CO_2 Storage Potential in the Mt Simon Sandstone, Western Kentucky

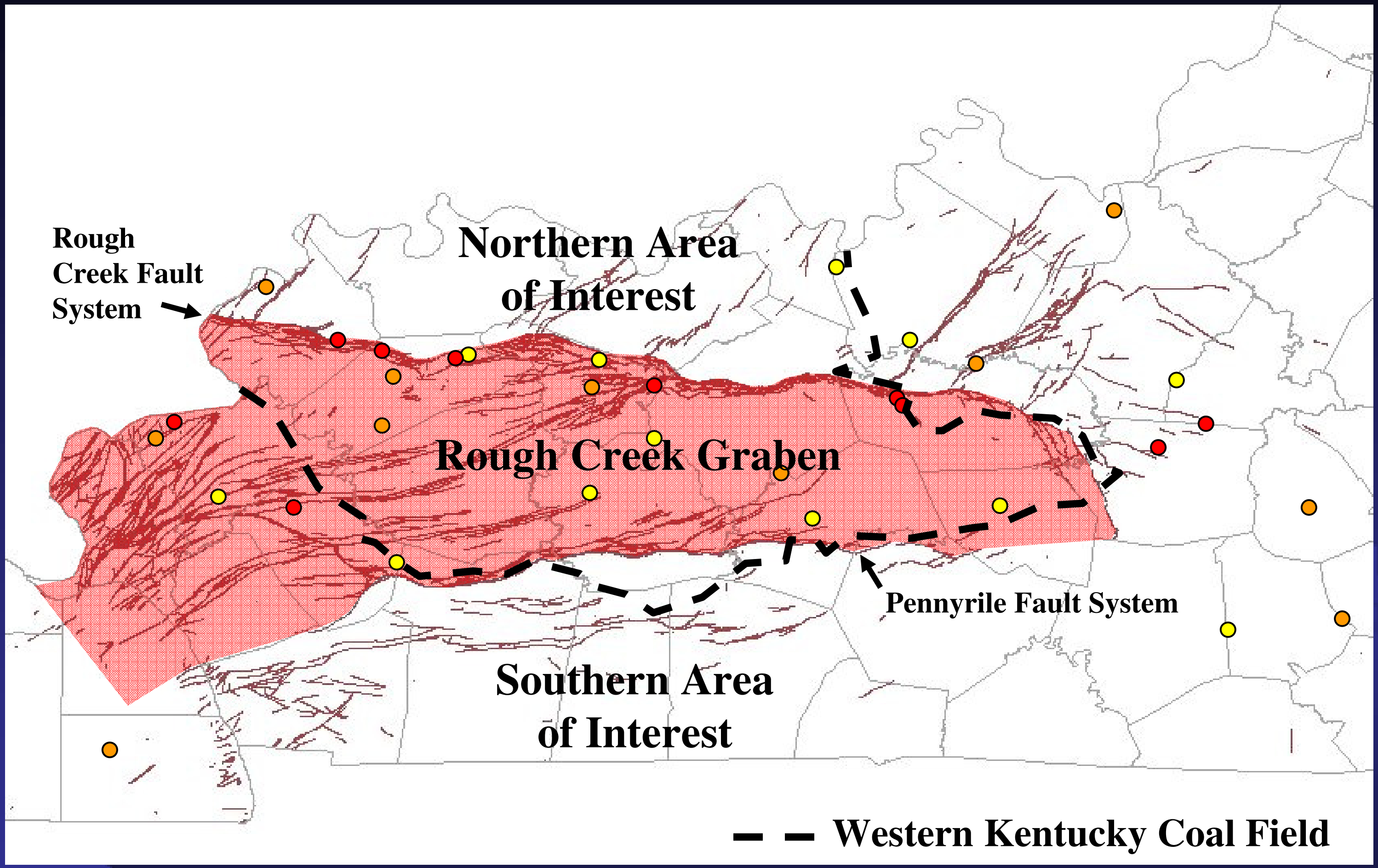
Rick Bowersox

January 22, 2008

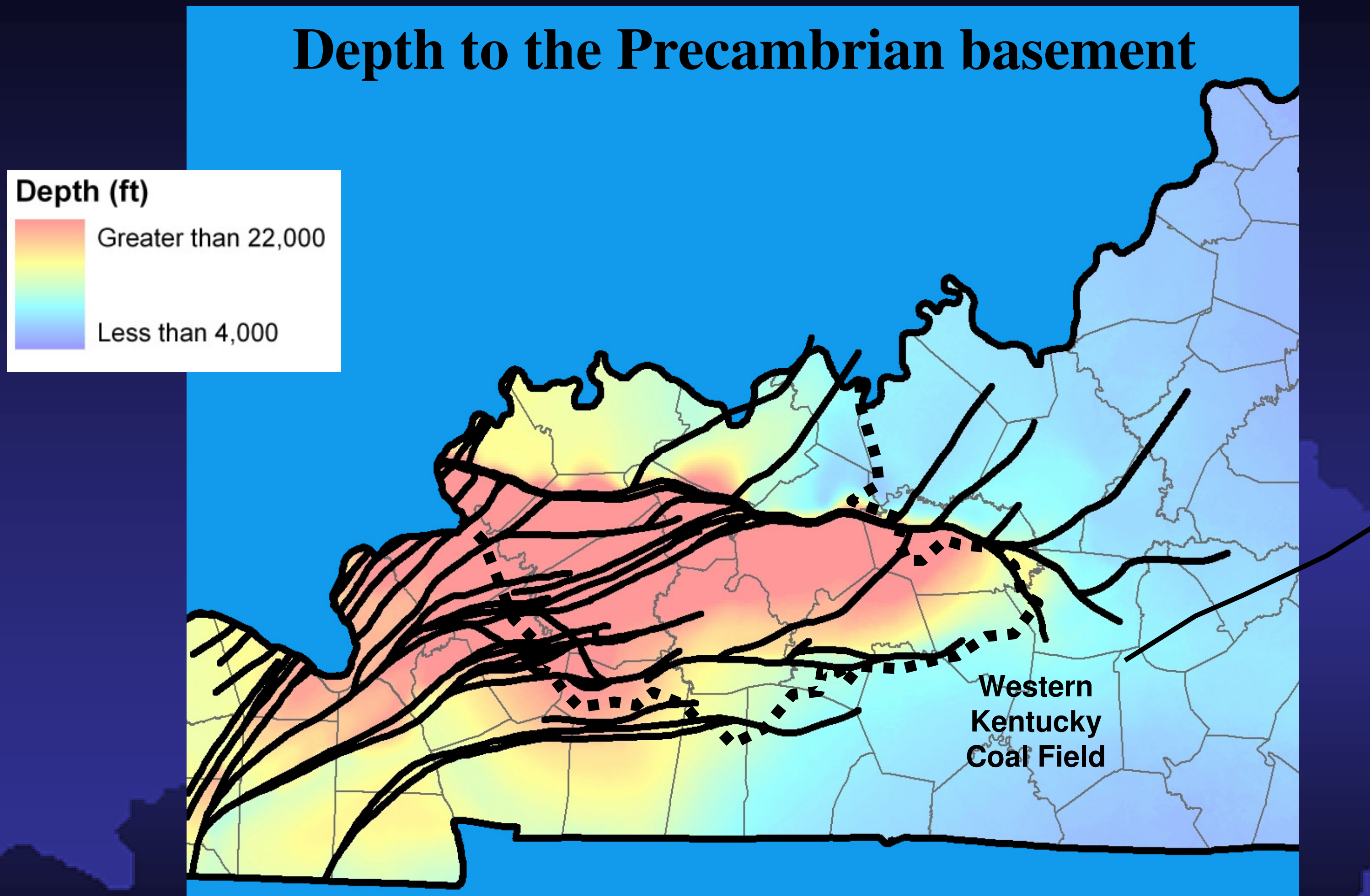
KY CCS

Presentation Outline

- Overview of Western Kentucky geology
- Review of CO_2 storage reservoir issues in western Kentucky
- Geology of the Mt Simon Sandstone
- Some issues with the Mt Simon Sandstone as a CO_2 storage reservoir in western Kentucky
- Alternative CO_2 storage reservoirs in western Kentucky

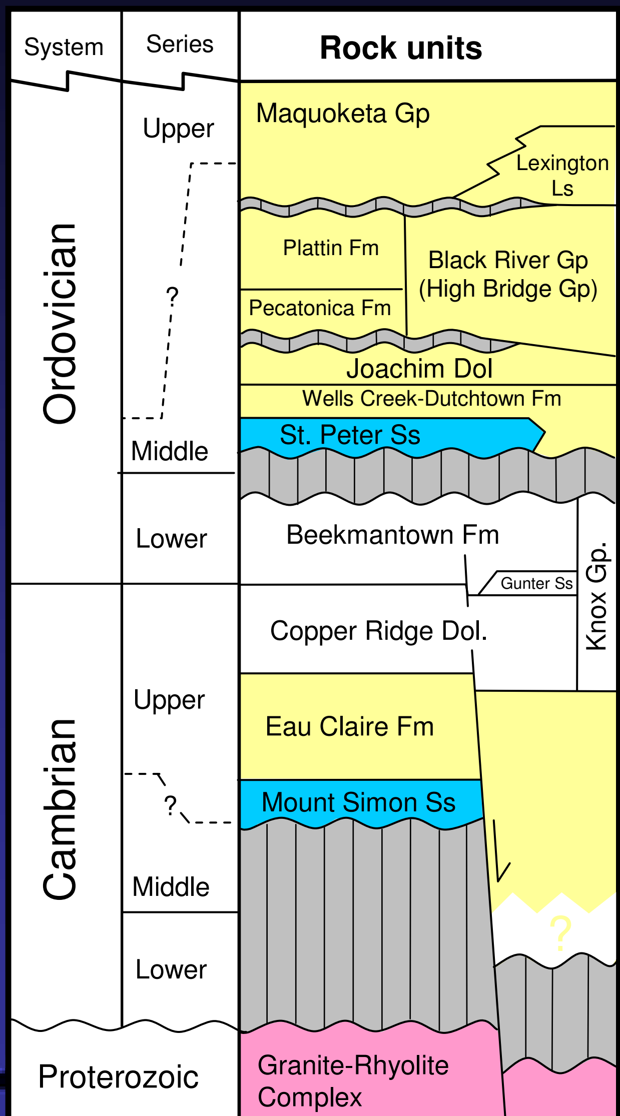


Our site evaluation needs to consider that there are at least three distinct geologic areas of interest in and adjacent to the Western Kentucky Coal Field.



There are major differences in depths to potential CO_2 storage reservoirs in the project area.

Western Kentucky Stratigraphic Units with CO_2 Storage Potential



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

KYCCS

CO_2 Storage Issues

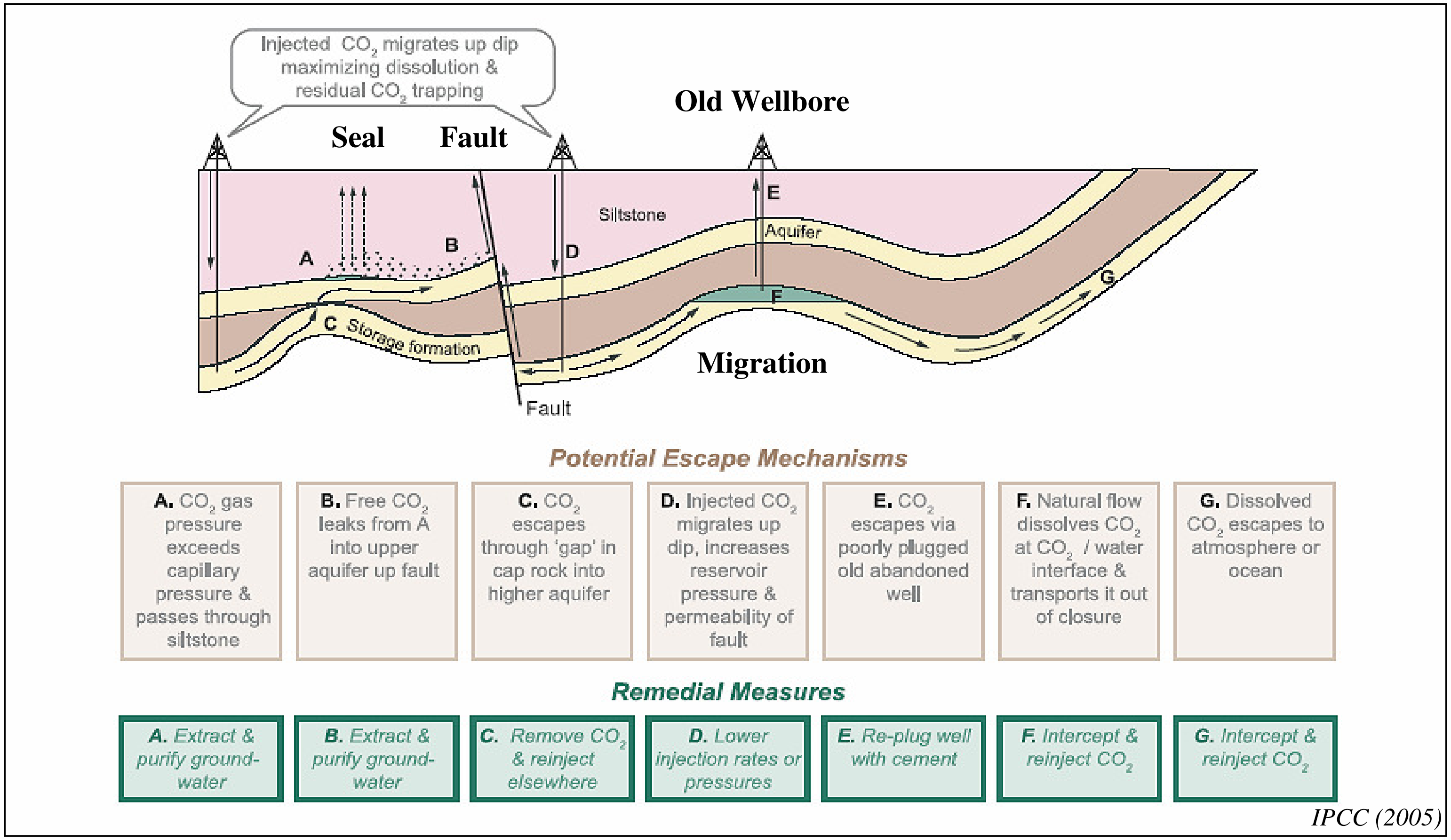
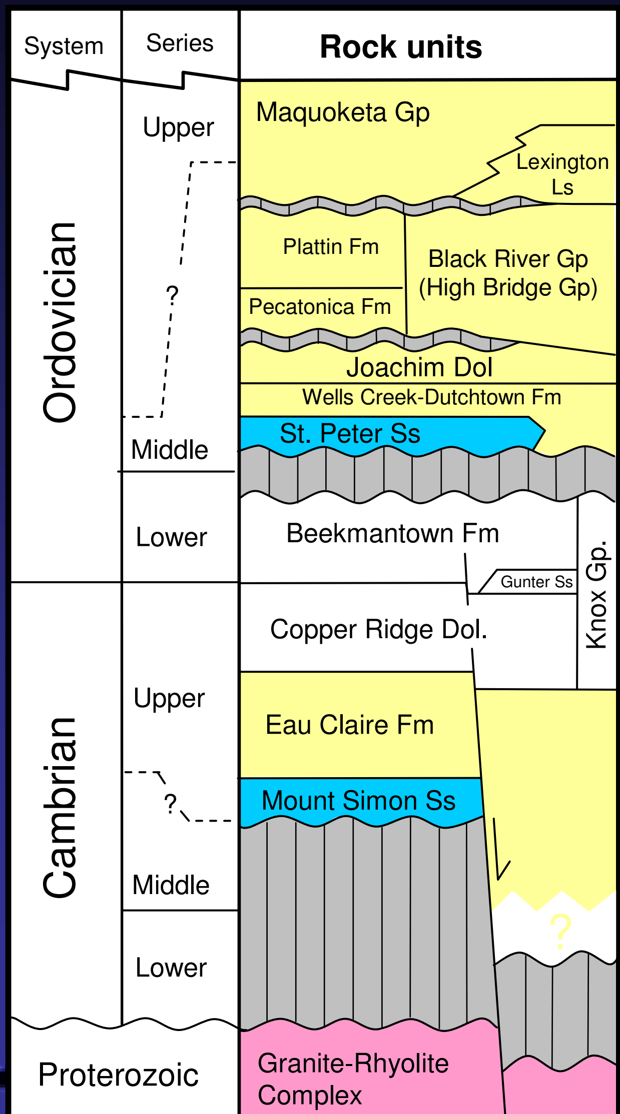


Figure TS.8. Potential leakage routes and remediation techniques for CO_2 injected into saline formations. The remediation technique would depend on the potential leakage routes identified in a reservoir (Courtesy CO2CRC).

