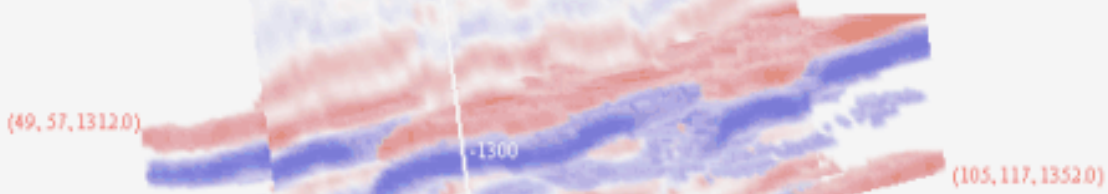
Viability of Seismic Imaging for Site Selection and Monitoring of CO_2 Sequestration in Illinois Coal Seams



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Abstract

- Gas Technology Institute, with support from Illinois Clean Coal Institute, and cooperation of the Illinois State Geological Survey, designed and implemented a comprehensive research project aimed at determination of viability of seismic techniques for site selection and monitoring of CO_2 sequestration in Illinois coals.
- Safety and permanency of the processes require the injected gas to remain within the target zone with no possibility of contamination, leaking, or escape.
- Diligent site selection and attentive monitoring are crucial.
- Advanced seismic technology has been proven successful in providing detailed subsurface images of conventional oil and gas reservoirs as well as thicker coal seams. However, Illinois coal seams are shallow and thin, with the thickness rarely exceeding 10 feet.

Objectives

Field Investigation

- Investigate resolution limits of seismic techniques relative to thin coal seams and detection of small discontinuities.
  - A series of seismic data acquisitions including surface seismic, vertical seismic profiling, and crosswell seismic imaging were carried out. Resulting data proved that thin coal seams can be reliably mapped by properly designed seismic surveys.

Laboratory Investigation

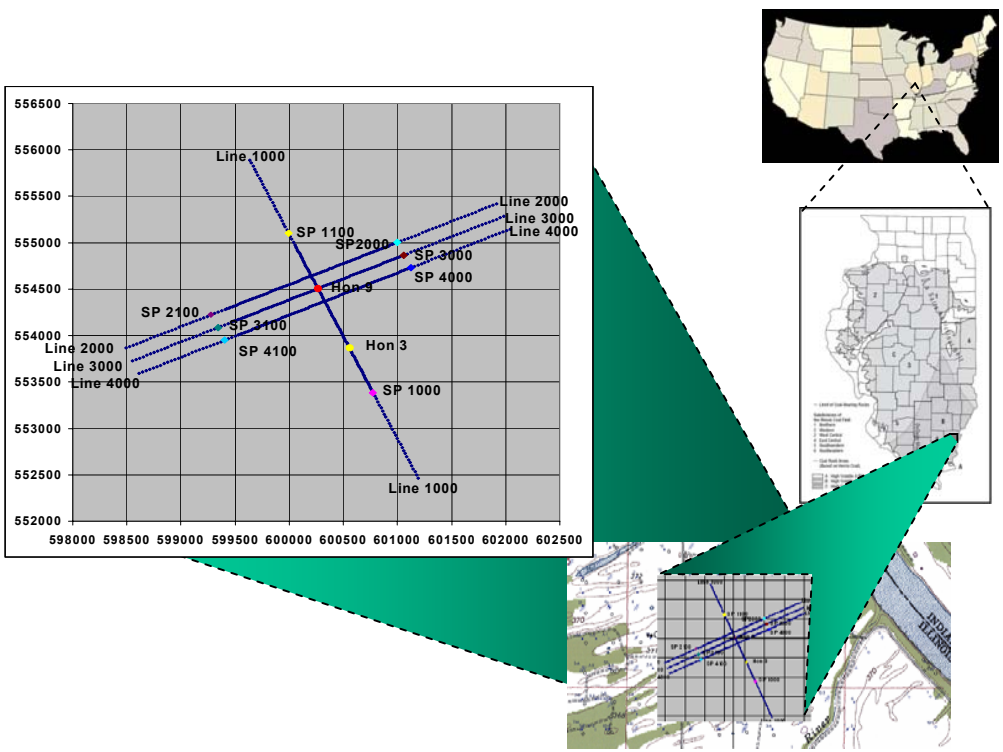
- Investigate changes in bulk elastic properties of coals due to changes in saturation.
  - A number of elaborate laboratory measurements of acoustic velocity in gas and water saturated coal samples were carried out.

