

FINAL TECHNICAL REPORT
March 1, 2005, through August 31, 2006

Project Title: **SEISMIC MONITORING OF METHANE PRODUCTION FROM COAL SEAMS IN ILLINOIS**

ICCI Project Number: 04-1/5.1A-1
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ABSTRACT

Gas Technology Institute, with support from the Illinois Clean Coal Institute and cooperation of the Illinois State Geological Survey, designed and implemented a comprehensive research project to determine the viability of seismic techniques for site selection and development of coalbed methane production from Illinois coals. The focus of the studies was on viability of seismic techniques for delineation of thin coal seams and tracking of the desorbed gas front by time-lapse (4-D) seismic surveys. Results from these studies would be equally applicable to monitoring of the CO₂ front in geologic CO₂ sequestration operations as in both cases the physical process involves the presence of a gas phase (CO₂ or methane) into initially water saturated coal seams.

The issue of seismic resolution relative to thin coal seams was investigated in a series of seismic surveys that included surface seismic, vertical seismic profiling, and crosswell seismic imaging. Results were positive and encouraging. The data proved that thin coal seams can be reliably mapped by properly designed seismic surveys. The first leg of the 4-D seismic survey was completed and the second leg awaits the onset of gas production at the ISGS site in White County, IL; expected to occur in late 2006 or early 2007. GTI will fund this survey at its own cost estimated at about \$29,000.00. Results from the 4-D survey will be submitted to ICCI as an addendum to the present report.

In the course of the project, the scope of work was expanded to include the study of hydraulic fracturing (a well completion technique used for enhancing gas production from coal seams and tight sands reservoirs) in south and south-central Illinois. The industry partner for these efforts was BPI-Energy. Hydraulic fracturing research involved forward modeling, fracture design, and fracture diagnostics. The work was performed with support and participation of BPI-Energy engaged in a coalbed methane production project in Shelby County, Illinois. The work was completed in July, 2006. Results from fracture modeling showed that fracture containment at this site would be very low and nearly all vertical fractures would grow out of zone. Fracture diagnostic survey proved that hydraulically created fractures were complex and except for the shallow seams where fractures were horizontal, all fractures had one vertical component and at least one horizontal component.

Appendix A contains proprietary information

EXECUTIVE SUMMARY

Gas Technology Institute (GTI), with support from the Illinois Clean Coal Institute (ICCI), cooperation of the Illinois State Geological Survey (ISGS), and participation of two Illinois producing companies (BP-I Energy and Royal Drilling Corporation) carried out a series of field and laboratory research aimed at the development of efficient methods and techniques for production of natural gas from coal seams in Illinois. In general, development of any coalbed methane project requires accurate mapping of the host seams, delineation of the preferred flow path; i.e., high permeability trend, and application of an appropriate production enhancement technique. With these requirements in mind, the present project was focused on the following three areas.

- 1- Determination of viability of seismic techniques for accurate imaging of thin coal seams in Illinois.

Advanced seismic techniques have proven successful in providing detailed subsurface images of conventional oil and gas reservoir rocks and thicker coal seams. However, Illinois coal seams are shallow and thin with the thickness rarely exceeding 10 feet and as such, they could be transparent to seismic waves. The issue of seismic resolution relative to thin coal seams was investigated in a series of seismic surveys that included surface seismic, vertical seismic profiling, and crosswell seismic imaging. Results were positive and proved that the thin Illinois coal seams can be seismically mapped through properly designed surveys. A simple guideline for these surveys was developed. This phase of work was initiated under a CO₂ sequestration project and continued in the present project.

- 2- Investigation of time-lapse seismic (4-D) for mapping the position of the desorbed methane and delineation of high permeability trends.

In the absence of any direct far-field permeability measurement technique, high permeability trends can be delineated by progressive mapping of the gas front. Although 4-D seismic (two or more surveys repeated over time) has proven successful in monitoring of gas movements in conventional oil and gas reservoirs, because of low velocity and high compressibility of coal seams, it is not known if the technique would be viable for mapping the gas front in thinner coals. This issue was investigated through a number of laboratory measurements and a planned 4-D survey.

