# Characterization of Springfield Coal Member of the Carbondale Formation (Pennsylvanian) in a CO, Sequestration Pilot Illinois Basin-Tanquary Site

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#### Abstract

As part of the U.S. Department of Energy's Regional Sequestration Partnership program, the potential for sequestering CO<sub>2</sub> in the largest bituminous coal reserve in United States -the Illinois Basin- is being assessed at the Tanquary site in Wabash County, southeastern Illinois. To accomplish the main project objectives, which are to determine CO<sub>2</sub> injection rates and storage capacity, we developed a detailed coal characterization program. The targeted Springfield Coal occurs at 900 ft depth, is 7 ft thick, and is of high volatile bituminous rank, having an average vitrinite reflectance (Ro) of 0.62%. Desorbed coal gas content in cores from four wells 50 to 100 ft apart varies from 150 to 210 scf/ton (dmmf) and consists generally of >92% CH<sub>4</sub> with lesser amounts of N<sub>2</sub> and then CO<sub>2</sub>. Adsorption isotherms indicate that at least three molecules of CO<sub>2</sub> can be stored for each displaced CH<sub>4</sub> molecule. Coal maceral composition affects sequestration potential and averaged 70.2% vitrinite, 3.6% liptinite, 13.9% inertinite, and 7.3% mineral matter. Well-developed coal cleats with 1 to 2 cm spacing contain partial calcite and/or kaolinite fillings that may decrease coal permeability. Shallow geophysical log induction curves show much higher resistivity in the lower part of the coal than the medium or deep curves because of invasion by freshwater drilling fluid, possibly indicating higher permeability. Gamma-ray and bulk density vary, reflecting differences in maceral, ash, and pyrite content. Because characteristics vary across the basin, it is critical to characterize injection site coals to best predict the potential for CO<sub>2</sub> injection and storage capacity.

This study is part of an ongoing research program to characterize the potential to sequester carbon dioxide in the coals of the Illinois Basin. This poster describes a site where carbon dioxide was injected into a coal seam in southeastern Illinois, a state with 211 billion tons of high volatile bituminous coal in place. Including Indiana and western Kentucky, the Illinois Basin has 284 billion tons of coal in place. Using a very conservative methane adsorption capacity of 80 scf/ton and with CO, having up to about 4.5 times greater adsorption capacity than for methane, it has been suggested that there is a carbon dioxide sequestration potential in deep, unmined coal strata of at least 2.4 billion tonnes of CO<sub>2</sub> in the Illinois Basin (NATCARB Atlas, 2008).

The purpose of this poster is to present coal characterization data from core from the four wells in our project area. This data will be used to predict and improve the understanding of the field observations made during the injection of over 100 tons of CO, into a single seam of coal, the Springfield Coal, at a depth of 900 ft.

## Acknowledgements

This work is being supported by the U.S. Department of Energy, National Energy Technology Lab, under award No. DE-FC26-05NT42588, as part of the Regional Sequestration Partnerships Program, and by the Illinois Department of Commerce and Economic Opportunity, through the Illinois Office of Coal Development and the Illinois Clean Coal Institute. Various sequestration projects in oil fields, coal beds and deep saline formations in the Illinois Basin are being carried out as part of the Midwest Geological Sequestration Consortium (MGSC).

The MGSC is a collaboration led by the geological surveys of Illinois, Indiana, and Kentucky, private companies, universities, and NGO's. Any opinions, findings, conclusions or recommendations expressed herein are those of the authors and do not neccessarily reflect the views of the DOE or MGSC members.

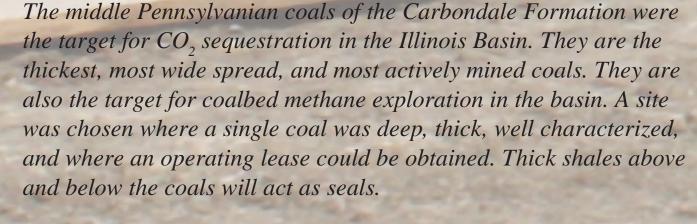
The project would not be possible without the assistance and cooperation of Gallagher Drilling, Inc. and the Locust Street Company, Inc.

#### Sequestration Project Purpose: To determine the CO, injection and storage capability and the ECBM recovery potential of Illinois coal.

