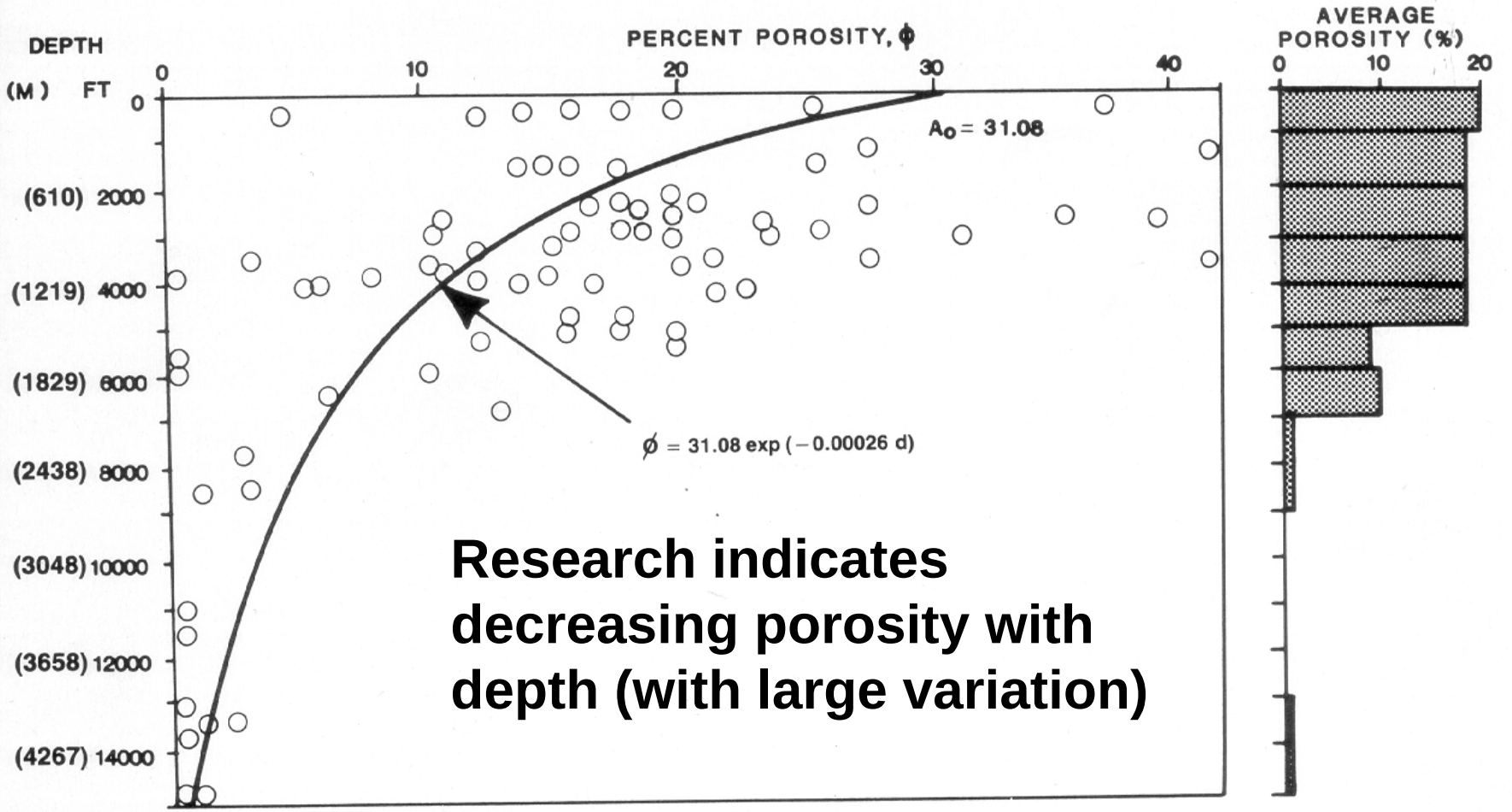

Figure 11—Porosity-depth relationships for 89 samples of Upper Cambrian Mount Simon Sandstone. Open circle = secondary porosity dominant.

From Hoholick and others, 1984, AAPG Bulletin

Data is mostly from Illinois and Indiana

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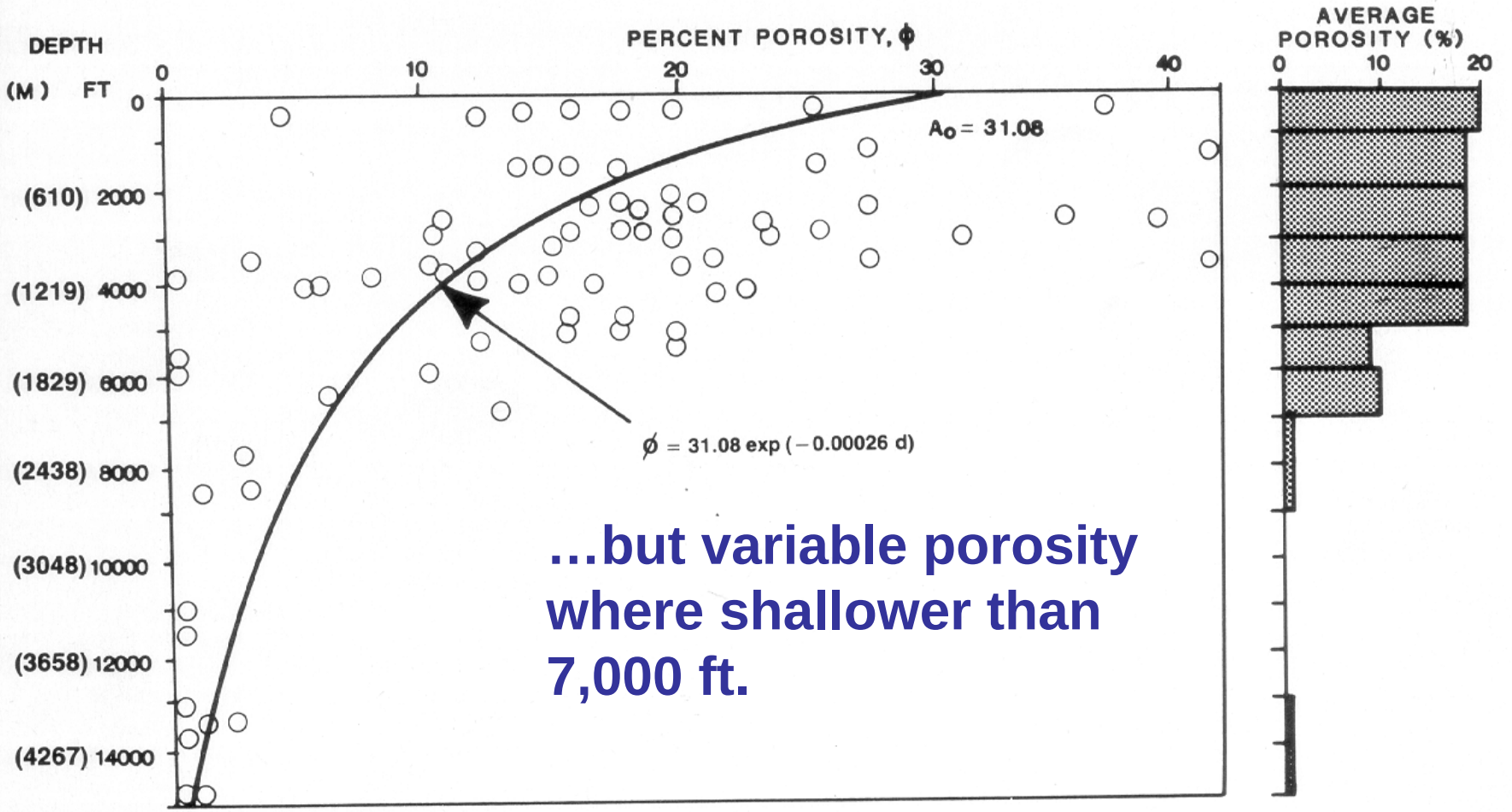
Potential reservoirs at depth: Mount Simon



…but variable porosity where shallower than 7,000 ft.

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

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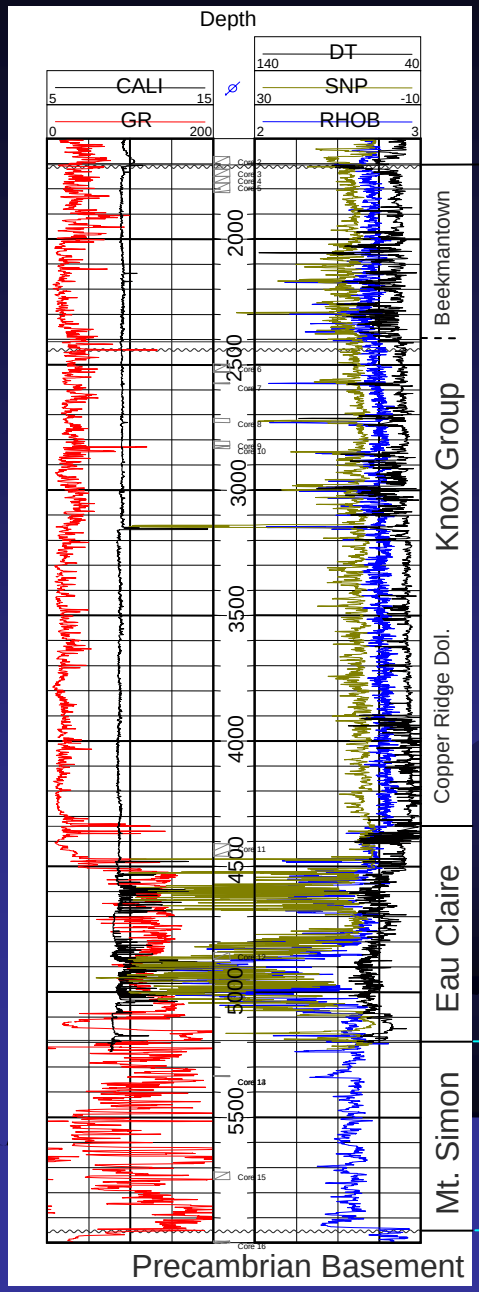
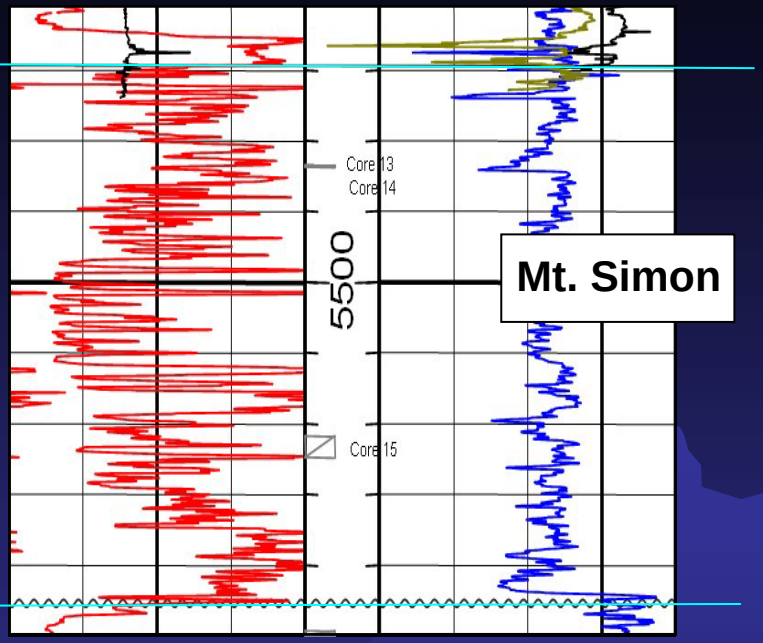
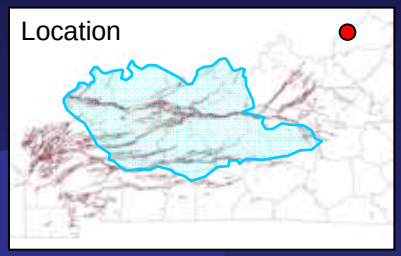
Potential reservoirs at depth: Mount Simon





Case in Point:

Dupont No. 1WAD, Louisville KY



Initially targeted Mt. Simon for waste injection

- **Depth: 5,193 ft**
- **Thickness: 761 ft**

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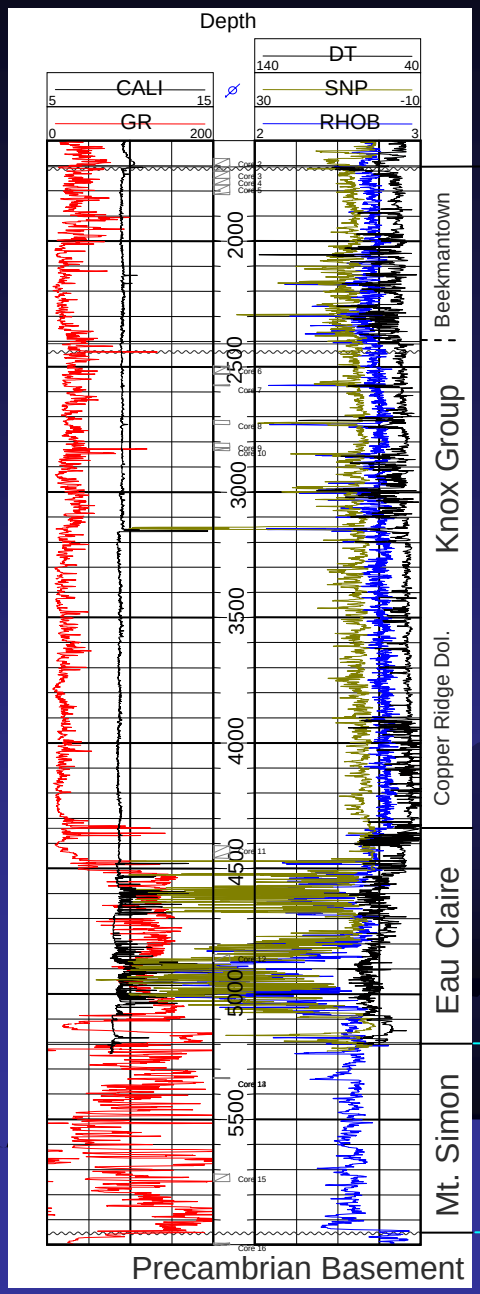
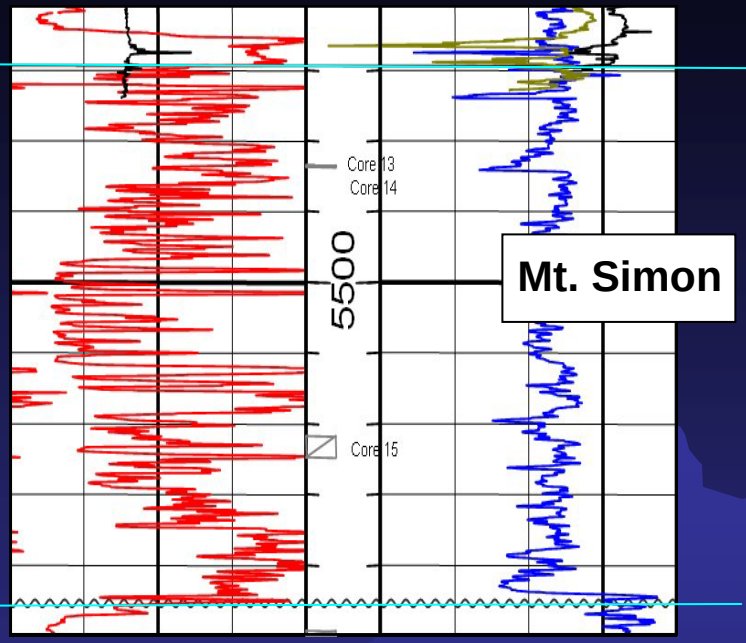
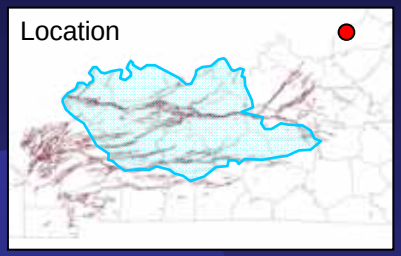
Potential reservoirs at depth: Mount Simon





Case in Point:

Dupont No. 1WAD, Louisville KY



Initially targeted Mt. Simon

- **Encountered tight sand, and came up the hole into the overlying Knox Formation**

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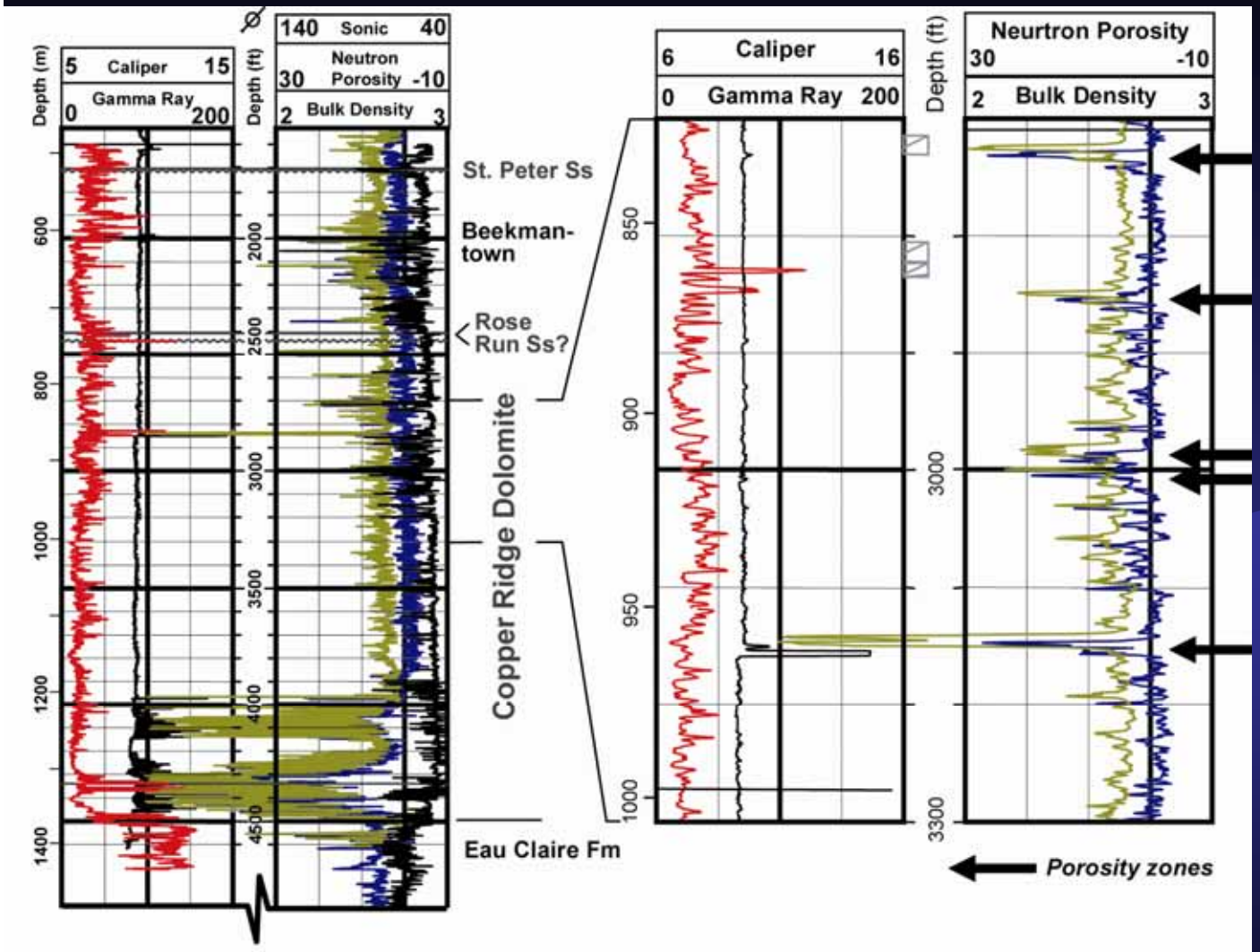
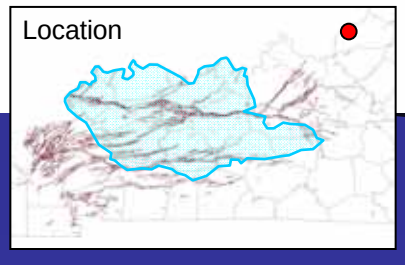
Potential reservoirs at depth: Knox





Case in Point:

Dupont No. 1WAD, Louisville KY

- Found multiple thin vuggy to cavernous and fracture-associated porosity zones in the Knox (2,775-3,160 ft)

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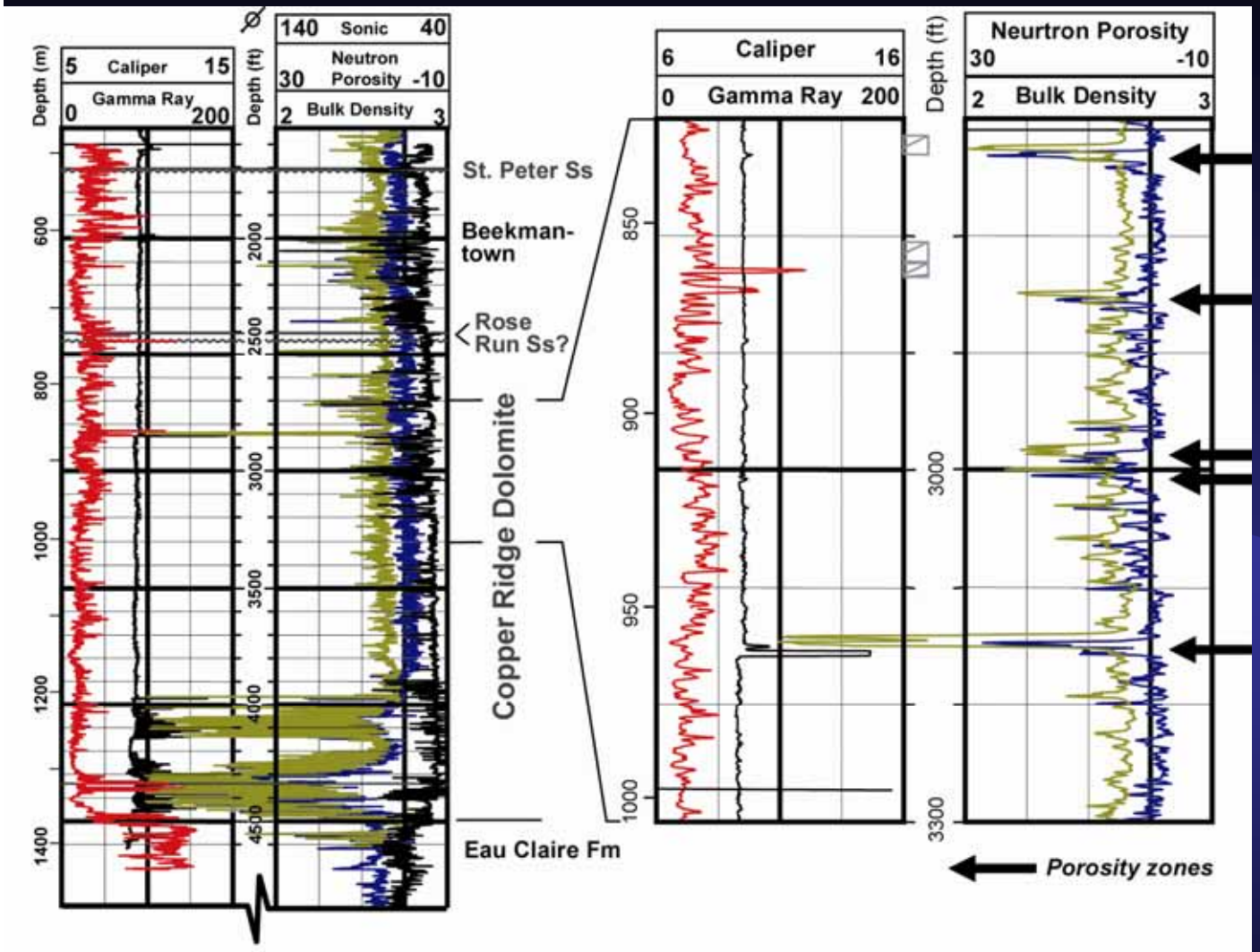
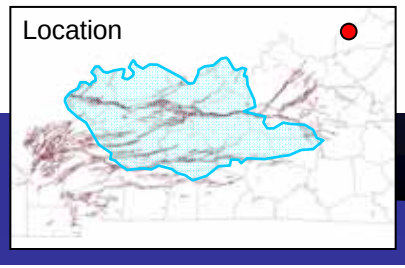
Potential reservoirs at depth: Knox





Case in Point:

Dupont No. 1WAD, Louisville KY

- Injection rates of 150 gallons per minute (5,100 bbls per day) with probably less than 100 psi differential into the zone
- Injected for 3 years.