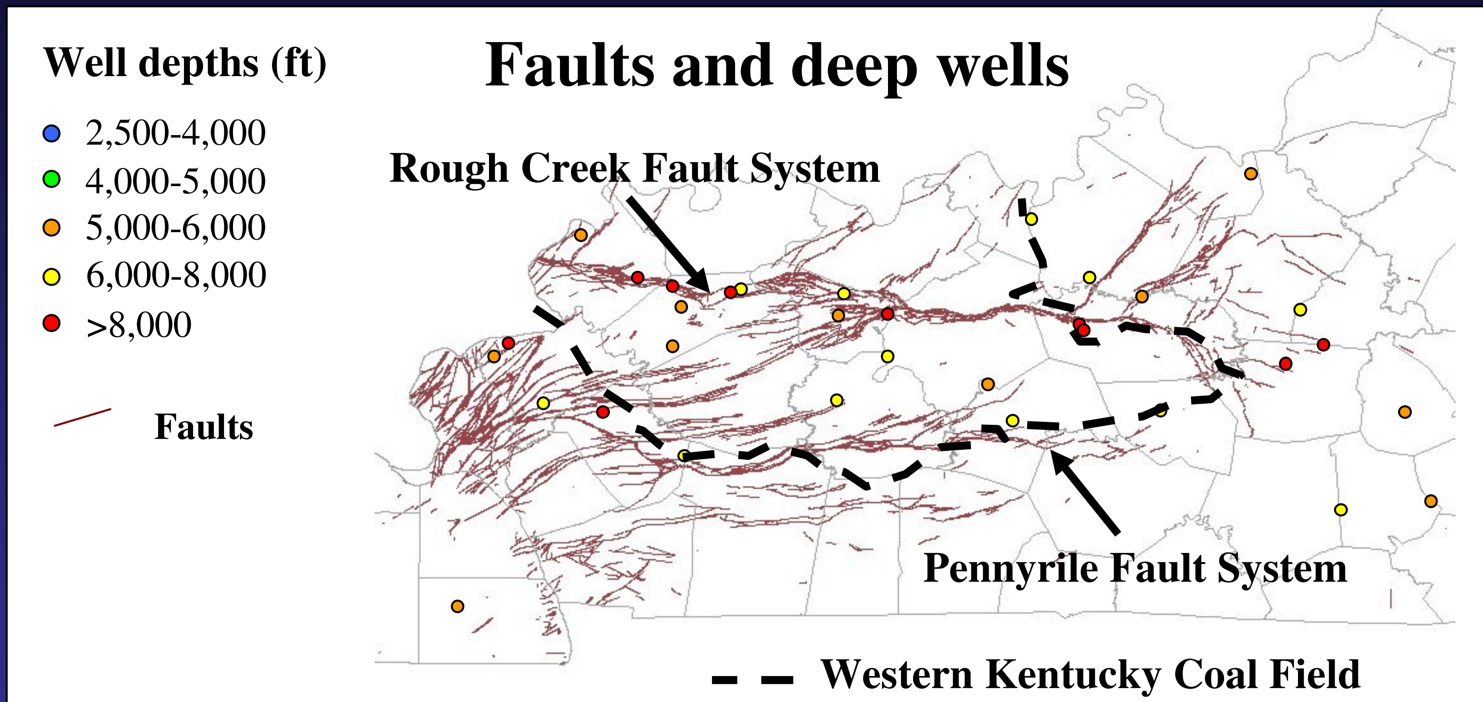
Western Kentucky Stratigraphic Units with Reservoir Seal Potential



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

KYCCS

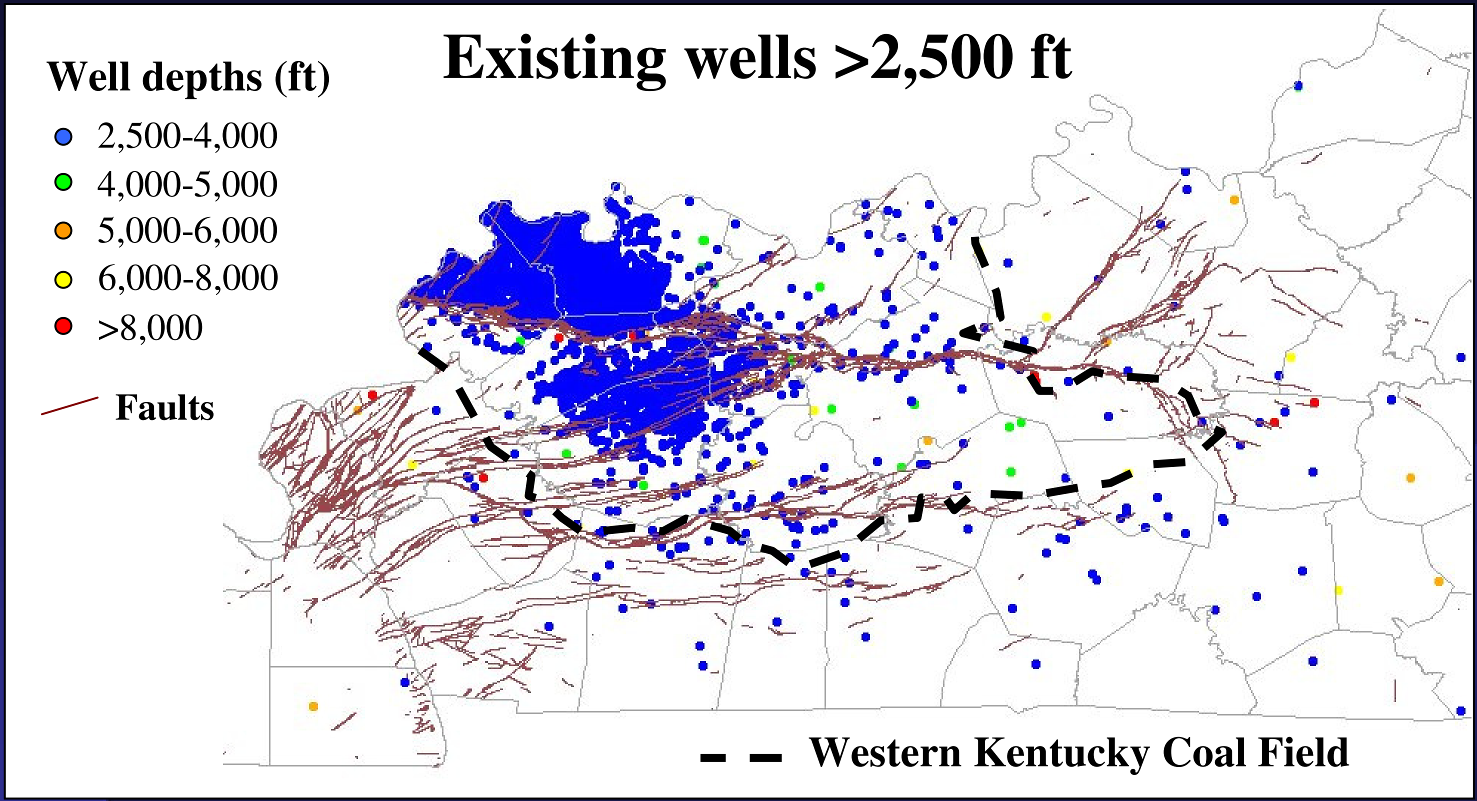
Fault Proximity Issues



Faults can act as both storage reservoir seals and pathways for CO_2 leakage to shallower intervals and the surface.

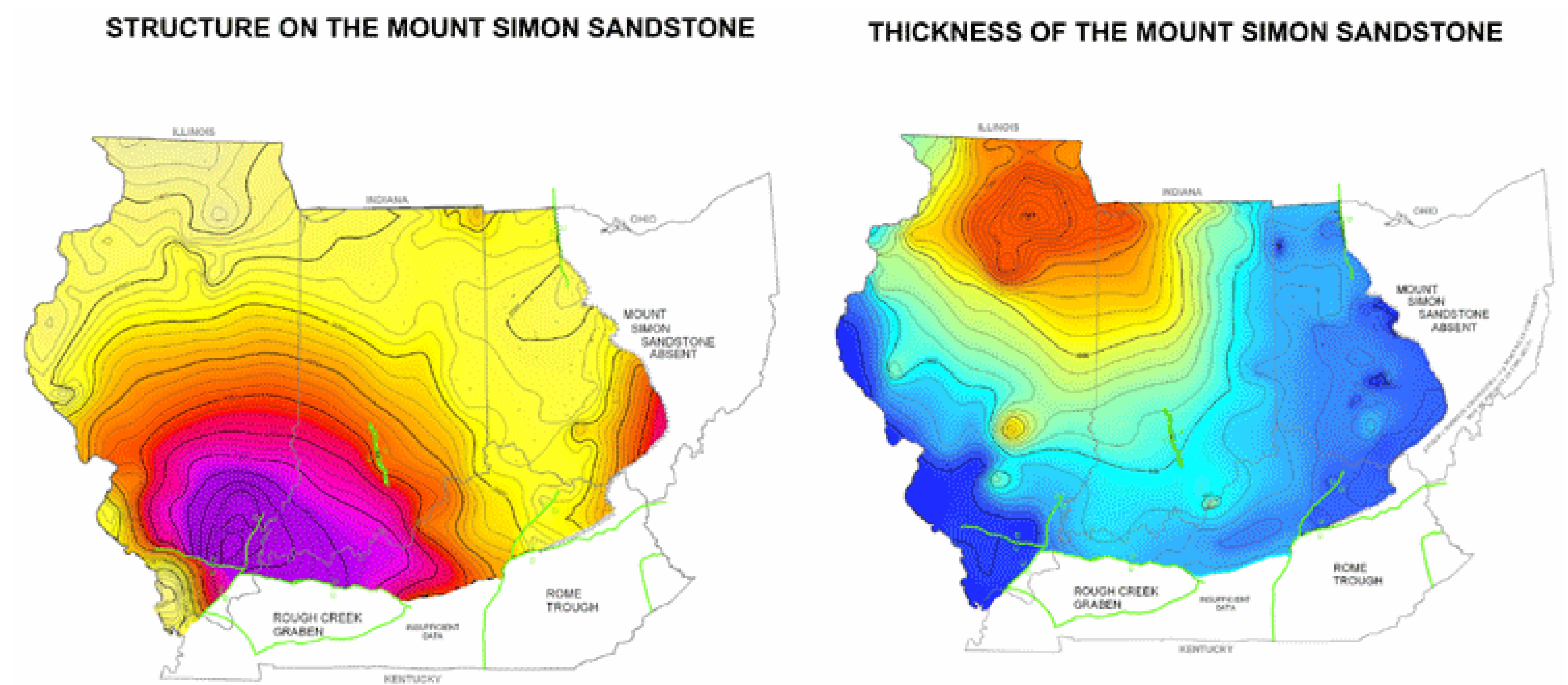
KYCCS

Old Well Bore Issues



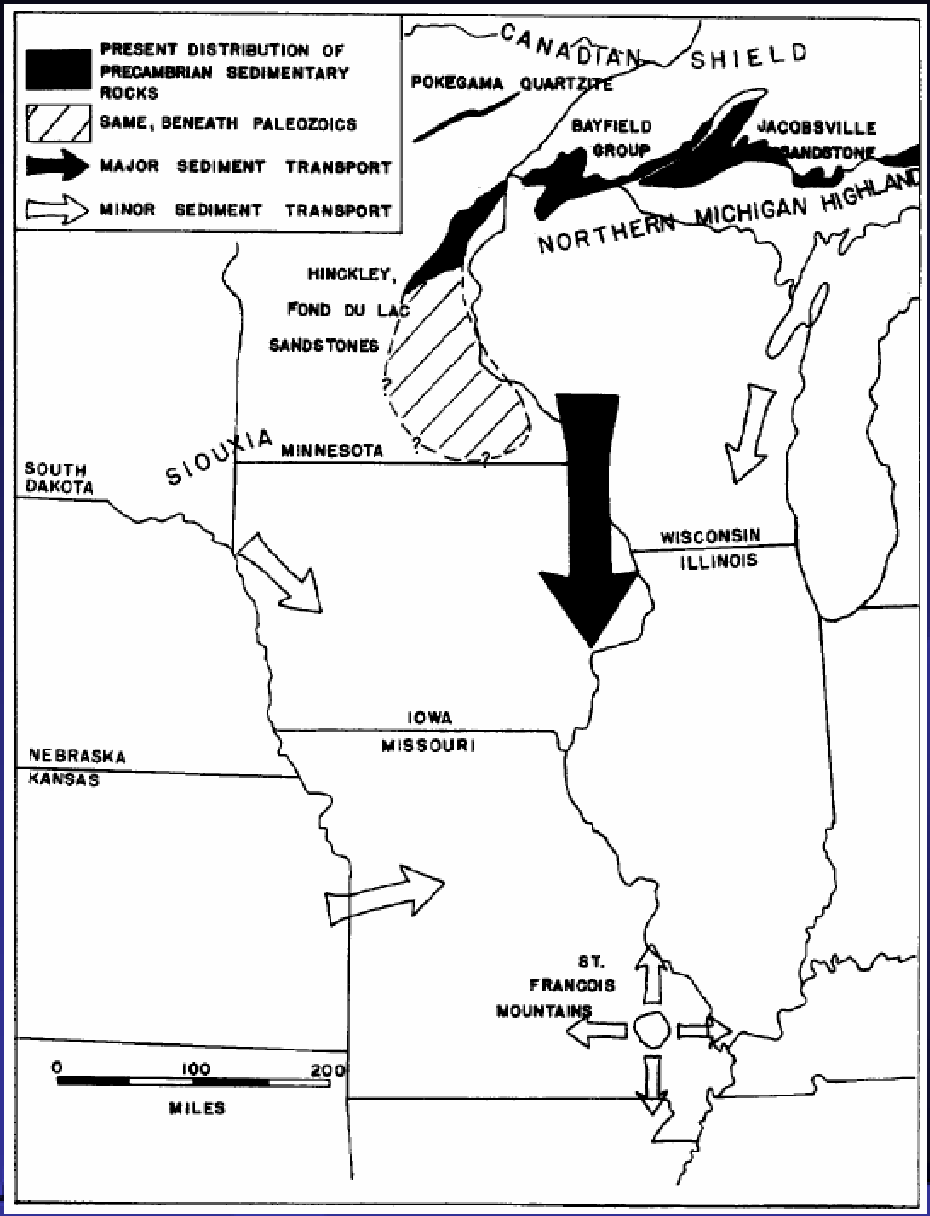
Old well bores with inadequate abandonment are a potential leakage pathway to the surface.