- Drill multi-well injection and monitor project obtaining coal cores for
- Characterize coal and coal gas (reported here)
- Simulation of CO<sub>2</sub> injection with COMET3
- Water Injection Pressure Transient Tests
- Injection of over 100 tons of gaseous CO, in pulses with pressure fall-offs in between, over a total test period of 200 days

#### Pennsylvanian Geologic Column

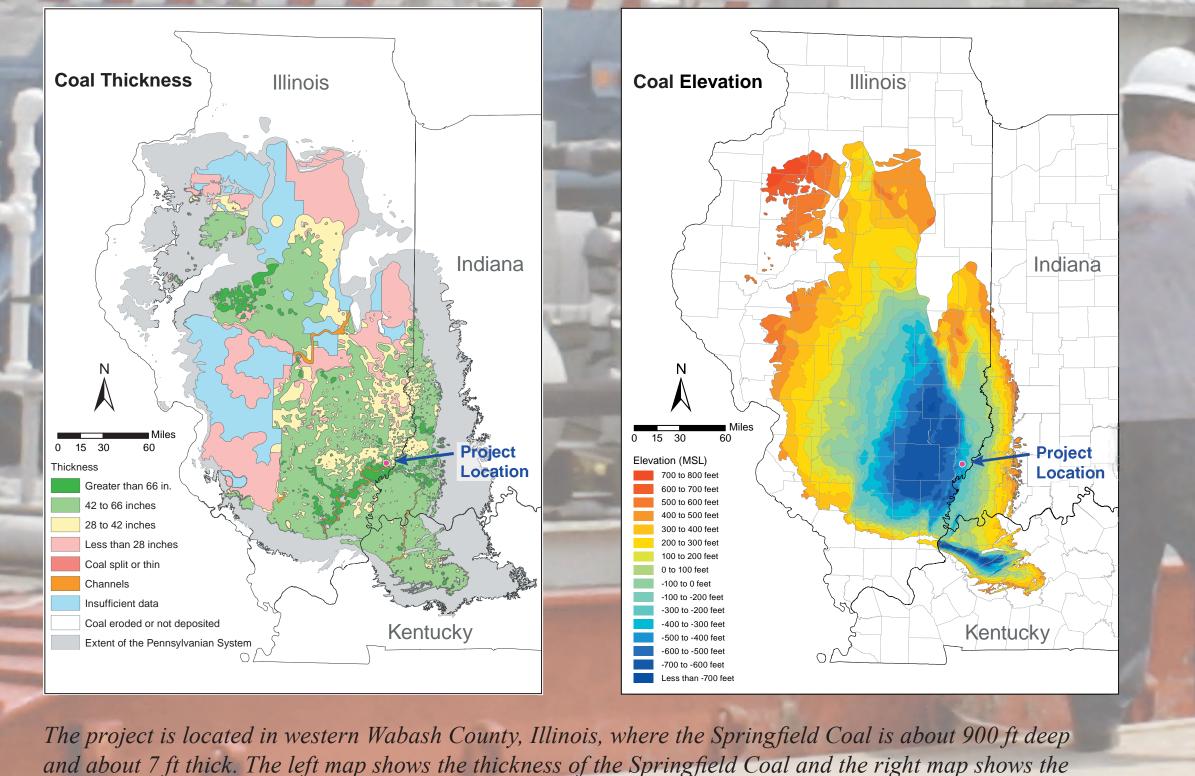
Г	SOUTHERN ILLINOIS (south of 40° North latitude)				
SYSTEM	SERIES	Sednence	Group	Formation - thickness in feet  Selected members and beds  "Oil well drillers' terms shown in quotation"	
PENNSYLVANIAN*	UPPER VIRGILIAN VIRGILIAN	אַלווּסאוֹא		Woodbury Ls Greenup Ls  Bogota Ls  Mattoon Fm 0-600'	
		Absaroka	McLeansboro	Bond Fm 0-350'  Flannigan Coal  Mt. Carmel Ss  Carthage Ls  Macoupin Ls  Carlinville Ls  Chapel Coal  Shelburn - Patoka Fms 0-560'  West Franklin Ls	Danv
	OLE DESMOINESIAN			Lonsdale Ls Piasa Ls Piasa Ls Danville Coal Bankston Fork Ls Breeton Ls Energy Sh Anna Sh Herrin Coal St. David Ls Turner Mine Sh Springfield Coal Excello Sh Carbondale Fm Houchin Creek Coal 0-350' Survant Coal Mecca Quarry Shale Colchester Coal Dekoven Coal Davis Coal Carrier Mills Sh Stonefort Ls	Major Coal Gas/CO <sub>2</sub> Injection Targets  Was a contract to the contract of the
	MIDDLE	AIOKAIN	Raccoon Creek	Mt. Rorah Coal  Murphysboro Coal  Delwood Coal  Tradewater Fm 0-650'  Curlew Ls Rock Island Coal  "Casey"  "Mansfield"  "3rd and 4th Siggins"  Bell Coal  Reynoldsburg Coal	Seely  The middle Pennsylvanian coals of the Carbona
		MOKKOWAN	Rac	Pounds Ss  Caseyville Fm 0-500'  "Biehl, Buchanan, Jordan, Pottsville, Ridgley"  Battery Rock Ss	the target for $CO_2$ sequestration in the Illinois E thickest, most wide spread, and most actively malso the target for coalbed methane exploration was chosen where a single coal was deep, thick and where an operating lease could be obtained



