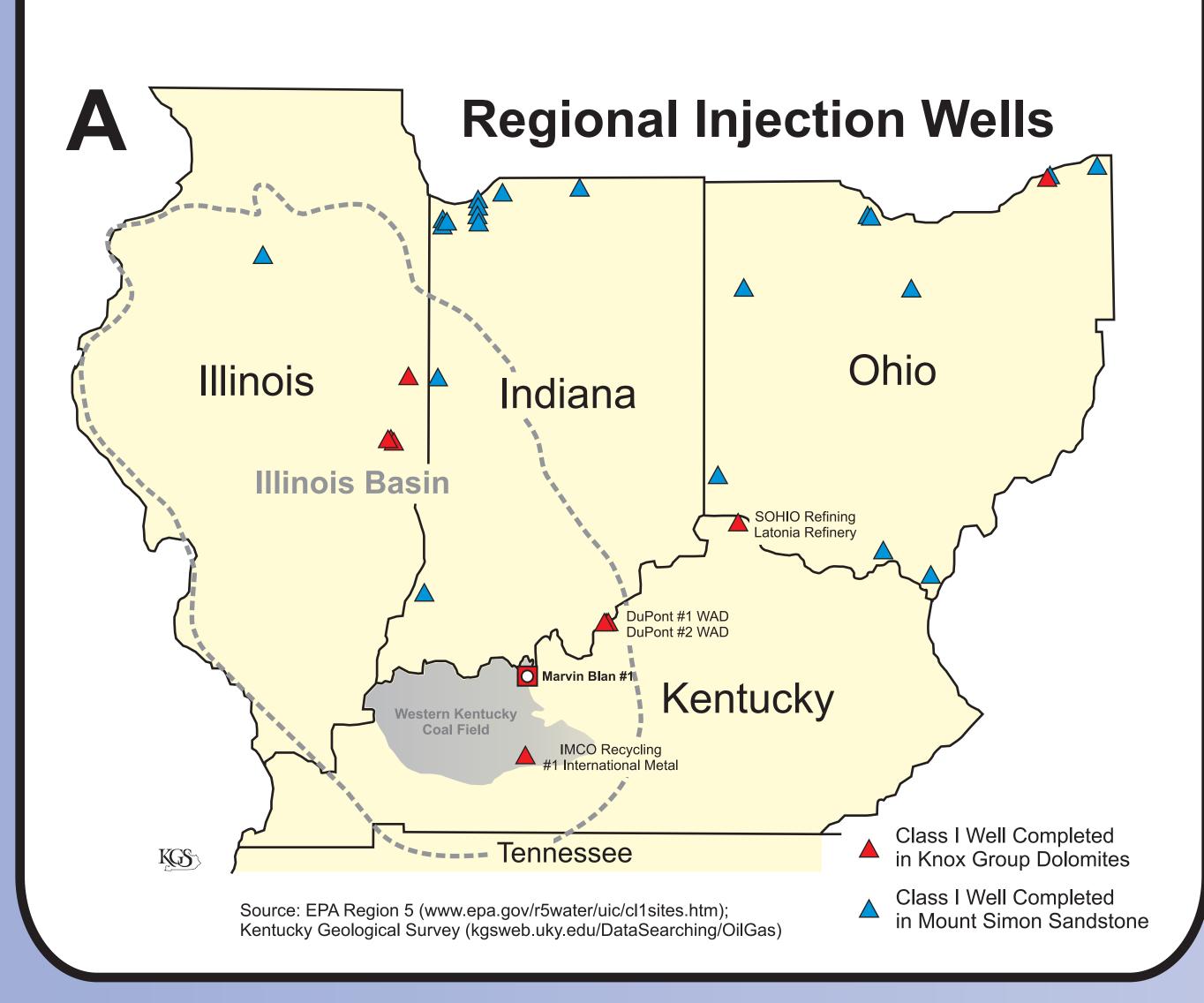
## Carbon Storage Potential in the Southern Illinois Basin: Preliminary Results of the KYCCS Test Well, Hancock County, Kentucky

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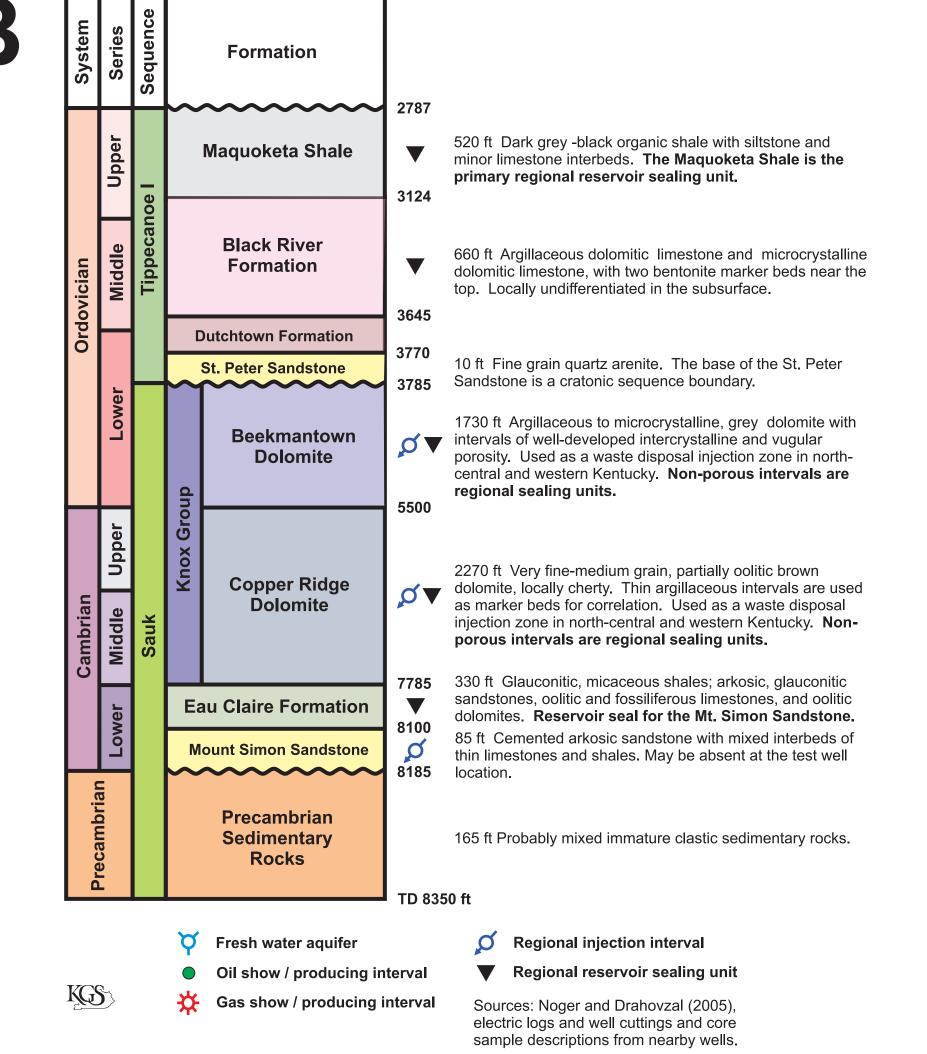
#### **Abstract**

The Kentucky Consortium for Carbon Storage (KYCCS), co-funded by the Commonwealth of Kentucky and industry through the Western Kentucky Carbon Storage Foundation, is testing geologic CO<sub>2</sub> storage potential of the southern Illinois Basin. Identification of commercial-scale carbon storage targets in the deeper part of the basin is challenging because this area lacks a thick, uniform porous reservoir zone. The upper Cambrian Mount Simon Sandstone has significant CO<sub>2</sub> storage potential in Illinois, Indiana, and parts of Michigan and Ohio, but in western Kentucky it is thin and deeply buried, with poor reservoir quality at depths greater than 8000 ft. Other clastic reservoirs, such as the Ordovician St. Peter Sandstone, are thin and lack regional continuity, but may be viable targets in some areas. KYCCS is focusing its efforts on the CO<sub>2</sub> storage potential of an ~4000 ft thick carbonate sequence, the Cambrian-Ordovician Knox Group. Knox dolostones are heterogeneous, containing porous zones up to 50 ft thick, separated by impermeable dolostone confining layers. Porosity ranges from solution vugs to intercrystalline pores, with a variable fracture component.

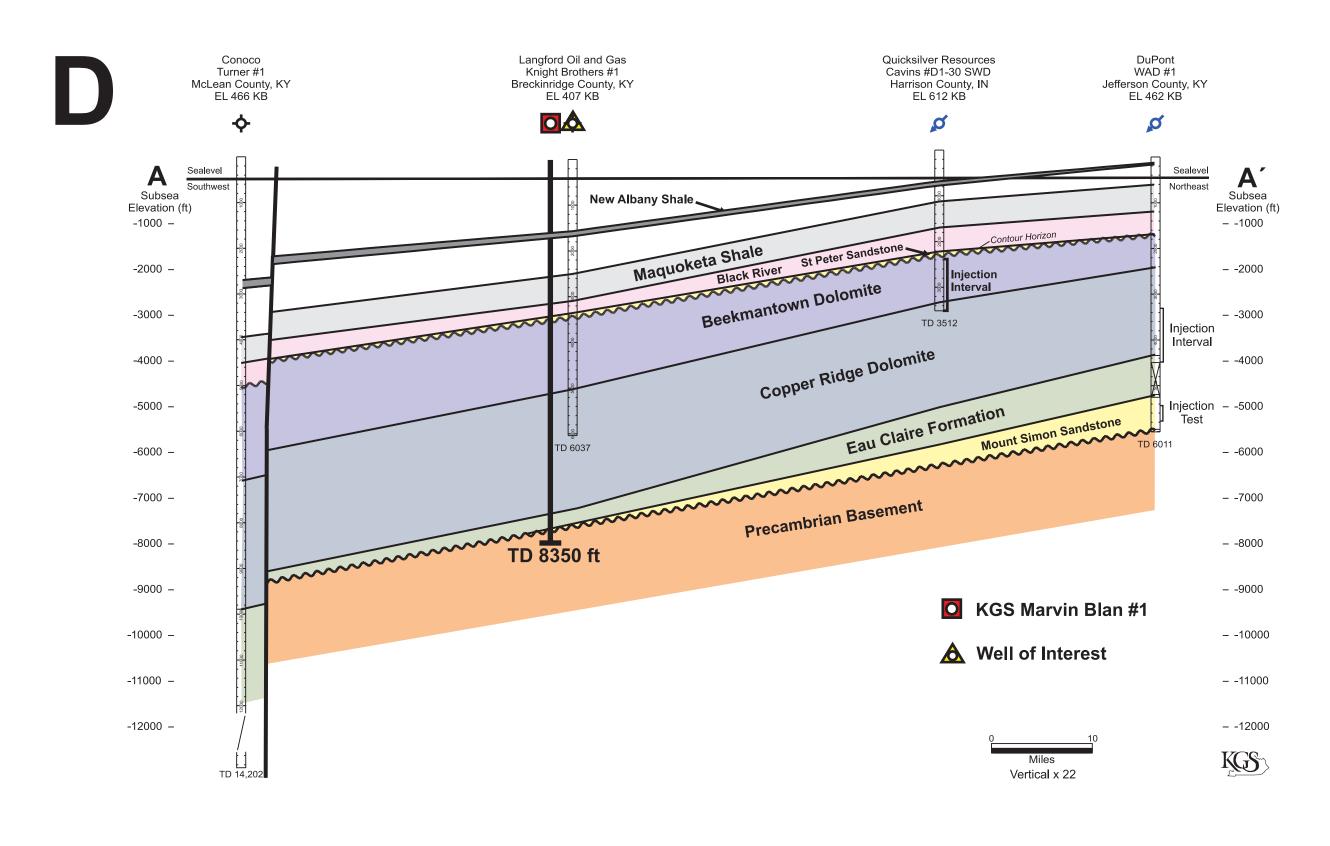
KYCCS will drill and evaluate an 8300-ft research well in Hancock County in the spring of 2009. Data from this well will characterize the St. Peter, Knox, and Mount Simon at this location, and test their CO2 injection capacity. Previous waste-disposal and gas-storage wells indicate good injectivity and containment in the Knox at depths of 3000-6400 ft, including a site where 4000 tons of supercritical CO<sub>2</sub> accumulated after acid dissolution of dolostone. Extensive cores and geophysical logs will be taken to characterize both the reservoir zones and the confining layers in the well. Geophysical characterization includes 26 mi of new 2-D seismic data that will be integrated with geologic data obtained from the well. Injection tests using brine and CO<sub>2</sub> will be conducted in the open hole, using straddle packer assemblies. Modeling the fate of injected CO<sub>2</sub> in the Knox will be difficult because of the complex nature of the carbonate pore system. If the Hancock County test shows the Knox to be a viable sequestration target in the southern Illinois Basin, further evaluation will be justified. The Knox occurs at depths suitable for supercritical CO<sub>2</sub> injection in the Illinois and Appalachian Basins, and comparable strata are present in west Texas (Ellenberger), and Kansas and Oklahoma (Arbuckle).