Approach

- Develop customized seismic survey techniques for CO_2 sequestration and CBM production site selection
  - Detailed surface survey
  - VSP
  - Crosshole seismic survey
- Lab work to investigate the viability of monitoring CO_2 front in coal seams
  - Measure changes in elastic properties of coal resulting from addition of a gas phase into the cleat system.
  - Blocks of coal collected from two coal mines, one in Southern Illinois near the site where ISGS is implementing a coalbed methane pilot project and one in Central Illinois near Springfield.
  - Experiments repeated multiple times on different samples to arrive at some meaningful average values. Over 140 data points for coal samples from the two Illinois mines were developed.

Field Investigation

Line 1000 shown in Figure is the line running across the two wells used for the cross-well survey and is the Northwest to Southeast line. Lines 2000, 3000, and 4000 were run perpendicular to Line 1000 for the purposes of understanding out-of-plane heterogeneity in Line 1000 and in the cross-well data.



Coal	*Top (ft)*	*Base (ft)*	*Log Thickness (ft)*	*Core Coal Thickness (ft)*
Danville	758.0	762.0	4.0	3.6
Herrin #6	806.0	810.0	4.0	5.0
Springfield #5	882.0	886.0	4.0	4.0
Houchin Creek #4	971.0	972.0	1.0	1.5
Survant #3	996.0	1000.0	4.0	4.1
Colchester #2	1066.0	1068.0	2.0	1.6
Davis - upper split	1110.0	1111.5	1.5	1.4
Davis - middle split	1114.0			2.1
Davis - lower split		1118.0	4.0	1.2

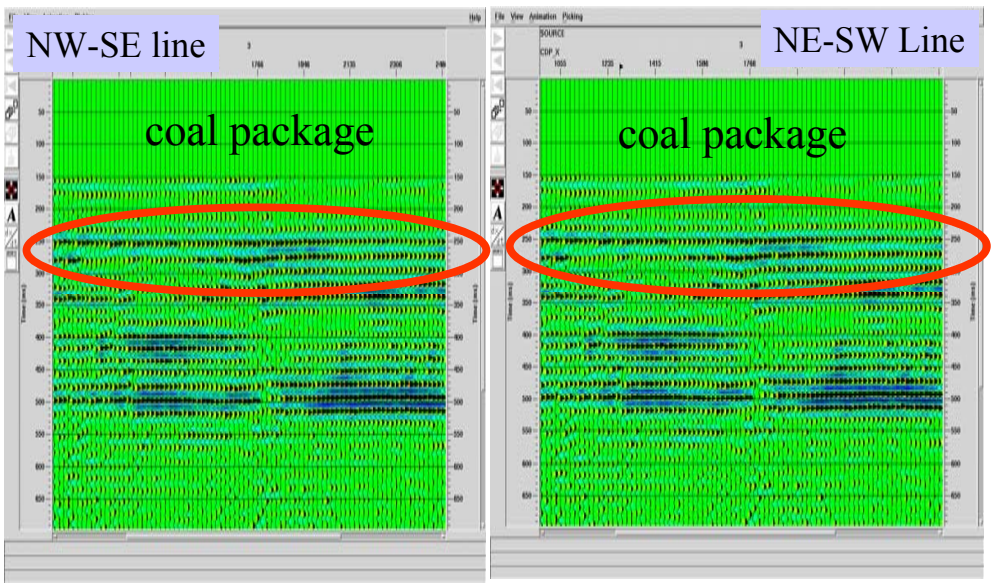
ISGS drilled and cored a well (Hon # 9) in the center of the pilot site and made this well available for VSP and cross-well surveys. Nine coal seams, each 1.2 to 5 feet in thickness were cored at this site.

Information from this well was used in our survey design to assure that the field efforts would lead to useful data and knowledge. These seams were thinner than we had anticipated and created a challenge to seismic resolution.

Cross-well data (frequencies of more than 500 Hz) was expected to have the highest resolution, but required the presence of two wells spaced less than 750 feet apart for deployment of sources and receivers and only provided a 2-D slice of the inter-well region. VSP was expected to have resolution intermediate between cross-well and surface seismic.