#### Coal and Coal Gas Properties Studied

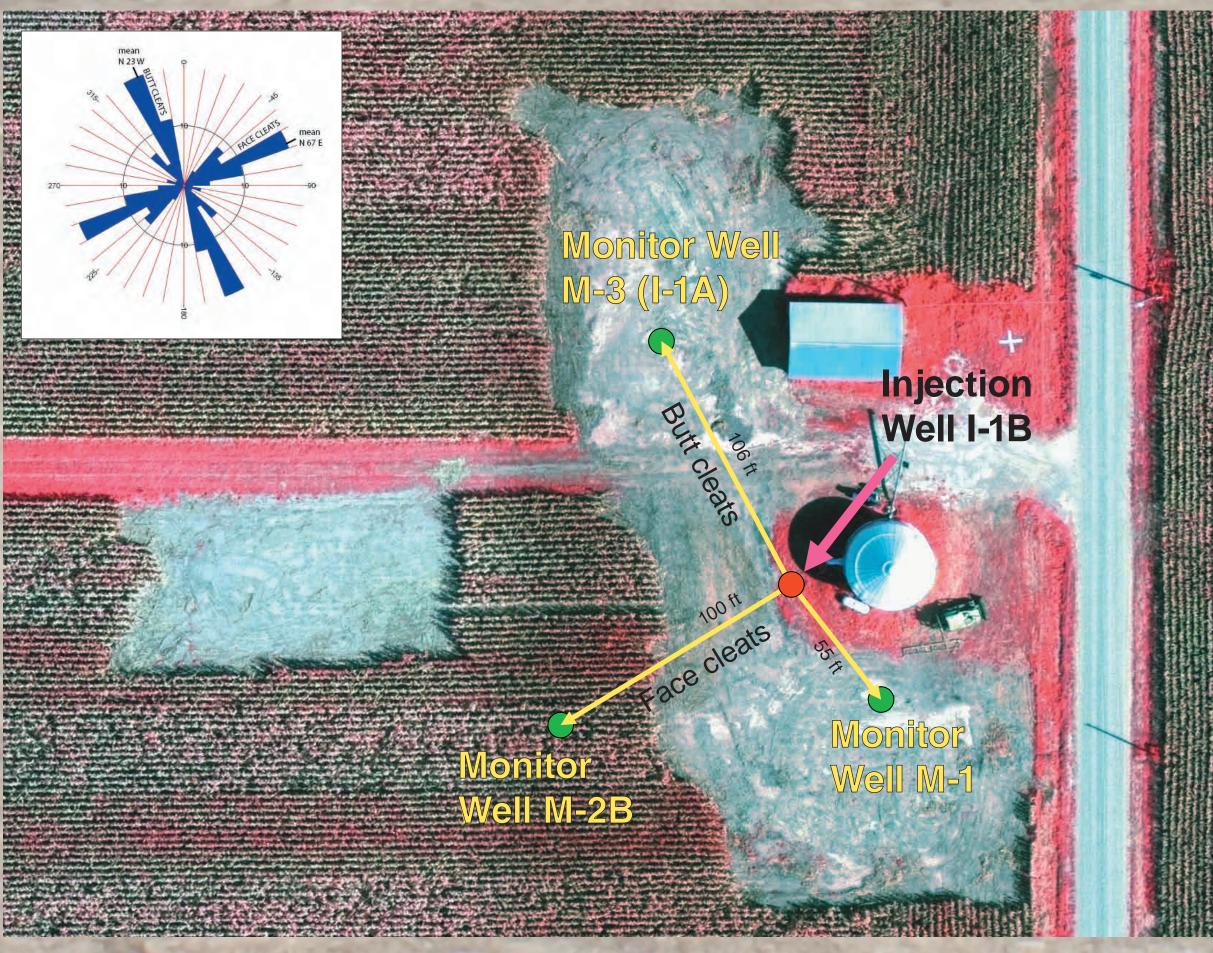
- Gas Content
- Coal Gas Composition
- Coal Gas Isotopic Composition
- Permeability
- Adsorption Isotherms CH<sub>4</sub>, N<sub>2</sub>, and CO<sub>2</sub>
- Maceral Analysis and Thermal Maturity
- Proximate Analyses
- Shrinkage/Swelling Lab Study
- Changes in mesopore and micropore sorption characteristics of