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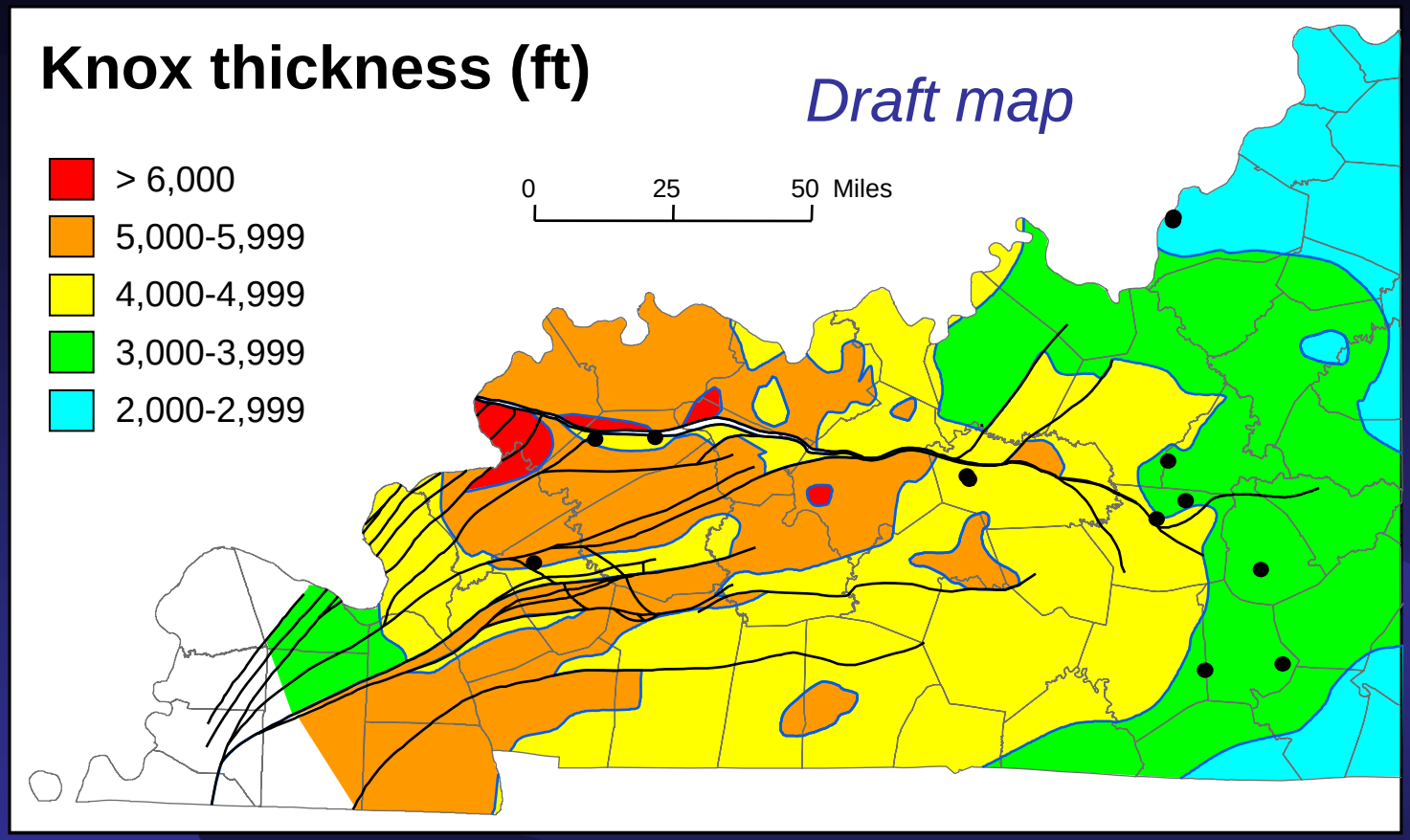
Potential reservoirs at depth: Knox



The Knox is a widespread, thick unit

- **Dominantly non-porous dolomite, but known to have several different porosity zones locally**

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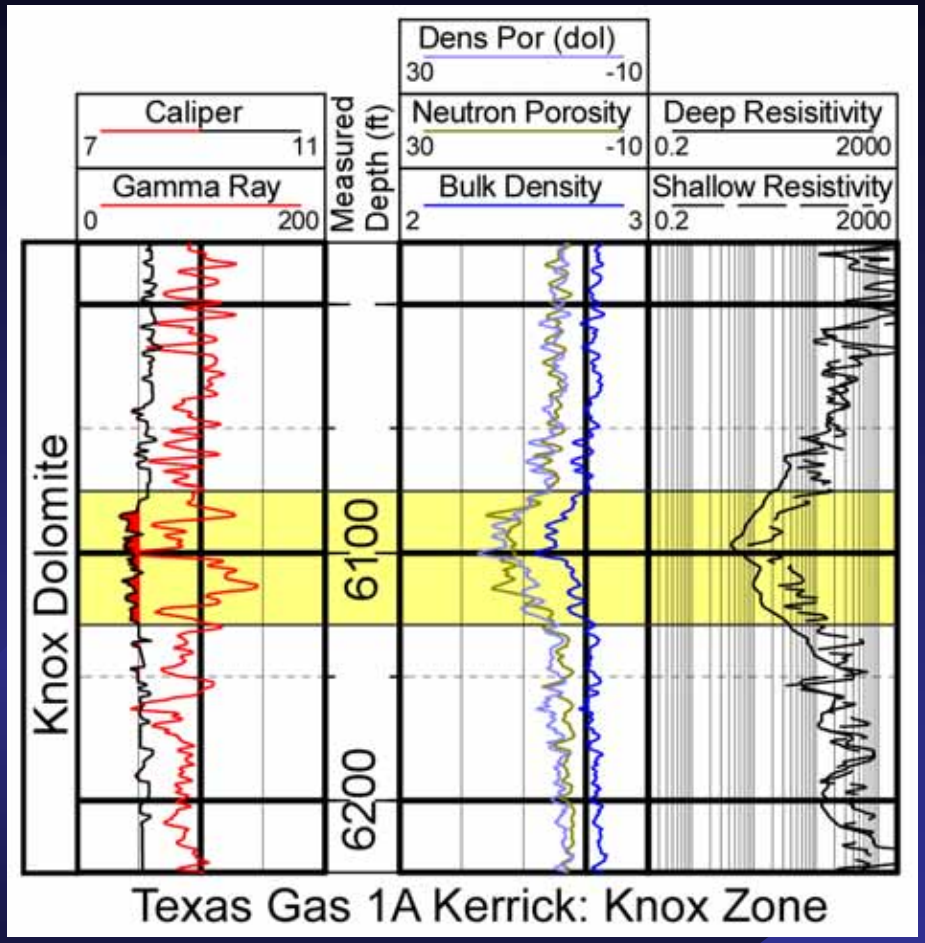
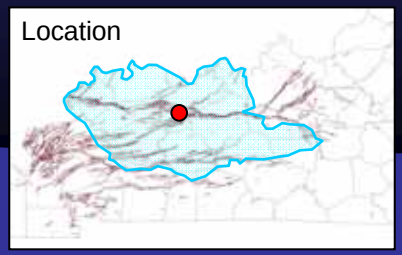
Potential reservoirs at depth: Knox

Texas Gas No. 1A Kerrick well, McLean County, Kentucky

This was Kentucky's FutureGen proposal target

- **54 ft net matrix porosity >4%**
- **Mean density porosity is 9.3% (range 4 to 17%).**
- **Mud cake on caliper log (shaded red), and invasion profile of resistivity logs indicate significant permeability**





Porosity in Copper Ridge (Lower Knox)

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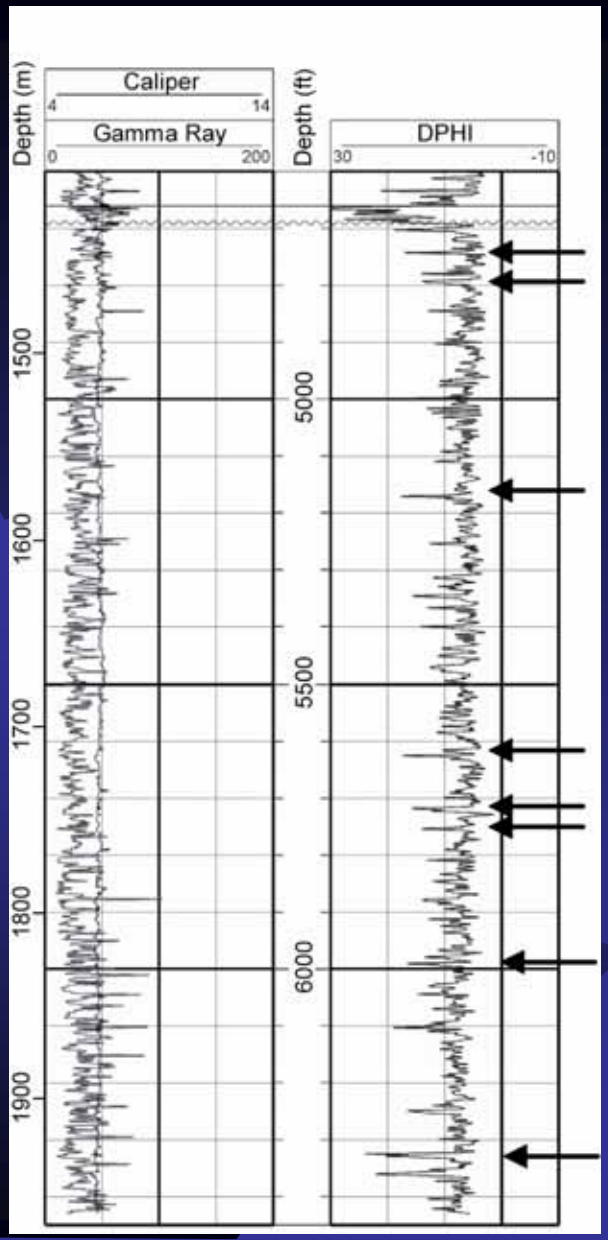
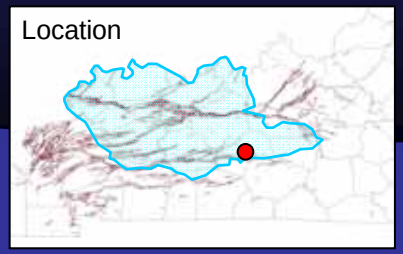
Potential reservoirs at depth: Knox

IMCO Recycling Waste Injection Site, Butler County, Kentucky

The only active waste injection site in Kentucky

- **Multiple, thin porosity intervals in the upper 1,760 ft of Knox**
- **Inject open hole through interval**
- **11 years, 3.5 million bbls injected**
- **No cores**





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Potential reservoirs at depth: Knox

Gas storage fields in central Kentucky

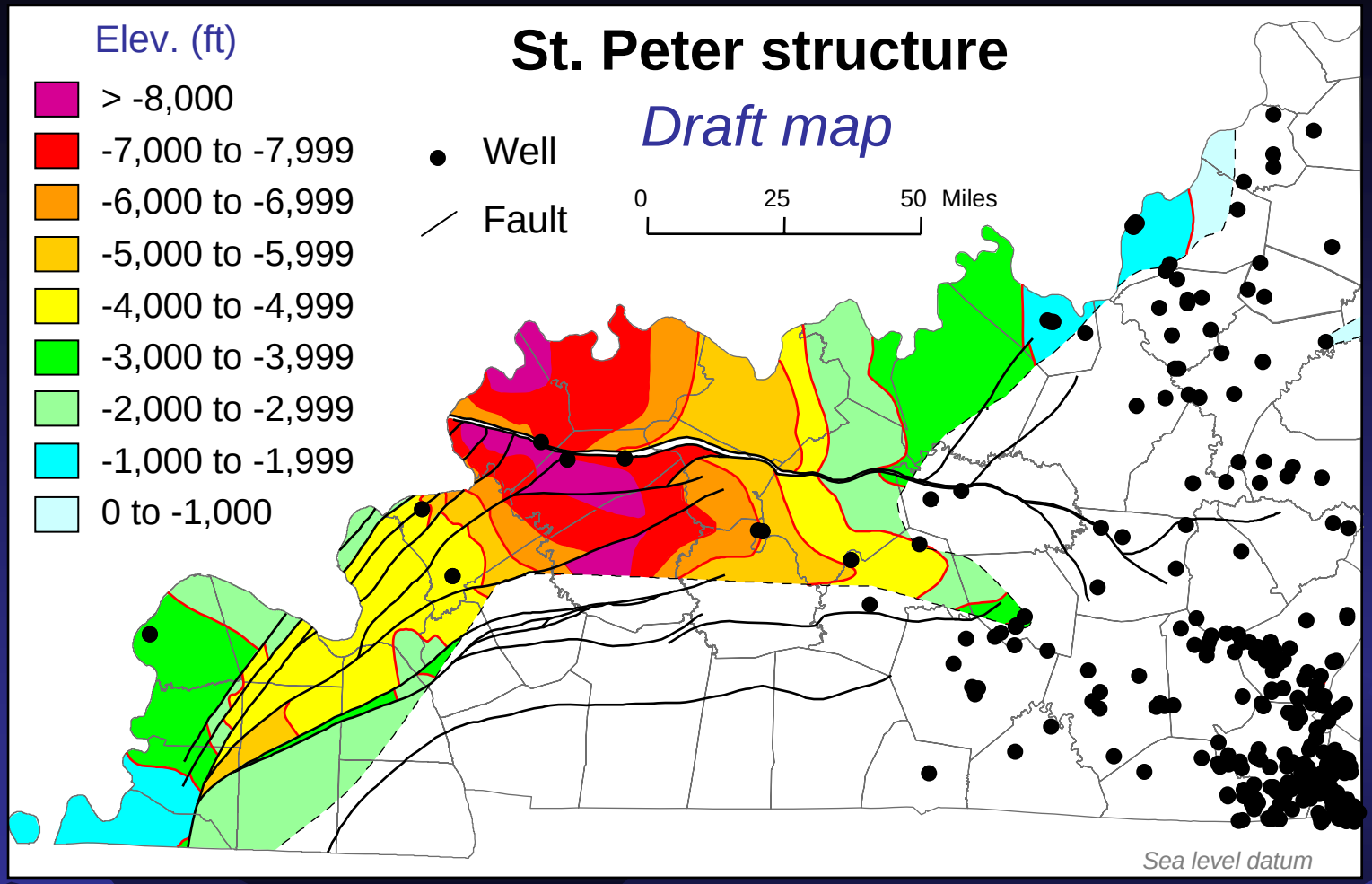
Several Knox gas (methane) storage fields at shallow (immiscible) depths in unconformity traps at the top of the Knox in north-central Kentucky

- **Numerous Knox oil fields associated with unconformity "highs" and fractures in south-central Kentucky**
- **Need close data spacing to detect**

- Knox gas storage
- Knox oil field area

KYCCS

Potential reservoirs at depth: St. Peter



The St. Peter Ss. overlies the Knox at depths of 3,000 to 8,500 ft. in most of western Kentucky