Results

Surface Seismic Survey



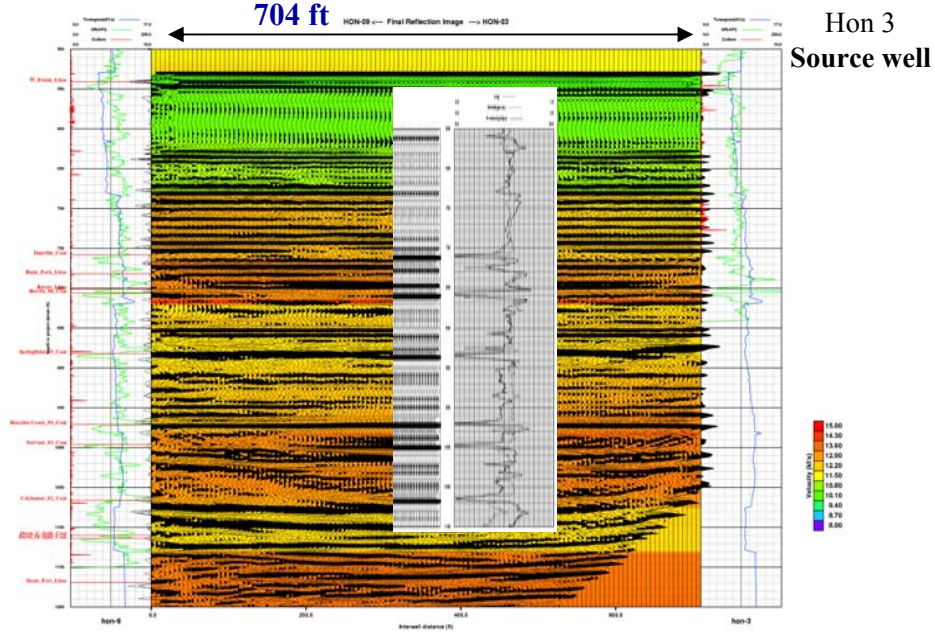
Seismic Section for Line 1000 **Seismic Section for Line 2000**

Note that although the reflection events from the coal package (inside the red ellipse) are clearly identifiable, individual coal seams have been transparent. Also note that the coal package as a whole is quite continuous and do not exhibit any discontinuity.

Lower in the section, at about 400 milliseconds, clear discontinuity is observed. These discontinuities do not appear to reach the coal zone and do not cause any concern.