#### Springfield Coal Distribution, Thickness, Structural Elevation, and Tanquary Site Location



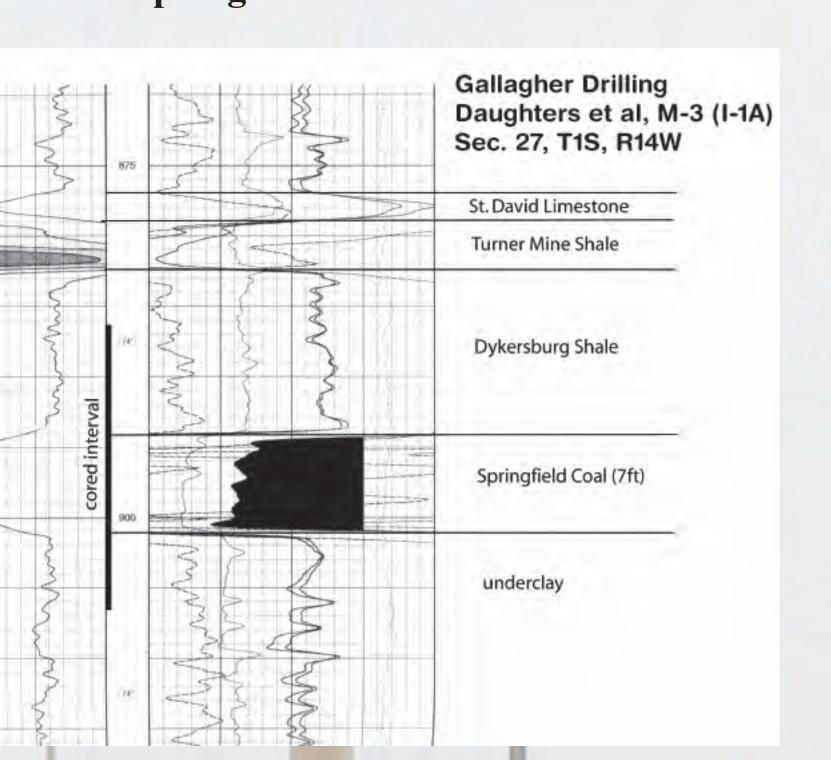
structural elevation. The project adopted the local farm name and is called the "Illinois Basin-Tanquary Site"

## **Tanquary Site Plan**

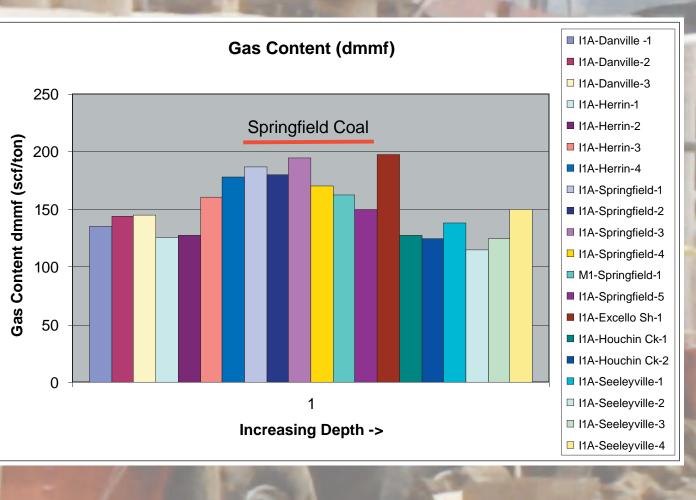


The Injection Well (I-1B) is 55 ft from the nearest monitor well (M-1) and about 100 ft from the other two monitor wells ((M-3(I-1A) and M-2B). The well arrangement is parallel to the coal face and butt cleat directions shown in the inset, measured at the Wabash Mine, located 6 miles southeast of the Tanquary site. Coal cleats may locally be filled with calcite or kaolinite that will reduce their permeability. Average permeability from water injection pressure falloff tests is about 4 to 6 mD.

