FINAL TECHNICAL REPORT
September 1, 2006, through August 31, 2007

Project Title: **ASSESSMENT OF A GEOPHYSICAL COAL EXPLORATION METHOD IN A FAULTED TERRANE**

ICCI Project Number:	06-1/10.1A-9
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ABSTRACT

Coal exploration projects are focused to accurately predict the geology of a coal field in a cost-effective manner. More geologic data generally yields a better geological model of the coal field. Advances in geophysical methods may provide tools to supplement traditional methods of coal exploration. Two seismic methods: 1) multi-channel analysis of surface waves (MASW), and 2) shear wave (SH-wave) analysis were evaluated to determine their usefulness as coal exploration tools.

The **MASW** method was useful to model the relief on the bedrock surface. Since the geophone spacing utilized was 5 feet (1.5 m) a very accurate mapping of the unconsolidated material thickness was generated as compared to a typical coal exploration program. The method was not useful in modeling below the bedrock surface due to poor vertical resolution and limited depth of penetration.

SH-wave survey was able to accurately model bedrock down to 150 to 200 feet (45 to 61 meters) below the surface. We relied on the amplitude change or the tuning effect to image existing thin coal layers less than 5 ft (1.5 m). Through the use of this method we were also able to predict the location of igneous dikes which intrude through the coal seams in this region. 2-dimensional geologic models constructed with this method were very useful in visualizing complex fault zones.

The surface wave survey was useful to accurately resolve the bedrock surface. The surface wave technique may be useful when unconsolidated overburden material is potentially problematic (e.g., “blue mud”) and precise unconsolidated thicknesses are desirable. The shear wave survey proved useful in resolving fault zones, igneous dikes, and coal seams approaching 5 feet (1.5 meters) in thickness. The maximum depth of penetration was approximately 200 feet (61 meters) of the surface.

This report contains data pertaining to coal thickness, depth to coals, chemical analyses of coal (sulfur, BTU, moisture, ash), geophysical models, and stratigraphic correlations. The project was located in Saline County approximately 5 miles southeast of Harrisburg, Illinois.

EXECUTIVE SUMMARY

This project was developed to determine if recent advances in seismic techniques are useful as a preliminary coal exploration tool. The primary goal was to determine if seismic techniques can be used to locate where relatively thin coal seams (less than 3 feet (1 m)) thicken and thin. A secondary goal was to locate tectonic structures within the project area where Pleistocene sediment has covered and concealed the bedrock structure. A final goal was to determine if these geophysical techniques could be used to locate igneous dikes. Several boreholes were drilled in Saline County, Illinois south of Harrisburg to identify a suitable project location and to verify the local geology. The project contained 5 tasks with specific objectives for each task.

Task 1: Preliminary core drilling to verify local geology.
Task 2: Seismic acquisition, data processing, and construction of geologic models.
Task 3: Additional core drilling to test seismic models.
Task 4: Chemical analysis of coals obtained through drilling.
Task 5: Compilation of data and reporting.

Methods

Two core borings were drilled in 2006 to verify the depth and thickness of coals within the project area. The Kent boring was drilled to 325 feet (99 m), and encountered six coal seams ranging in thickness from 0.5 feet (0.15 m) to 4.5 feet (1.4 m) thick within 240 feet of the surface. The Evans boring was drilled to a depth of 295 feet (90 m), and encountered five coal seams within 240 feet (73 m) of the surface.

The multi-channel analysis of surface wave (MASW) and shear wave (SH-wave) surveys were conducted along several county roads during the fall of 2006 and the spring of 2007. Coal from the borings drilled during the fall of 2006 were sampled and sent to the ISGS coal lab in Champaign, Illinois for chemical analyses. During the Spring of 2007 four additional core borings were completed and coals from these holes were logged, sampled, and sent to Champaign for analyses. While drilling the Rector #1 boring artesian water was encountered. The well was free flowing approximately 80 gallons (300 L) per minute from the 4-inch (10 cm) diameter well boring. No tests were run concerning the water quality, but the water was probably fresh. The aquifer was less than 125 feet (38 m) below the ground surface. The Rector #2 boring was drilled to a depth of 95 feet (29 m), and encountered three coal seams. The Fox boring was drilled to a depth of 189 feet (58 m), and encountered three coal seams. The Blackman boring was drilled to a depth of 145 feet (44 m), and encountered three coal seams. The coals were analyzed for total sulfur, moisture, ash, and BTU.