Geology of the Mt Simon Sandstone



Wickstrom et al (2003) MIDCARB

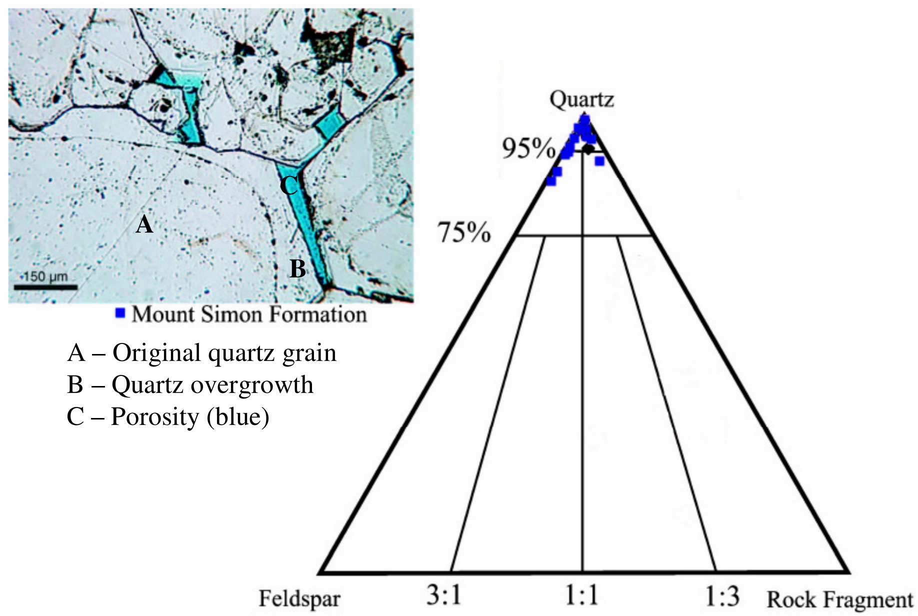
The Mt. Simon Sandstone is the deep saline reservoir being targeted for CO_2 storage in much of the Midwest. It is deepest in the subsurface and thinnest in western Kentucky.



Inferred Transport of the Mt Simon and Lamotte Sandstones in the Illinois Basin and adjacent regions.

(Ojakangas, 1963, Fig. 9)

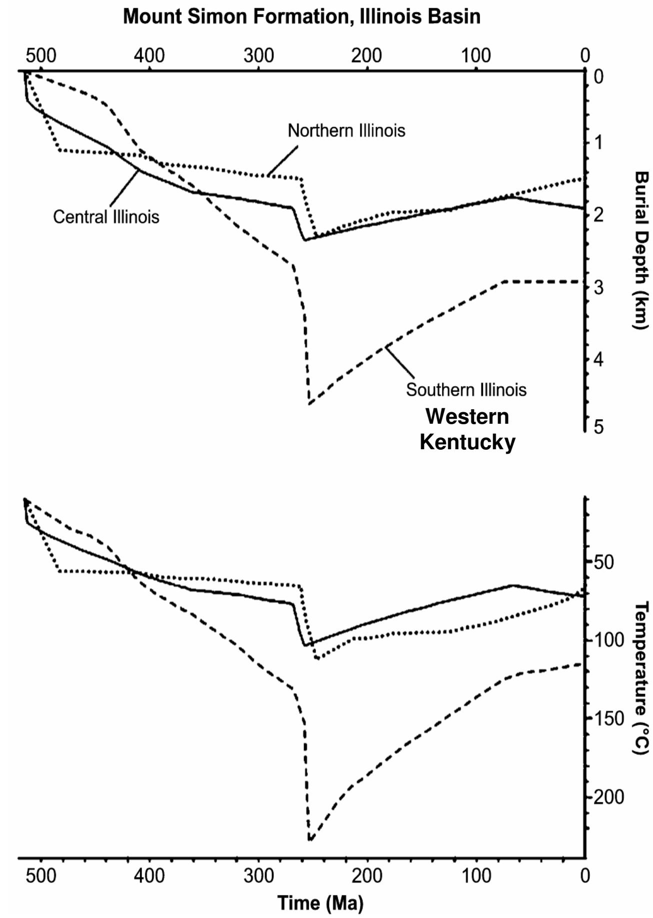
Mount Simon Sandstone Reservoir



Makowitz and Milliken (2003, Fig. 2)

Quartz-overgrowth cement forms in sandstones at temperatures >90-100℃ (>200° F).

(Bjørlykke and Egeberg, 1993)



Makowitz et al. (2006, Fig. 5)

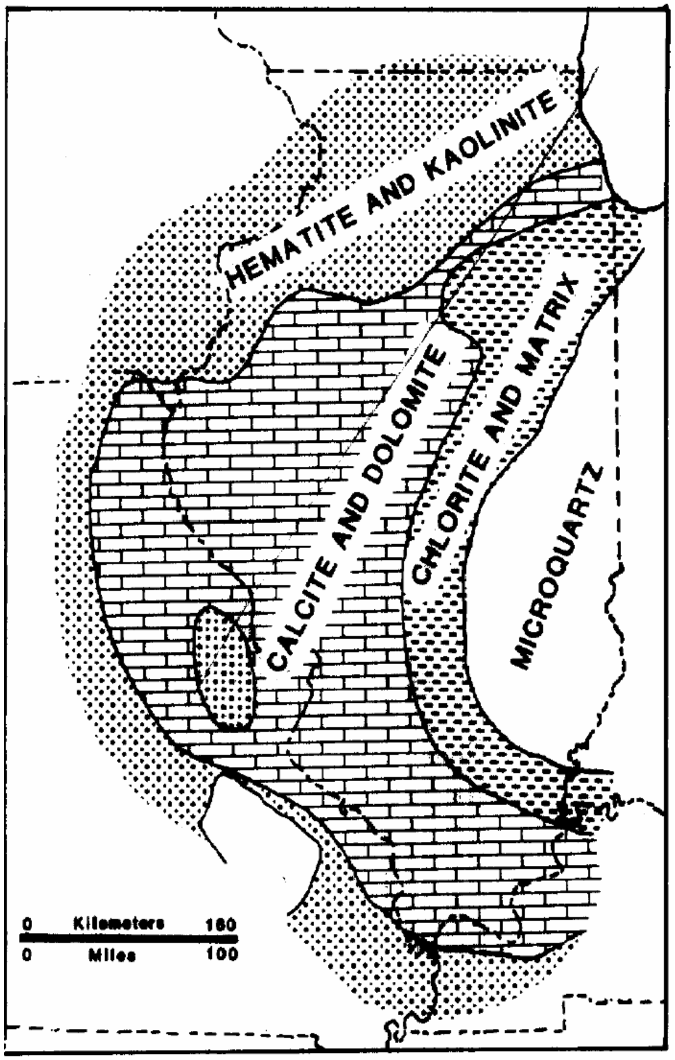


Figure 9—Map of dominant cements in Mount Simon Sandstone.

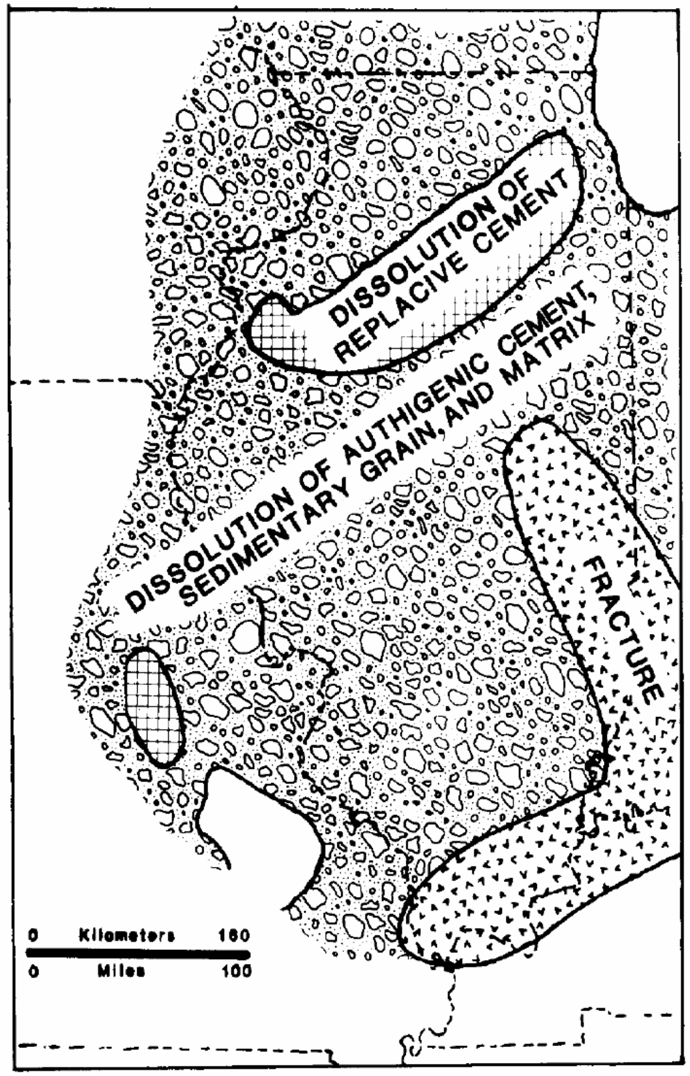


Figure 10—Map of secondary porosity in Mount Simon Sandstone.

Porosity development in the Mt Simon Sandstone.

(Hoholick et al., 1984)

CO_2 Core Flood Tests

O'Connor and Rush (2005)

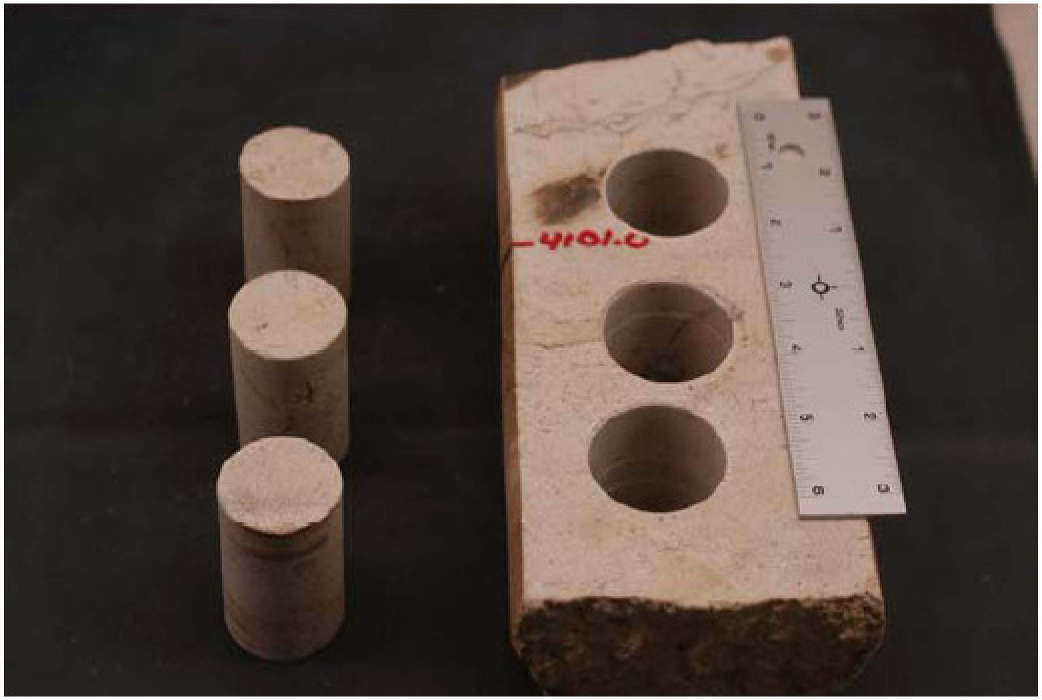


Figure 3. Mt. Simon sandstone core.

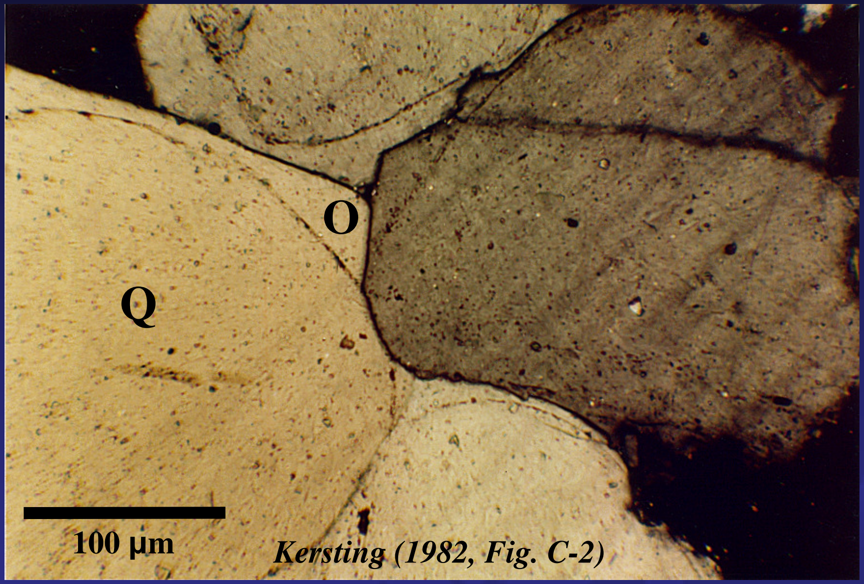
Test conditions for the CO_2 flood tests included: Illinois Basin brine solution; temperature = 35˚C, P_{CO2} = 1,400 psig; and 1,500 hour duration. The impact of the CO_2 flood on the physical properties of the Mt. Simon core samples, namely porosity, permeability, and compressive strength, ranged from modest to dramatic (Table 2).

Table 2. Pre- and post-CO_2 flood test physical properties of the Mt. Simon core samples.