Laboratory measurements showed that velocity changes resulting from the addition of a gas phase into water saturated coal samples are large enough to render the 4-D seismic imaging a viable technique for monitoring the gas front and delineation of high permeability trends. The first leg of the field survey was completed at the ISGS pilot site in White County, Illinois. The second leg will be surveyed upon the establishment of sustained gas production expected to occur in late 2006 or early 2007. In the event that no sustained gas flow would occur at ISGS site, a crosswell survey in a gas producing well at BP-I site will be performed. Results from the second survey will be submitted as an addendum to the present report.

- 3- Development of knowledge and understanding of hydraulic fracturing as a production enhancement technique for Illinois coal seams.

Work relative to hydraulic fracturing research involved forward modeling, fracture design, and fracture diagnostics. The work was performed with support and participation of BPI-Energy engaged in a coalbed methane production project in Shelby County, Illinois. The work was completed in July, 2006. Results from fracture modeling showed that fracture containment at this site would be very low and nearly all vertical fractures would grow out of zone. Fracture diagnostic survey proved that hydraulically created fractures were complex and except for the shallow seams where fractures were horizontal, all fractures had one vertical component and at least one major horizontal component.

A brief summary of research activities and results is presented in the remainder of this section. The original task structure proposed in the proposal will be followed.

Task 1. Laboratory Experiments and Analyses

Laboratory experiments included measurement of acoustic velocity of coal samples with water and gas saturation. The data proved that addition of a gas phase into water saturated coal causes substantial velocity reductions. Figure 1 exhibits sonic travel time for gas saturated portion of a core sample (the top trace) and water saturated portion of the same sample (other four traces). The corresponding velocities for gas and water saturated sections are 1859 and 2555 meters per second.

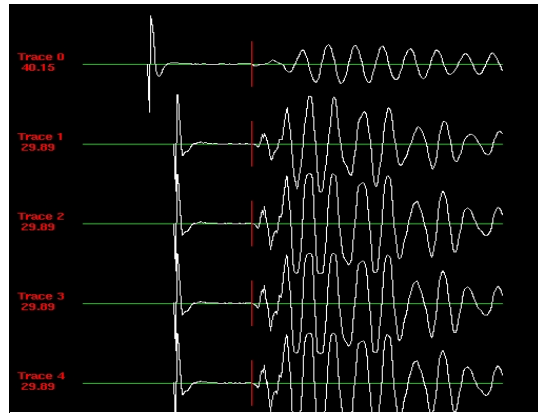


Figure 1. Travel time for a gas and water saturated coal sample

Task 2. Data analysis and Modeling

Data analysis and modeling included seismic and hydraulic fracture modeling. Forward seismic modeling showed that: 1) It is indeed possible to seismically detect the thin coal seams at the ISGS site, and 2) Hydraulic fractures created in coal seams at both ISGS and BPI sites would be mostly horizontal with the vertical section breaking out of the intended seams.

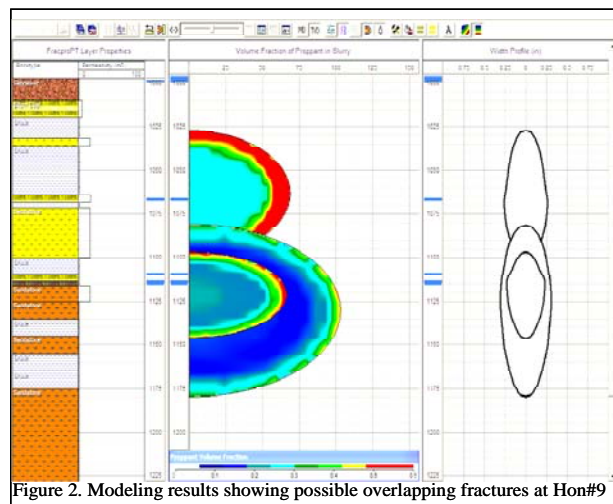


Figure 2. Modeling results showing possible overlapping fractures at Hon#9

Figure 2 exhibits results from fracture modeling for simultaneous fracturing of three seams at the ISGS site. Note that all three fractures grow out of their

corresponding target seams (shown as thin blue bands) and extend to considerable distances above and below the seams. Modeling also showed that concurrent fracturing of other seams would result in the overlap of fractures.