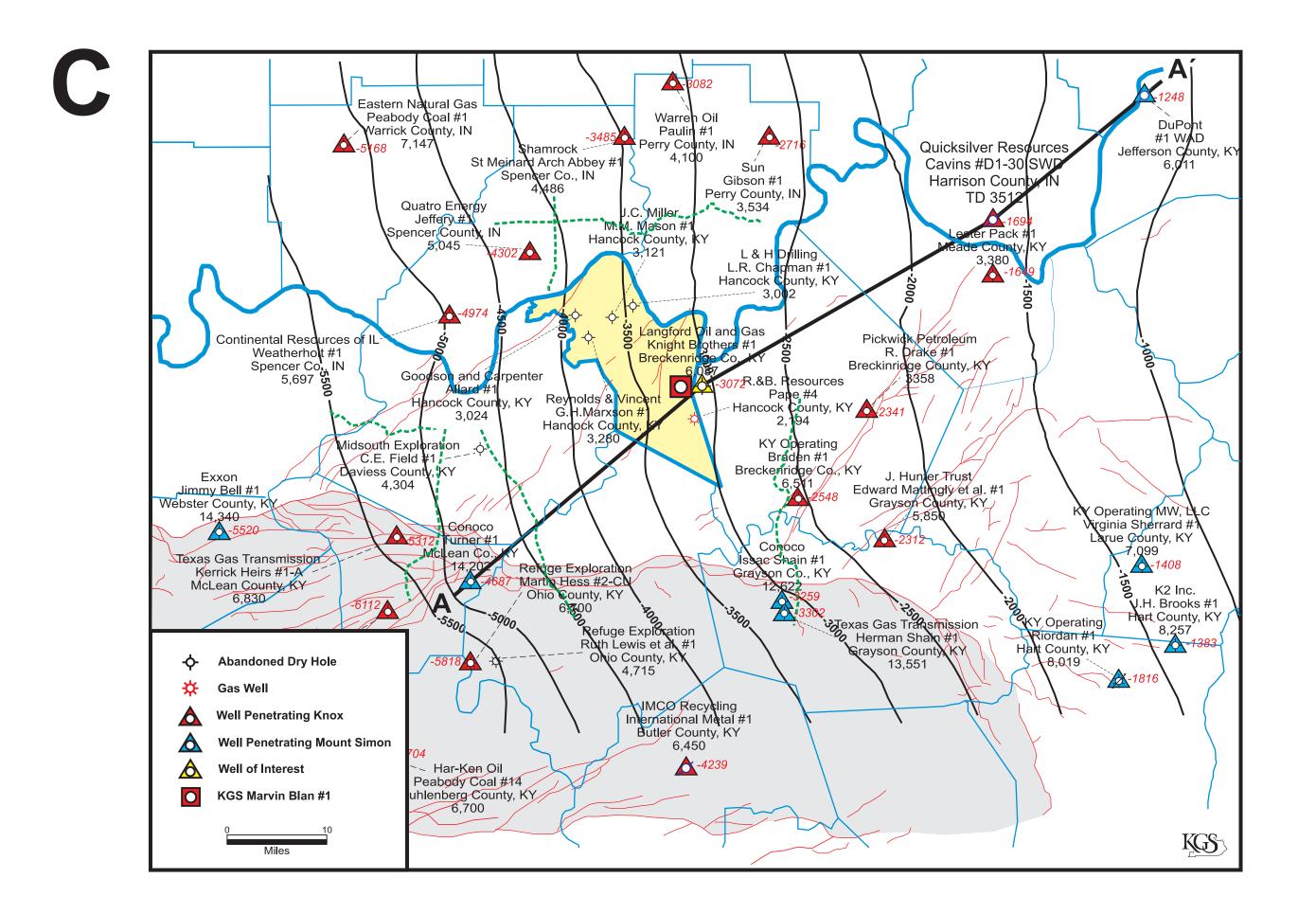
# Generalized Lower Paleozoic Stratigraphy and Structure of Western Kentucky



Lower Paleozoic stratigraphy of western Kentucky. Potential CO<sub>2</sub> storage intervals and sealing intervals are noted. Injection testing in the Marvin Blan #1 will focus on porous and permeable intervals within the Knox Group dolomites. It is unlikely that the Mount Simon Sandstone, if present in the well, will have sufficient reservoir quality to merit testing.

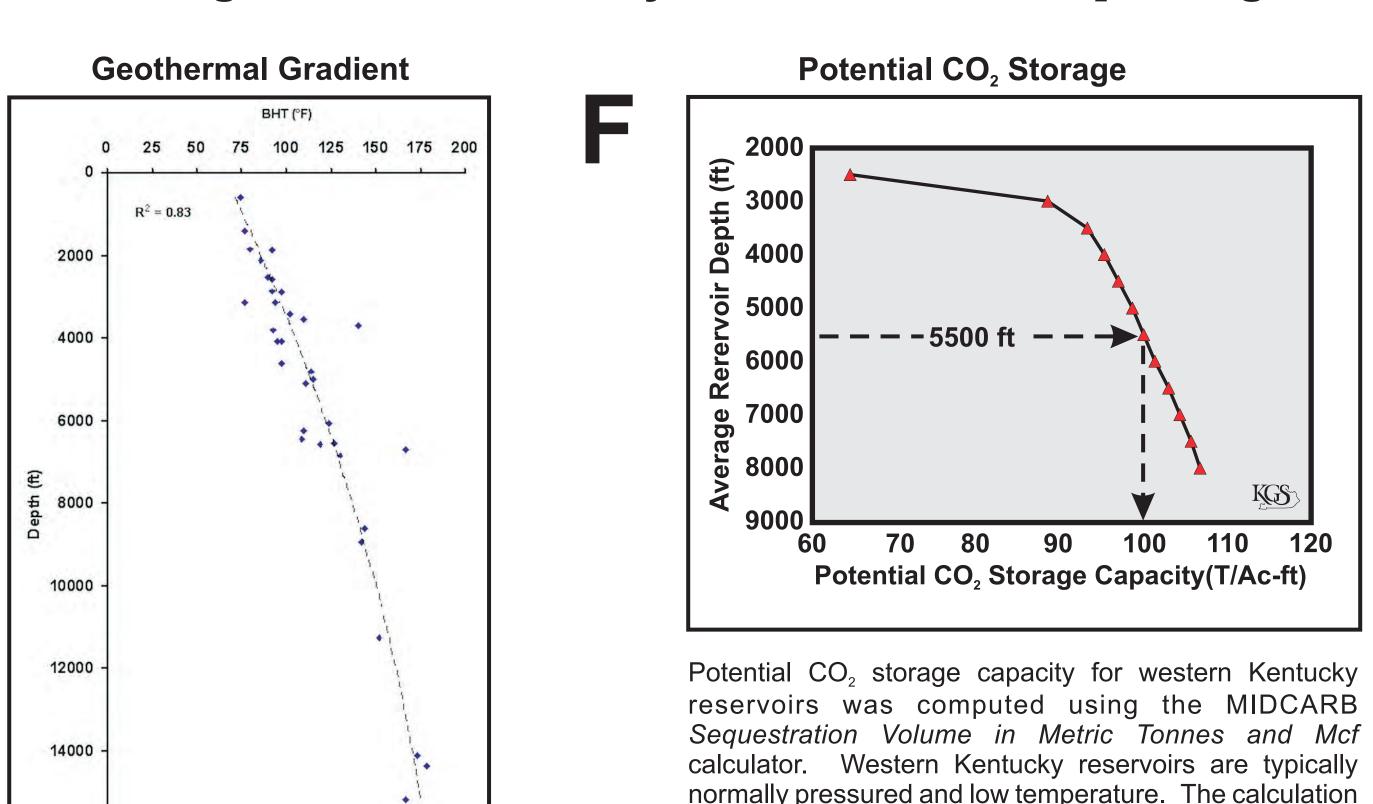


**Generalized stratigraphy and structure of western Kentucky.** Interpretation of 2-D seismic data suggests that the sub-Knox Paleozoic section thins to the west and south. The Knox is ~4000 ft thick in western Kentucky. The Mount Simon is ~700 ft thick in the #1 WAD well, whereas it the Marvin Blan #1 it is expected to be very thin or absent.



Structural contours on top of the Knox Group. Wells penetrating the Knox Group are noted by red triangles and wells penetrating the Mount Simon Sandstone noted by blue triangles. The Knox unconformity dips ~0.5° southwest, whereas deeper strata dips ~1° southwest. Few wells in Kentucky penetrate the entire Knox section and fewer penetrate the Mount Simon. The Knox has been used for both Class I hazardous waste injection as well as Class II oilfield brine disposal in Kentucky.