Crosswell Seismic Imaging Result

Final Crosswell Reflection Image

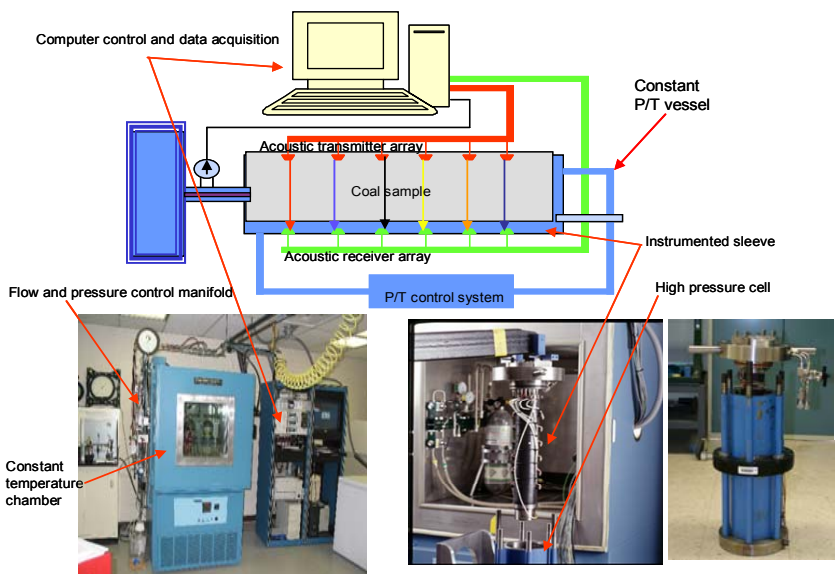


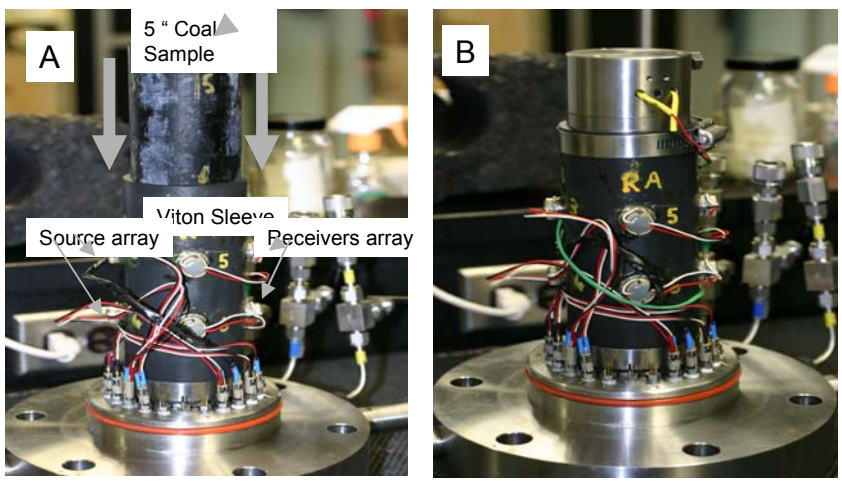
This image covers the section between wells Hon 3 and Hon 9. All coal seams present at the site have been clearly imaged, as shown by the superposition of the well log from well Hon 9 on the section.

Laboratory Investigation

> GTI lab studies focused on measuring changes in acoustic velocity resulting from addition of a gas phase into water saturated coal samples.