#### GR-Density-Neutron log of the M-3 (I-1A) well with Springfield Coal from 894–901 ft.

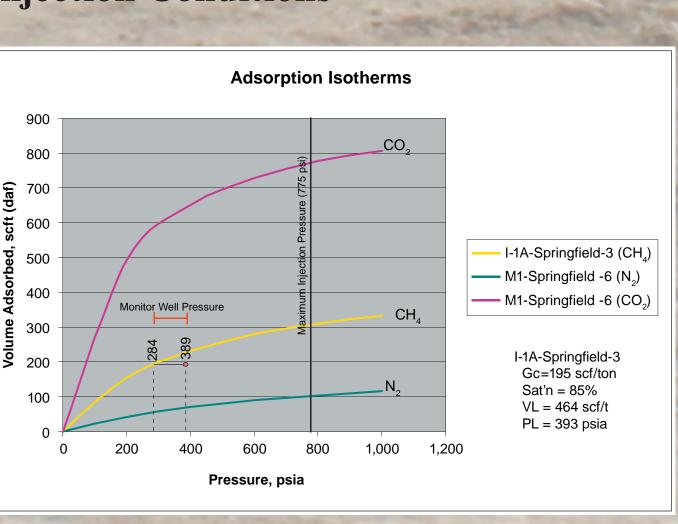


# **Coal Gas Content**



tale for the M-3(I-1A) well. These coals, especially the Springfield, have particularly high gas contents. The basin average is only about 100 scf/ton (Demir et al, 2004). The desorbed gas is primarily methane with minor amounts of nitrogen and a small amount of carbon dioxide Carbon and deuterium isotopes of the methane and the dry gas composition indicate the gas is of biogenic origin.

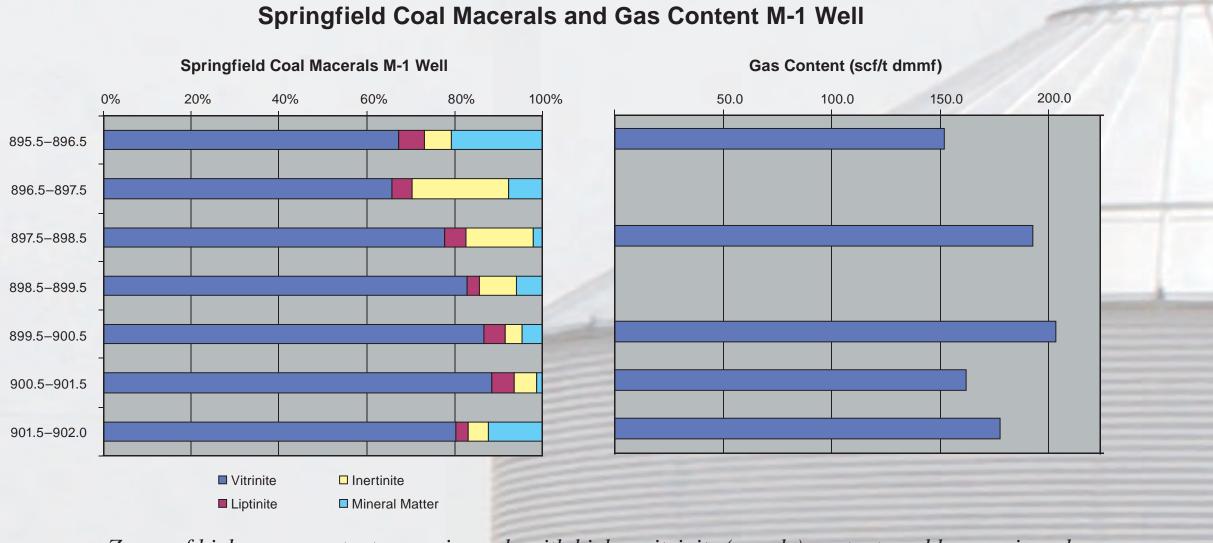
## Langmuir Isotherms and **Injection Conditions**