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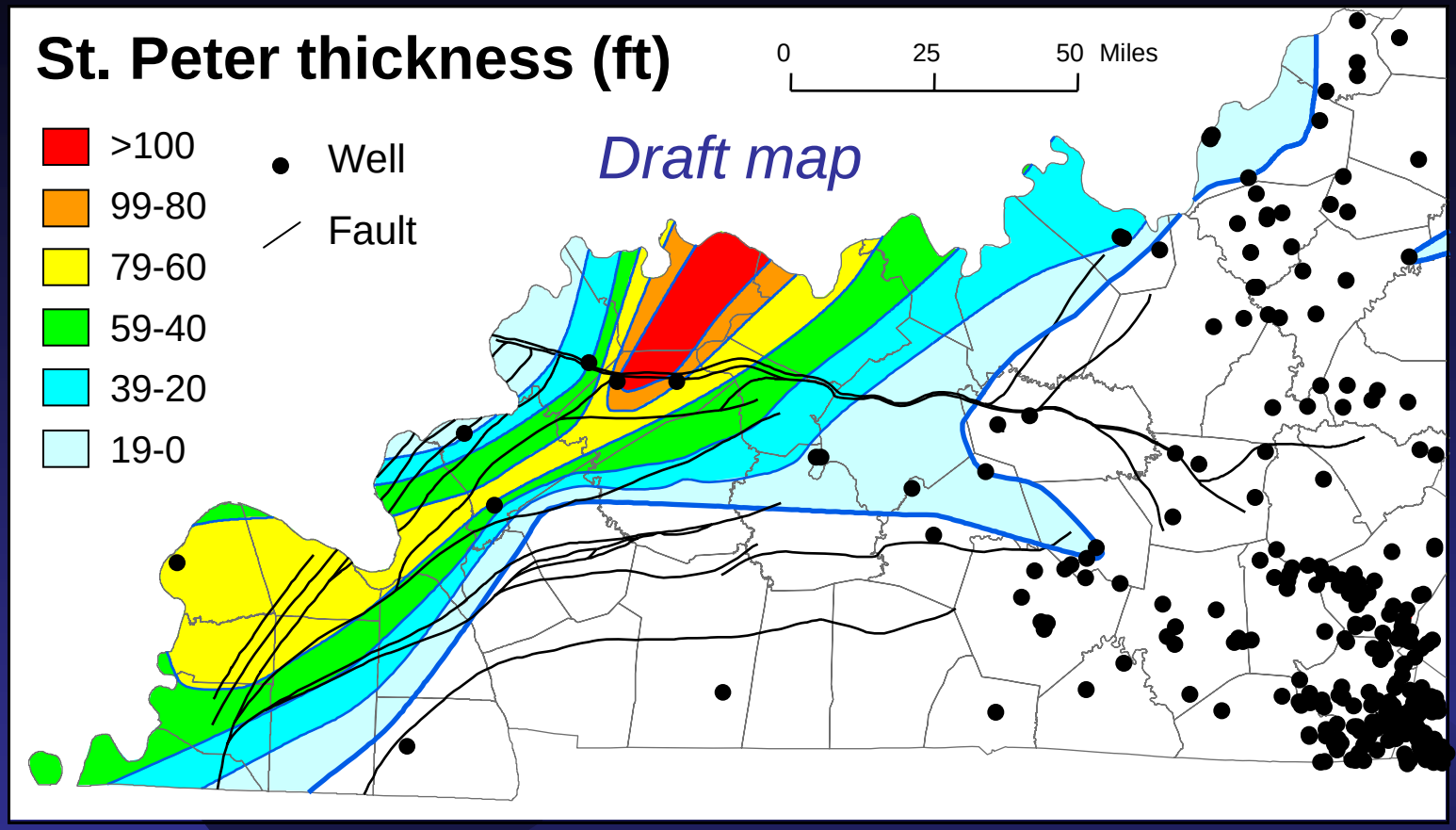
Potential reservoirs at depth: St. Peter



The St. Peter is 0 to 100 ft thick in western KY

- **Extends partly into Rough Creek Graben**

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Potential reservoirs at depth: St. Peter

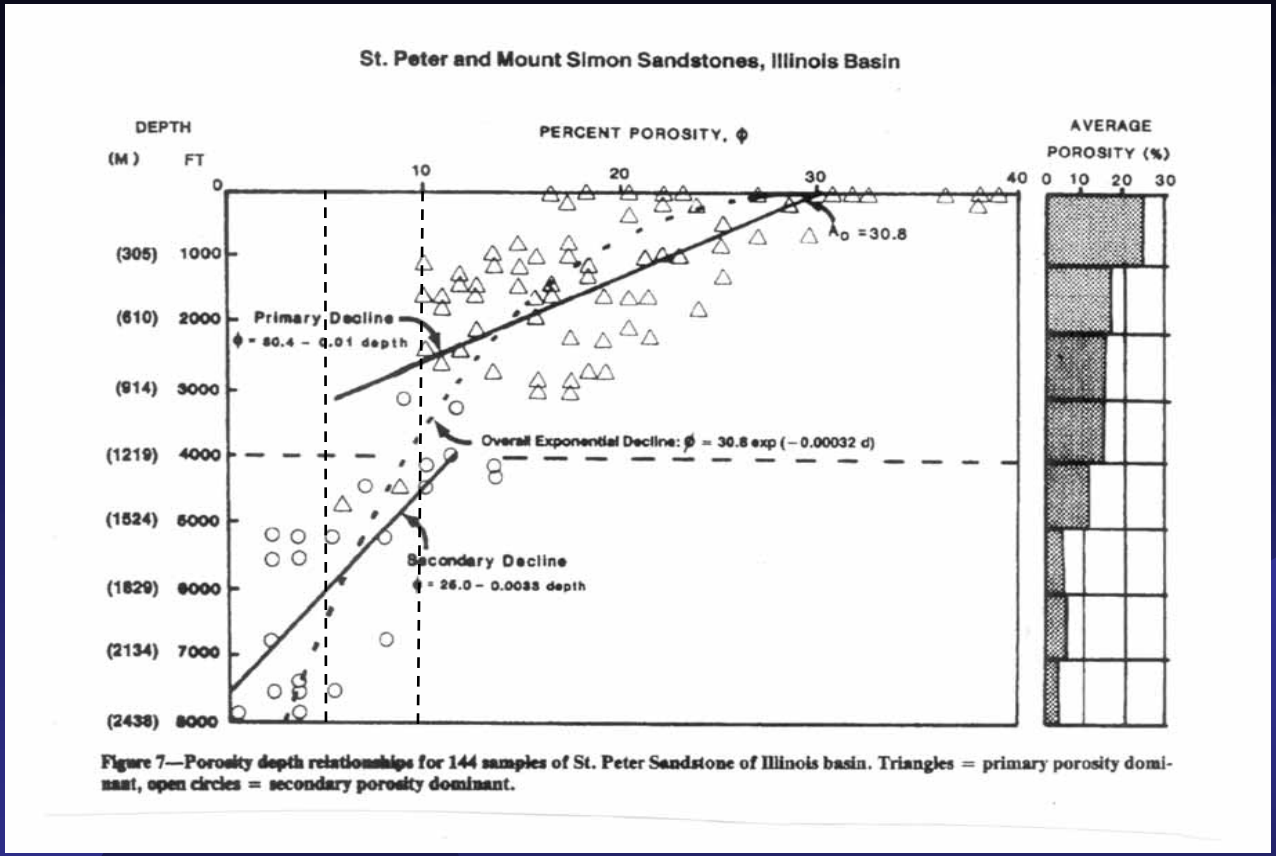


Figure 7—Porosity depth relationships for 144 samples of St. Peter Sandstone of Illinois basin. Triangles = primary porosity dominant, open circles = secondary porosity dominant.

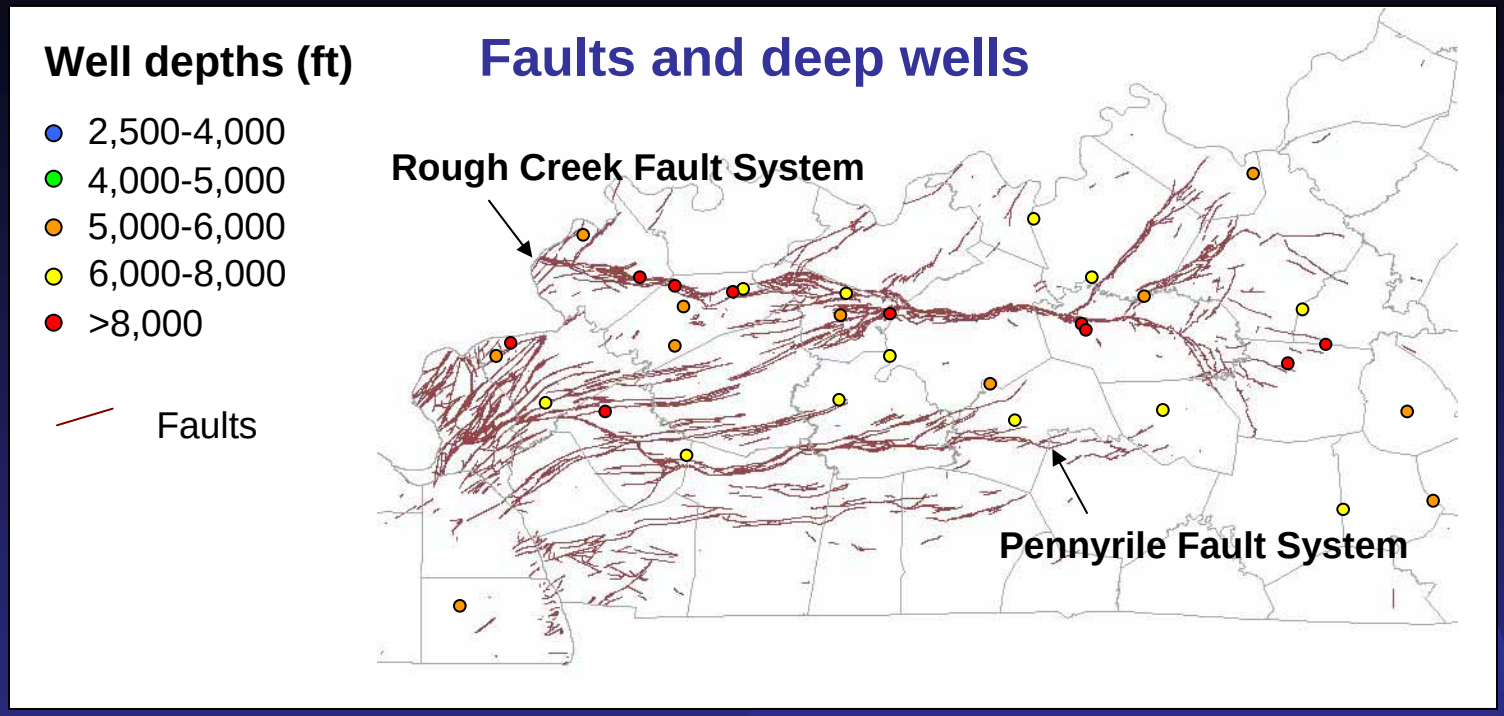
Similar to the Mt. Simon, research indicates decreasing porosity with depth for the St. Peter

- **Few data in western Kentucky**

From Hoholick and others, 1984, AAPG Bulletin

KYCCS

Fault Leakage issues



Faults can act as both reservoir seals and pathways for leakage

- **Most of the deep wells in Kentucky were drilled on structures associated with faulting**
- **If storage-plume areas intersect faults, sealing properties will need to be determined**

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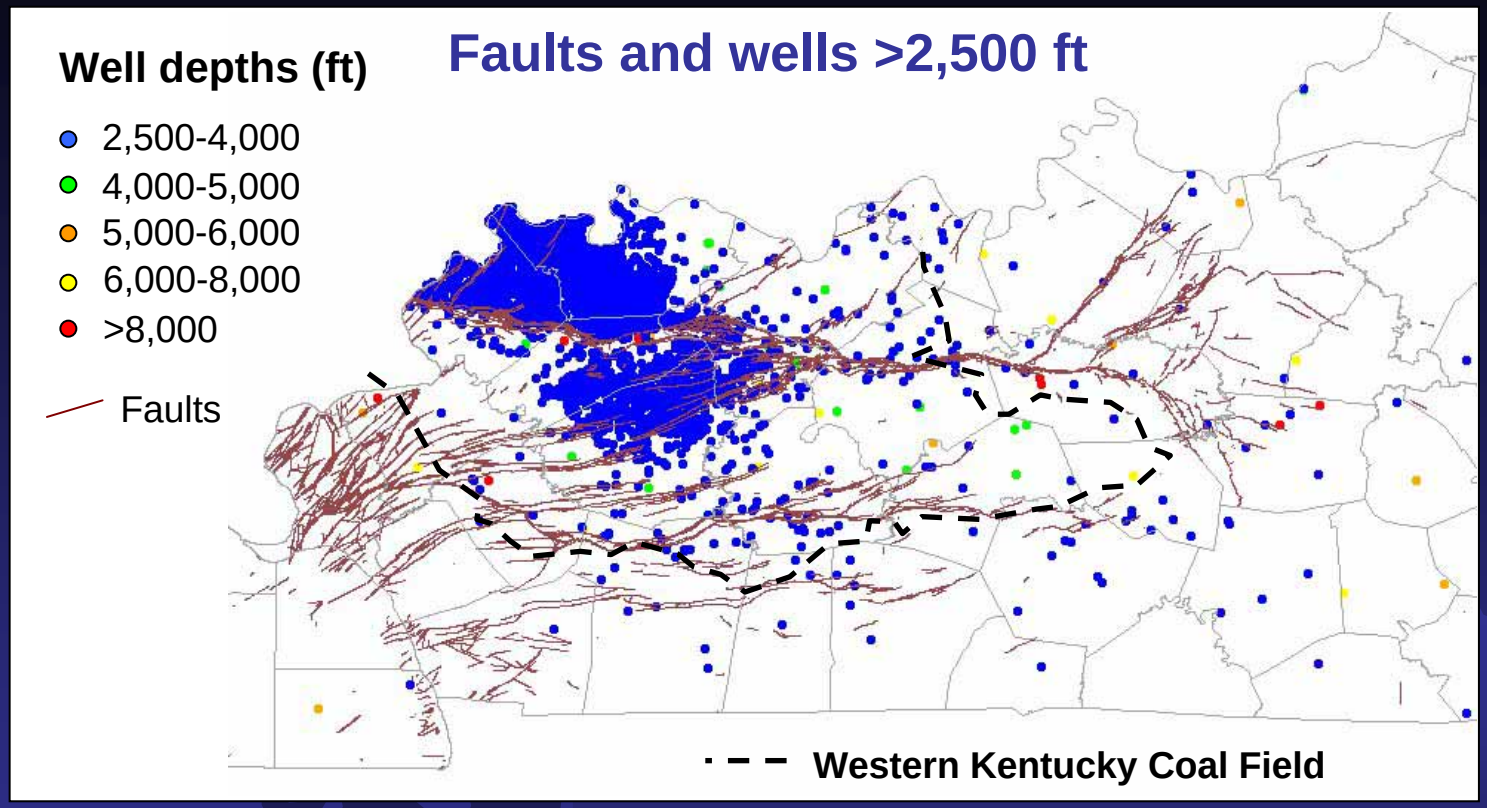
Old Well Bore Leakage Issues