Schematic Diagram of Experimental Apparatus

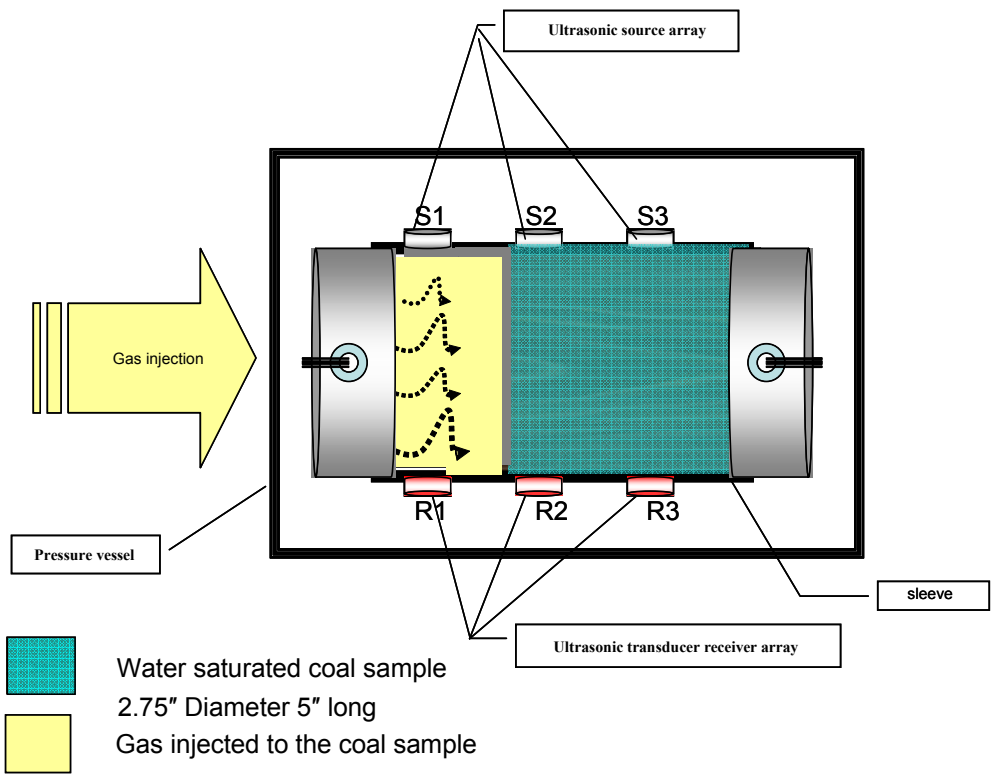




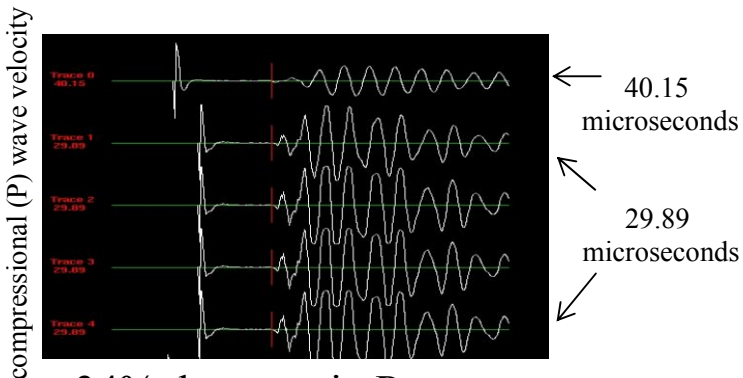
When the high friability of the coal prevented us from cutting sufficient cores to the desired length for all of the tests, the test apparatus was reconfigured to accommodate shorter (five-inch) cores.

Data Acquisition

Velocity Variations Resulting from Saturation Change

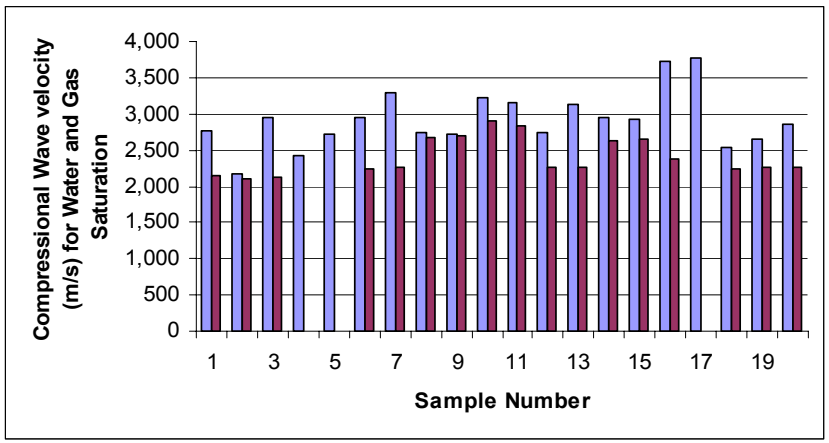


Screen Dump Showing Recorded Travel Times



34% decrease in P wave velocity

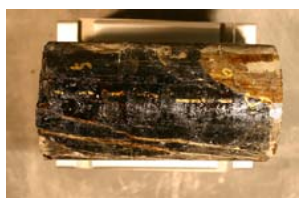
Data Analysis & Visualization

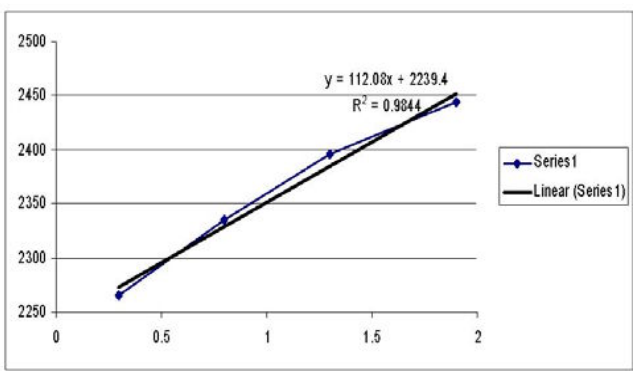


Graphic representation of water saturated and gas saturated acoustic wave velocity (Magenta and purple bars correspondingly) under ~3 MPa confining pressure.

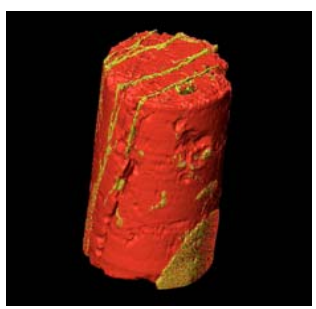
> Substantial velocity differences for two adjacent points of seemingly uniform samples frequently noticed during data analysis. To investigate, CT scan imaging performed on a sample.