Core depth	Porosity, pct			Permeability, mD			Compressive strength, kpsi		
	Pre	Post	Δ, %	Pre	Post	Δ, %	Pre	Post	Δ, %
4101.0	7.9	8.3	4.7	8.9	8.0	-10.1	na	na	nc
4105.5	11.5	13.0	13.0	344.5	351.4	2.0	12.2	4.8	-61.0
4106.0	13.3	na	nc	288.9	na	nc	10.8	4.2	-61.6

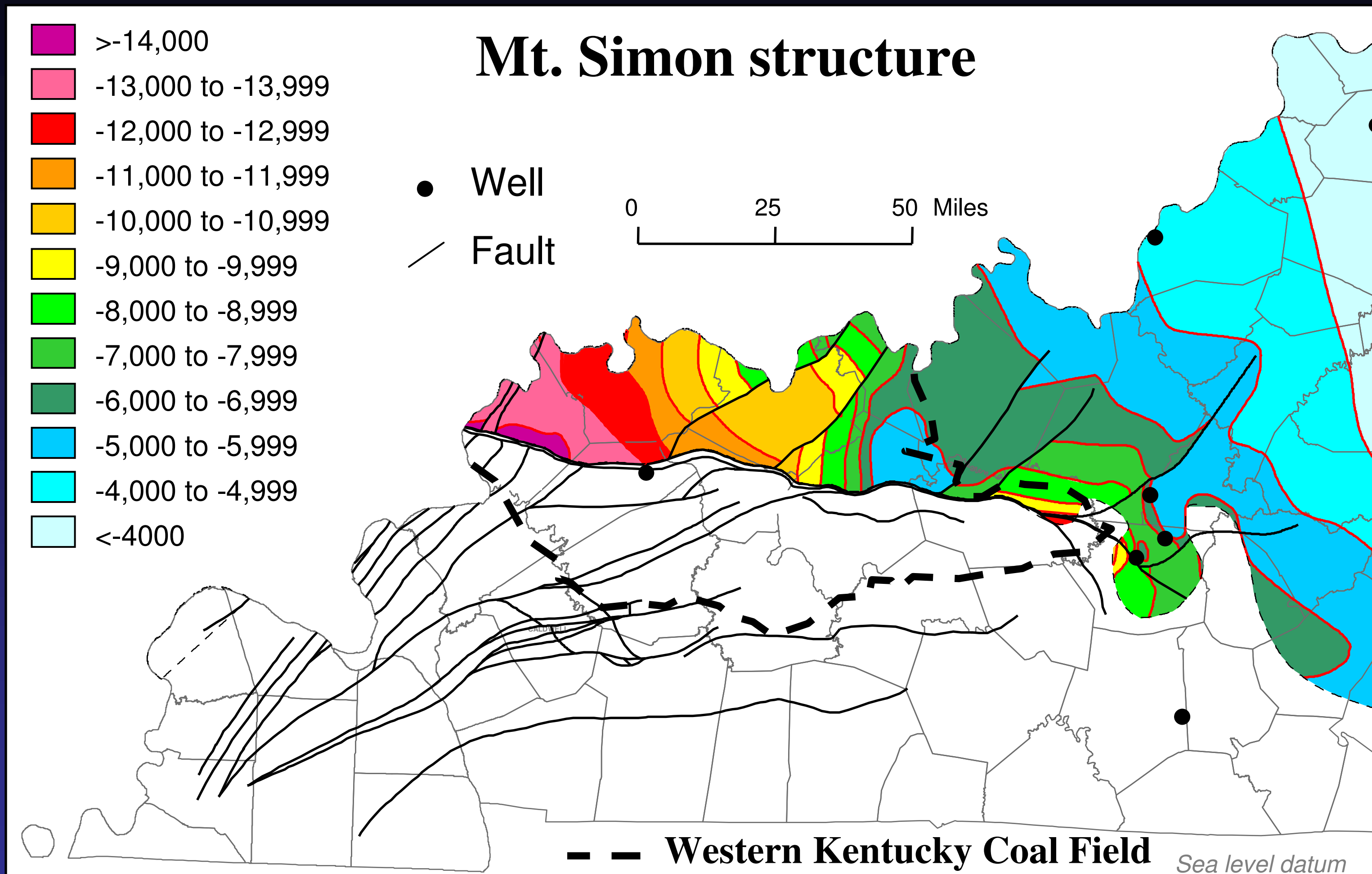
KY CCS

Mount Simon Sandstone Reservoir

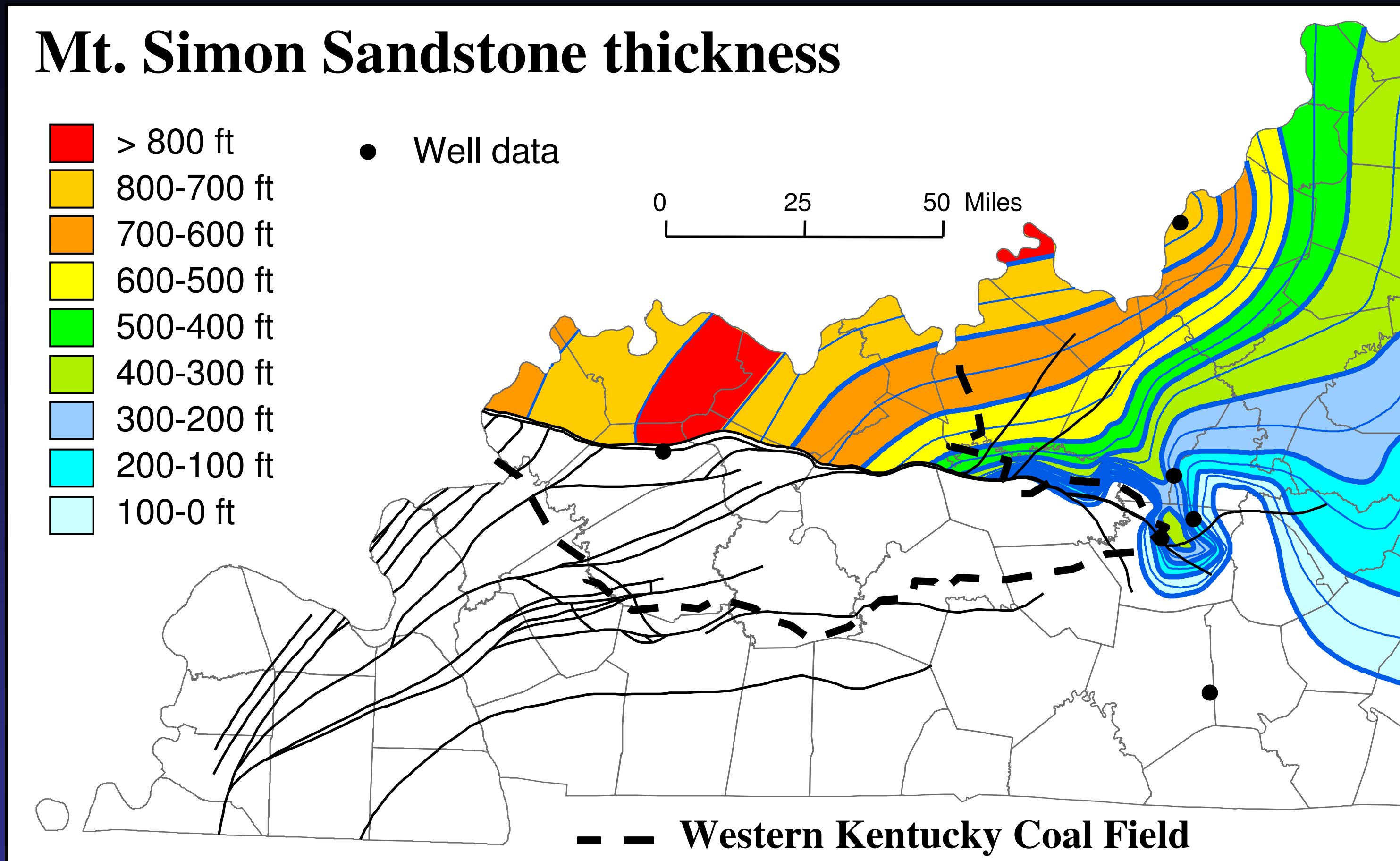


Cutting at 6660 ft from Allied Chemical well #1 Fee, Vermillion County, Illinois. Quartz grains (Q) with euhedral quartz overgrowth (O). Quartz grains are rimmed with secondary hematite cement. Dark areas between grains is smectitic clay-lined porosity.

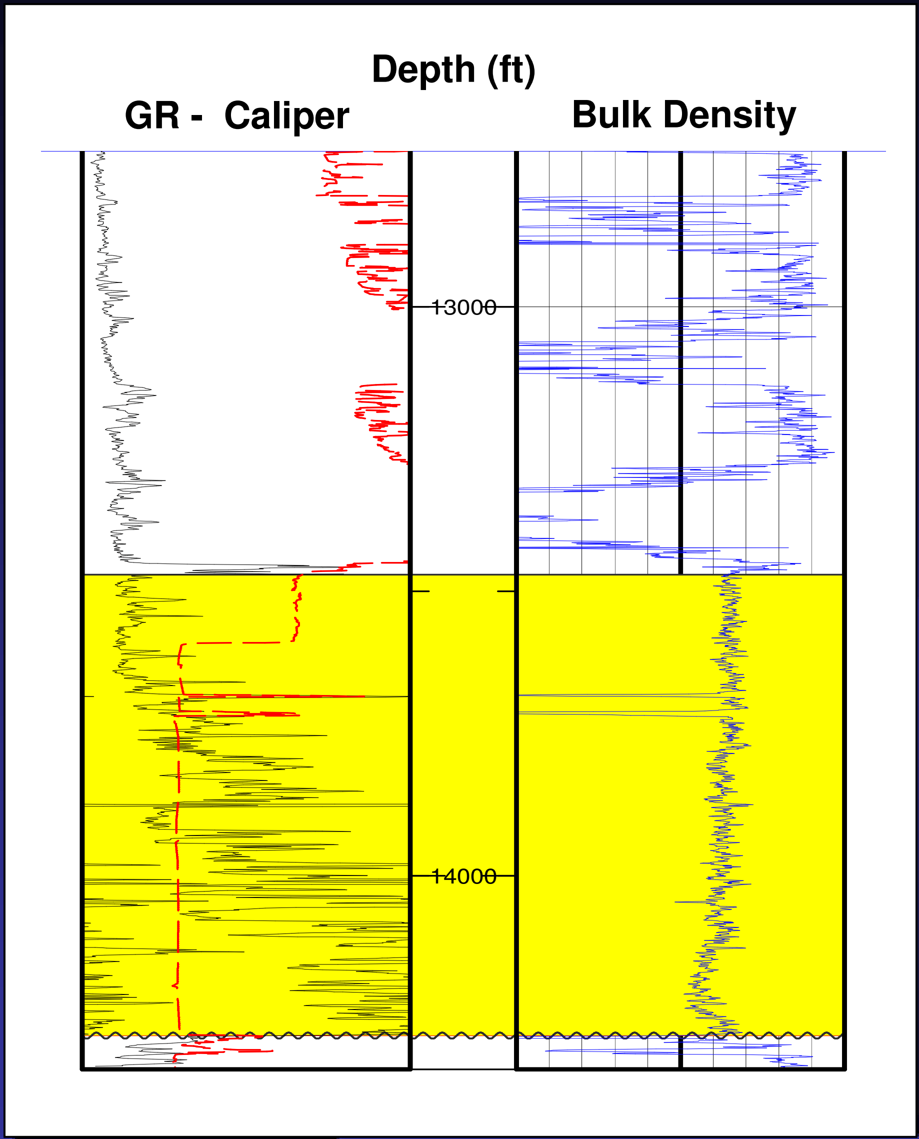
Data from wells drilled in deeper portions of the Illinois Basin indicate that cements in the Mt. Simon Sandstone are quartz and potassium feldspar overgrowths with lesser hematite, kaolinite, chlorite, chert, and carbonate (Metarko, 1980; Hoholick et al, 1984; Makowitz and Milliken, 2003; Makowitz, 2004; Kunledare, 2005).



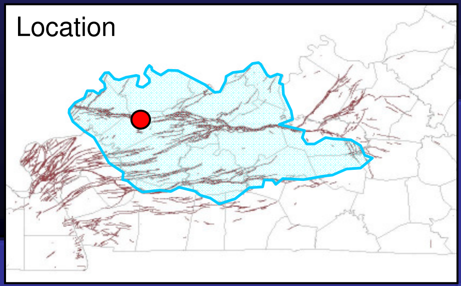
However in the vicinity of the Western Kentucky Coal Field the Mt Simon Sandstone is at a depth that reduces its potential for CO_2 storage.



The Mt Simon Sandstone occurs north of the Rough Creek Graben and generally north of the Western Kentucky Coal Field. The thickest potential CO2 storage reservoir in the Mt Simon Sandstone is also where it is at its greatest depth.

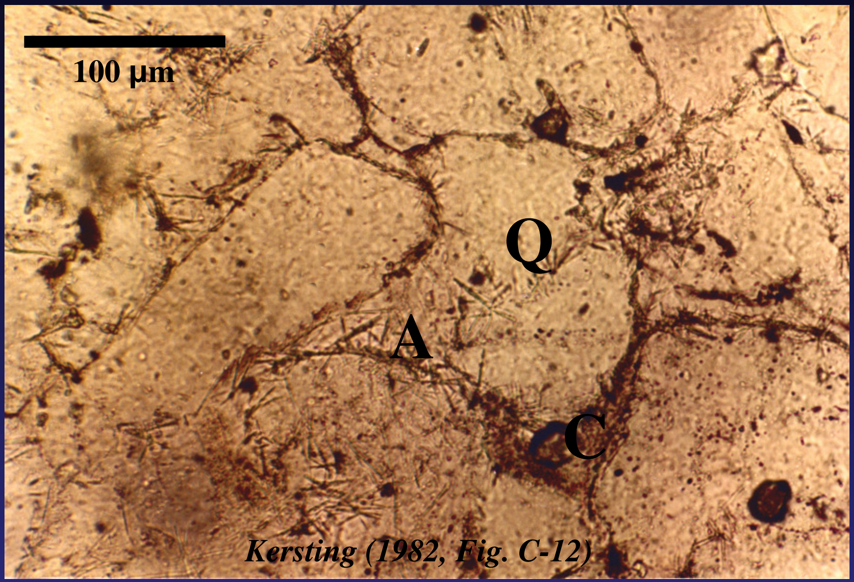


The Exxon Jimmy Bell #1 well was drilled on the northern margin of the Rough Creek Graben in Webster County. It encountered 750 ft of low porosity Mt Simon Sandstone at a depth of 13, 490 ft immediately above granitic basement rocks.