#### Evaluating Western Kentucky Reservoirs for CO<sub>2</sub> Storage



The geothermal gradient of the southeastern

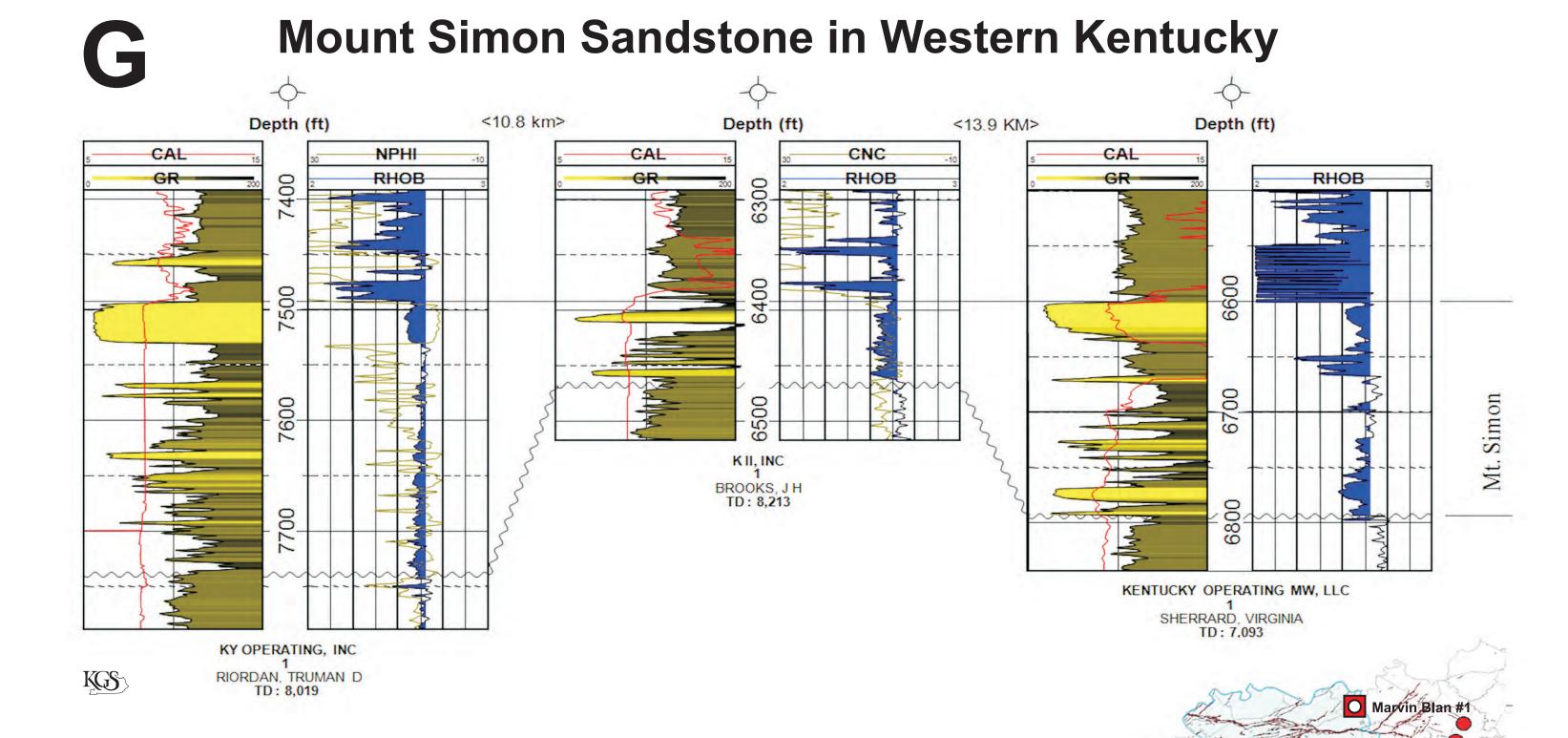
1° F/ 100 ft of depth.

Illinois Basin, western Kentucky, averages

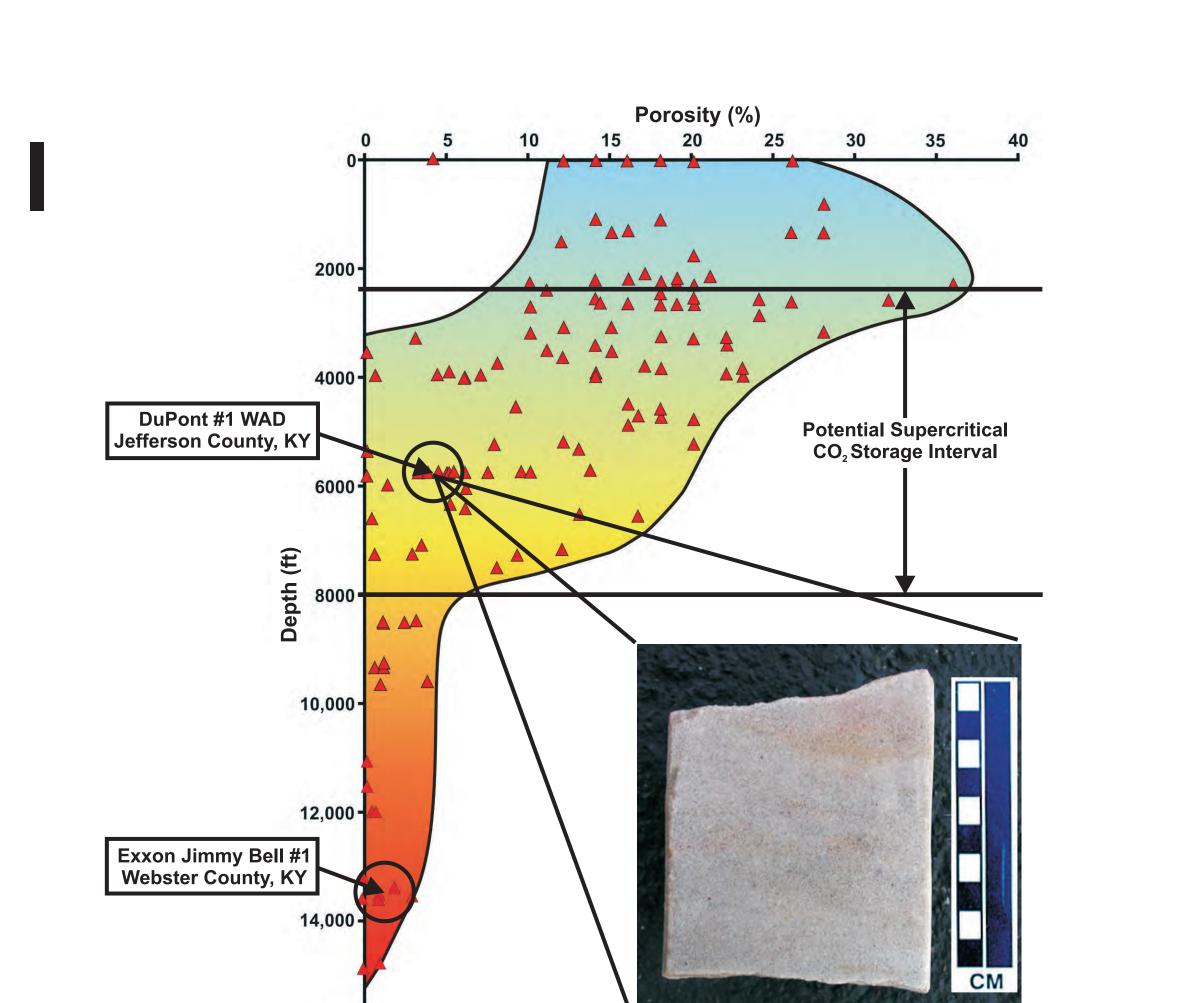
was made assuming 10% average porosity, 0.44 psi/ft

pressure gradient, and the western Kentucky geothermal

## Mount Simon Sandstone in Western Kentucky



Stratigraphic cross section through the Mount Simon in western Kentucky shows it thinning and facies changes approaching the Cincinnati Arch. These three wells are located ~50 mi southeast of the Marvin Blan #1 well.

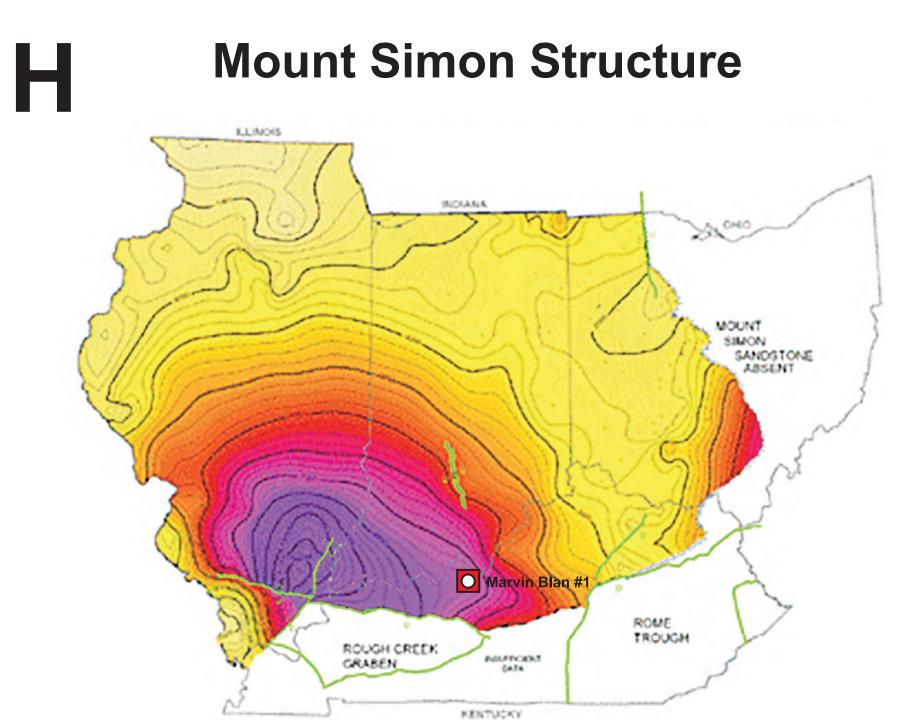


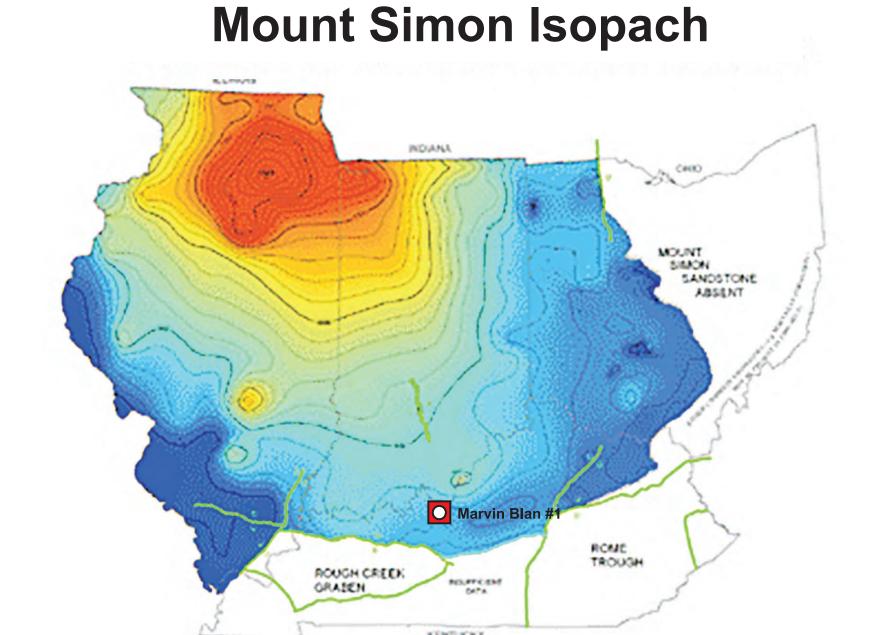
Data Sources (828 samples): Metarko (1980; 89 samples), Shebl (1985; 9 samples), Makowitz (2004; 27 samples, Kunledare (2005; 690 samples), and DuPont #1 WAD (13 samples). Average porosity from cores from the #1 WAD is 5.5%, although analysis of electric logs suggests a net 150 ft of Mount Simon Sandstone with porosity greater than 10%.

Porosity measured from cores of the Mount Simon Sandstone in the Illinois

KGS

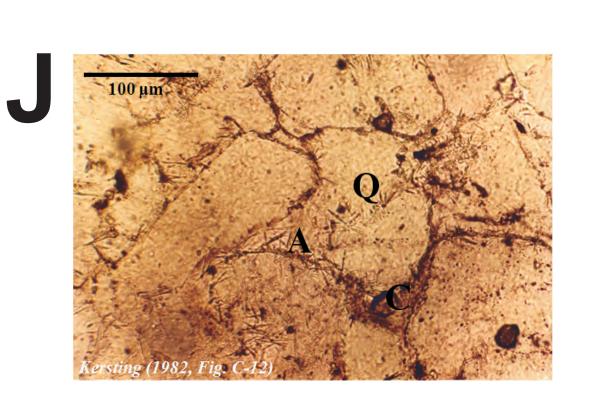
Basin. Locations of the #1 WAD and Jimmy Bell #1 wells are noted in Figure C. The Mount Simon is not considered as a potential CO<sub>2</sub> storage reservoir in western Kentucky due to its being thin, where present. At depths below 8000 ft, diagenesis has reduced porosity to generally less than 5%.