Another potential leakage pathway is old well bores

- Saline formations not penetrated by large numbers of wells are favorable to units that are widely penetrated

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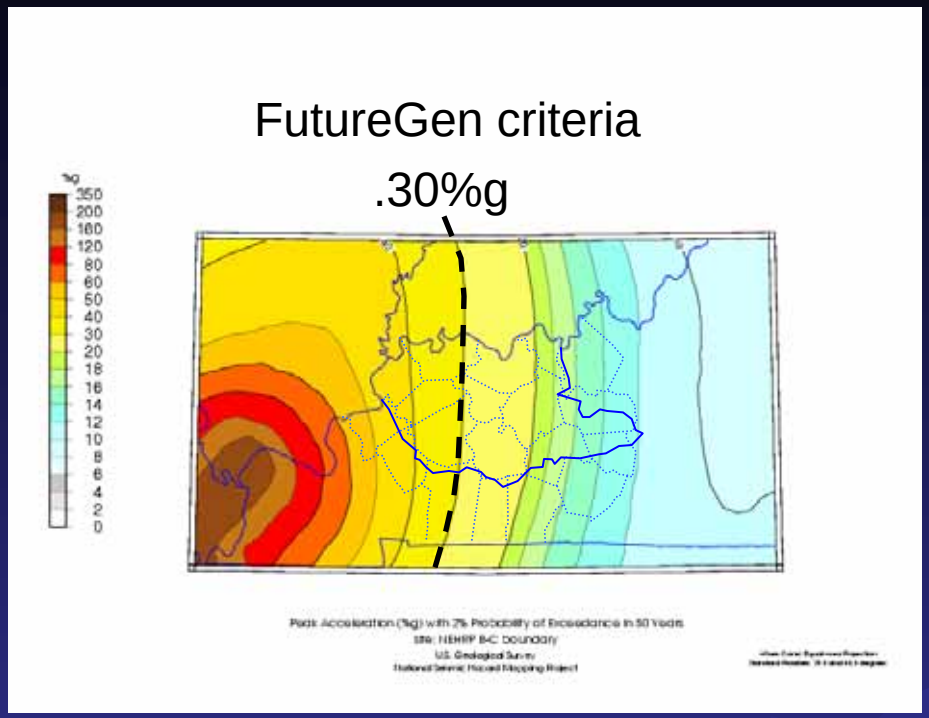
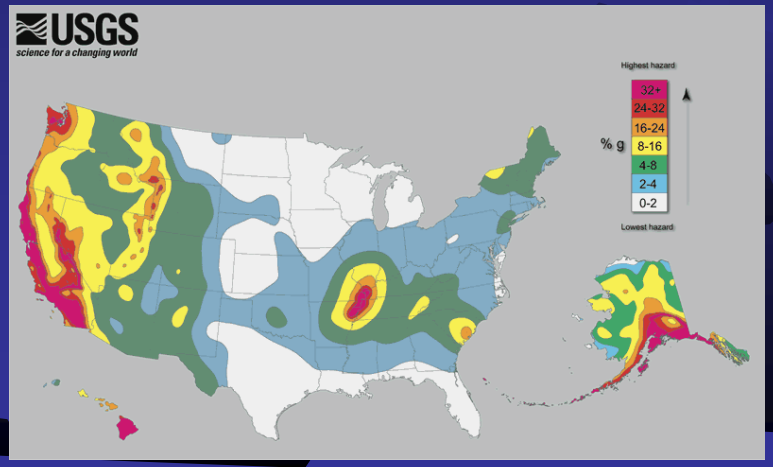
Seismic risk Issues



In the FutureGen proposals, seismic risk limits were set at peak acceleration of 0.3% g with 2% probability of exceedence in 50 years by the Federal government

- **Such a limit would restrict the western part of the Western Kentucky Coal Field from consideration**
- **We don't have to use this restriction, but we need to be aware that similar seismic risk restrictions are likely for future plants using Federal funds**



http://earthquake.usgs.gov/research/hazmaps/products_data/images/nshm_us02.gif

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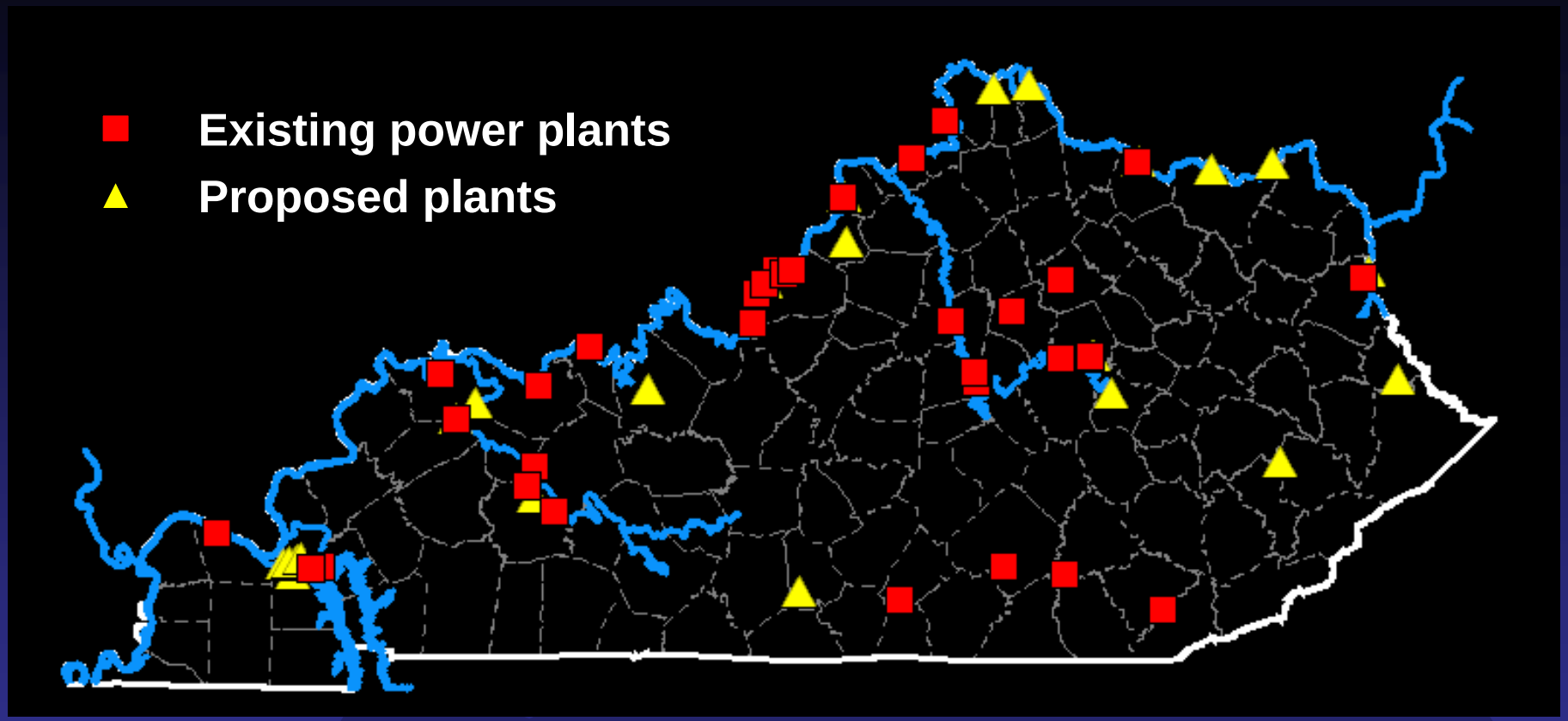
Water supply issues



Another issue might be proximity to large water supplies

- Power plants and potential coal-to-liquids plants that will need CO_2 storage also need large water supplies
- Not needed for test hole, but may need to be considered when choosing sites

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Maximum? project depths

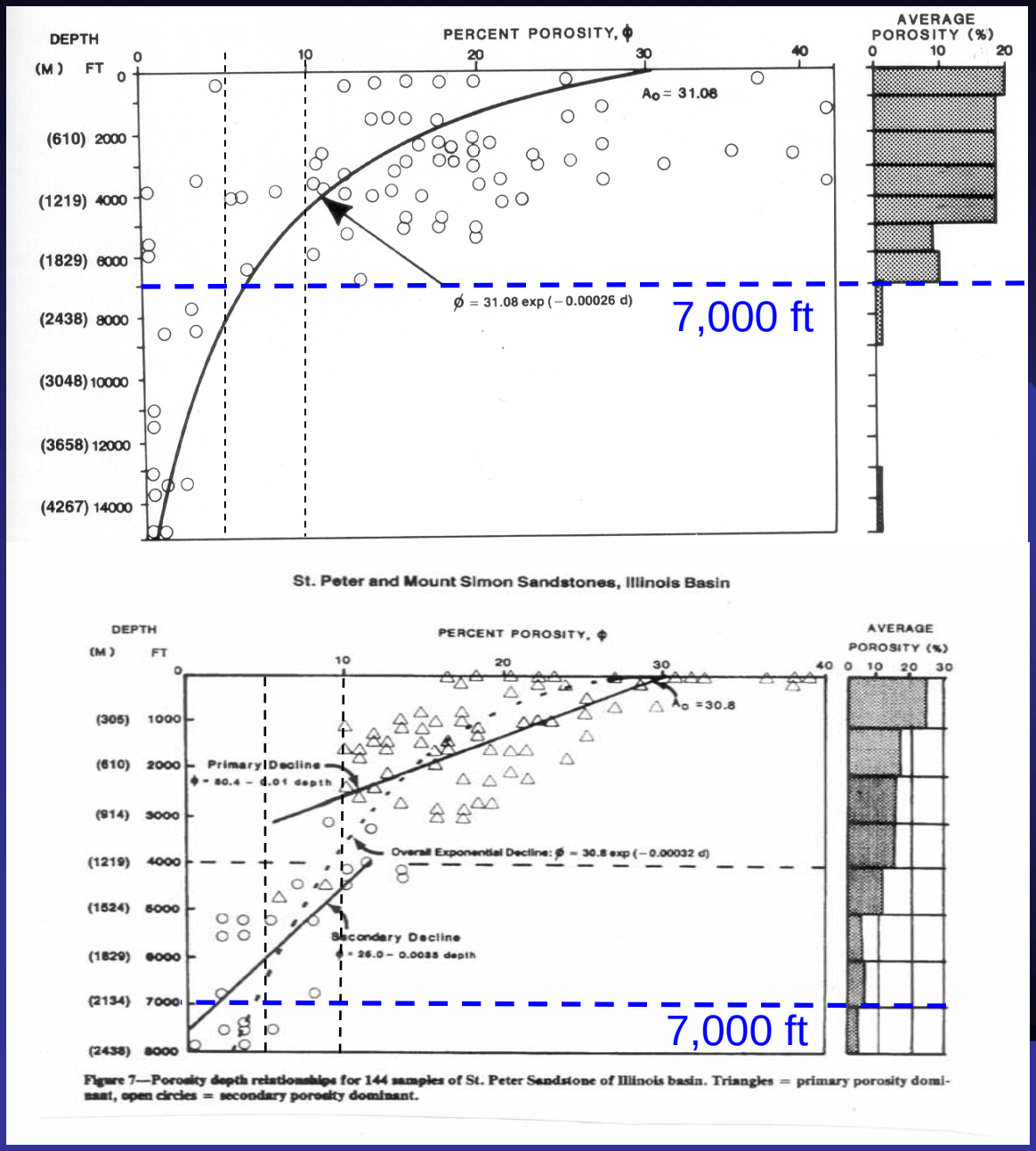

Figure 7—Porosity depth relationships for 144 samples of St. Peter Sandstone of Illinois basin. Triangles = primary porosity dominant, open circles = secondary porosity dominant.