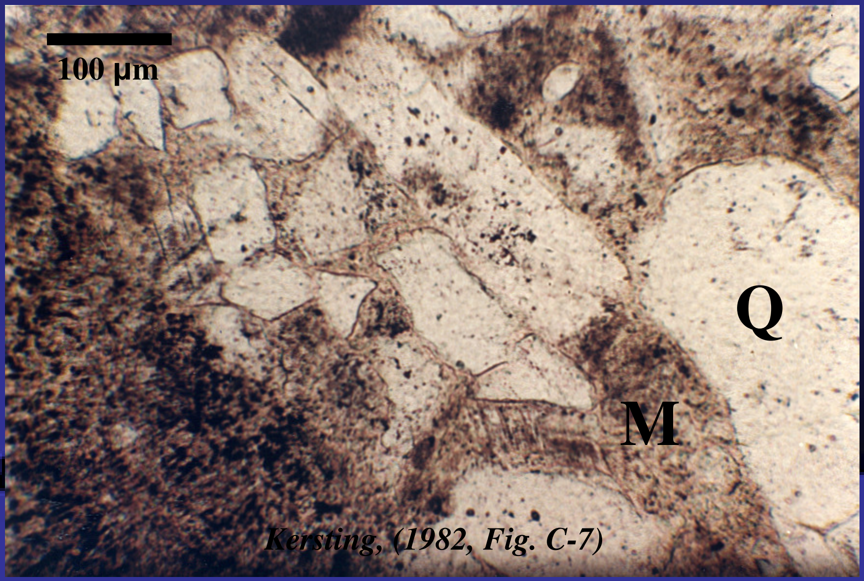


KYCCS

Exxon Jimmy Bell #1

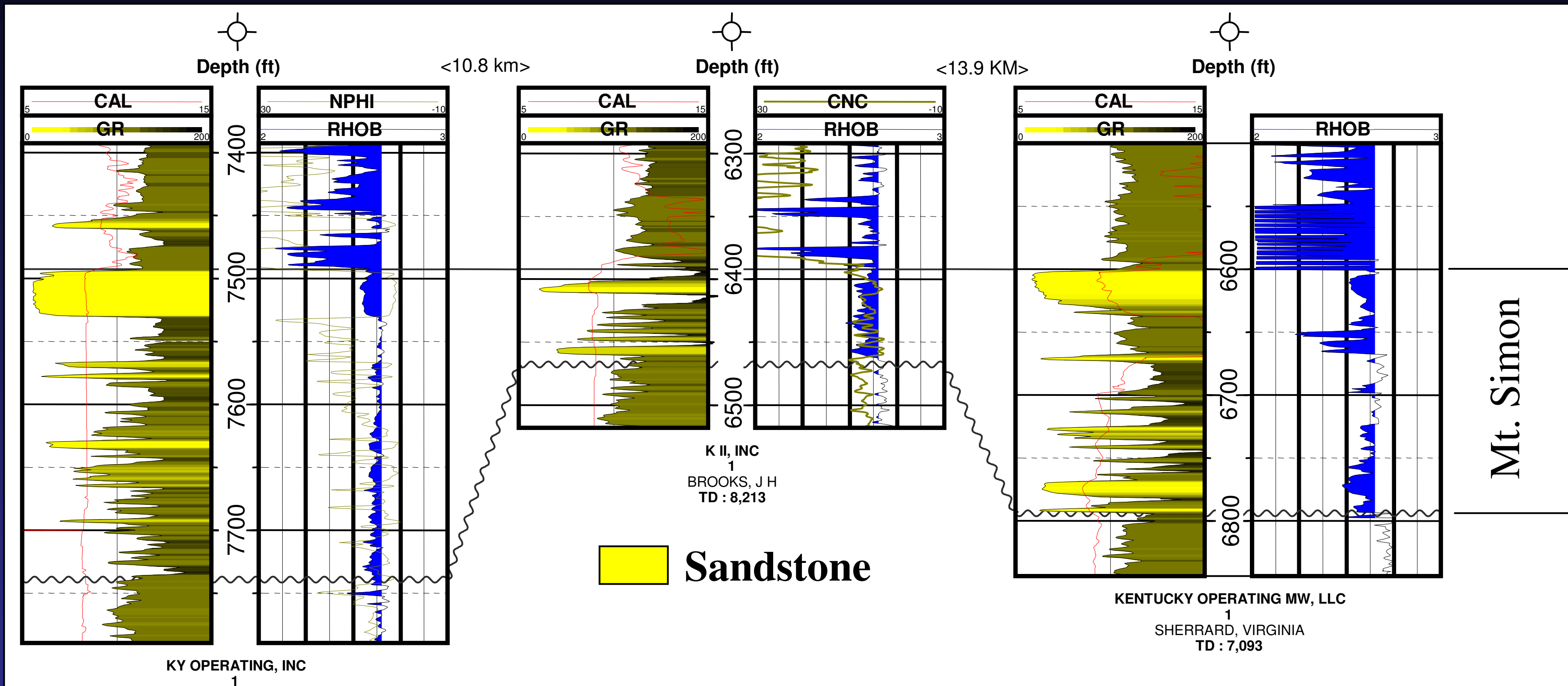


Cutting from 13,700 ft shows quartz grains (Q) with concave contacts due to pressure dissolution at grain boundaries rimmed with smectitic clays (C). Authigenic apatite crystals (A) grew between quartz grains.



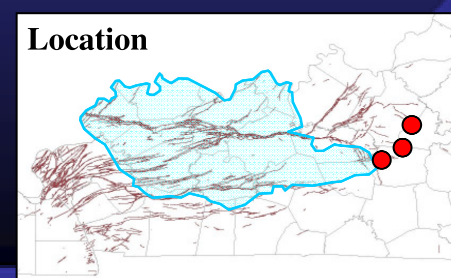
Cutting from 14,220 ft shows microquartz (M) filling the pores between quartz grains (Q).

KYCCS



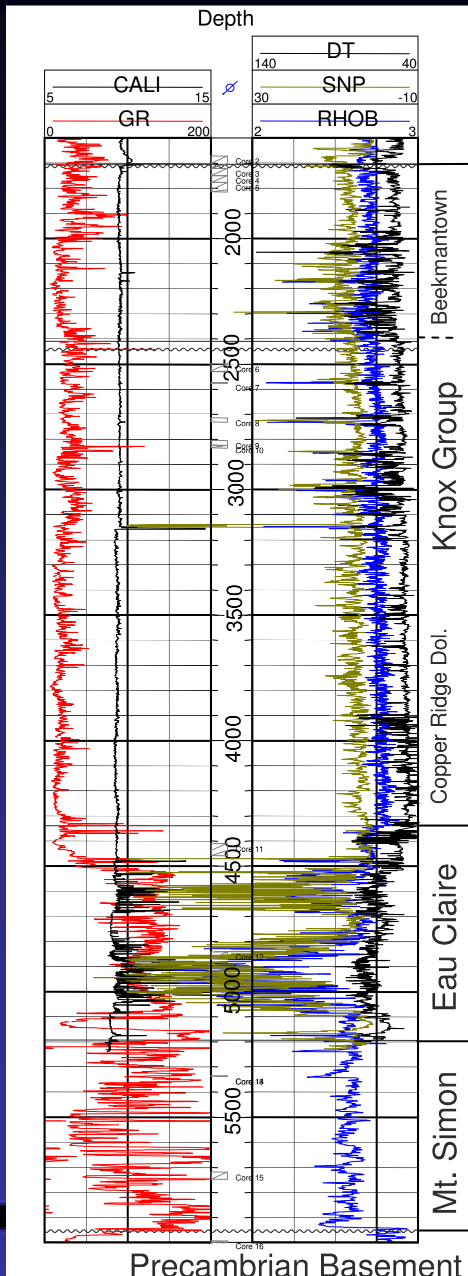
Top of Mt. Simon datum

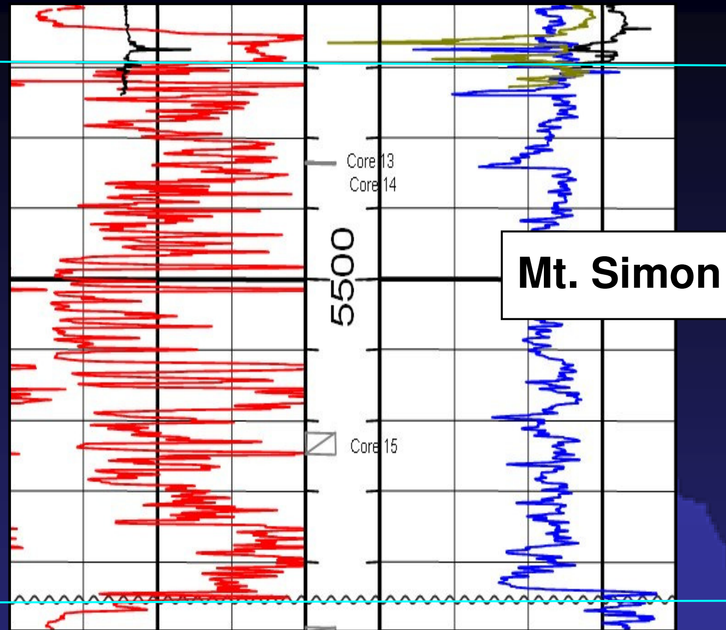
Three shallower tests of Mt. Simon Sandstone drilled just east of the coal field suggest limited reservoir potential.

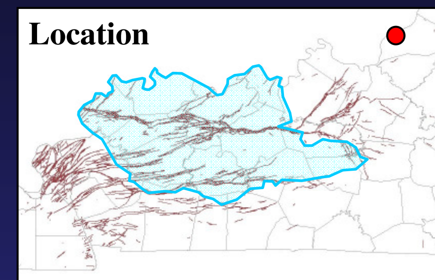


DuPont #1 WDW

Mt Simon Sandstone test







The DuPont #1 WDW injection well was drilled near Louisville and encountered 761 ft of Mt Simon Sandstone at a depth of 5193 ft. After testing, the Mt Simon was abandoned and the well recompleted on injection in the Knox Limestone.

KYCCS

DuPont #1 WDW

DuPont #1 WDW, Louisville, KY, ~5730 ft

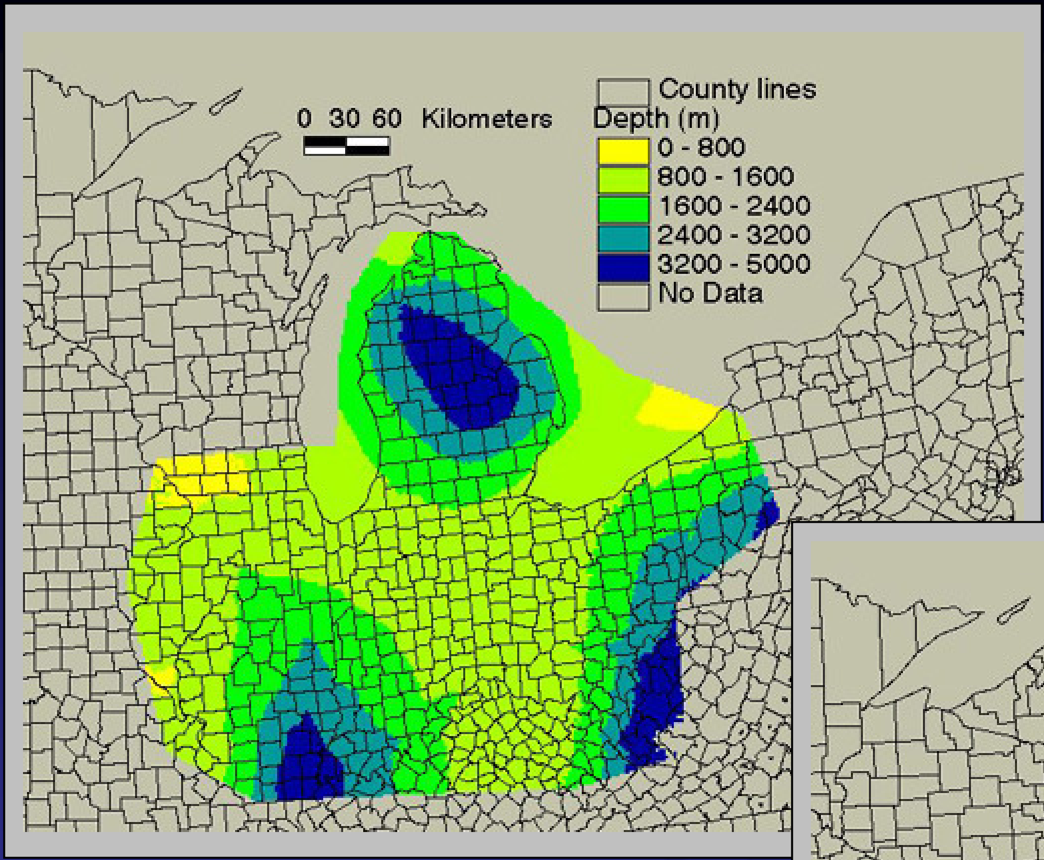
Although a core from this well showed low porosities averaging 5.5%, analysis of electric logs suggests that there was ~150 ft of Mt Simon Sandstone with porosity >10% in the well. There is also evidence suggesting that the Mt Simon Sandstone reservoir was damaged by fresh water injection during testing.

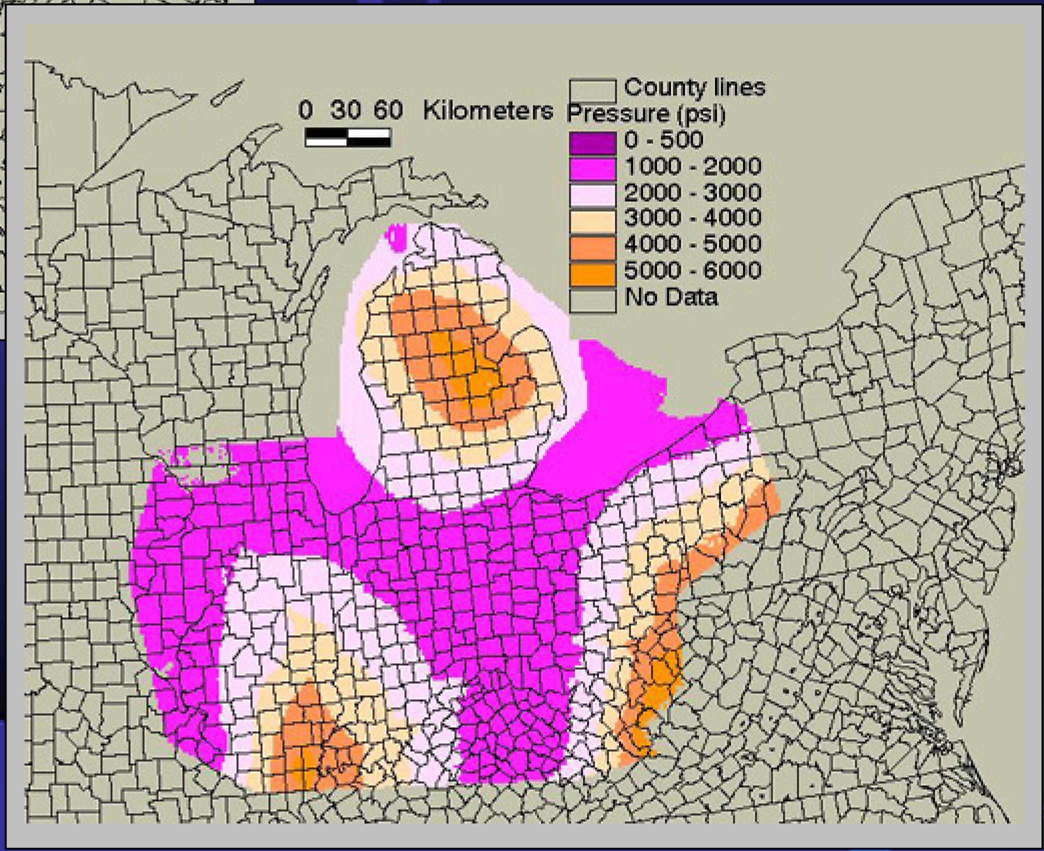
Minimum Criteria for a CO_2 Storage Zone

- **Base of the sealing interval ≥2500 ft**
  - Sufficient lithostatic pressure to ensure CO_2 remains in a supercritical state at ≥1070 psia and 88 ° F
  - Sufficient sealing strata overlying the storage zone to mitigate the possibility of leakage to shallower intervals and the surface
- **Porous and permeable storage zone**
  - Storage capacity of supercritical CO_2 ~10,000 T/Ac-ft for each incremental percent porosity
  - Greater porosity and permeability at shallower depths allow lower injection pressures and costs
- **Remote from geologic and man-made features that might compromise the integrity of the storage reservoir**
  - Faults and fractured intervals
  - Mine shafts
  - Buildings