From Wickstrom et al. (2003) MIDC

The Mount Simon Sandstone in western Kentucky is in the deepest part of the Illinois Basin, generally at drill depths exceeding 8000 ft. The Mount Simon is also near its depositional limit, and shales and thin limestones are common in the section (Fig. G).





Thin section photomicrographs of the Mount Simon Sandstone from the Jimmy Bell #1 well. **Left:** Cutting sample 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. **Right:** Cutting sample from 14,220 ft shows microquartz (M) filling the pores between quartz grains.



## Evaluation of the Knox Dolomite Carbon Storage Reservoir

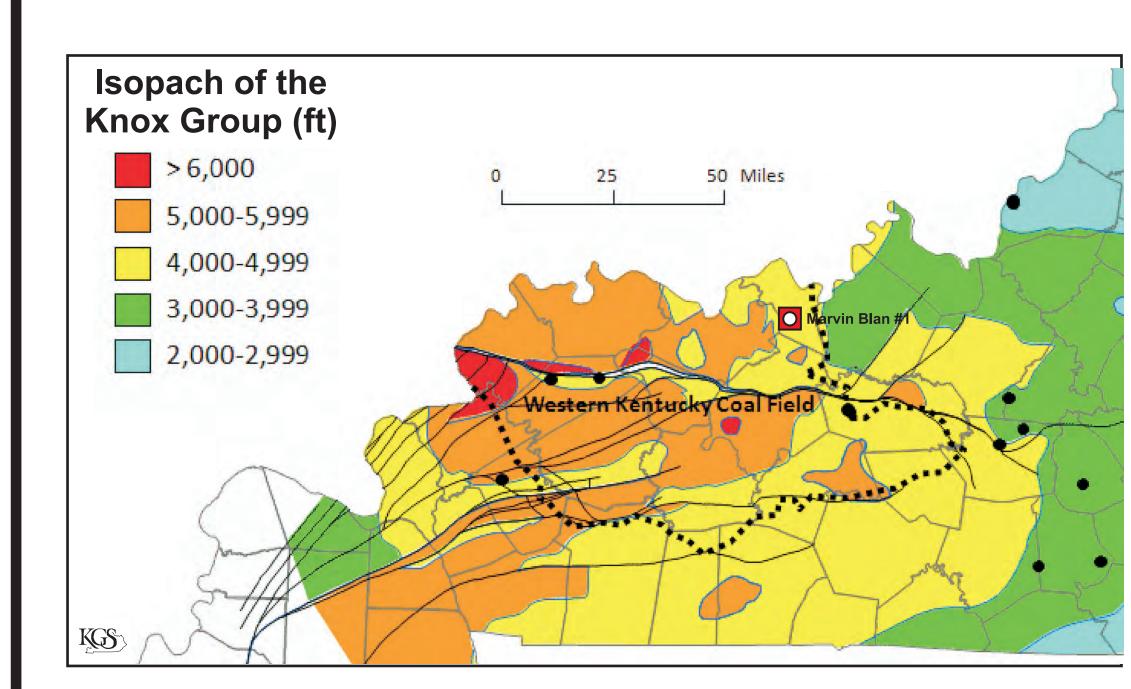
### Knox Group Dolomites CO<sub>2</sub> Storage Reservoir

- Knox Group dolostones are the primary reservoir objective. As many as five suitable intervals are expected to be found.
- Injection into the Knox dolostones has been demonstrated
- in many Midwest wells (Fig. A):

   Kentucky has had three UIC Class I wells and one historical injection well
- DuPont #1 WAD and #2 WAD, Jefferson County
- SOHIO Latonia Refinery, Kenton County
   UIC Class I wells are permitted for injection in the Knox in Illinois and Ohio
   Indiana has 43 disposal wells permitted for oilfield brine disposal in the
- Knox dolostones are not homogeneous.
- Porosity distribution from electric log analysis of the #1 WAD well shows a mean of 5.5%, but with a wide range of values about this mean(Fig. J)
- Reservoir zones are thin and widely distributed throughout the section • Only the lower part of the Beekmantown Dolomite was preserved in the DuPont #1WAD
- The most porous and permeable intervals are in the lower Beekmantown and lower
- Dolomitization and porosity and permeability in the Knox appears to be related to diagenesis of parent limestones
- and early-stage dolomites (Fig. L). The Knox shows several generations of diagenesis, based on thin-section
- petrographyDiagenesis by flow of late-stage hydrothermal fluids

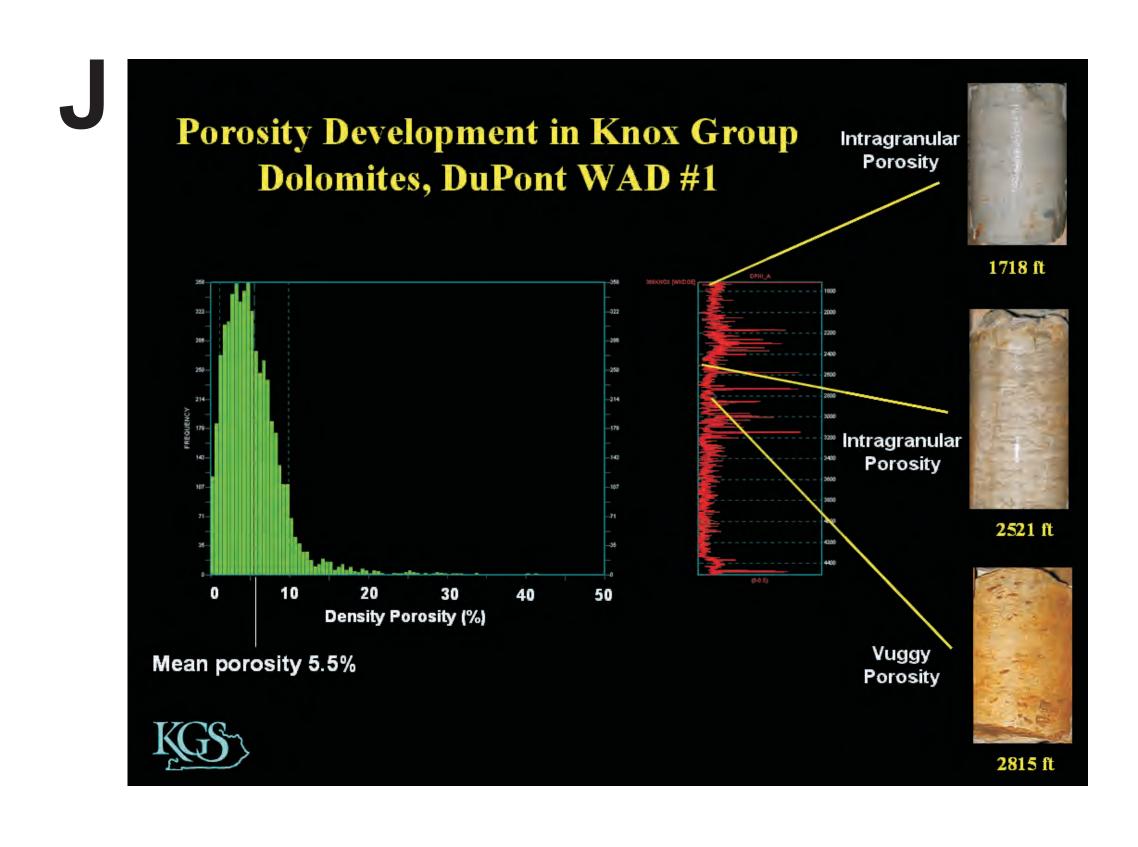
### Knox Group Dolomites CO<sub>2</sub> as a Reservoir Seal

- Porosity and permeability were measured in whole cores from five intervals in the Knox in the DuPont #1 WAD well.
- Less than 3% porosity and less than 0.10 md vertical permeability in the dense sections cored that comprise the majority of the Knox section Maximum of 8.2% porosity and 0.34 md permeability
- Whole cores have been cut in the Knox section in the Marvin Blan #1 well, with additional rotary sidewall cores
- St. Peter Sandstone, and uppermost Knox in the first 120 ft core Lower Beekmantown in the second 120 ft core
- Middle Copper Ridge in third 120 ft core Comprehensive laboratory analysis program planned
- Routine porosity and permeability analysis
- Confinement zone testing for micropermeability and permeability to liquids Rock strength testing

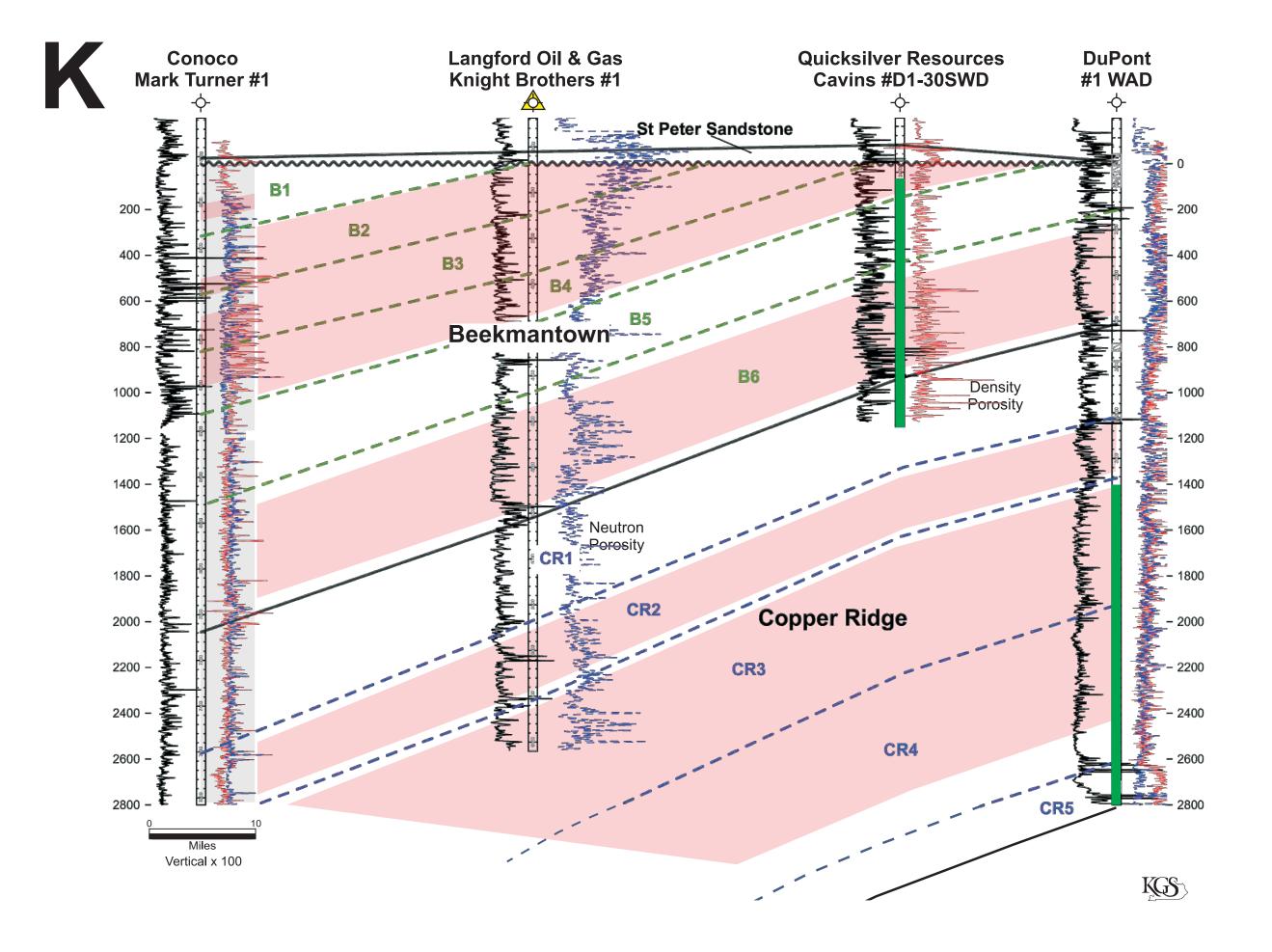


Isopach map of the Knox Group in western Kentucky. The western Kentucky Coal Field is noted by the dashed line. Interpretation of 2-D seismic data and correlation with nearby deep wells suggests that the Knox is ~4000 ft thick in the Marvin Blan #1 well. Evaluation of the Knox in the Marvin Blan #1 well includes and extensive program of electric logs, including a formation micro-imaging log, as well as comprehensive analyses of conventional whole cores and rotary sidewall cores