Previous research (Hoholick and others, 1984) shows diminishing porosity with depth in the St. Peter and Mount Simon sandstones

- Little evidence for more than 5% porosity at depths of more than 7,000 to 8,000 ft
- Expenses of drilling increase with deeper depths

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Potential site selection method

We can use the existing site bank developed for commercial-scale CTL and CTG plants by the Governor's Office of Energy Policy or look for other available areas for drilling. Then we need to compare site characteristics through a series of weighted criteria

- Geologic and non-geologic criteria will have to be considered
  - ➢ The following shows how an initial geologic site selection might be done. It is not the final selection. It is only meant to show how a set of criteria might be used to help select an area. The actual criteria used have yet to be decided.

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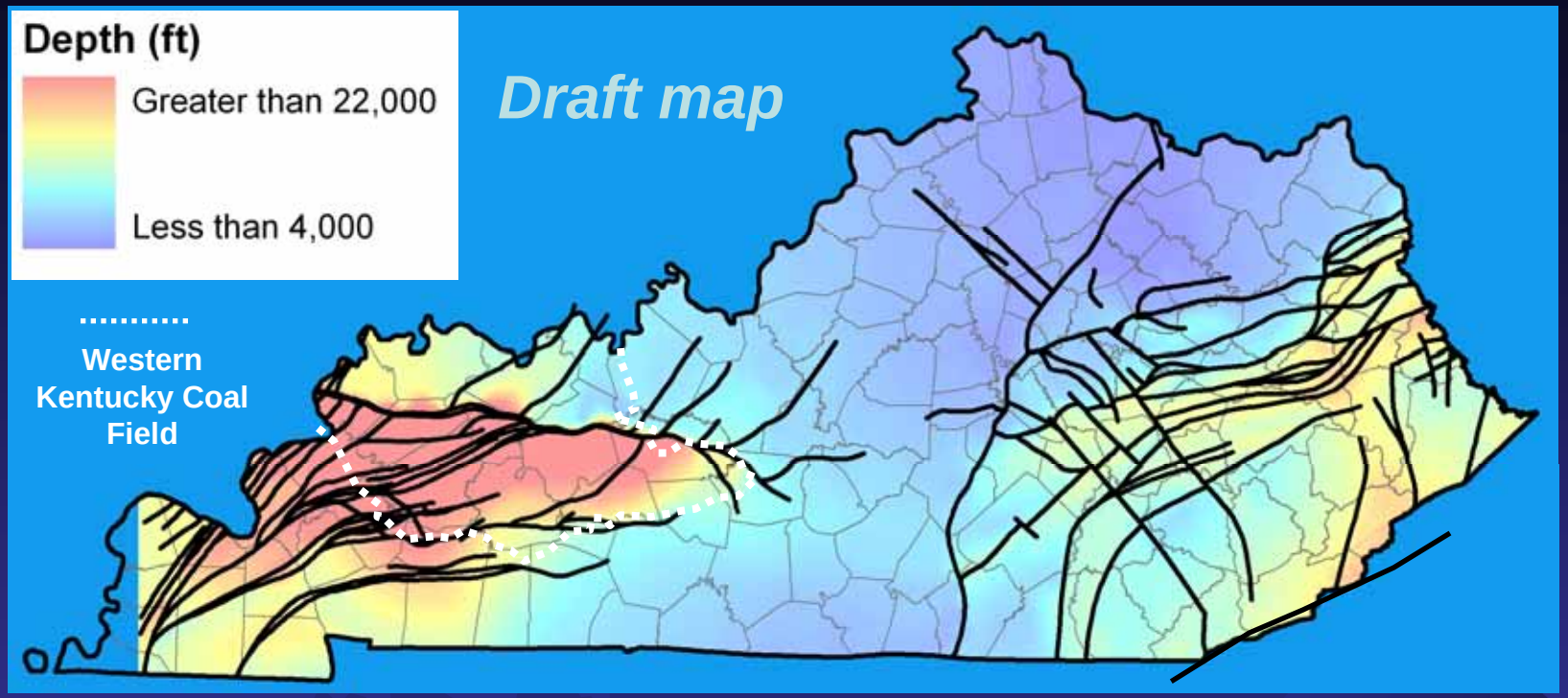
Potential site selection method to show how a set of criteria might be used to help screen sites



Depth to the Precambrian basement

For example, if we want to test the major regional saline reservoirs, including basal sands, but at depths not exceeding 8,000 ft. in order to maximize potential for porosity in deep sandstones, then….

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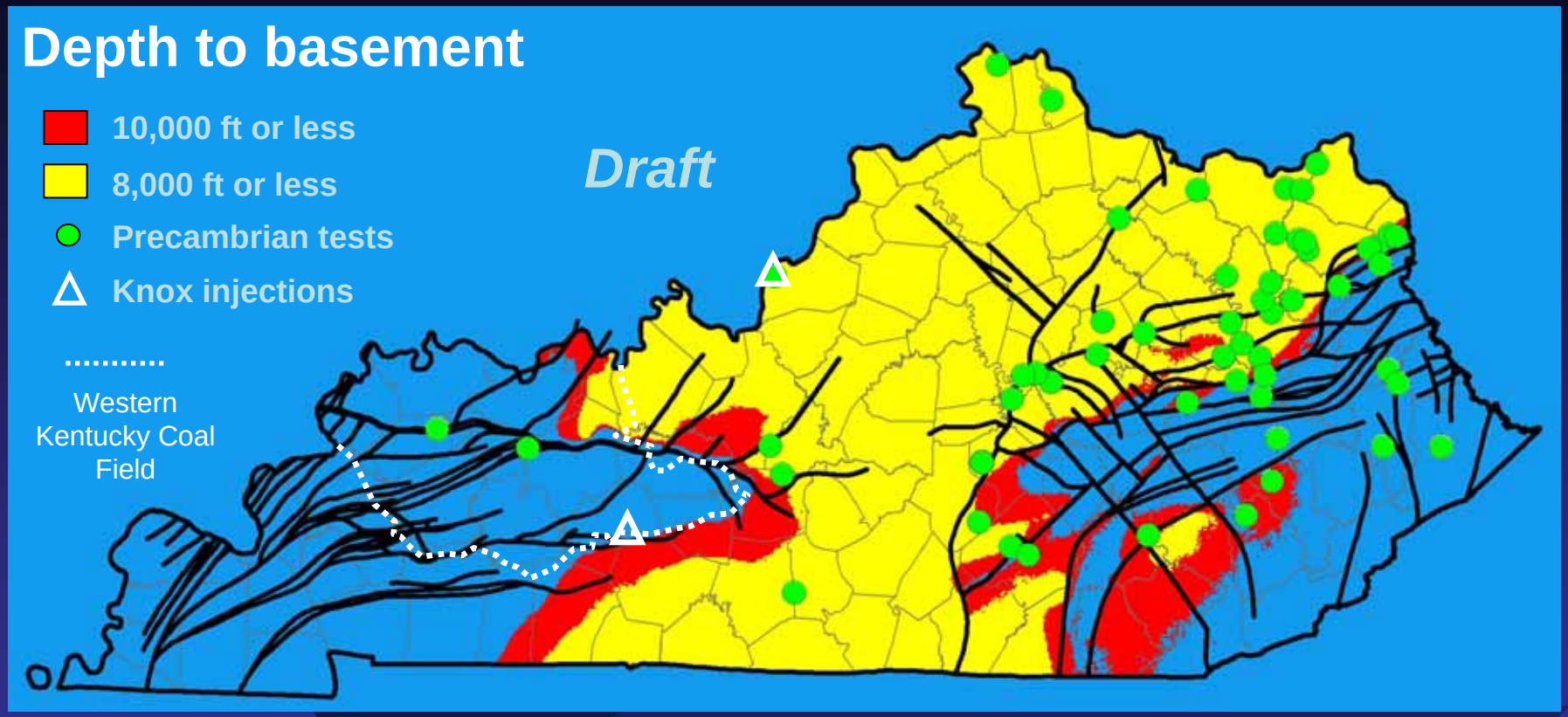
Potential site selection method to show how a set of criteria might be used to help screen sites



This would result in site selection weighted toward the eastern margin of the WKY coal field (and areas east of coal field)

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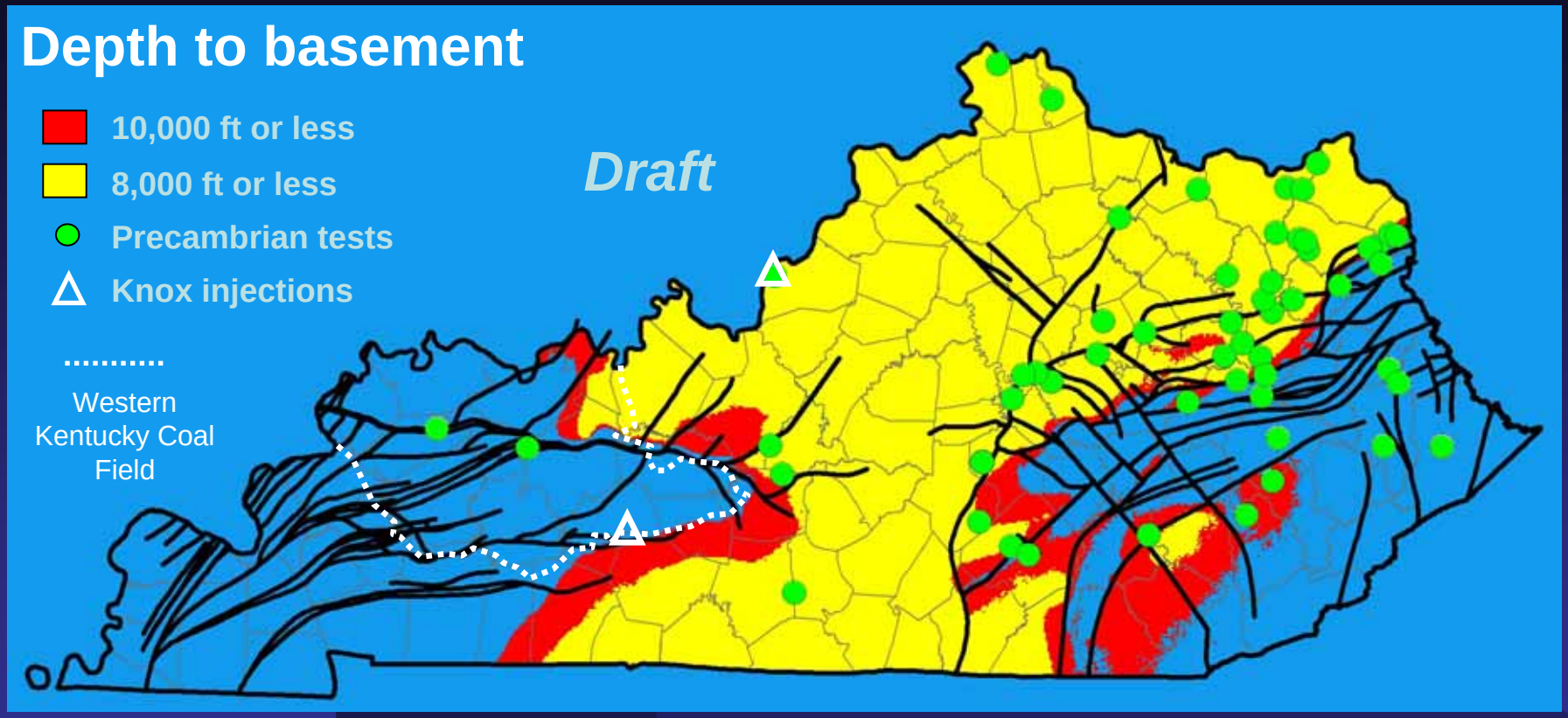
Potential site selection method to show how a set of criteria might be used to help screen sites



- The farther west we look in the WKY coal field, the deeper and more expensive a well will be to test the Mt. Simon

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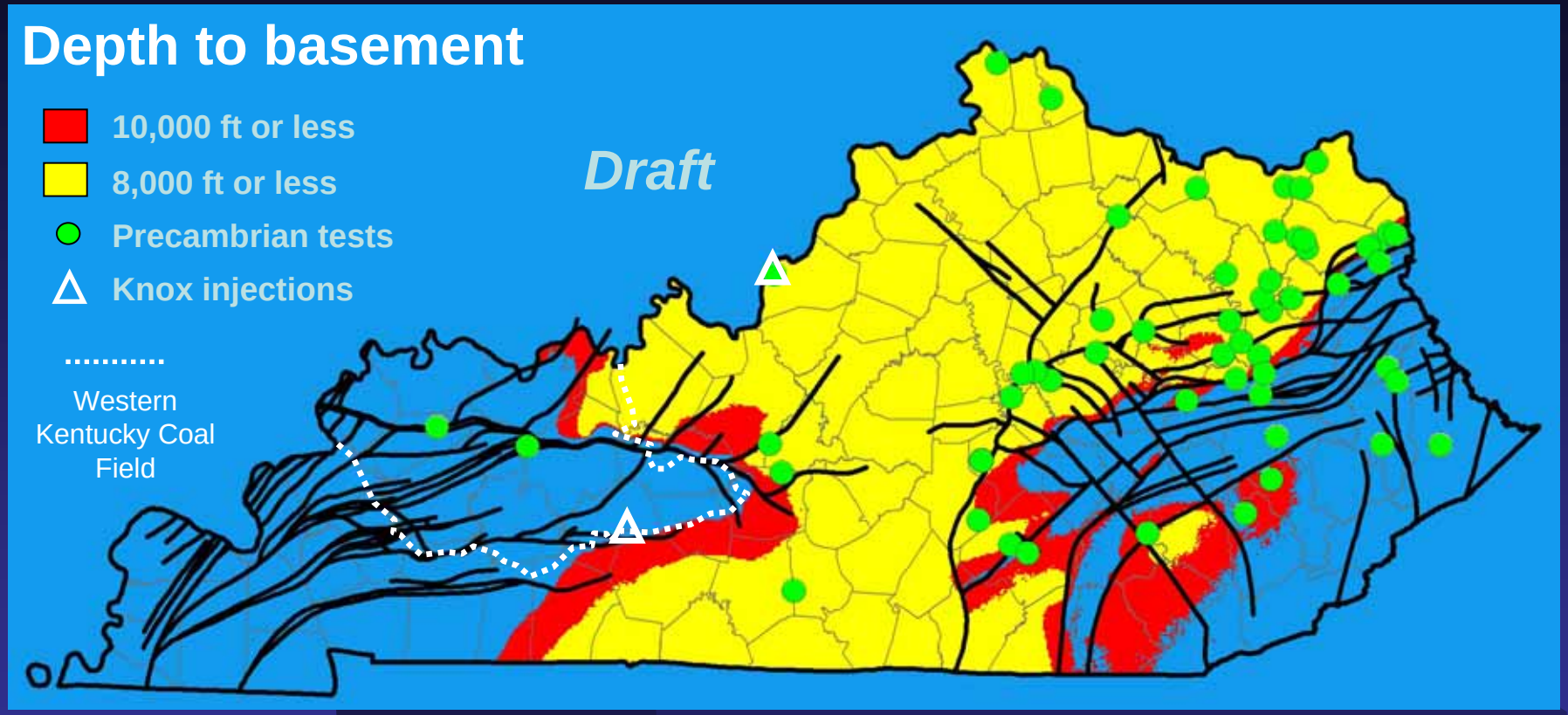
Potential site selection method to show how a set of criteria might be used to help screen sites