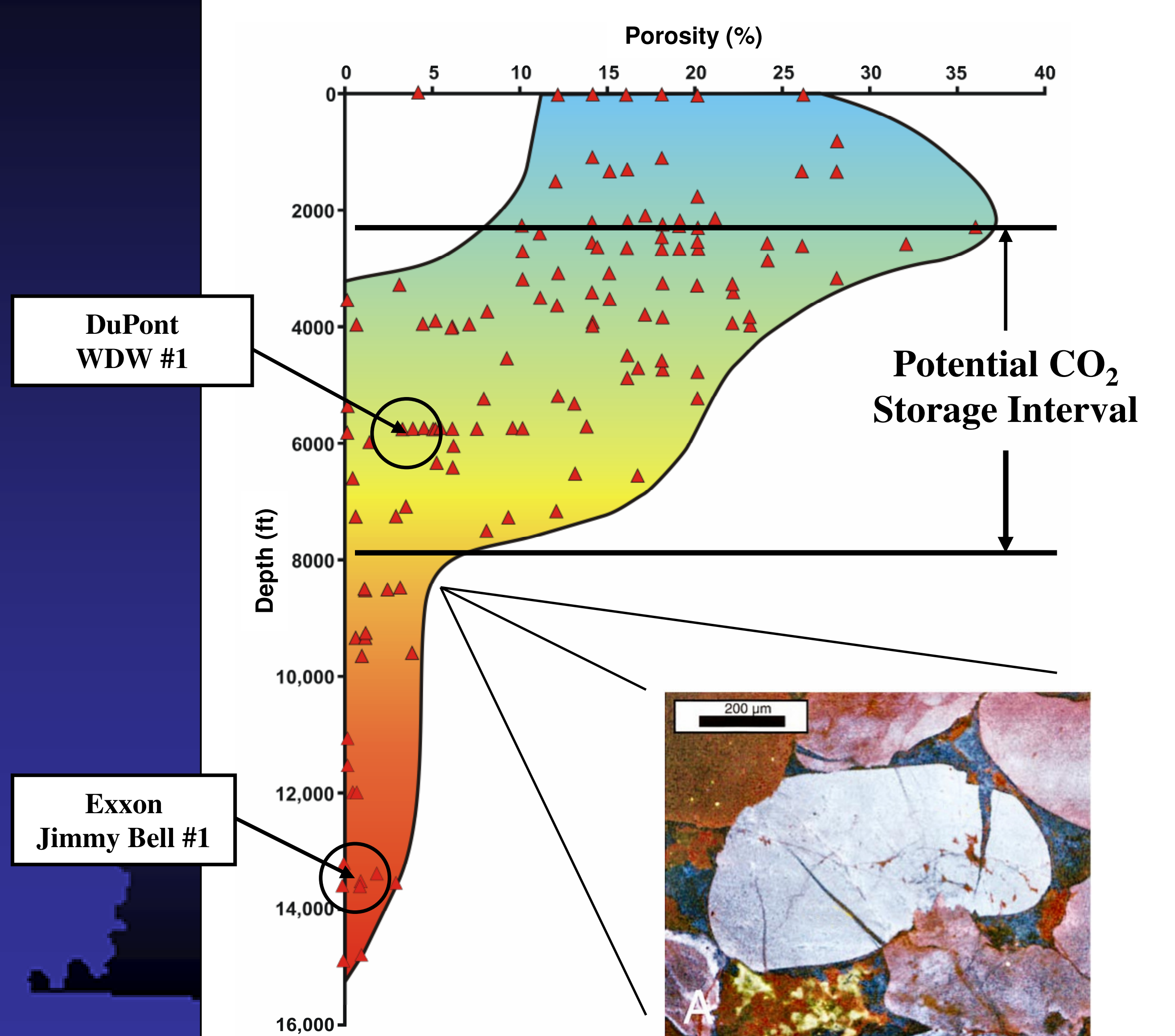
Mt Simon Sandstone Reservoir Depth and Pressure

www.beg.utexas.edu/environqlty/co2seq/12bmtsimon.htm





Mt Simon Sandstone Porosity



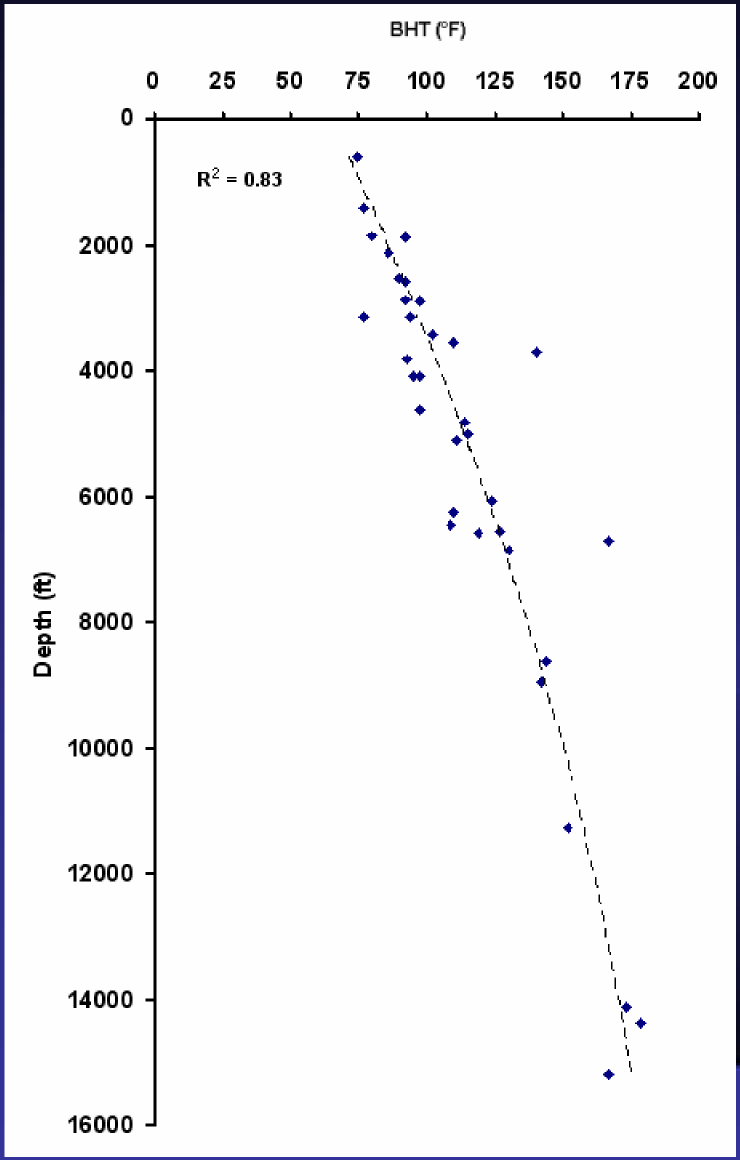
Makowitz and Milliken (2003, Fig. 10A)

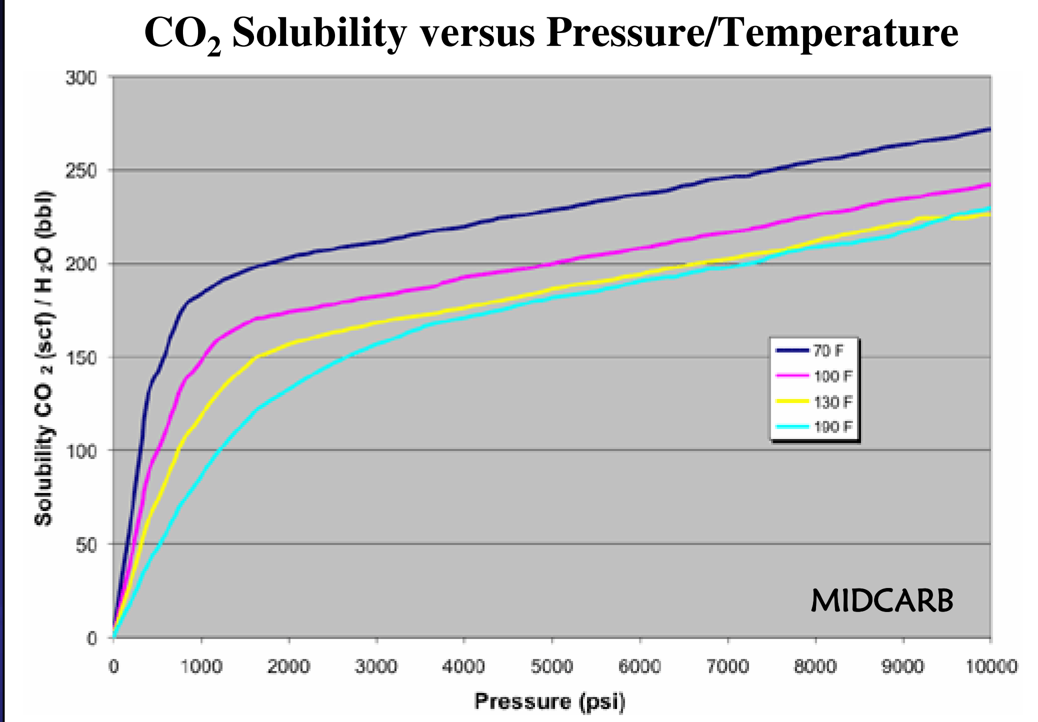
Data sources (828 samples):

Metarko (1980; 89 samples)
Shebl (1985; 9 samples)
Makowitz (2004; 27 samples)
Kunledare (2005; 690 samples)
DuPont #1 WDW (13 samples)

KYCCS

Western Kentucky Reservoir Temperature





www.kgs.ku.edu/PRS/publication/2003/ofr2003-33/P1-05.html

The western Kentucky geothermal gradient is ~1° F/100 ft of depth (36 measurements). In the prospective range of the CO2 storage reservoir the temperature will be ~85-140° F.

Western Kentucky Reservoirs P-T Trend

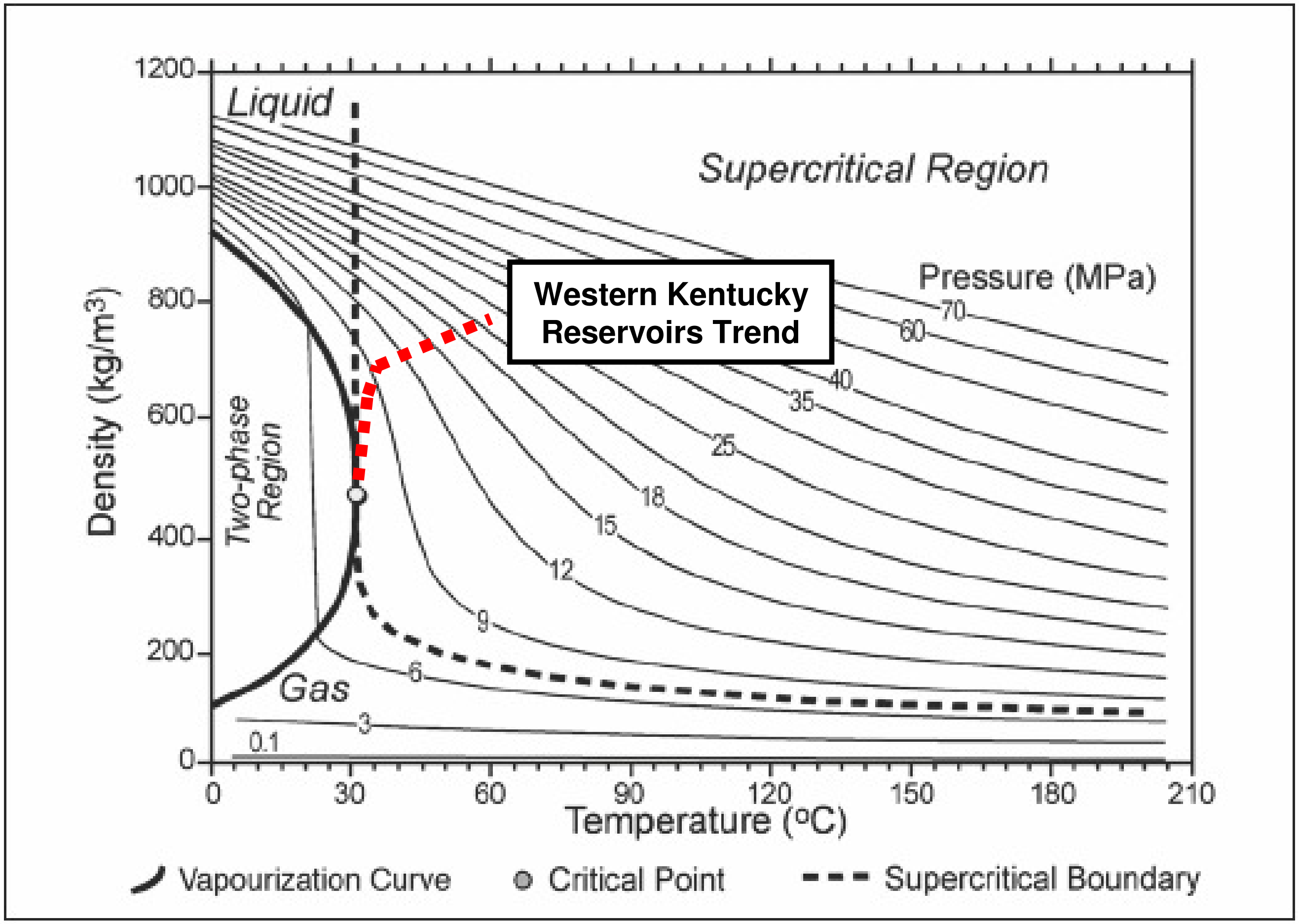
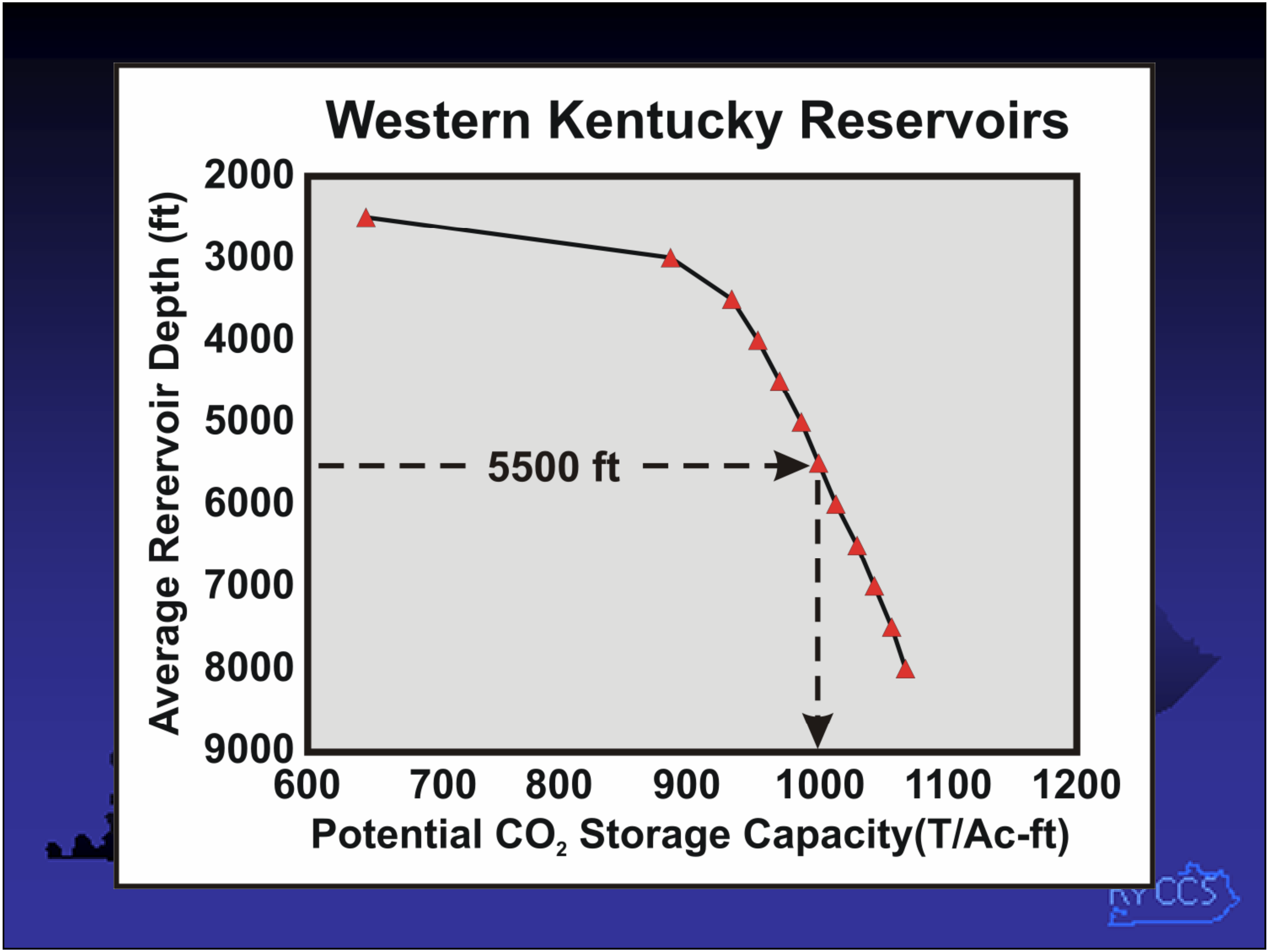


Figure AI.2 Variation of CO_2 density as a function of temperature and pressure (Bachu, 2003).