Bowersox et al. (2009): Carbon Storage Potential in the Southern Illinois Basin: Preliminary Results of the KYCCS Test Well, Hancock County, Kentucky

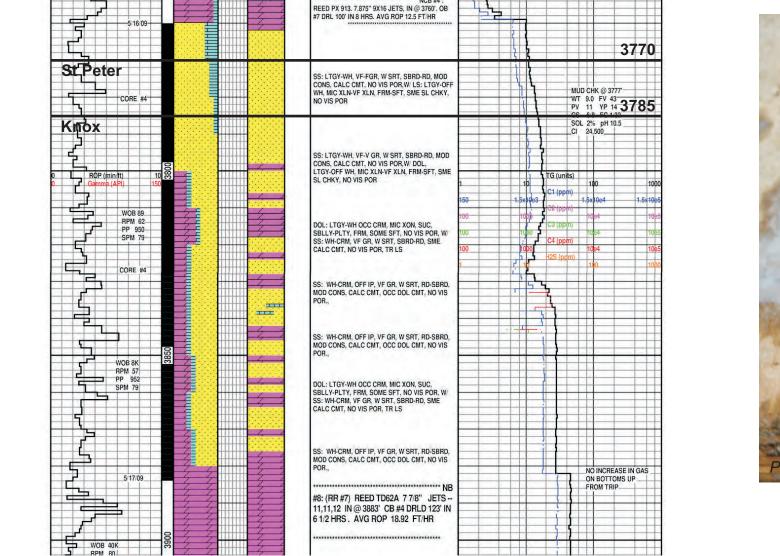


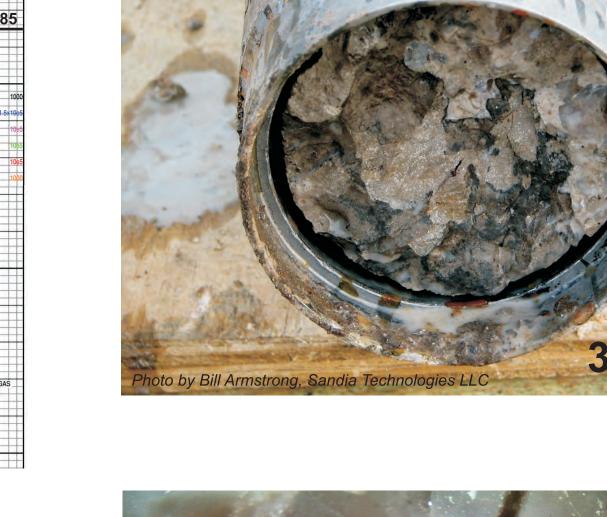




Stratigraphic cross section of the Knox Group following the line of section in Figure C. Porosity in the Knox dolomites is best developed in the B2-B4, B6, and CR2-CR 4 members. Neutron porosity is shown in blue, density porosity in red, and injection intervals in green. Rough Creek Graben is shaded grey.

## Cores of Uppermost Knox Marvin Blan #1

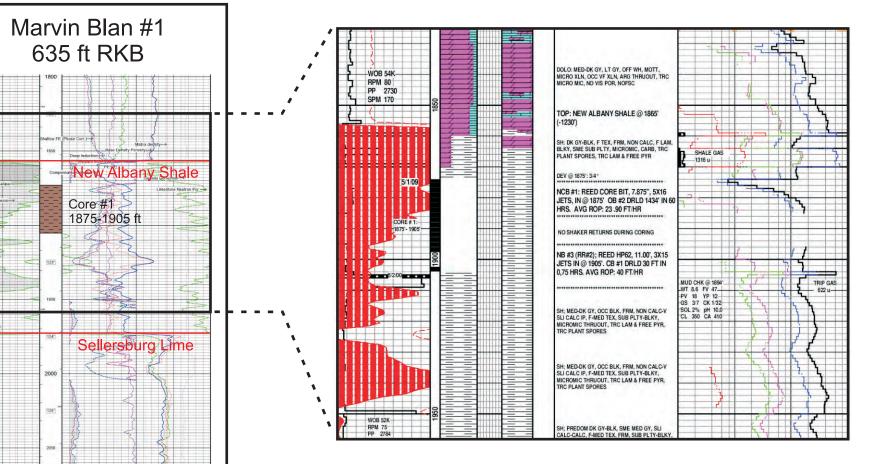








## **Evaluation of Reservoir Seals**

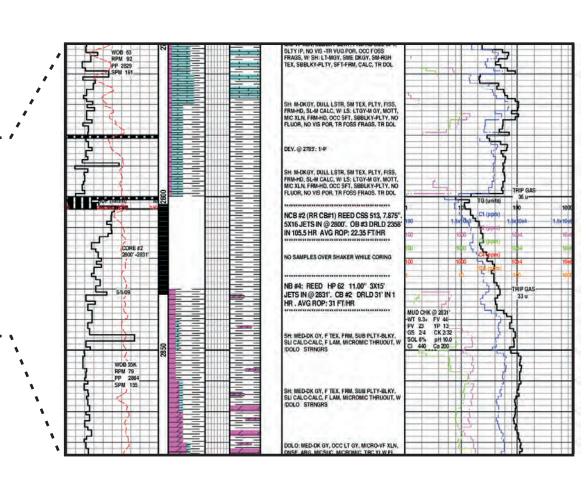




A 30 ft core of the New Albany Shale was cut in the Marvin Blan #1 well to evaluate its capacity as both a CO<sub>2</sub> storage reservoir and reservoir seal. This research is being conducted by KGS separately as a study of CO<sub>2</sub> storage and enhanced gas recovery from organic-rich Devonian black shales in Kentucky.

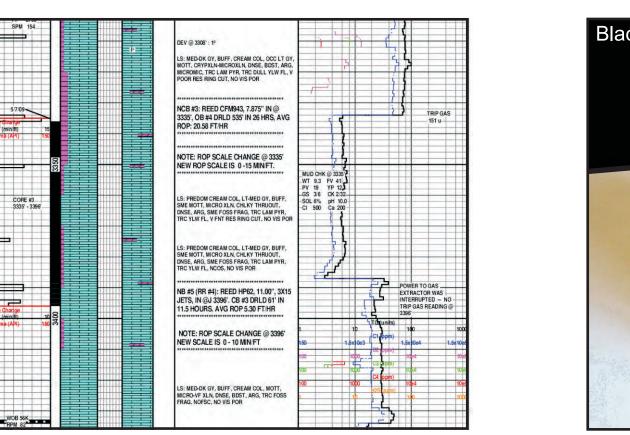
#### Characterization of Reservoir Sealing Intervals

Each of the injection zones to be tested in the Marvin Blan #1 well have thick sealing units overlying them to ensure the permanent storage of the injected CO<sub>2</sub>. These seals will include dense dolomite sections within the Knox, and the overlying Black River Group carbonates and Maquoketa Shale. The Devonian New Albany Shale will provide the ultimate reservoir seal. Laboratory analyses will include routine core analysis, capillary pressure, threshold entry pressure, permeability to liquids and CO2, petrographic analysis, and rock mechanics.





A 30 ft core of the Maquoketa Shale was cut in the Marvin Blan #1 well to evaluate its capacity as a CO<sub>2</sub> storage reservoir seal.

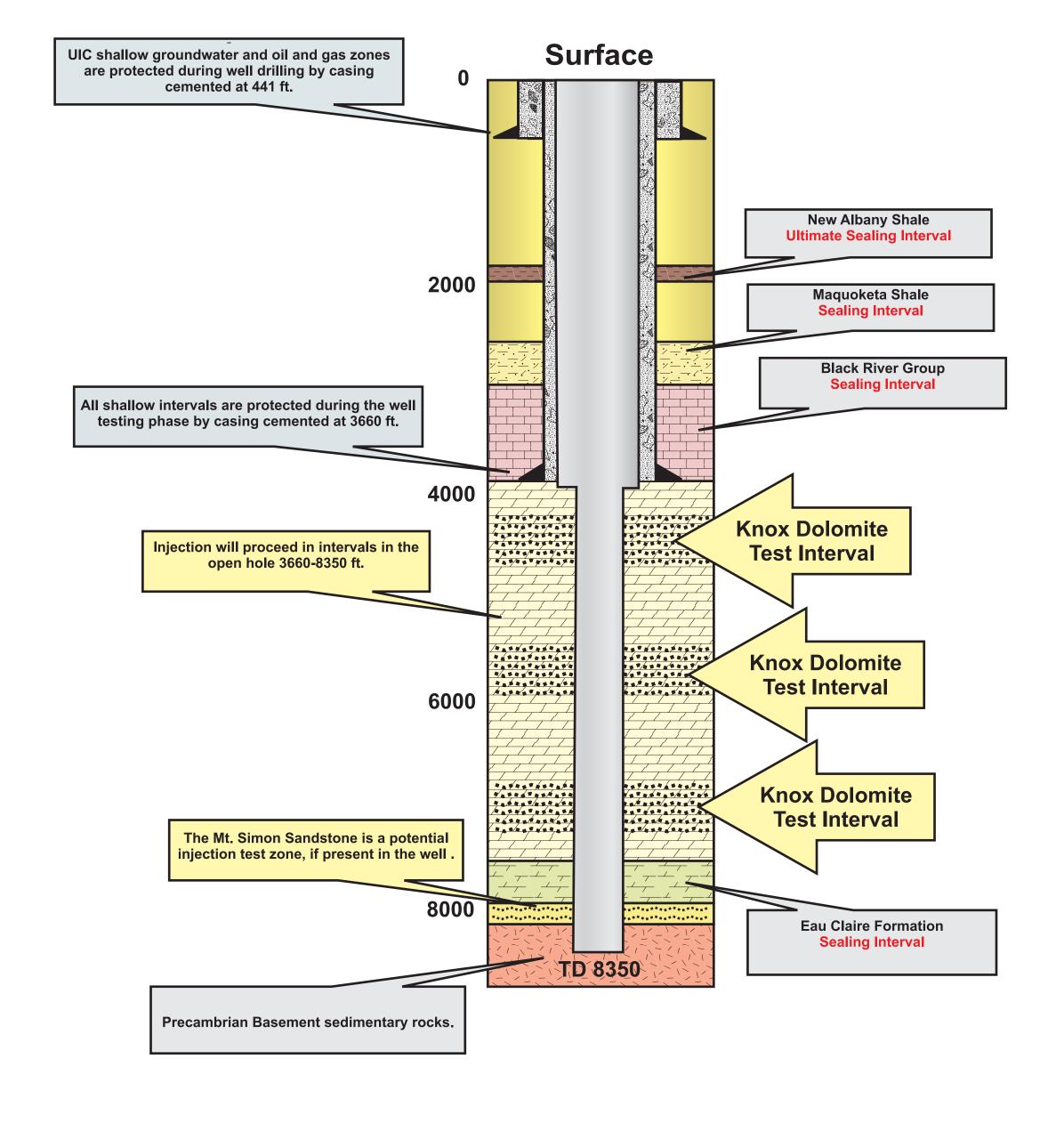




A 60 ft core of the Black River Limestone was cut in the Marvin Blan #1 for analysis as a reservoir seal. A correlative core form the #1 WAD showed half of the samples with vertical permeability less than 0.10 md with associated porosity averaging 4.6%.