Surface wave data was processed using SurfSeis processing software from the Kansas Geological Survey (KGS). Each set of Rayleigh wave data (48 channels data set for each station location) was transformed from the time domain into frequency domain using Fast Fourier Transform (FFT) techniques. These field-based data were used to generate site-specific dispersion curves (velocity versus frequency) for each station location. The site-

specific dispersion curves generated from the field-acquired Rayleigh wave data were then transformed into vertical 1-D shear-wave velocity profiles through an inversion method. The maximum depth of investigation is determined from the longest surface wave wavelength measured from the dispersion curve. The thickness or layer model is then created by successively increasing the thickness of each layer as its depth increases, to the maximum depth of investigation. A ten-layer model is initially assigned. The iterative inversion procedure can continue uninterrupted until a minimum root-mean-square error (RMSE) is reached. The obtained 1-D shear-wave velocity profiles for each station were then placed side-by-side and interpolated to generate a 2-D MASW shear-wave velocity profiles consisting of multiple traces. The SH-wave seismic reflection data was processed using WINSEIS Seismic Processing Software also from the Kansas Geological Survey. The processed data was interpreted and presented as 2-D velocity and depth sections using Kingdom Suite (SMT) software. Downhole acoustic surveys were conducted in two boreholes which yielded shear wave velocities ranging from 500 to 2100 ft./sec. (152 to 640 m/sec).

Conclusions

The MASW method was useful to model the relief on the bedrock surface. Since the geophone spacing utilized was 5 feet (1.5 m) a very accurate mapping of the unconsolidated overburden thickness was generated as compared to a typical coal exploration program which might employ a 500-foot (150 meter) borehole spacing. The method was not useful in modeling below the top of the bedrock surface due to poor vertical resolution and limited depth of penetration. This survey would be useful if the unconsolidated material is potentially problematic. Thick accumulations of the Equality Formation, which is present in this region, would certainly be a concern for spoil stability. The Equality Formation has a high clay content and will absorb water thereby increasing the load of spoil material. The increased spoil load and the nature of the clay material can create rotational slumps and impact mine production.

The shear wave (SH-wave) analysis accurately modeled bedrock down to approximately 150 to 200 feet (45 to 61 meters) below the surface. We relied on the amplitude change or the tuning effect to image existing thin coal layers less than 5 ft (1.5 m). Coal seams that were less than 4 feet thick were discernable through this technique. We conclude that the SH-wave survey is able to model coal seams but maximum depths and thicknesses will vary depending upon the velocity contrasts of the strata directly above and below the individual coal seam. This method was also able to predict the location of igneous dikes which intrude through the coal seams in this region. Additionally, the SH-wave data was useful in locating faults and allowed 2-dimension models to be constructed which aid in understanding the geology of the area. An apparent tectonic structure, modeled through the SH-wave technique, may be the structural trap for productive oil wells near Mitchellsville, Illinois. Research concerning this tectonic structure as a potential oil and gas trap is continuing.

OBJECTIVES

This project was designed to determine the usefulness of two different seismic methods as preliminary coal exploration tools. Lower Desmoinesian coal in southern Illinois are not laterally continuous and the thickness of individual seams varies considerably over relatively short distances. The primary goal of this project was to determine if geophysical profiles are useful to predict where coals thicken to economically viable levels. Traditional coal exploration techniques (e.g. core drilling) were employed in order to test the accuracy of the geophysical models. Chemical analyses on all coal seams greater than 12 inches thick were accomplished in conjunction with the core drilling. Data from exploration drilling and chemical analyses were added to the coal database of the Illinois State Geological Survey (ISGS). A secondary objective was to determine the usefulness of various seismic methods to locate igneous dikes and fault zones suspected to be present in the project area. This project was to determine if seismic methods are useful as a “preliminary” coal exploration technique to locate relatively thin coal seams in a faulted terrane.