Western Kentucky Reservoirs
Average Rerervoir Depth (ft)
2000
3000
4000
5000
6000
7000
8000
9000
5500 ft
600
700
800
900
1000
1100
1200
Potential CO2 Storage Capacity(T/Ac-ft)
KY CCS

Water in the Mt Simon Sandstone reservoir of western Kentucky is extremely high salinity, about six times that of sea water.

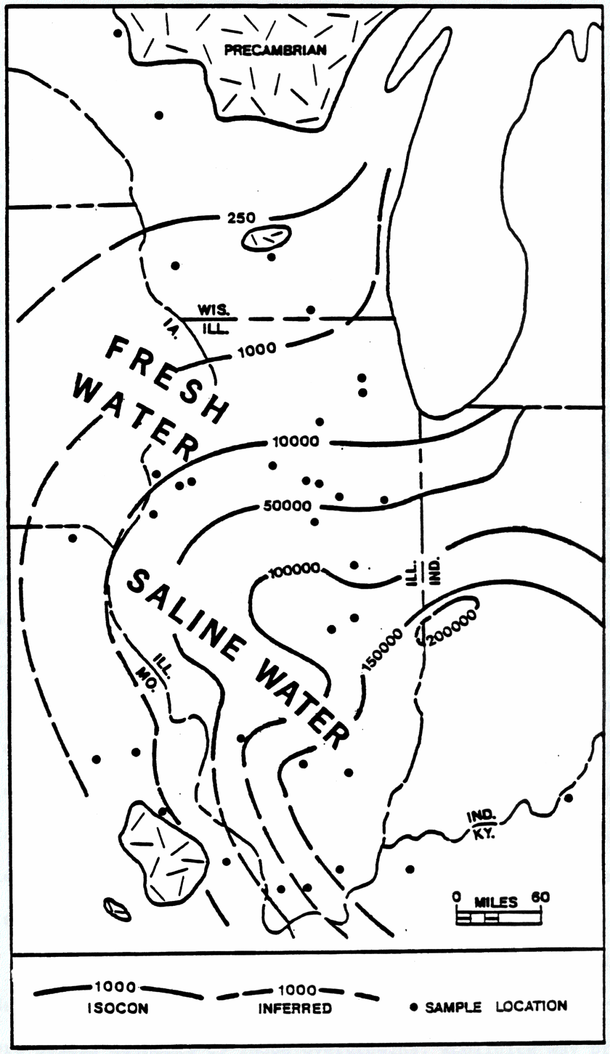
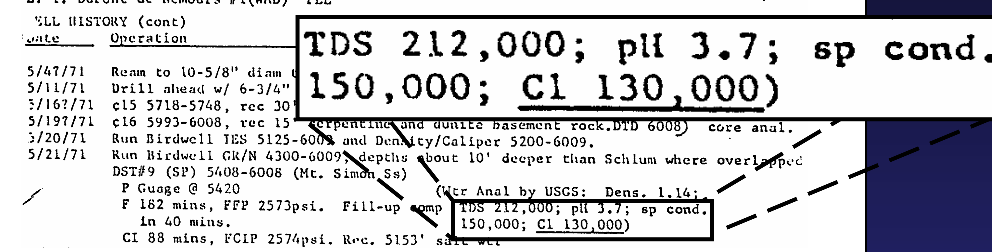


Fig. 10.—Isocon map (in mg/l - total dissolved solids) of interstitial waters in the basal sandstones with samples locations (modified from Orsanco, 1976, Map 7).

Metarko (1980, Fig. 10)

DuPont #1 WDW



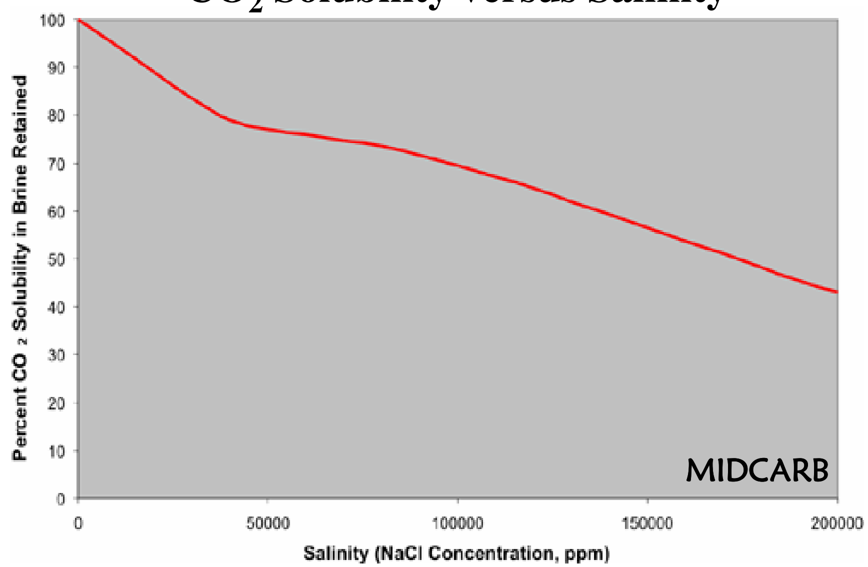
E. I. DuPont de Nemours #1(WAD) FEE

ELL HISTORY (cont)

Date	Operation
5/4?/71	Ream to 10-5/8" diam
5/11/71	Drill ahead w/ 6-3/4"
5/16?/71	c15 5718-5748, rec 30'
5/19?/71	c16 5993-6008, rec 15' serpentine and dunite basement rock.DTD 6008) core anal.
5/20/71	Run Birdwell TES 5125-6009 and Density/Caliper 5200-6009.
5/21/71	Run Birdwell GR/N 4300-6009, depths about 10' deeper than Schlum where overlapped
	DST#9 (SP) 5408-6008 (Mt. Simon Ss)
	P Guage @ 5420 (Wtr Anal by USGS: Dens. 1.14;
	F 182 mins, FFP 2573psi. Fill-up comp TDS 212,000; pH 3.7; sp cond.
	in 40 mins. 150,000; Cl 130,000)
	CI 88 mins, FCIP 2574psi. Rec. 5153' salt wtr

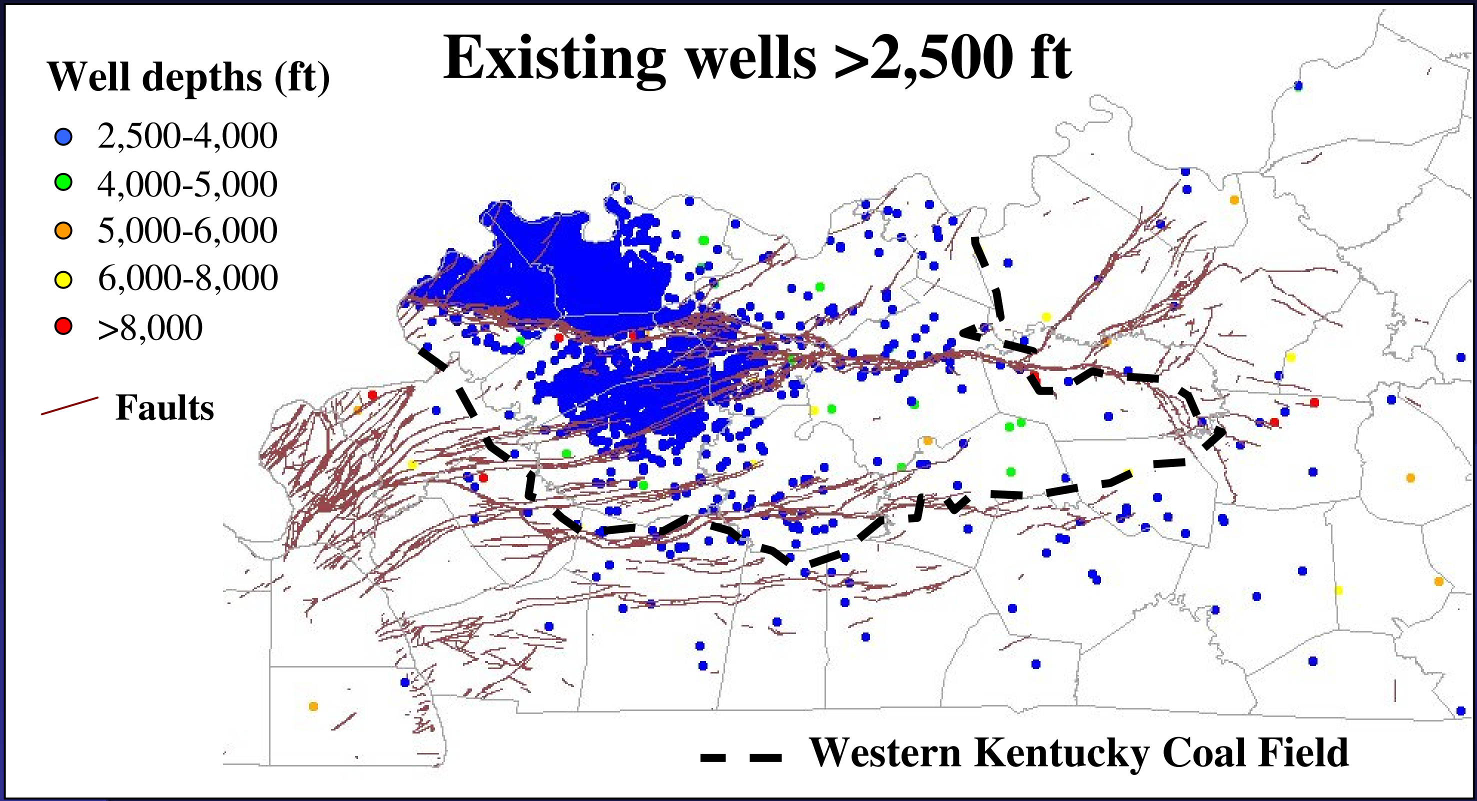
TDS 212,000; pH 3.7; sp cond. 150,000; Cl 130,000)

CO_2 Solubility versus Salinity



www.kgs.ku.edu/PRS/publication/2003/ofr2003-33/P1-05.html

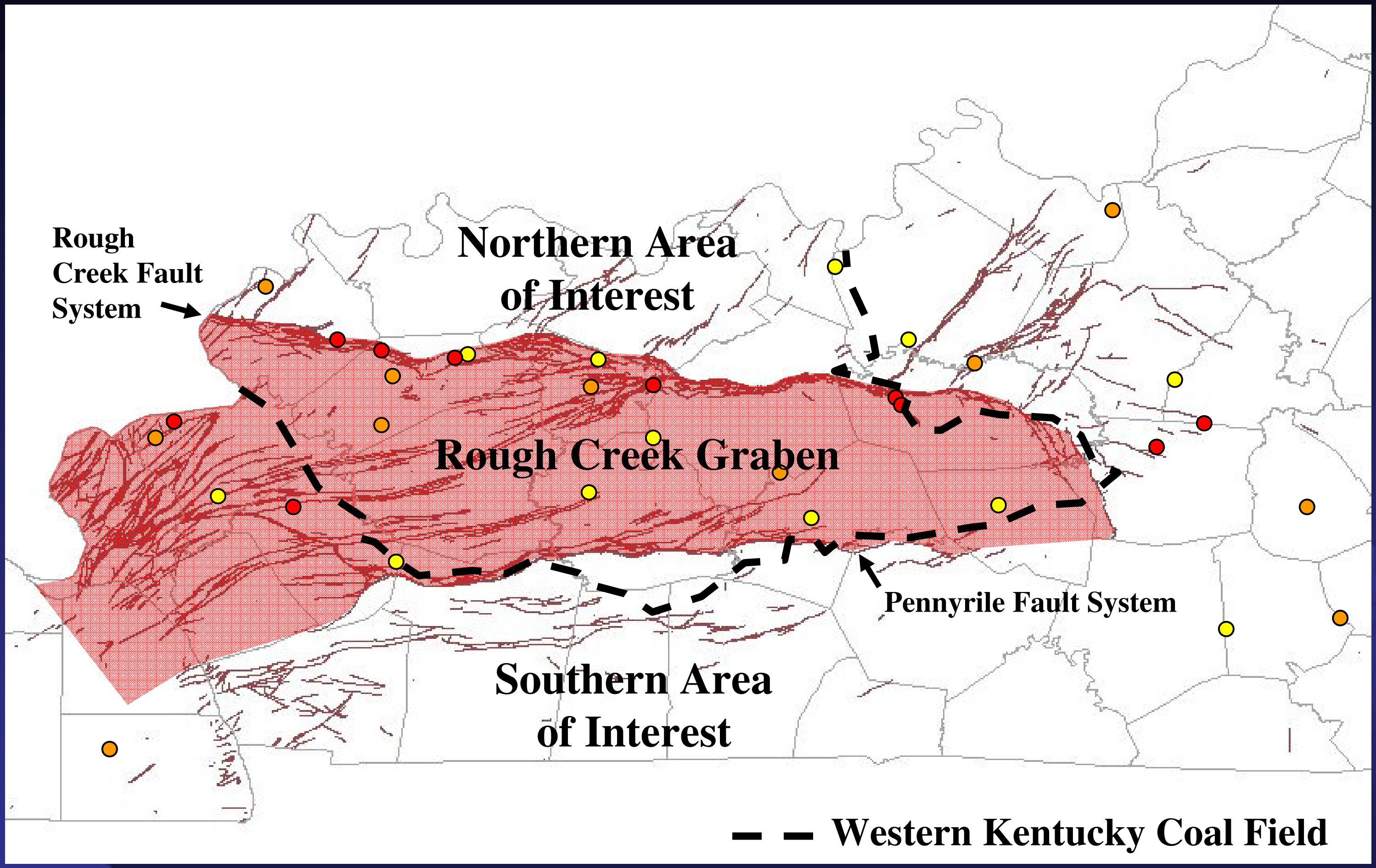
Mt Simon Sandstone Reservoir



The Mt Simon Sandstone reservoir is in an area of considerable faulting and existing oil field development