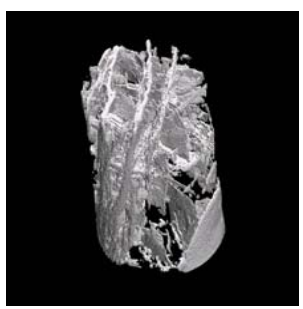
CT Scan Imaging





Pressure dependency of the acoustic velocity for all of the coal samples





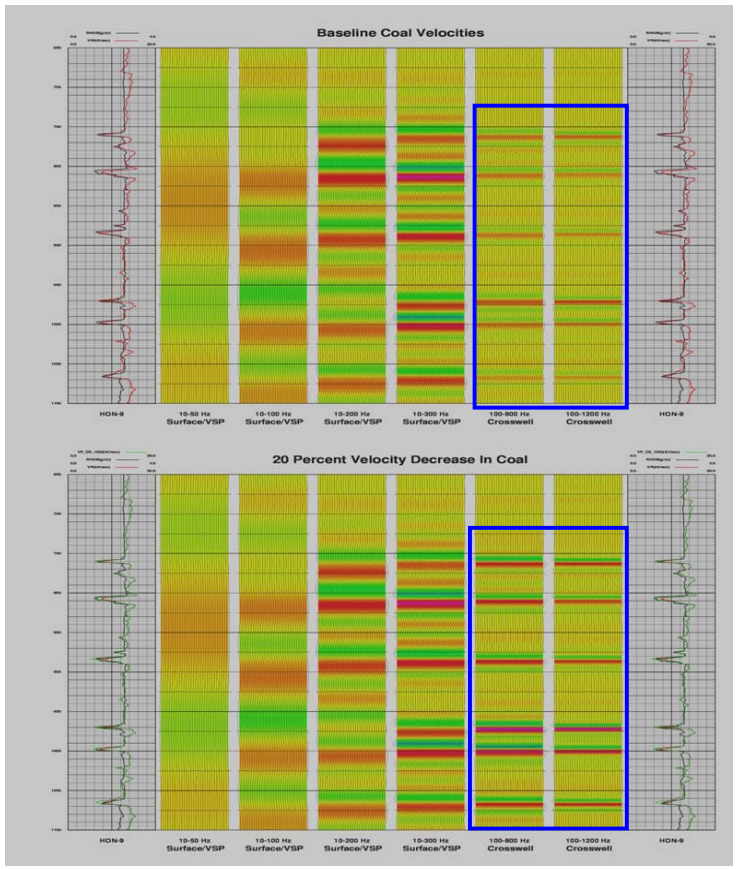
Removing the pixels corresponding to coal material through image processing produced the image of the open and filled cleats.

gti

Forward Modeling Seismic

Creating a Synthetic Tie

- The purpose of the modeling was to investigate the feasibility of time-lapse seismic technology for imaging the injected or evolved gas phase within the coal seams using laboratory result.
- Results from laboratory measurements had shown that addition of a gas phase to initially water saturated coals would cause substantial decrease in the compressional wave velocity. However, in our modeling, a conservative 20% velocity reduction was assumed.



The top part of the figure exhibits the seismic response of individual seams before velocity reduction and the bottom part shows the response after 20% velocity reduction.

Note that changes in the seismic response resulting from injection of carbon dioxide or evolution of coalbed methane can only be observed at frequencies in the 100-800 Hz and 100-1200 Hz bandwidths (Area within the blue rectangles).

Results from forward modeling work strongly suggest that accurate monitoring of the injected CO_2 front through repeated crosswell surveys is quite possible.

Conclusions

Monitoring CO_2 sequestration in coal seams of Illinois appears to be quite practical and can be used as means for determination of high permeability trends.

- At 10-50 Hz bandwidth the resolution is very low and results from surface seismic surveys are not reliable.
- At 10-200 Hz bandwidth, high resolution imaging is possible and surface seismic data would be reliable for mapping of the “coal seam packages” as a whole.
- The use of impulsive sources for surface seismic survey is recommended.
- VSP surveys (10-300 Hz bandwidth) noticeably enhance the resolution.
- Under geologic conditions similar to those at the ISGS pilot site, position of the injected or evolved gas can only be imaged at higher frequencies through cross-well seismic applications.
- Changes in acoustic properties of coal resulting from the addition of a gas phase into the cleat and pore spaces is substantial.