The following tasks were proposed for this project:

- Task 1 - Core Drilling: Continuous core drilling of 2 preliminary boreholes was conducted in the project area to confirm the existence of coal seams thick enough to be resolved through the proposed seismic methods.

- Task 2 - Seismic Acquisition: Six miles of seismic data were collected. Downhole acoustic surveys to assist the seismic processing were conducted to assist with seismic interpretations.

- Task 3 - Core Drilling: 2 boreholes were drilled to compare with results from seismic modeling.

- Task 4 - Chemical Analysis: Coals with thicknesses of 1 foot or greater obtained through core drilling were analyzed for total sulfur, moisture, ash, and BTU.

- Task 5 - Reporting of results.

INTRODUCTION AND BACKGROUND

The project area is located in Saline County, approximately 5 miles (8 km) southeast of Harrisburg, Illinois (Fig. 1). Several coal mines have extracted Herrin and Springfield Coals near Harrisburg and Dekoven and Davis Coals have been mined east and west of the project area. Bedrock geologic maps identify several normal faults striking northeasterly through the project region (Denny et al., 2007; Nelson and Lumm, 1986). The faults have vertical offsets of less than 65 feet (20 m) and displacement is mapped as normal. The faults are parallel with the Lusk Creek Fault Zone and the Dixon Springs Graben which are located

9 miles (14.4 km) to the south (Fig. 1). The regional strike of bedrock, where not effected by faulting, is slightly north of due east-west (N80^{0}E) with dips of 2 to 3 degrees to the northwest. Northwesterly striking igneous dikes also project into the project area. The igneous dikes and sills in the region are ultramafic and have been classified as alnöite (Denny, 2005). The trend of these dikes is in-line with a regional arch called the Tolu Arch which extends from northwestern Kentucky into southeastern Illinois. Hicks Dome is present along the axis of this regional arch approximately 8 miles (12.8 km) southeast of the project area. Hicks Dome exposes Lower to Middle Devonian System sedimentary rocks at the center with younger Mississippian rocks dipping away from the center of the dome. Concentric and radial faults are present along with younger northeast trending normal faults which offset the circular structural fabric of the dome. Baxter and Desborough (1965) estimated vertical uplift on bedrock units at Hicks Dome to be 4000 feet (1200 m) and the diameter to be nearly 10 miles (16 km).

