Poster 106: CO_2 Sequestration in Gas Shales of Kentucky

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ABSTRACT

Carbonaceous (black) Devonian gas shales underlie approximately two-thirds of Kentucky. In these shales, natural gas occurs in the intergranular and fracture porosity and is adsorbed on clay and kerogen surfaces. This is analogous to methane storage in coal beds, where CO2 is preferentially adsorbed, displacing methane. Black shales may similarly desorb methane in the presence of CO2.

Drill cuttings from the Kentucky Geological Survey Well Sample and Core Library were sampled to determine both CO2 and CH4 adsorption isotherms. Sidewall core samples were acquired to investigate CO2 displacement of methane. An elemental capture spectroscopy log was acquired to investigate possible correlations between adsorption capacity and mineralogy.

Average random vitrinite reflectance data range from 0.78 to 1.59 (upper oil to wet gas and condensate hydrocarbon maturity range). Total organic content determined from acid-washed samples ranges from 0.69 to 14 percent. CO2 adsorption capacities at 400 psi range from a low of 14 scf/ton in less organic-rich zones to more than 136 scf/ton in the more organic-rich zones. There is a direct linear correlation between measured total organic carbon content and the adsorptive capacity of the shale; CO2 adsorption capacity increases with increasing organic carbon content.

Initial volumetric estimates based on these data indicate a CO2 sequestration capacity of as much as 28 billion tons total in the deeper and thicker parts of the Devonian shales in Kentucky. In the Big Sandy Gas Field area of eastern Kentucky, calculations using the net thickness of shale with 4 percent or greater total organic carbon, indicate that 6.8 billion tonnes of CO2 could be sequestered in the five county area. Discounting the uncertainties in reservoir volume and injection efficiency, these results indicate that the black shales of Kentucky are a potentially large geologic sink for CO2. Moreover, the extensive occurrence of gas shales in Paleozoic and Mesozoic basins across North America make them an attractive regional target for economic CO2 storage and enhanced natural gas production.

Executive Summary

Increased emissions of carbon dioxide (CO_2), especially from the combustion of fossil fuels, are being linked to global climate change and are of considerable concern. These concerns are driving initiatives to develop carbon management technologies, including geologic sequestration of CO_2. One option for sequestration may be Devonian black shales, organic-rich rocks that are both the source and trap for natural gas (primarily methane). In gas shales, natural gas occurs as free gas in the intergranular and fracture porosity and is adsorbed on clay and kerogen surfaces, very similar to the way methane is stored within coal beds. It has been demonstrated in gassy coals that on average, CO_2 is preferentially adsorbed, displacing methane at a ratio of two for one or more. Black shale reservoirs may react similarly and desorb methane in the presence of adsorbing CO_2. If this is the case, black shales may serve as an excellent sink for CO_2 and have the added benefit of serving to enhance natural-gas production. A bibliography of Devonian shale gas references has been compiled to identify previous work and provide supporting data for continued research.

Drill cuttings collected from recent shale wells were used as the primary material for analyses. The volume of material lost when cuttings were washed dictated a modification of the original sampling protocol; composite cuttings samples were collected before washing. Candidate samples were selected and prepared for total organic carbon, vitrinite reflectance, petrographic, and CO_2 adsorption analyses to determine the gas-storage potential of the shale and to identify facies in the shale with the most sequestration potential. For the Devonian shale, average total organic carbon is 3.71 (as received) and mean random vitrinite reflectance is 1.16.

Columbia Natural Resources (CNR) provided access to a drill hole for collecting sidewall cores and an elemental capture spectroscopy (ECS) logging suite for correlation and mineralogical analysis. A shale analysis integrating the standard nuclear log suite and ECS log data was acquired. The data from this log analysis and other digital logs were processed to determine TOC and adsorption capacity data.

Samples from the CNR well were submitted for TOC and CO_2 adsorption analyses. Additional samples from the New Albany Shale (Illinois Basin) and the Battelle deep well in Mason County, West Virginia (AEP #1) were acquired and submitted for determination of adsorption isotherms. Qualitative X-ray diffraction analyses were conducted to assist in mineral characterization and for correlating results from electron capture spectroscopy logging.