## KGS Marvin Blan #1

## CO<sub>2</sub> Injection Test Well



#### Conclusions

The western Kentucky carbon storage test well is an ambitious project designed to demonstrate the feasibility of CO<sub>2</sub> injection in the Knox and the integrity of the reservoir sealing strata. If the Marvin Blan #1 test shows the Knox to be a viable CO<sub>2</sub> storage reservoir, evaluation elsewhere will be justified. Comparable strata are present in the Knox throughout the Illinois and Appalachian Basins, the Ellenberger Limestone in Texas, and Arbuckle Limestone in Kansas and Oklahoma.



the University of Kentucky, and a consortium of more than 20 industry partners. Principal contributors include the Western Kentucky Carbon Storage Foundation, TVA, Illinois Office of Coal Development, U.S. Department of Energy - National Energy Technology Laboratory, R&B Resources LLC, GEO Consultants, LLC, Schlumberger Carbon Services, Smith Management Company, and Wyatt, Tarrant & Combs, LLP.

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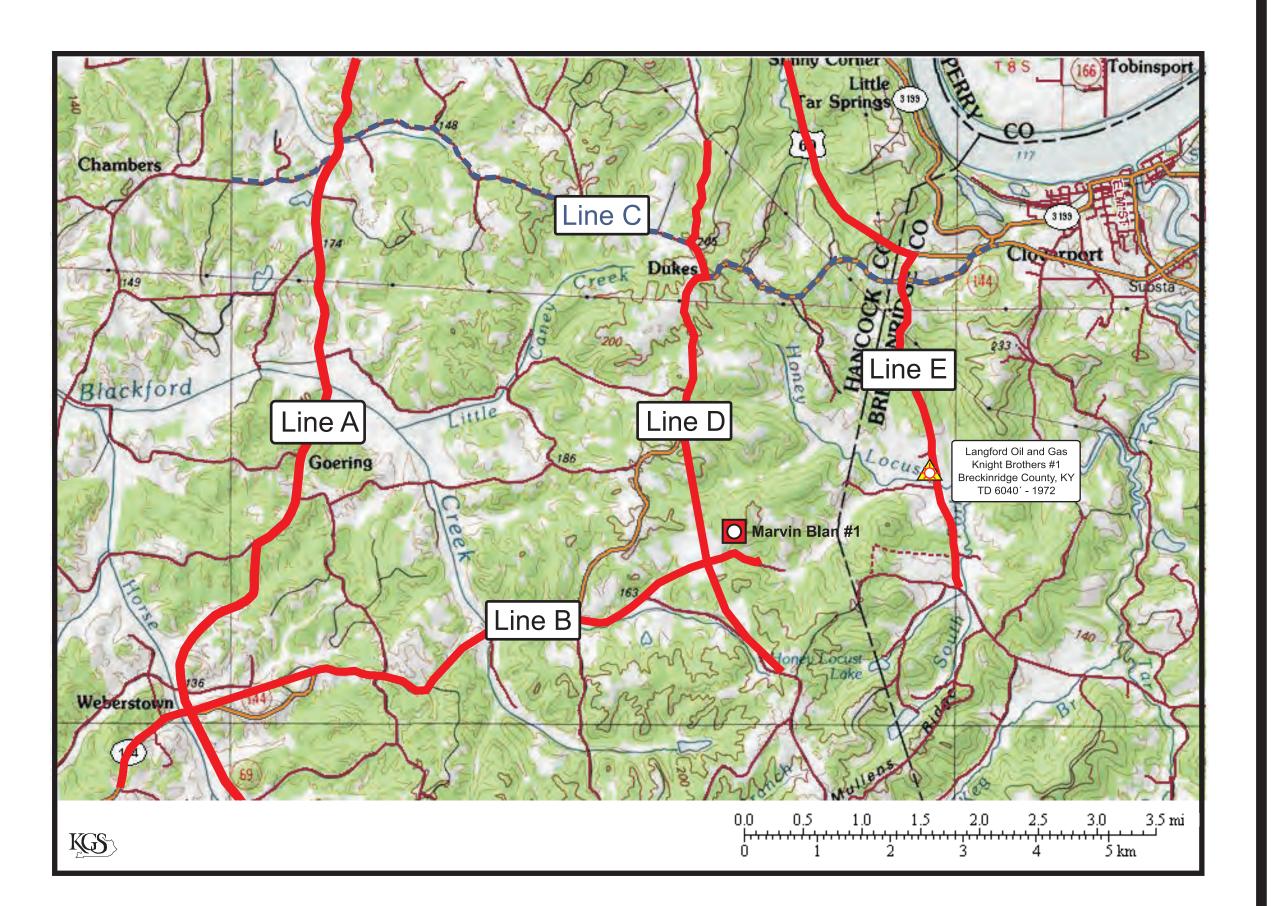




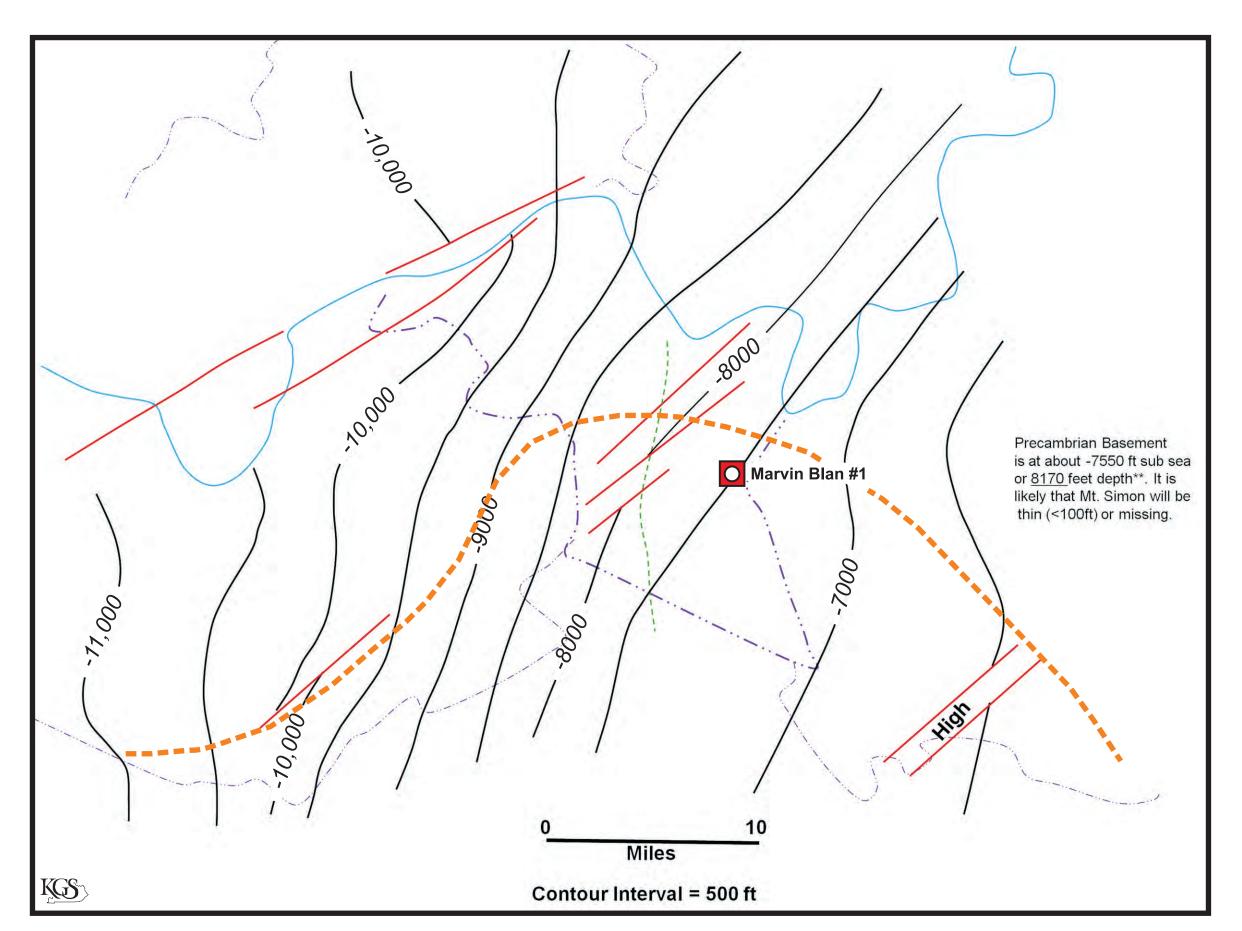
## 2008-2009 Hancock County, Kentucky, 2-D Seismic Program

## KGS Hancock County 2-D Seismic Program In December 2008, KGS initiated a 24-mile, 2-D seismic acquisition

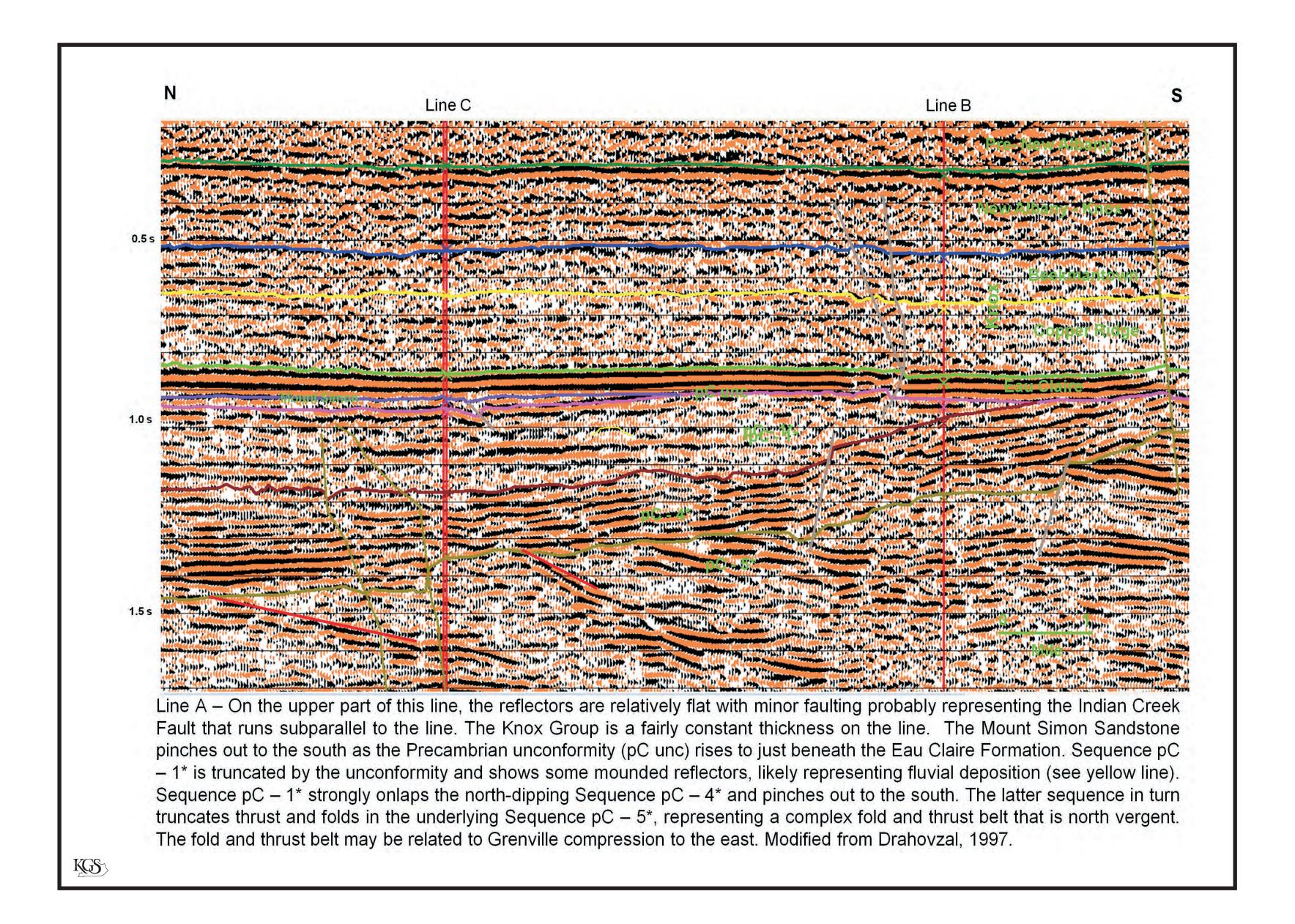
program in Hancock County. The purpose of the program was to provide a better interpretation of the subsurface stratigraphy in the vicinity of the Marvin Blan #1 wellsite, and to ensure that the well was free of faults that might compromise the integrity of CO<sub>2</sub> storage reservoirs. The new seismic also aids in the interpretation of the structure of the Precambrian basement strata and the evaluation of its potential for CO<sub>2</sub> storage.