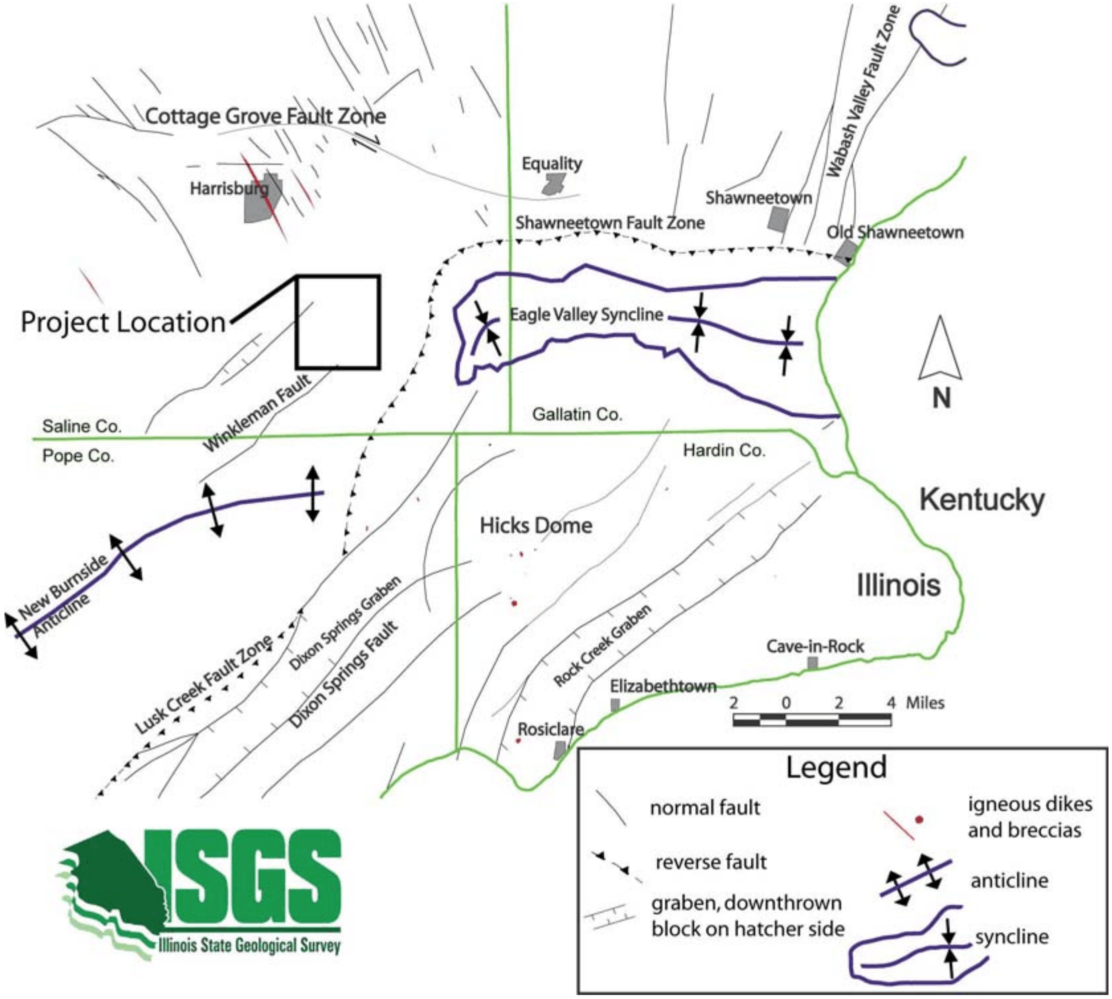

Fig. 1. Project location map with major tectonic structures and igneous intrusions.

The uppermost geologic unit beneath the Pleistocene loess in this region is the Equality Formation. The Equality is dominated by fine grained lake bed clay and silt with occasional sand and gravels lens. The unit is present in the valleys but is not present on the upland hills. Where the Equality is not present (on upland hills) loess lies directly over Pennsylvanian bedrock.

The Pennsylvanian System units of southern Illinois lie unconformably on Mississippian Age Chesterian Series units. The Caseyville Formation (Fig. 2) is a Morrowan Series unit composed of well sorted clean quartz sand (quartz arenite), with minor amounts of siltstone and shale. The sandstones are fine to very coarse grained with quartz pebbles up to ½ inch in diameter. Coals are known to be present within the Caseyville Formation but are thin, discontinuous, and of limited economic potential. Above the Caseyville the Tradewater Formation is present. The Tradewater Formation is composed of 70 to 80 percent shale and siltstone and 20 to 30 percent sandstone and generally less than 5 percent limestone and coal (Tri-State Committee on Correlation of Pennsylvanian System in the Illinois Basin, IBC Study 5, 2001). The sandstones in the Tradewater are fine to coarse grained and inter-bedded with siltstones. The sandstones in the upper portion of the Tradewater Formation contain abundant clay and mica and are commonly classified as lithic arenites while the lower Tradewater sandstones are transitional between the quartz arenites of the Caseyville Formation and lithic arenites of the Upper Tradewater Formation. Additionally, sandstones in the Lower Tradewater are