In cooperation with Interstate Natural Gas, Pikeville, Kentucky, another ECS log and 10 sidewall cores were acquired for a well in Martin County, Kentucky. The shale gas analytical model developed by Schlumberger was applied to the logs for this well. Five sidewall core samples were analyzed for quantitative x-ray diffraction, porosity, and permeability. Mineralogically, quantitative x-ray diffraction data from this well average 46% quartz and 39% clay minerals. Phyllosilicate minerals (clays and mica) include Illite, Kaolinite, and Chlorite. As received, porosity averaged 0.9 percent and permeability averaged 0.0005 millidarcys. CO_2 adsorption isotherm data using whole rock (not crushed) techniques and data have been received for one of 5 sidewall cores. The reported Langmuir volume is 174.75 scf/ton and the Langmuir pressure is 993.88 psia.

Sidewall cores were submitted for methane and CO_2 adsorption isotherms and methane displacement analyses. The results of the displacement and flow through experiments are pending.

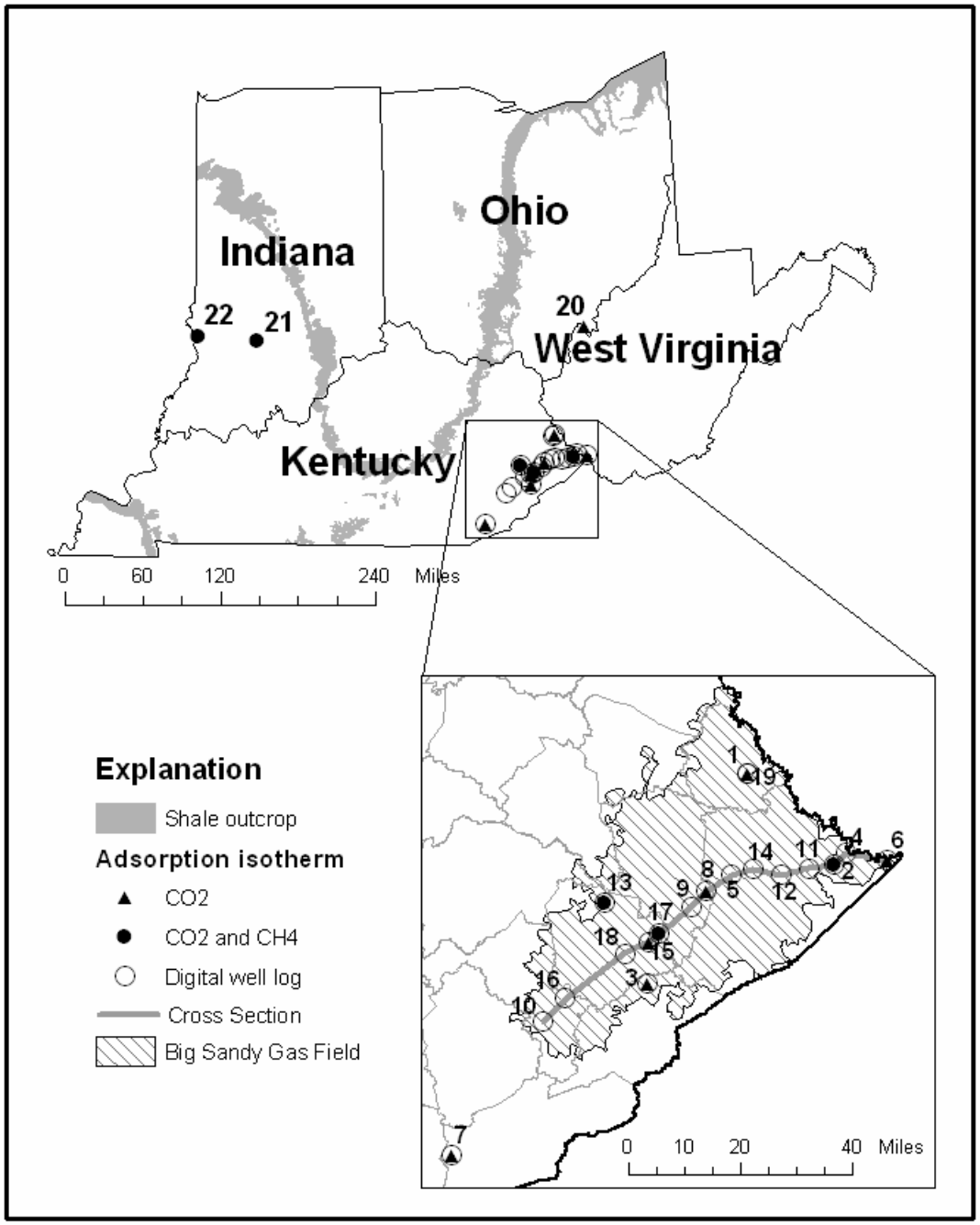
Adsorption capacity reported as measured Langmuir volumes ranges from 37 to 2,078 standard cubic feet CO_2 per ton of shale (scf/ton) at Langmuir pressures ranging from 243 to 14,284 psia. These values represent the range of values for coefficients of the selected Langmuir model. At a constant pressure of 400 psia, the CO_2 adsorption capacity ranges from 14 to 136 scf/ton with a median value of 40 scf/ton. Methane adsorption capacity ranges from 2 to 38 scf/ton with a median value of 8 scf/ton. At 400 psia, CO_2 adsorption exceeds CH_4 adsorption by a factor of 5. These data were correlated with data from nuclear log suites for modeling TOC and CO_2 storage capacity for individual wells.