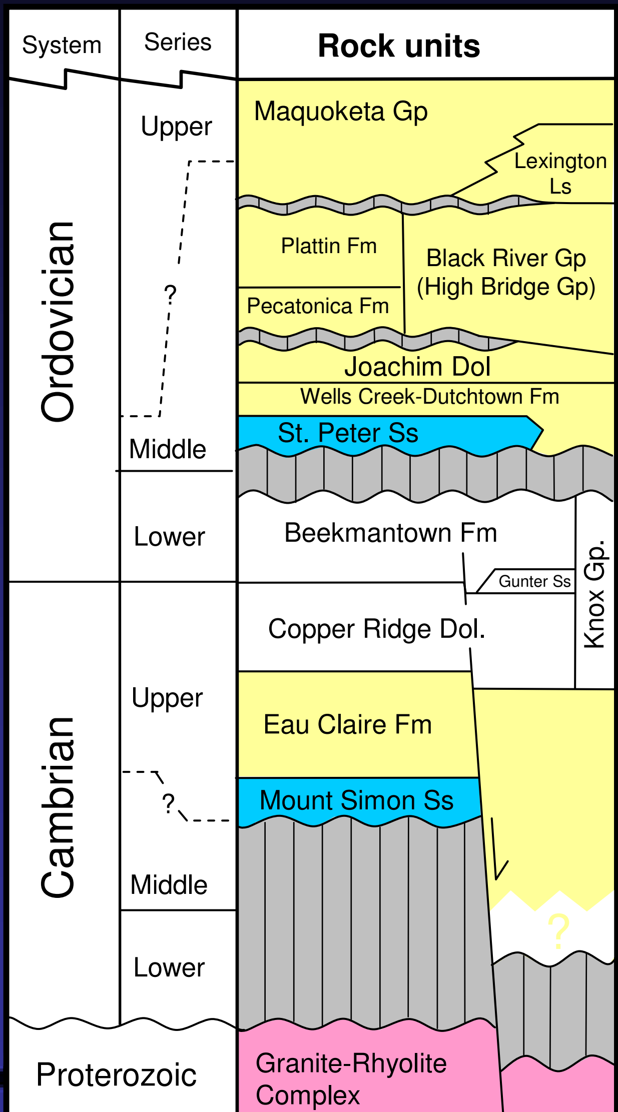
Alternative Storage Possibilities

- **Strata outside of the Rough Creek Graben**
  - Knox Group carbonate reservoirs
  - St Peter Sandstone
  - High Bridge Group carbonate reservoirs
  - Potential for re-entering, deepening, and sampling abandoned exploratory wells
- **Strata inside the Rough Creek Graben**
  - Central to the Western Kentucky Coal Field
  - Few deep tests
  - Unknown reservoir characteristics
  - Potential for re-entering, deepening, and sampling abandoned exploratory wells



There are at least three distinct geologic areas of interest in and adjacent to the Western Kentucky Coal Field with potential CO_2 storage reservoirs.

Western Kentucky Stratigraphic Units with CO_2 Storage Potential



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

KYCCS

Rough Creek Graben

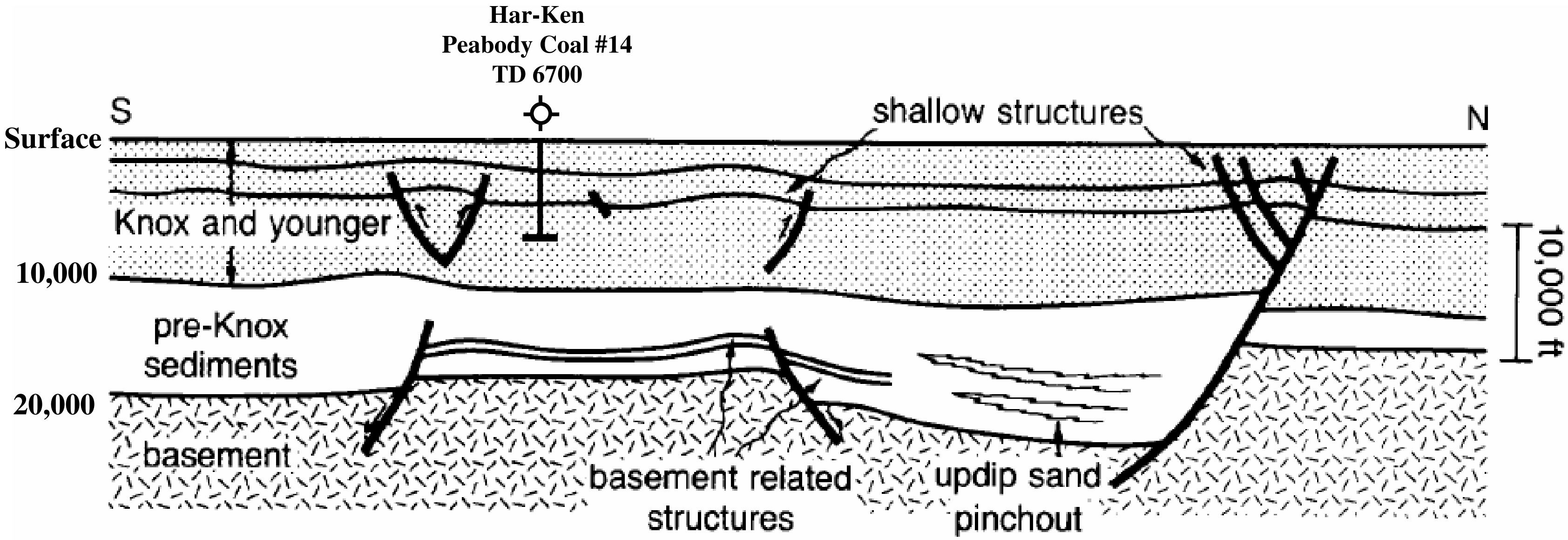
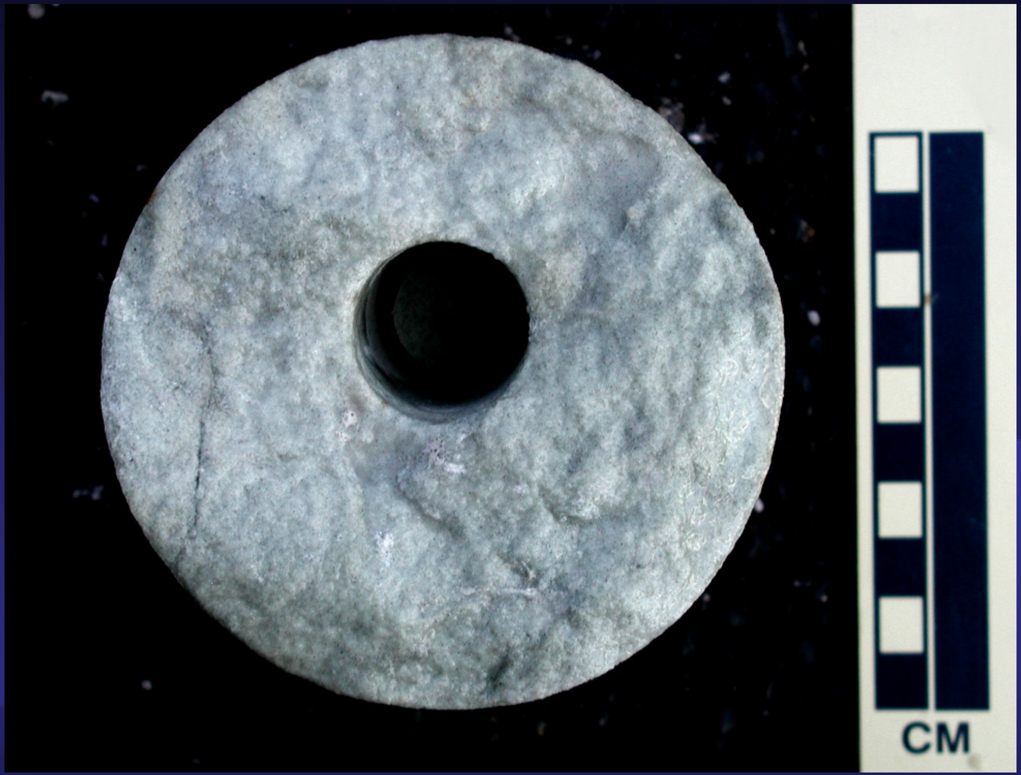


Figure 15-8. Schematic cross section showing trap types in the Rough Creek graben area.

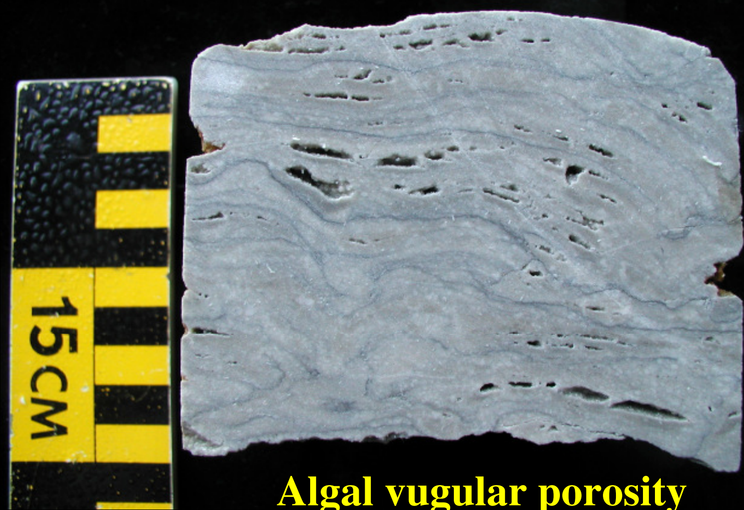
Bertagne and Leising (1991, Fig. 15-8) with annotation

St Peter Sandstone



St. Peter Sandstone is dominantly a fine-grained quartz sandstone with shale and carbonate interbeds. Cements are carbonates, authigenic anhydrite, and silica (Hoholick, 1980; Hoholick et al., 1984)

Knox Group Carbonates

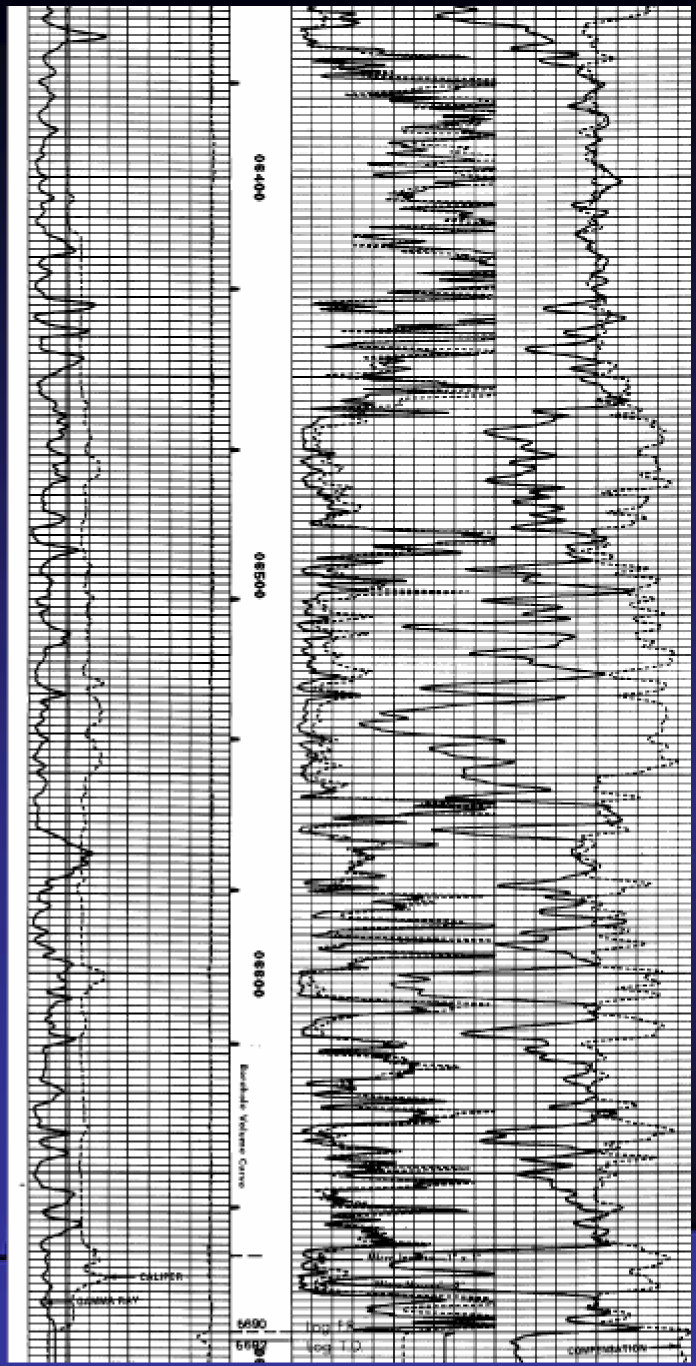


Algal vugular porosity

Dissolution and brecciation porosity

Fracture porosity

All cores are from the DuPont #1 WDW, Louisville, Kentucky



Re-entry Candidate

Har-Ken well Peabody Coal #14 Muhlenberg County

- **Drilled to 6700 ft in March 1985**
  - 16 inch conductor pipe at 30 ft
  - 10¾ inch casing cemented at 184 ft
  - 7 ⁷/₈ inch hole drilled to TD
- **Nine intervals tested by open hole DST 1540-2842 ft**
- **Plugged and abandoned in April 1985**
  - Casing cut off 3 ft below surface
  - Cement plug 3-80 ft
  - Mud 80-360 ft
  - Cement plug 360-400 ft
  - Mud 400-1350 ft
  - Cement plug 1350-1750 ft
  - Mud 1750-6700 ft TD

KYCCS

Conclusions

- There are several potential storage issues to address when choosing a CO2 storage test site
- The Mt Simon Sandstone is a potential candidate as a storage reservoir but is not the only one
- There are many deeper abandoned exploratory wells in the Western Kentucky Coal Field to review for re-entry and testing of CO_2 storage potential in reservoirs other than the Mt Simon Sandstone

Conclusions

Now what is the message there? The message is that there are known 'knowns.' There are things we know that we know. There are known 'unknowns.' That is to say, there are things that we now know we don't know. But there are also unknown unknowns. There are things we don't know we don't know. So when we do the best we can, we pull all this information together and we then say, 'Well that's basically what we see as the situation, that is really only the known knowns and the known unknowns.' And each year, we discover a few more of those unknown unknowns.

Secretary of Defense Donald Rumsfeld, Press Conference at NATO Headquarters, Brussels, Belgium, June 6, 2002

KYCCS.ORG

KYCCS