- Also, the Mt. Simon will be at depths where it has little porosity elsewhere in the basin
- Shallower options might have to be considered

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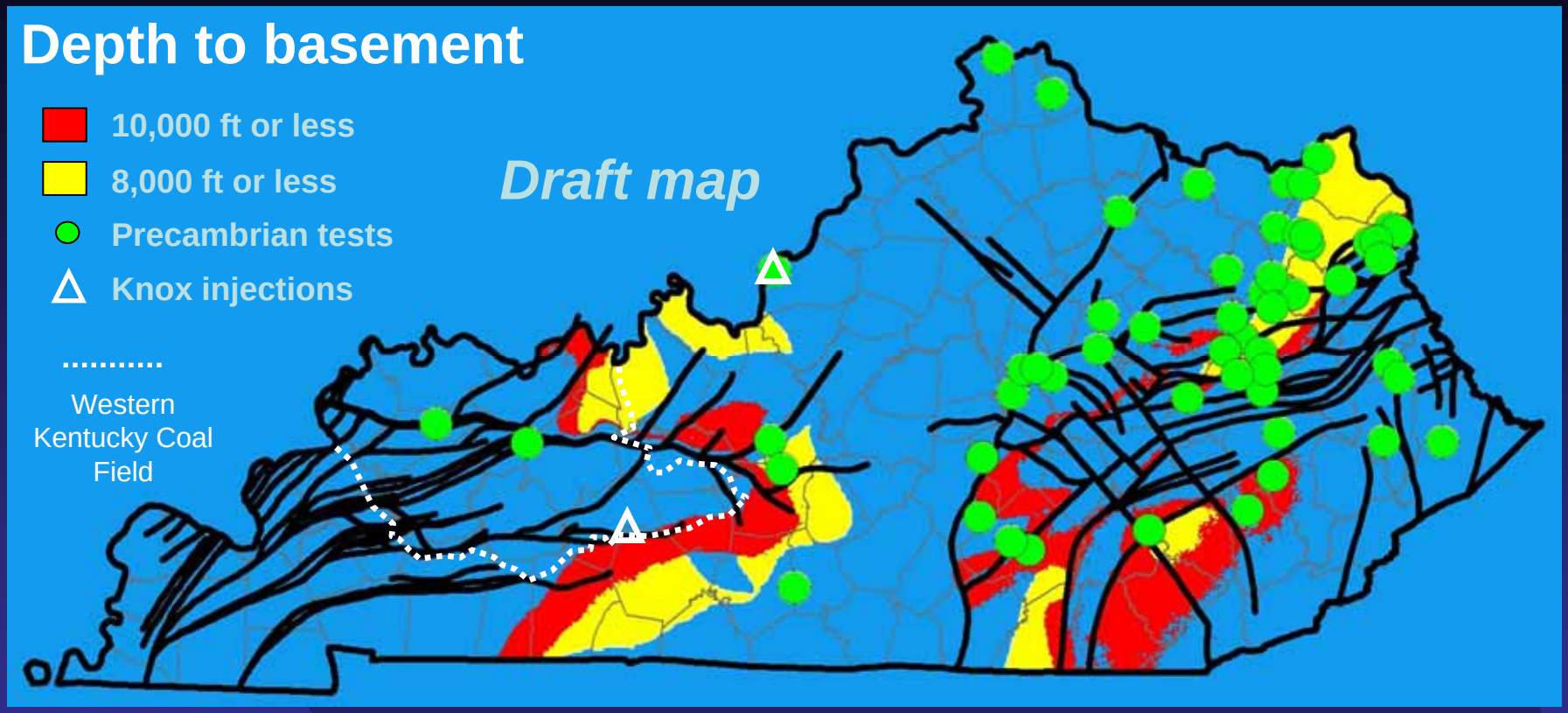
Potential site selection method to show how a set of criteria might be used to help screen sites



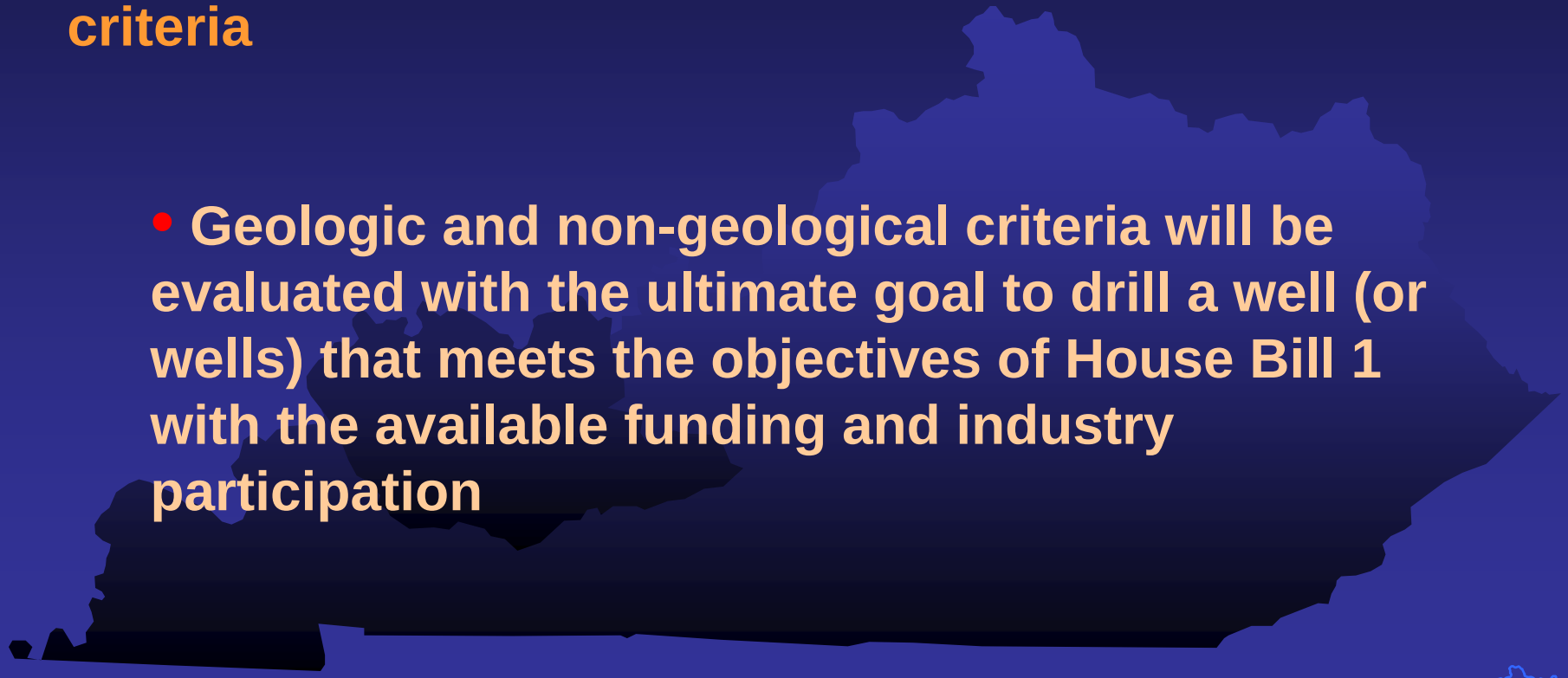
- If we further restrict area to where there is basal sands, Mt. Simon, St. Peter (or other deep sandstones including some Silurian sands) at depths between 8,000 to 2,500 ft, in order to intercept multiple horizons in this range, the area is more limited

KYCCS

Potential site selection method to show how a set of criteria might be used to help screen sites

This example scenario shows how a set of criteria might be developed to aid in determining the area best suited for a test well. It is not the final set of criteria

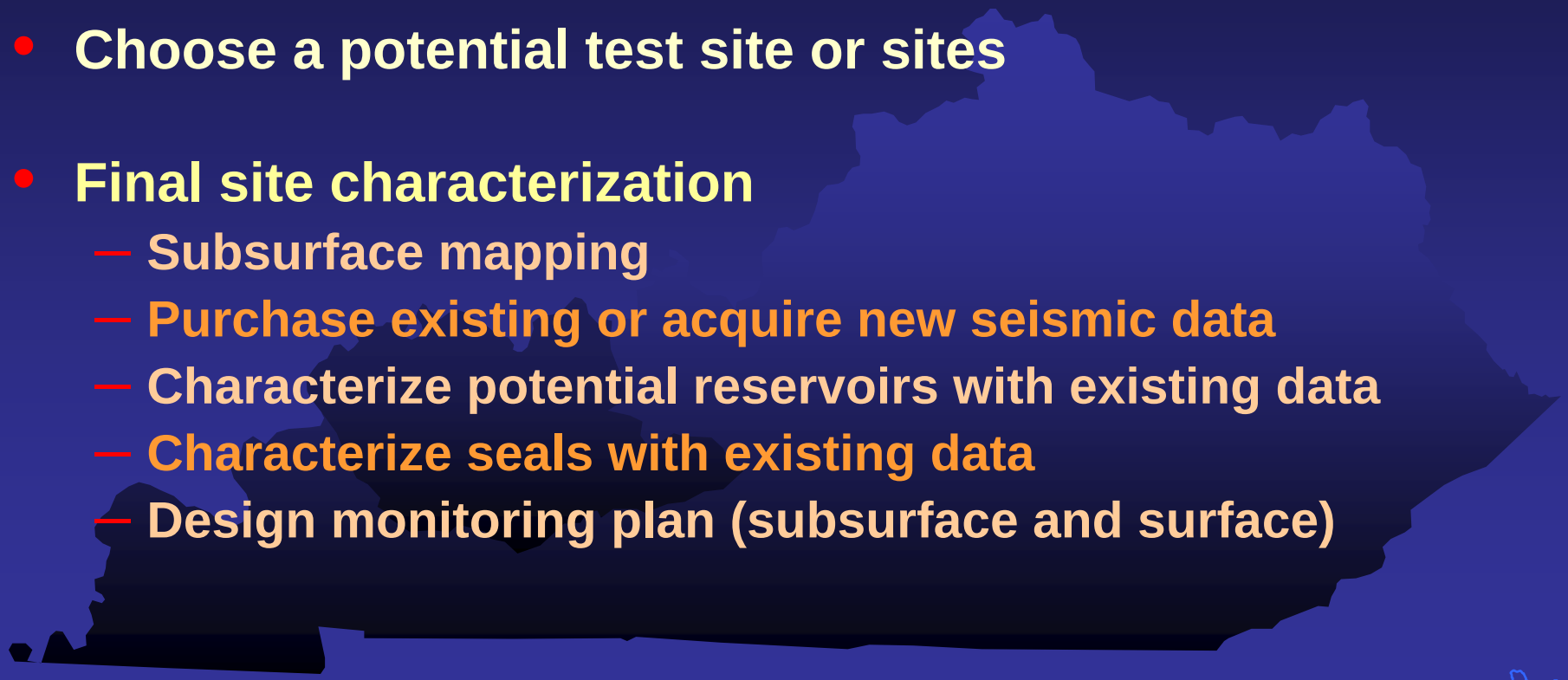
- **Geologic and non-geological criteria will be evaluated with the ultimate goal to drill a well (or wells) that meets the objectives of House Bill 1 with the available funding and industry participation**



Western Kentucky Deep Well Planning

A working committee that includes KGS and industry partners must work together to:

- **Finalize site screening criteria**
- **Choose a potential test site or sites**
- **Final site characterization**
  - **Subsurface mapping**
  - **Purchase existing or acquire new seismic data**
  - **Characterize potential reservoirs with existing data**
  - **Characterize seals with existing data**
  - **Design monitoring plan (subsurface and surface)**



Western Kentucky Deep Well Planning

- Well design and engineering
- Permitting
- Drilling
  - 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, cements, mechanical strength, and other physical properties
  - Conduct injection tests using fluid, air or CO_2
- Monitoring, verification, and closure
- Public education and outreach
- Reporting and technology transfer