Gamma ray and density log data have been digitized for 18 wells in the Big Sandy Gas field. These data have been correlated and models are being developed to calculate CO_2 sequestration capacity as adsorbed gas in place from the shale density log data. ASCII text files of digital log data for 722 wells throughout Kentucky have been converted to log ASCII standard (LAS) format and loaded into mapping software for calculation and spatial analysis of TOC and CO_2 adsorption capacity.

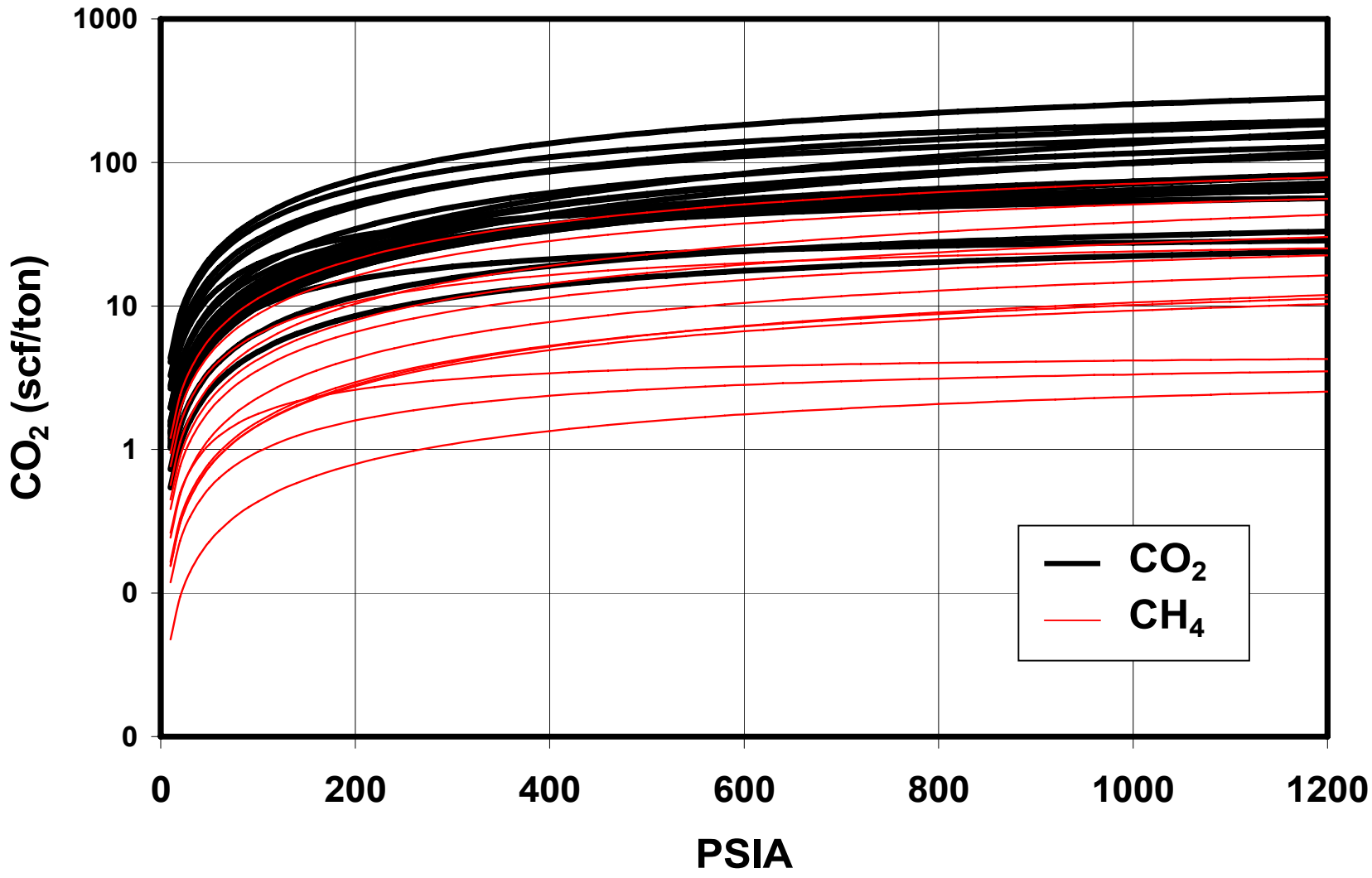
Enhanced production of natural gas displaced by CO_2 injection remains to be demonstrated; the experiments to investigate enhanced gas recovery from the shale are continuing. These pending flow-through data and the data developed by this project will be expanded in research conducted through the Regional Carbon Sequestration partnerships active in the Illinois and Appalachian Basins. Two-phase dual-porosity reservoir modeling will be used to history match shale gas production and to study CO_2 injection. These efforts will result in a better understanding of continuous, low permeability shales as gas reservoirs, sequestration targets, and seals for sequestration.

General conclusions:

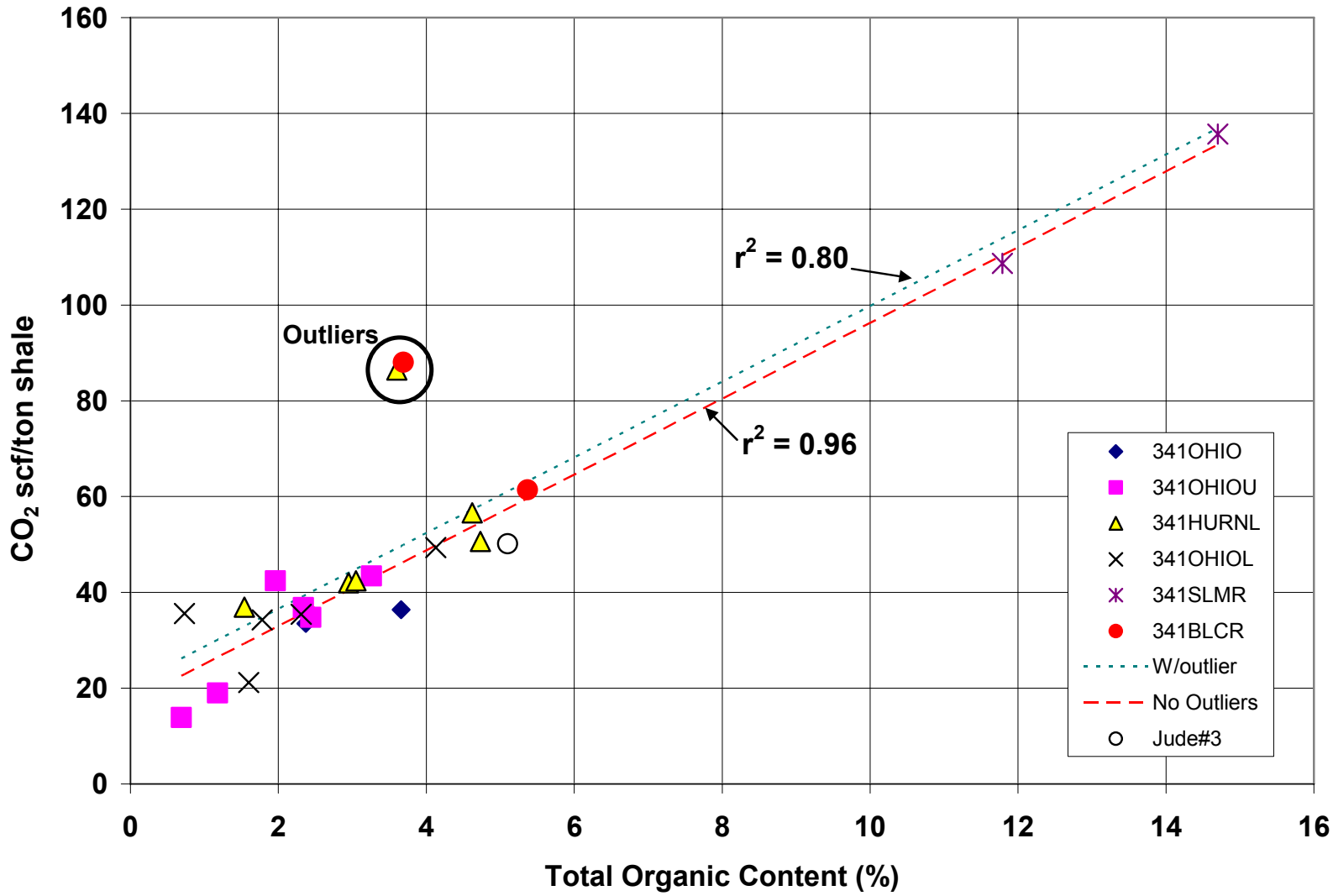
- Estimates using the distribution of gas storage capacity of CO_2 from TOC data indicate a sequestration capacity of 6.8 billion tonnes in the five-county area of the Big Sandy Gas Field of eastern Kentucky.
- Assuming a thickness weighted average adsorption capacity of 40 scf/ton (at 400 psia), as much as 25 billion tonnes of CO_2 could be sequestered in the deeper and thicker portions of the Devonian shales in the Appalachian and Illinois Basins of Kentucky.
- These results indicate that Devonian black shales of Kentucky are a potentially large geologic reservoir for CO_2 storage. The extensive occurrence of gas shales in Paleozoic and Mesozoic basins across North America would make them an attractive regional reservoir for economic CO_2 sequestration and enhanced natural gas production.