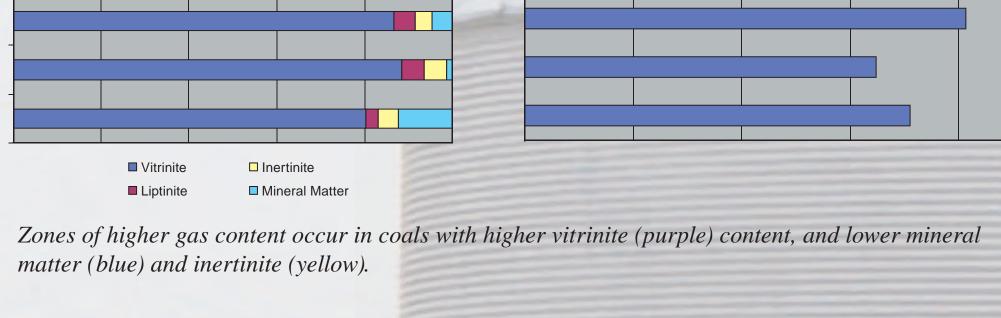


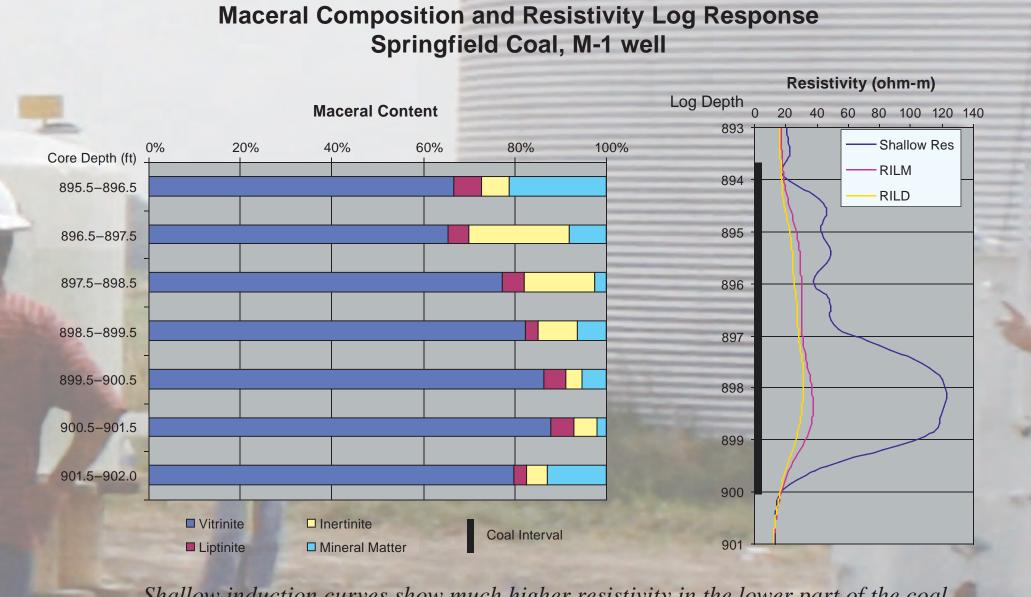
CO, delivery was by 20 ton liquid CO, tanker trucks. CO, was transferred to a 50 ton liquid storage tank and then pumped through an inline heater to ensure the CO, is in the gas phase before entering the coal seam. Injection was at a steady pressure equal to 80% of the fracture pressure or about 775 psi.

The pure gas isotherms for  $N_2$ ,  $CH_2$ , and  $CO_2$ , shown above, indicate the amount of gas that can be adsorbed by the coal. The coal is naturally undersaturated in CH<sub>4</sub> by 105 psi. It has an initial hydrostatic pressure of 389 psi. Observation well pressure will be maintained above the critical CH<sub>4</sub> adsorption pressure of 284 psi to ensure that free gas is the result of injected CO<sub>2</sub> displacement, not pressure reduction. Free gas at the monitor wells may be migrated CO, and/or coalbed gas that has been displaced by CO<sub>2</sub>. Injection of CO<sub>2</sub> was continued until significant breakthrough was achieved at the monitor wells.