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Thank you

Let’s open the floor for questions

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Minimum storage depths

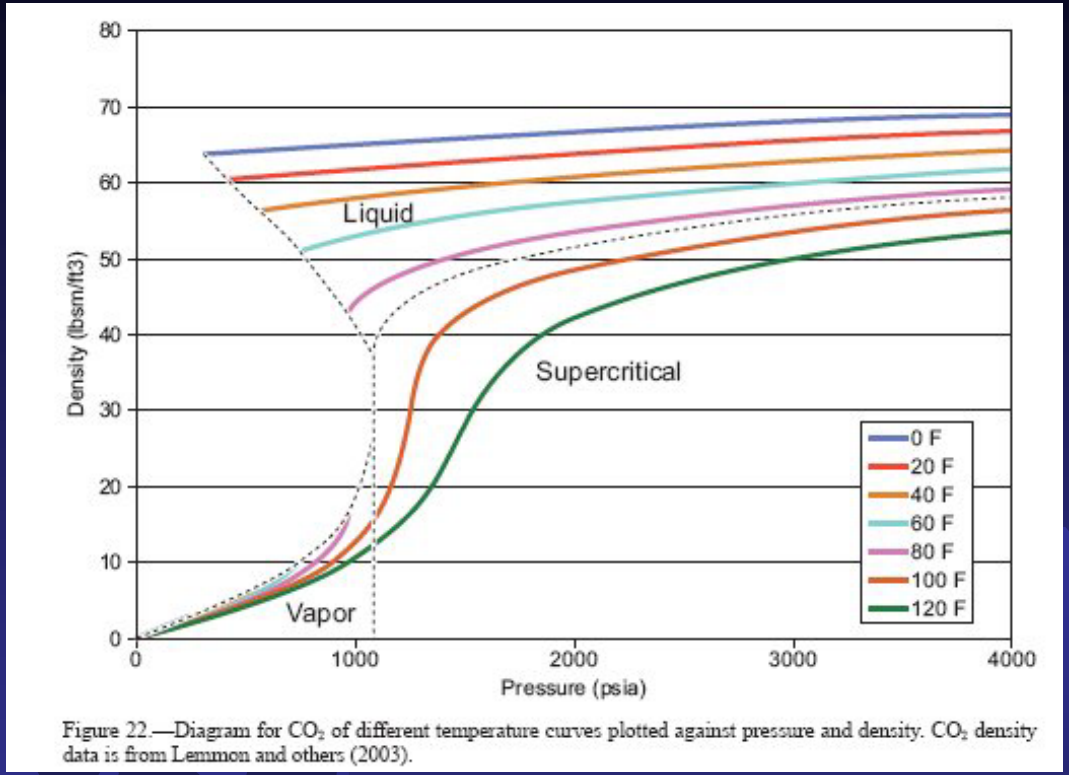


Figure 22.—Diagram for CO_2 of different temperature curves plotted against pressure and density. CO_2 density data is from Lemmon and others (2003).

Graph from MRCSP Phase 1 Final Report (Wickstrom end others, 2004)

The actual density and volume change of injected CO_2 will depend on the salinity (and density) of the formation water, reservoir temperature, and reservoir pressure…

…downhole data that is relatively lacking in Kentucky, and that will need to be collected in this test

KYCCS

Potential reservoirs at depth: Mount Simon

Mt. Simon core, Dupont well, Louisville, KY

Existing basin data (few in KY) indicates Mt. Simon cements are quartz and potassium feldspar overgrowths with lesser hematite, kaolinite, chlorite, chert, and carbonate (Hoholick and others, 1984).

KYCCS

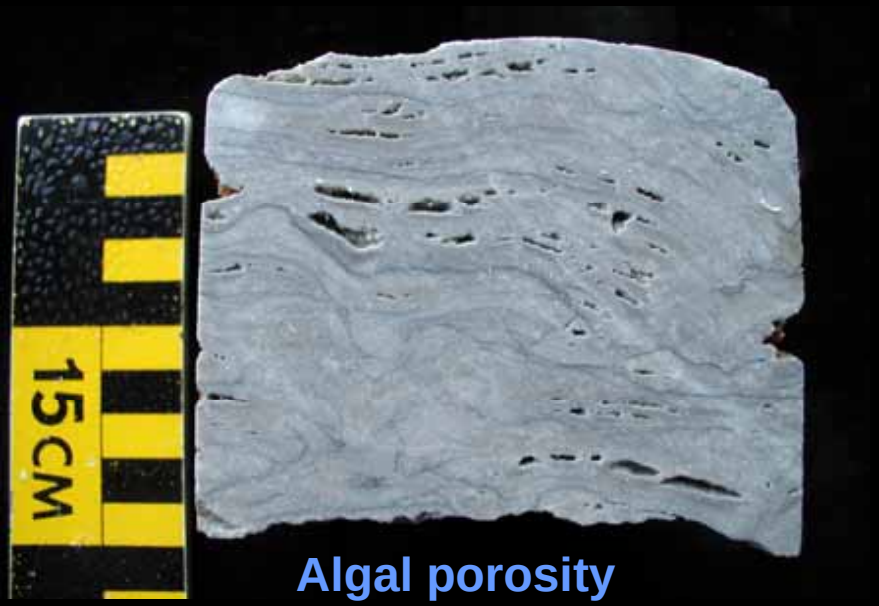
Potential reservoirs at depth: St. Peter

St. Peter is dominantly a fine-grained quartz sandstone with shale and carbonate interbeds

- Existing basin data (few in KY) indicates cements are calcite, dolomite, authigenic anhydrite, chert, chalcedony, chlorite, and quartz overgrowths (Hoholick and others, 1984).

KYCCS

Potential reservoirs at depth: Knox



Algal porosity

Dissolution and brecciation porosity

Fractures

Knox core, Dupont wells

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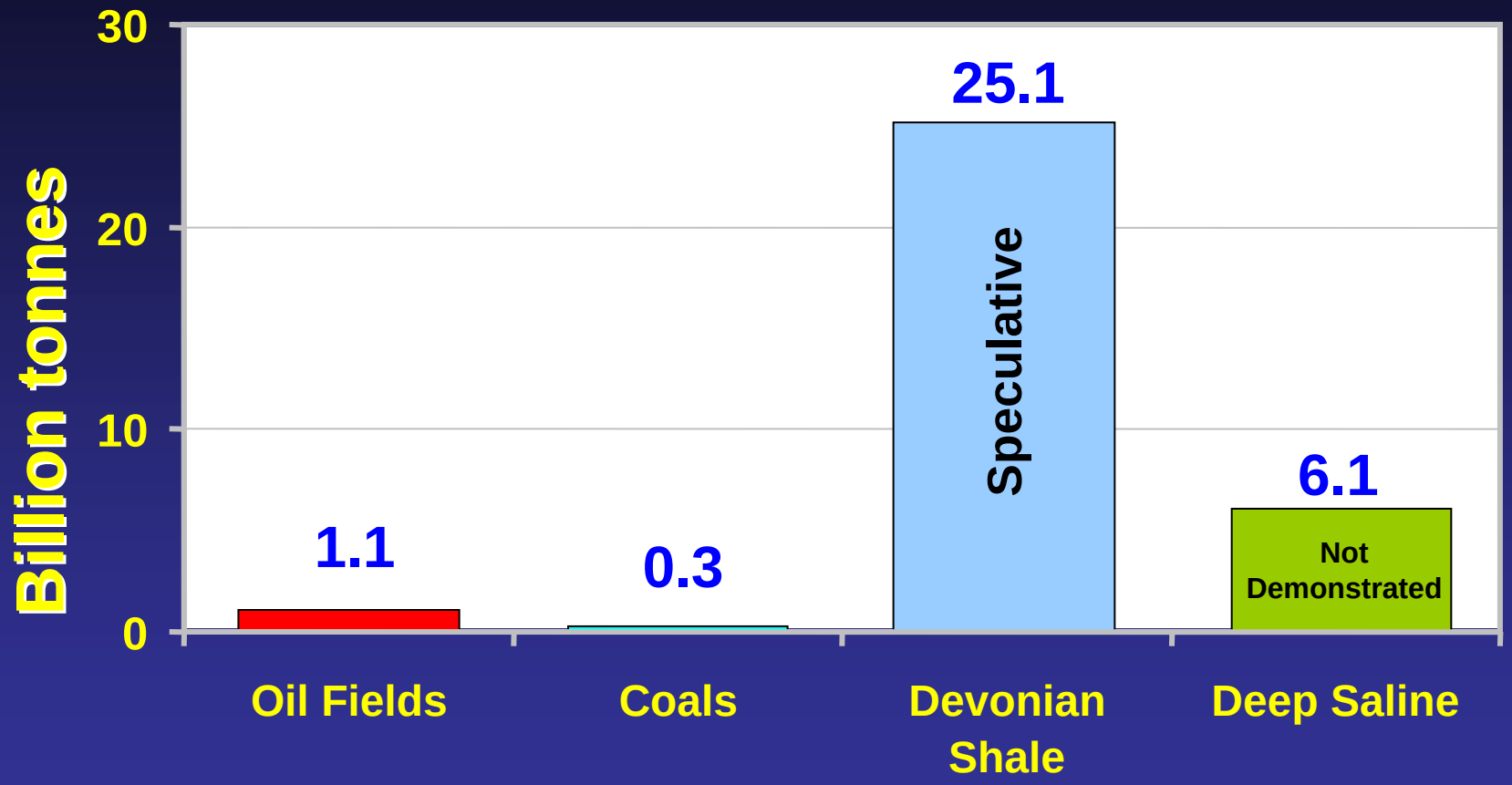
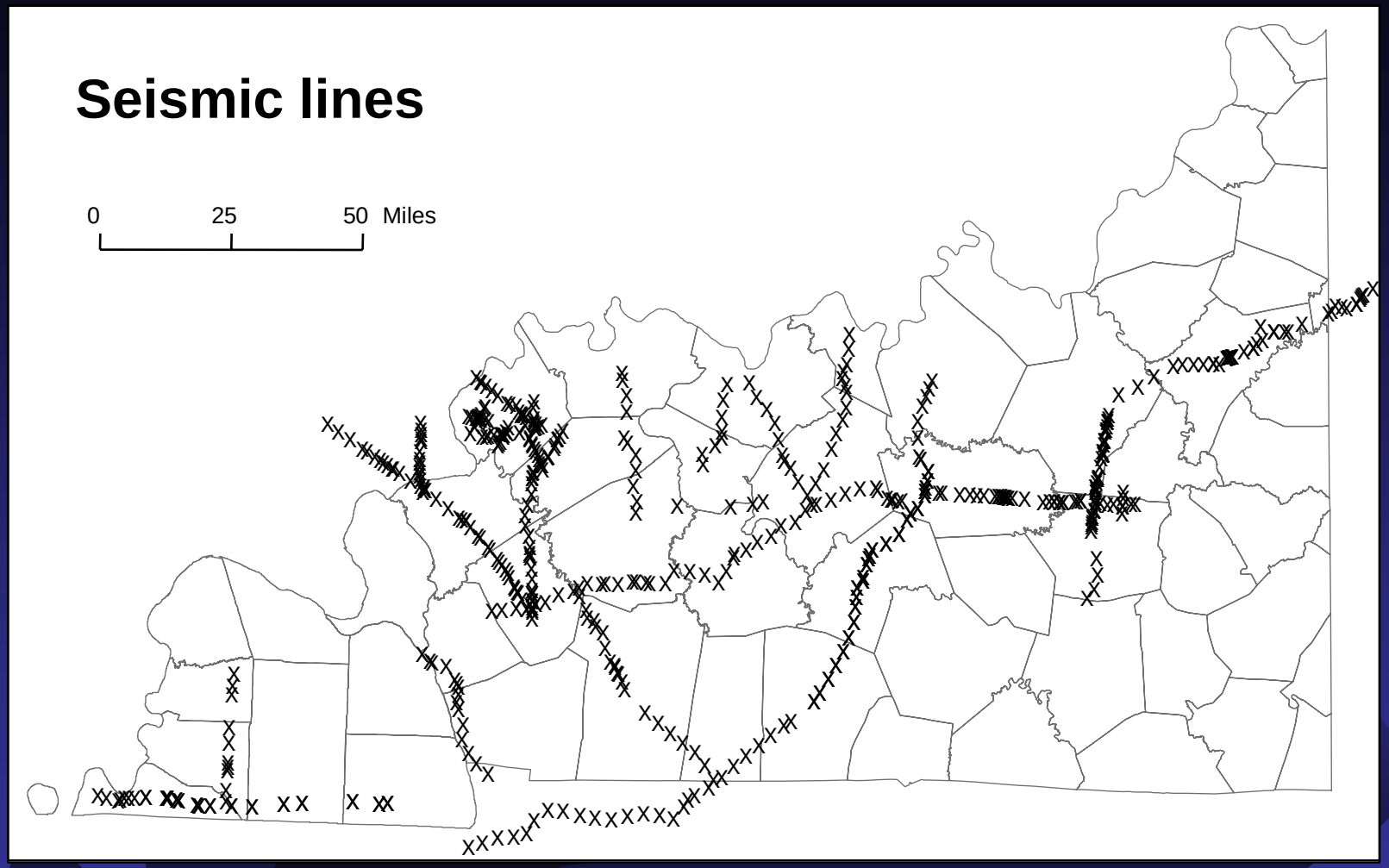
DOE Phase I CO_2 Storage Estimates



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

Kentucky data below minimum storage depths



Seismic data is used to infer rock units and faults at depth where well data is lacking

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