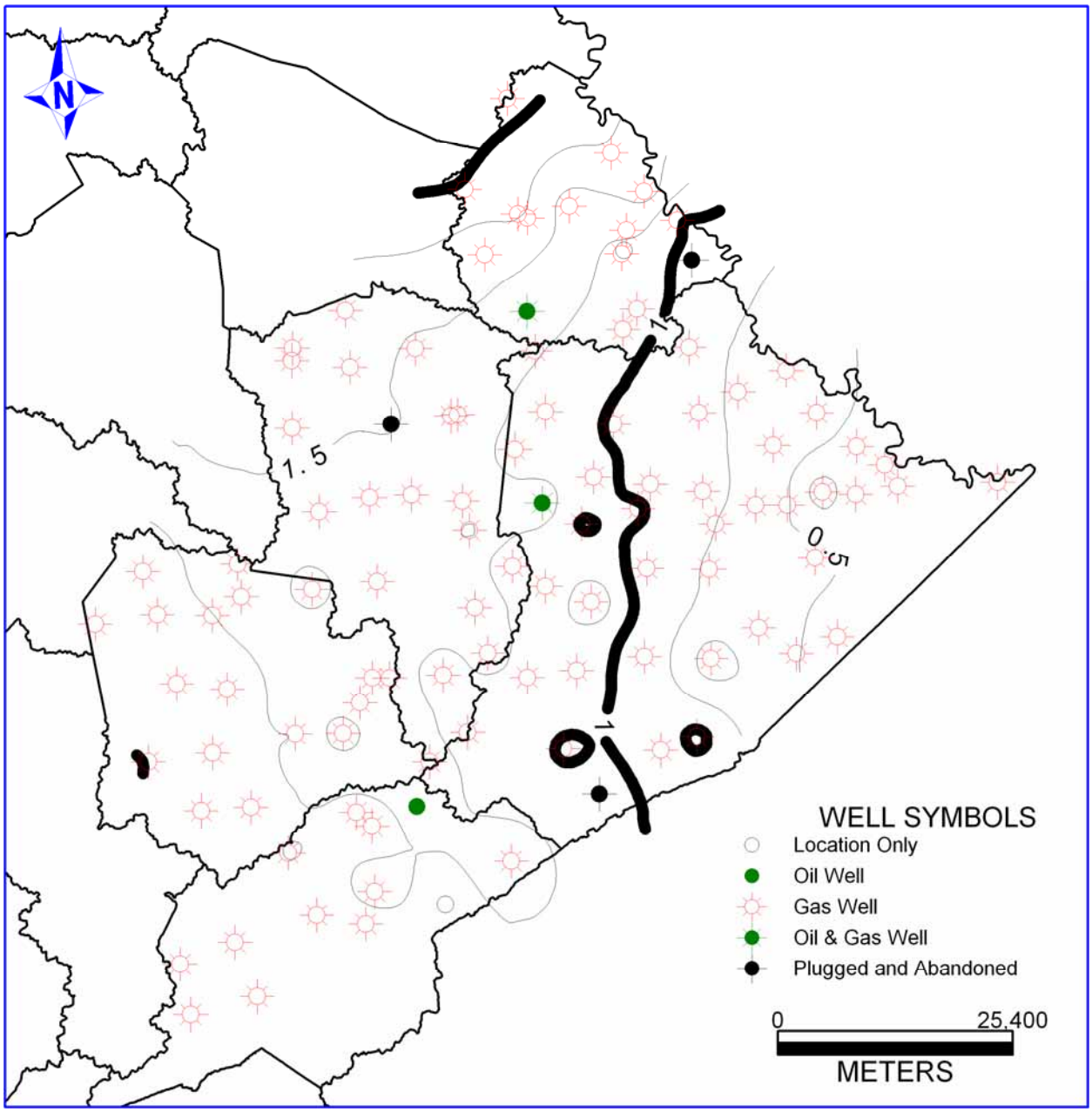
Location of wells used in study.



Summary of adsorption isotherms.



Models relating TOC to CO2 gas storage capacity



Million metric tonnes of carbon storage capacity per square kilometer in the Big Sandy Gas Field area. Contour interval is 0.25 million metric tonnes per square kilometer.

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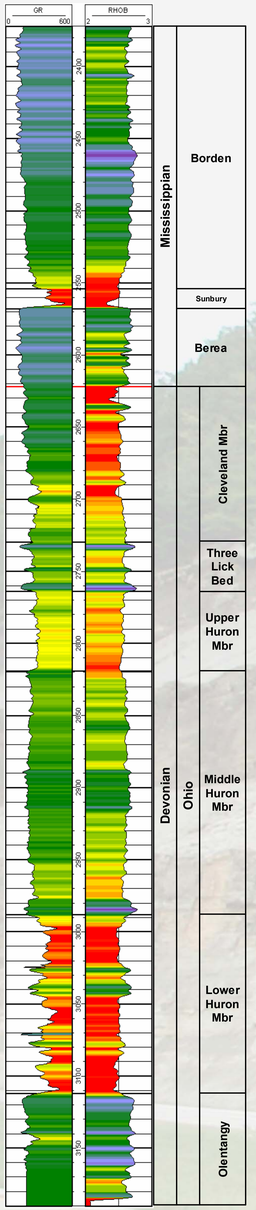

Total Depth: 3,190 ft.