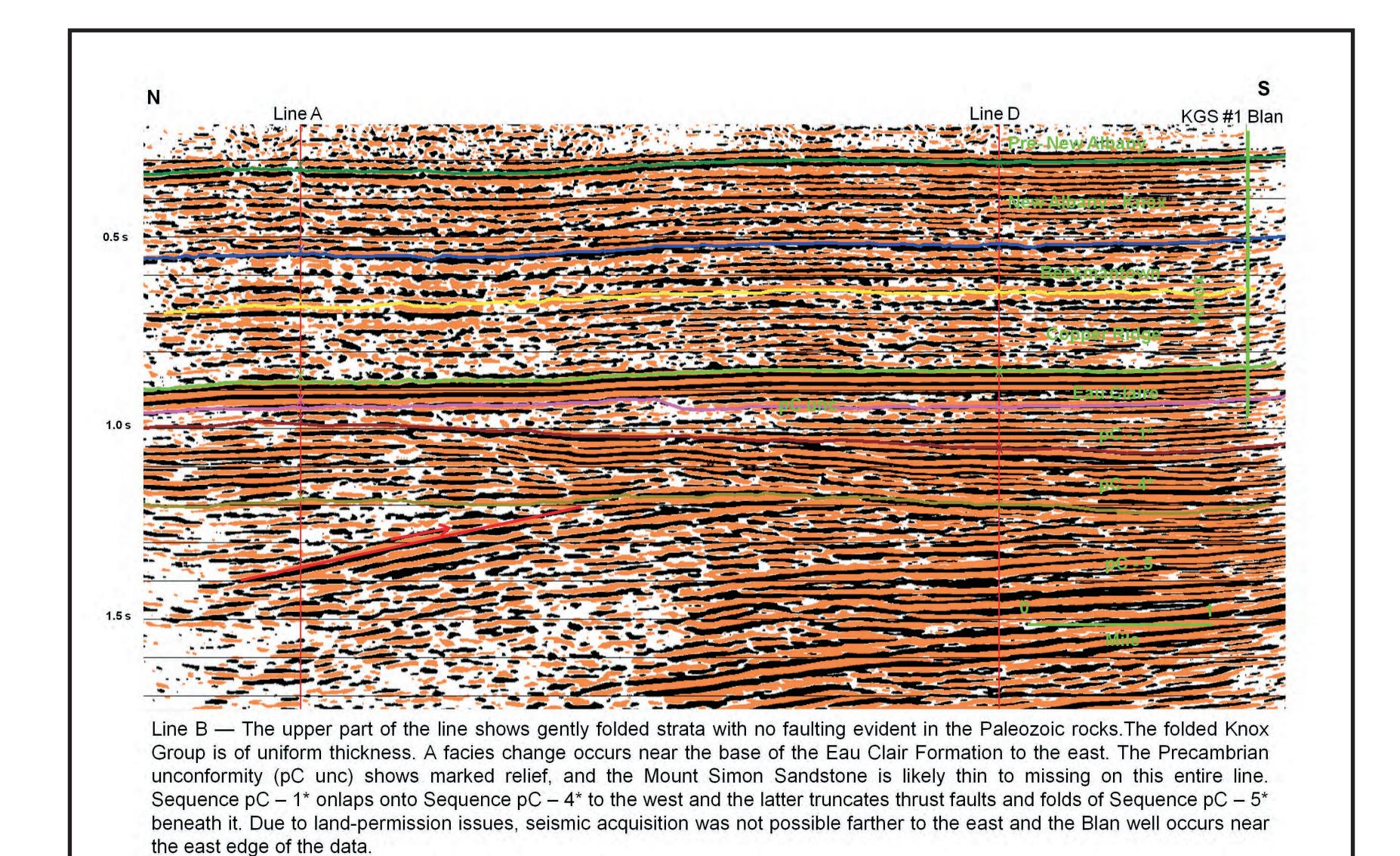


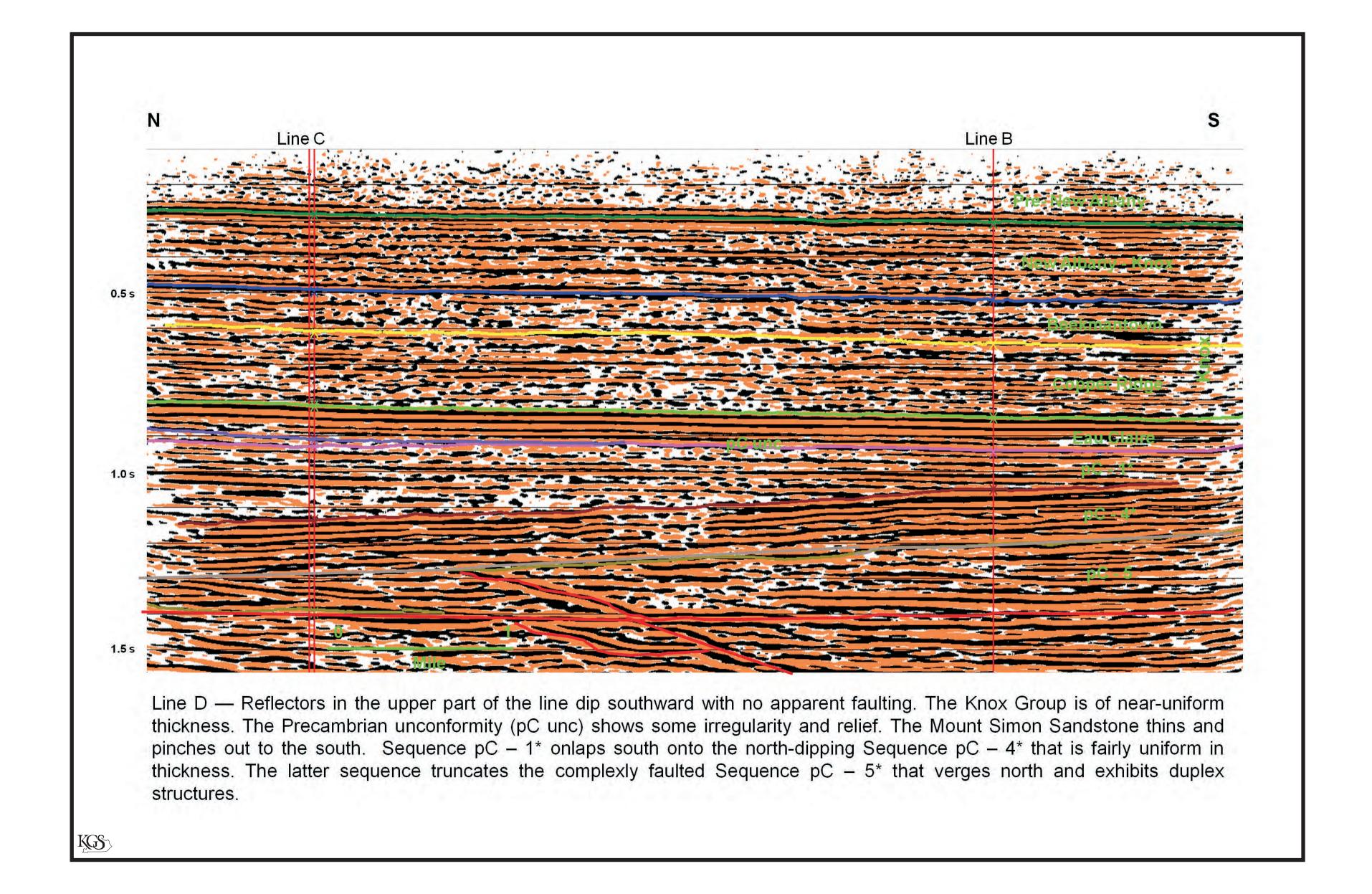
Index of KGS 2-D seismic data. Line C (blue dashes) is not included in this presentation.