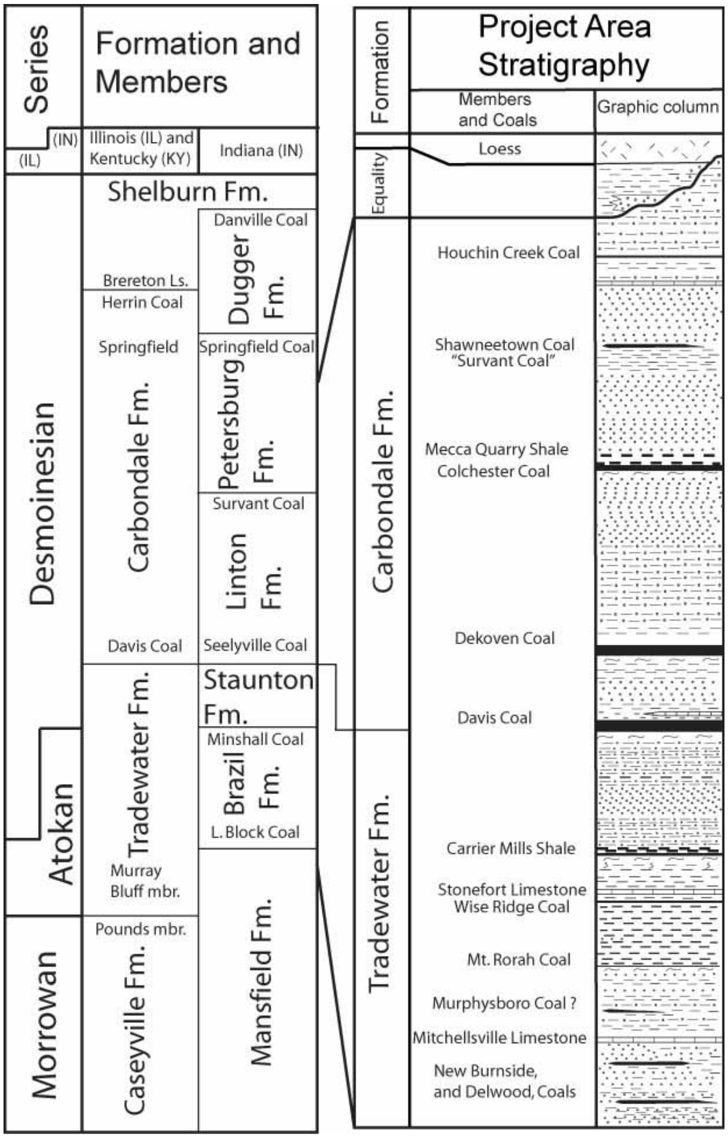

Fig. 2. Stratigraphic correlations of the Lower Pennsylvanian System in the project area. Adapted from IBC study 5, 2001.

more abundant and occur in thicker beds. Above the Tradewater, the Carbondale Formation is present. The Carbondale Formation contains the principle economic coals in the Illinois Basin. The coals within the Carbondale Formation are laterally persistent and several studies and exploration programs have documented the thickness and chemical properties of these coal seams. In contrast, the coals within the Tradewater Formation are smaller in geographic extent and are not necessarily laterally consistent. The coals of the Tradewater Formation (Lower Desmoinesian) are the primary focus of this research project.

Coal mining activities within the region

Substantial mining activity within the immediate project area extracted Davis and Dekoven Coals of the Lower Carbondale Formation. Coals of the Tradewater Formation have been mined in a few isolated areas near the southern tip of Saline County (Fig. 3). These coals were mined by both surface and underground methods. Coal stratigraphically below the Davis (Upper Tradewater) have been mined only at a few small isolated pods. This may be a result of the lack of coal or lack of continuity of the coal seam. Little historical information is available concerning these mines, probably due to a combination of their limited geographic extent and the short time for which the mines were active. The Directory of Coal Mines in Illinois (Saline County), lists all of these coal mines as extracting the Delwood Coal. The two small drift mines near JJ Track Mine list these underground operations as mining the Davis Coal.