Low GR High RhoB — High GR Low RhoB

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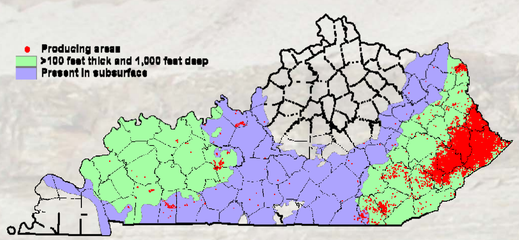
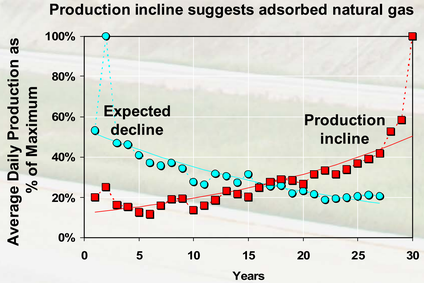
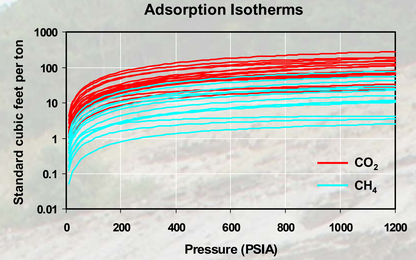


Distribution of the Devonian shale and associated gas production in Kentucky

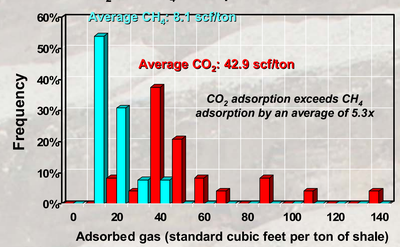
Production incline suggests adsorbed natural gas



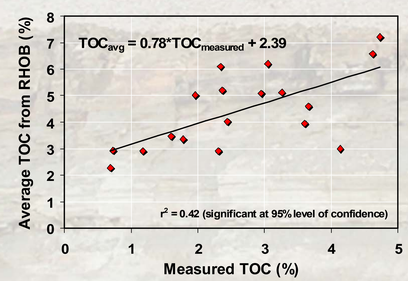
Adsorption Isotherms



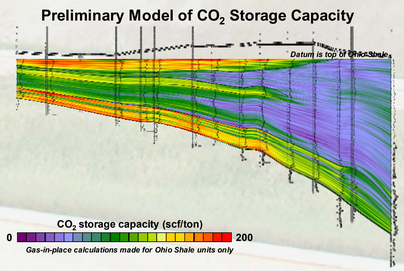
CO_2 and CH_4 Adsorption at 400 PSIA



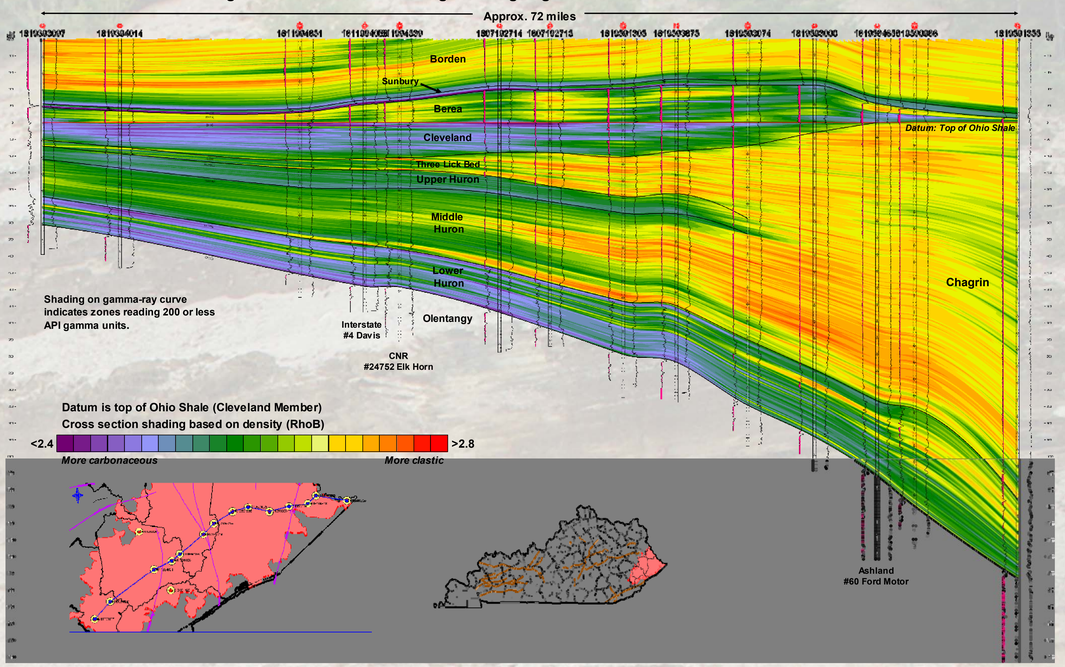
Measured and Calculated Total Organic Carbon