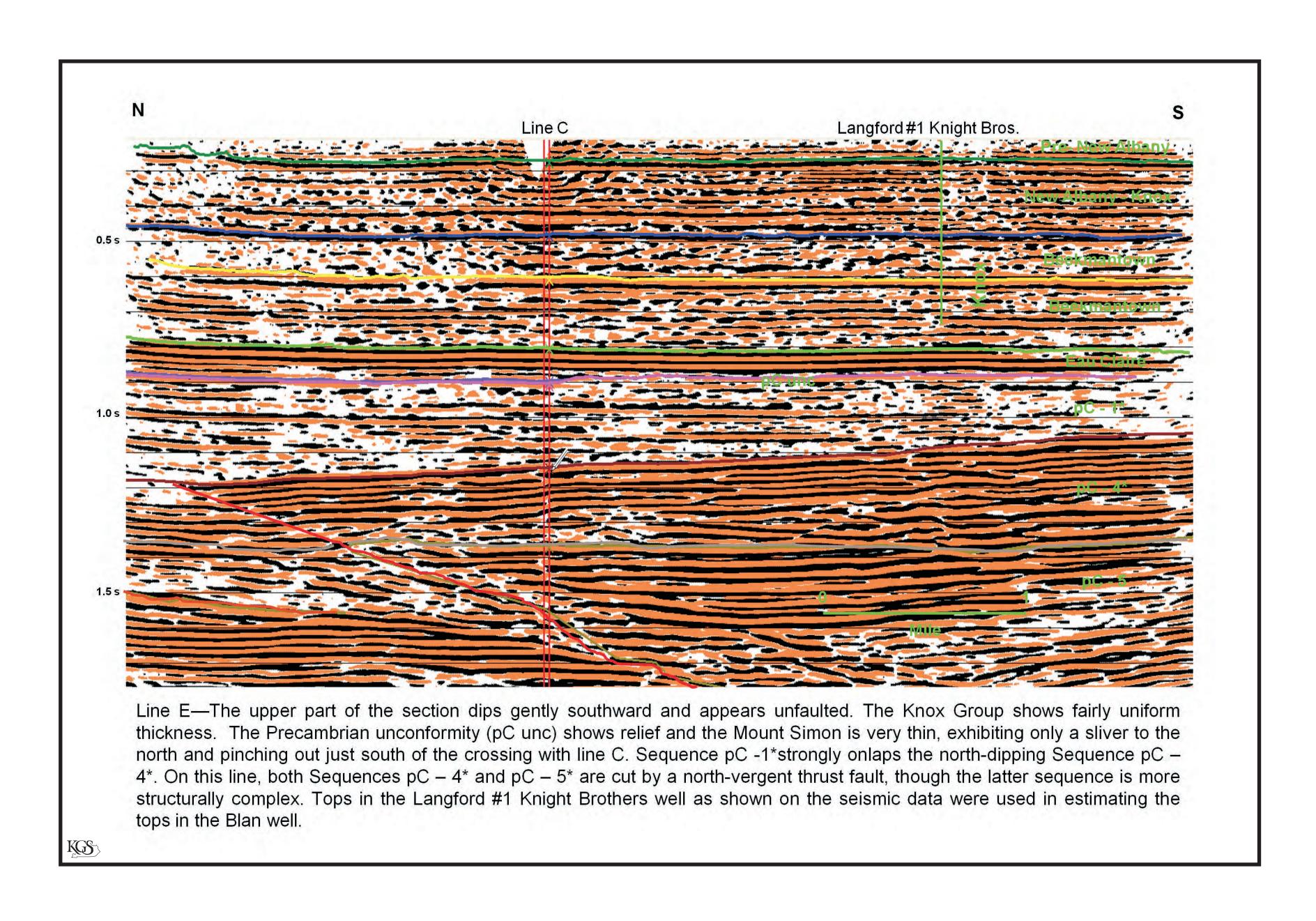


Structure of the Precambrian unconformity surface in the Hancock County region, interpreted from 2-D seismic data in northern Kentucky and southern Indiana. Hancock County seismic lines are shown with green dashes. Surface faults and faults interpreted from seismic data are shown in red. At the Marvin Blan #1 wellsite, Precambrian basement is estimated to be at ~8200 ft (-7550 ft subsea). The northeasterly strike of the contours reflects the westerly dip away from the crest of the Cincinnati Arch to the east, into the Illinois Basin to the west, as well as differential uplift along the north edge of the Rough Creek Graben. The Mount Simon Sandstone pinches out to the south on Precambrian basement (orange dashed line).

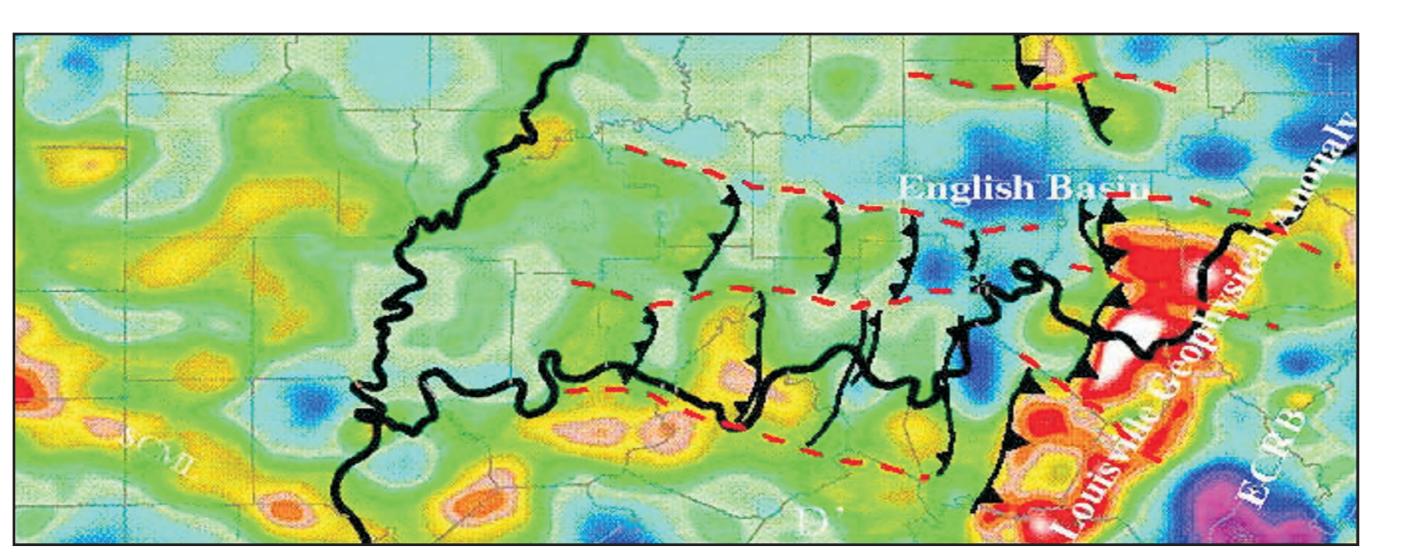




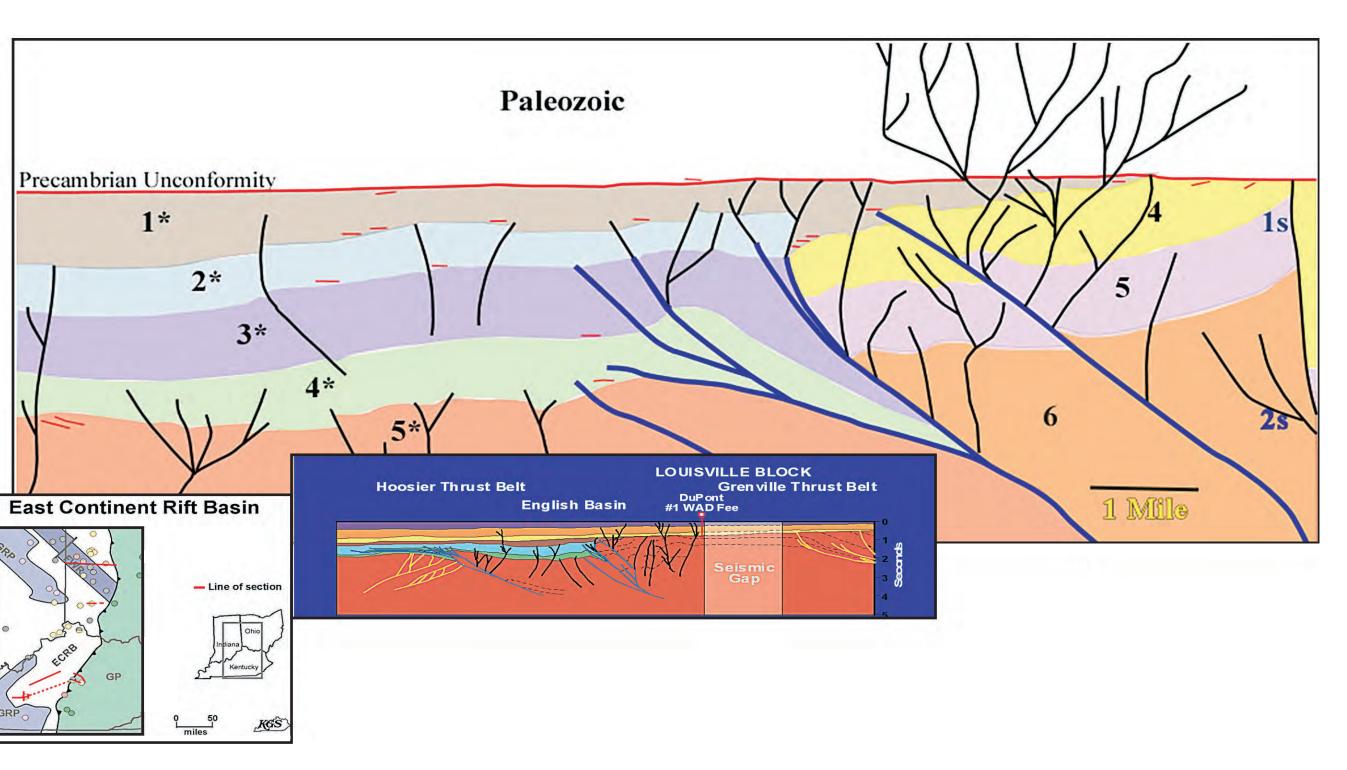




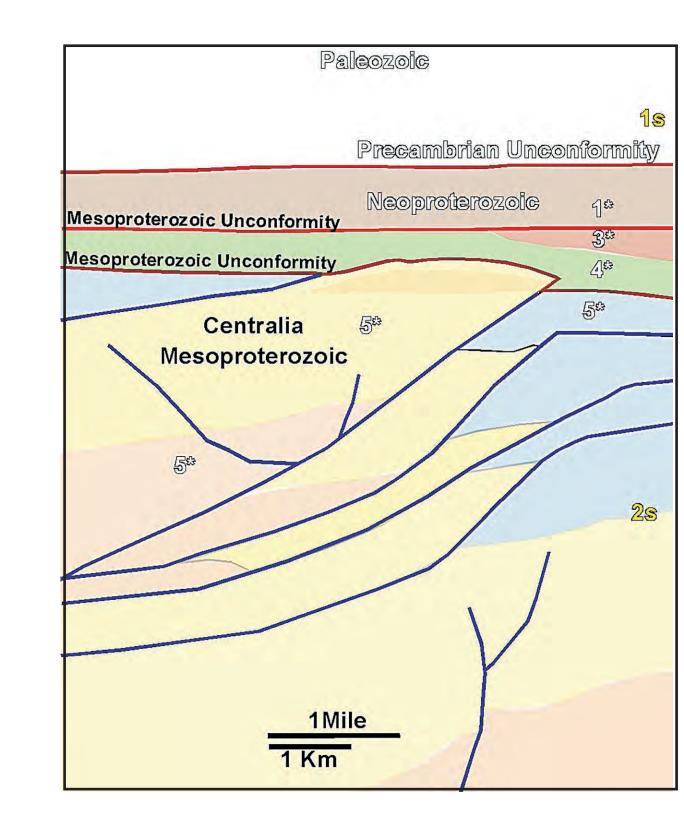
# Precambrian Structure of the Hancock County Region, Kentucky



Aeromagnetic map of southern Indiana and adjacent northern Kentucky and eastern Illinois. The Louisville Magnetic Anomaly coicides with basaltic rocks encountered in the DuPont #1 WAD well in Jefferson County, Kentucky.



This figure was constructed from 2-D seismic data located just northeast of Hancock County in Indiana. The pC-1\* through pC-5\* sequences were defined west of the Louisville Block (Drahovzal, 2002). In the Hancock Co. area only sequences pC-1\*, pC-4\* and pC-5\* are present, the intermediary sequences having pinched out to the north, in Indiana. Sequence pC-1\* will be cored in the Marvin Blan #1 well. It is likely that, at least in part, the sequence is composed of rocks eroded from the Louisville Block that was uplifted 4-8 km by west-vergent basement thrust faults (blue thrusts) at ~0.6 Ga (Stark et al., 2002). The likely core lithology will be a lithic arenite with volcanic rock fragments deposited 0.57–0.59 Ga. In comparison, the DuPont #1 WAD well on the Louisville Block is in a > 1.5 Ga basalt at TD.



This cross section is interpreted from 2-D seismic data just north of Hancock County in Indiana. The complex ramp anticline culminates a group of stacked, east-vergent thrust faults in sequence pC-5\* rocks. The thrust faults are part of the Hoosier Thrust Belt (Stark et al., 2002). Farther southeast in Hancock County, thrust faults in the same sequence are north vergent. It is likely that these thrust faults are part of the Hoosier Thrust Belt and represent Grenville-age compression. Note that Sequence pC-1\*, pC-3\*, and pC-5\* are also present in this area lying above the thrust belt.