#### **Influence of Coal Macerals**

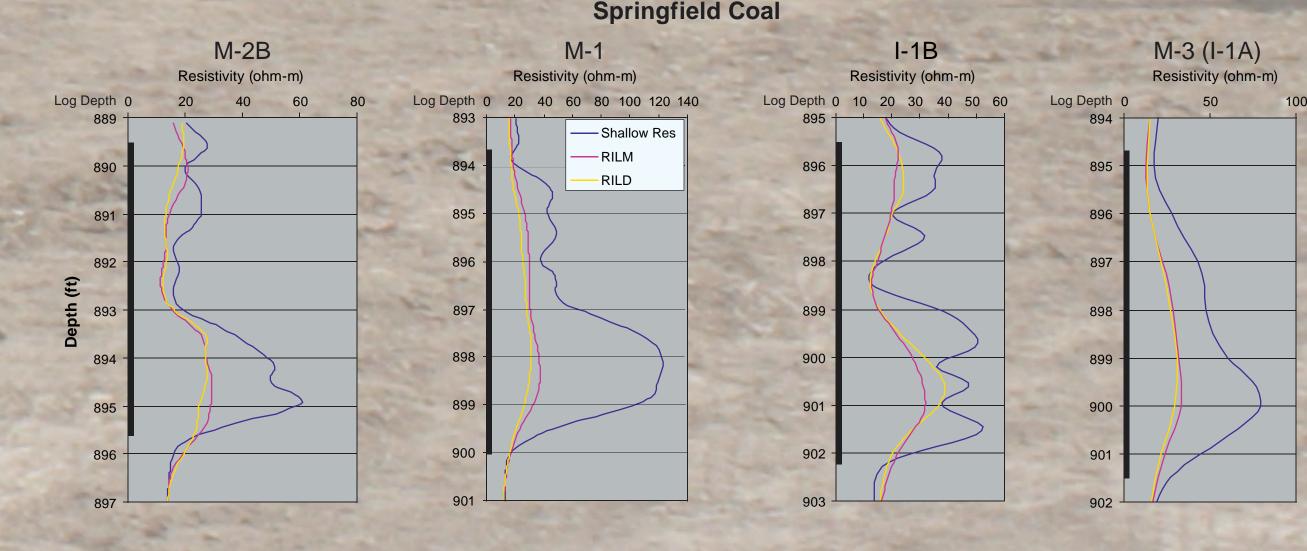




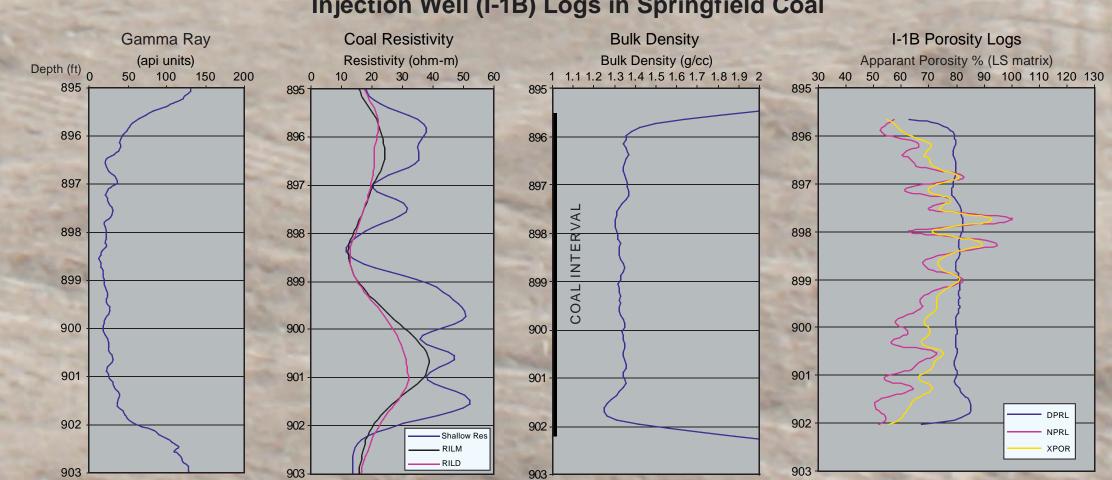


Shallow induction curves show much higher resistivity in the lower part of the coal than the medium or deep curves, which may be due to increased fresh water drilling fluid invasion, possibly indicating higher permeability. This occurs in the intervals of greatest vitrinite content, the maceral that shows the most pronounced cleating. This shallow resistivity effect is seen, as shown below, in all four of the project wells.