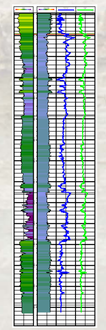


Preliminary Model of CO_2 Storage Capacity



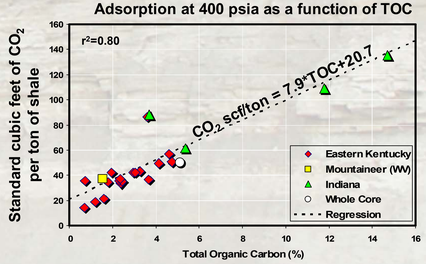
Regional Cross Section Showing Intertonguing of Carbonaceous and Clastic Shale Units

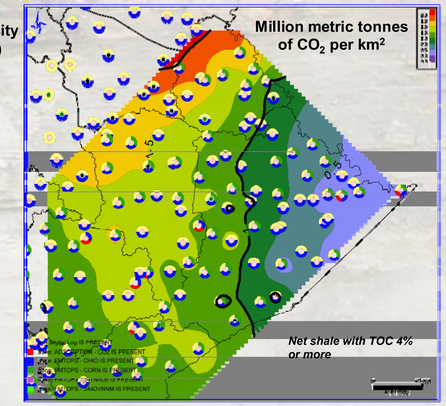




Formation bulk density (Rhob) → Total organic carbon (TOC) → CO_2 capacity (scf/ton)

Adsorption at 400 psia as a function of TOC





CONCLUSIONS:

- TOC content of the shale can be estimated from density log data.
- TOC data can be used as a proxy to estimate adsorptive capacity of the shale.
- Within the Devonian shale of eastern Kentucky, the Lower Huron Member of the Ohio Shale has the greatest CO_2 adsorption capacity.
- Limited data (one sample) suggests adsorption isotherm data determined from whole rock samples are comparable to data derived from powdered drill cuttings.
- Limited data (four samples) from the Illinois Basin suggest the Devonian New Albany Shale has adsorption characteristics similar to the Ohio Shale of the Appalachian Basin.
- Estimates using the distribution of gas storage capacity of CO_2 from TOC data indicate a sequestration capacity of 6.8 billion tonnes in the five-county area of the Big Sandy Gas Field of eastern Kentucky.
- Assuming a conservative, thickness-weighted average adsorption capacity of 40 scf/ton (at 400 psia), as much as 25 billion metric tonnes (28 billion tons) of CO_2 could be sequestered in the deeper and thicker portions of the Devonian shales in the Appalachian and Illinois Basins of Kentucky.
- Enhanced production of natural gas displaced by injected CO_2 would contribute to a long-term increase in the supply of what is considered a "greener" fuel.
- Adsorption data indicate that black, organic-rich gas shales can serve as targets for sequestration of significant volumes of anthropogenic CO_2.

Project: Analyses of Devonian Black Shale in Kentucky for Potential Carbon Dioxide Sequestration and Enhanced Natural Gas Production
Survey: www.uky.edu/kgs
Project: www.uky.edu/KGS/emsweb/devsh/devshseq.html
Funded by the National Energy Technology Laboratory, U.S. Department of Energy
Grant DE-FC26-02NT41442