Task 3. Field Data Acquisition

Field data acquisition included seismic survey at ISGS site and fracture diagnostic survey at BP-I site. Figure 3 is an overlay of core and log data on the crosswell seismic section obtained in well Hon #9 in White County, Illinois exhibiting the accuracy of crosswell seismic imaging. As mentioned earlier, this survey will be repeated in late 2006 or early 2007 and results will be presented in an addendum to the present report.

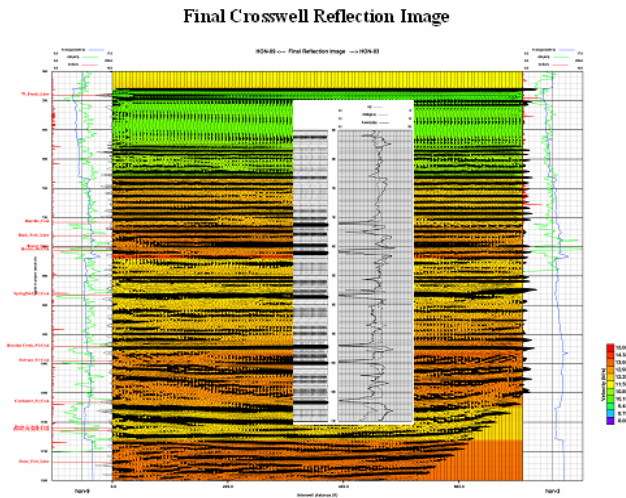


Figure 3. Corsswell seismic section at well Hon #9 site, White County, Illinois

Fracture diagnostic data acquisition included the deployment of 16 super sensitive tiltmeters capable of continuous measurement of surface deformations resulting from hydraulic fracturing. The data and subsequent data analysis showed that all shallower fractures were horizontal and the deeper fractures had a minor vertical component and a major horizontal component. Results from fracture diagnostic surveys depict the nature of fracturing and provide valuable information for design of the optimal field development pattern.

Task 4. Integration, Report, and Technology Transfer

Compilation of data and preparation of reports continued throughout the project and will continue albeit at a lesser extent. Although no new funding is presently available for continuation of efforts, we believe pursuing the development of coalbed methane production has the promising of turning a portion of the 14 trillion cubic feet of gas resource in Illinois to a substantial producible reserve.

Our technology transfer efforts included presentations at the Pittsburgh Coal Conference, the annual meeting of the American Association of Petroleum Geologists, and publication in two issues of GasTips, a GTI-DOE publication featuring the major results from the ongoing research and development.

Conclusions and Recommendations

Despite the sizeable coalbed methane resources of Illinois, production from this statewide source of natural gas has lagged behind and it has been only recently that some producing companies have begun considering serious coalbed methane exploration and production efforts. The parameters contributing to this lag are the shallow depth causing the gas content to be relatively small and difficulties in completion of shallow seams. However,

with the prevailing high gas prices, investments in the development of this resource are beginning to become economically justifiable. The key to success in coalbed methane production in Illinois is modification of technologies that have been proven in the San Juan basin and elsewhere and their tailoring to the Illinois coal environment. Specific recommendations from the work performed are summarized below:

A - Seismic Delineation of Coal Seams

Combining the results from the actual surveys, spectral decomposition, and forward modeling, the following conclusions can be drawn:

- 1- At 10-50 Hz bandwidth the resolution is very low and results from surface seismic surveys are not reliable.
- 2- At 10 -200 H z bandwidth, high resolution imaging is possible and surface seismic data would be reliable for mapping of the “coal seam packages” as a whole.
- 3- The use of impulsive sources for surface seismic surveys is strongly recommended.
- 4- VSP surveys (10-300 Hz bandwidth) noticeably enhance the resolution.
- 5- 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.

B - Hydraulic Fracturing

Extensive fracture modeling and fracture diagnostic survey resulted in a clear understanding of the process and proved that:

- 1- Shallower hydraulic fractures at depths to about 750 feet grow horizontally and deeper fractures have a minor vertical component and a major horizontal component. These parameters should be taken into account for design of field development patterns and determination of drainage zone for each well.
- 2- Vertical fractures grow out of zone and therefore, simultaneous fracturing of seams at close proximity of each other has the same results as those achieved through staged fracturing.
- 3- Under conditions similar to the BPI site, it is safe to assume a circular drainage pattern for coalbed methane wells.

Appendix A to this report contains proprietary information and is not available for public distribution except to the sponsors of this project.