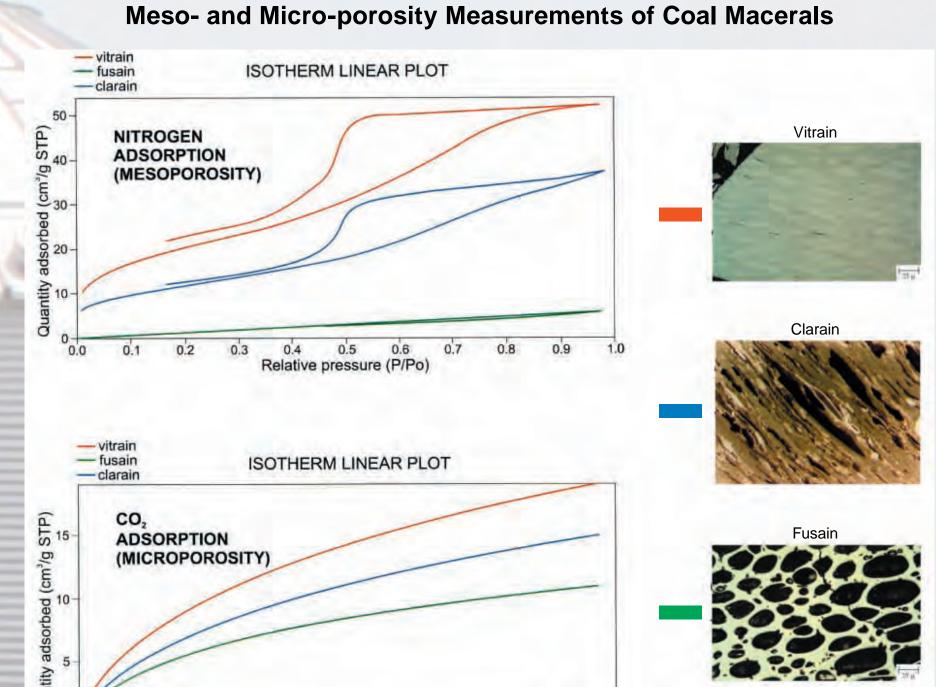
### **High Resolution Resistivity Log Comparison**



Injection Well (I-1B) Logs in Springfield Coal



High Resolution Gamma Ray and Bulk Density and density porosity log variations reflect small differences in maceral, ash and pyrite content, whereas neutron porosity (NPRL), which is sensitive to hydrogen atoms, shows high variability.



Lithotype composition of coal influences the amount of gas that can be adsorbed by the coal. such composition favors significant CO, adsorption capacity

- 1. The Springfield, a high volatile bituminous b coal, has good gas content (150 to 210 scf/ton dmmf), and can adsorb three times that amount of CC 2. The desorbed coal gas is of biogenic origin and is comprised of >92%
- methane with lesser amounts of  $N_2$  and then  $CO_2$ . 3. Combined data of low pressure adsorption of  $N_2$  and  $CO_2$ , and high pressure adsorption of methane and CO, indicate that lithotype composition influences micro-and meso-porosity and gas adsorption capacity to a large extent. Lithotype vitrain has the most meso- and
- significantly depending on the maceral composition. 4. High resolution Gamma ray, resistivity and density logs can be used to

identify subtle variations within the coal.

micro-pore space available and highest adsorption capacity, and fusain

- the least. Clarain adsorption capacity is intermediate, but may vary

5. Shallow resistivity logs in the coal show high resistivity in the lower third of each of the four wells. Maceral analyses show these intervals are particularly rich in vitrinite. This maceral appears to be better fractured and thus the resistivity effect, potentially, may indicate a more permeable

#### References

Demir, I., D.G. Morse, S.D. Elrick, C. A. Chenoweth, 2004, Delineation of the Coalbed Methane Resources of Illinois: Illinois State Geological Survey Circular 564, CD. U.S. Department of Energy Office of Fossil Energy, National Energy Technology Laboratory, November 2008, Carbon Sequestration Atlas of the United States and Canada, Second Edition,