Geophysical survey parameters

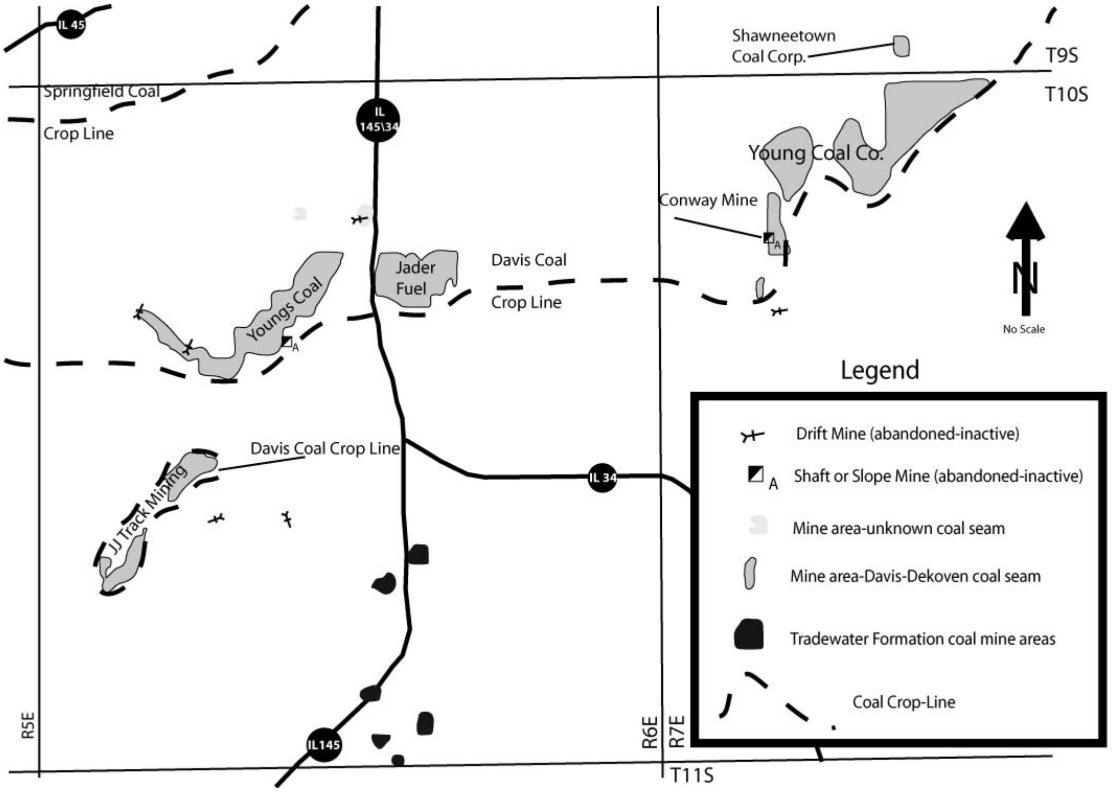

Fig. 3. Coal mines within the project area and coal crop lines. All mines are inactive.

The multi-channel analysis of surface waves (MASW) technique was first introduced into the geotechnical and geophysical community in early 1999 (Park et al., 1999). MASW is a seismic method which generates a shear-wave velocity (Vs) profile (i.e., Vs versus depth) by analyzing Rayleigh-type surface waves on a multi-channel record. The method uses multi-channel recording and processing concepts widely used for several decades in reflection surveying for oil exploration. MASW utilizes Rayleigh wave energy, commonly considered as noise on conventional reflection seismic surveys. Rayleigh wave energy is defined as signal in MASW analysis, and needs to be enhanced during both data acquisition and processing steps. Because of this reversed definition of signal and noise in comparison to traditional seismic methods, the method requires slightly different considerations and approaches to data acquisition. The main advantage of the multi-channel approach is in its capability to distinguish all of these noise waves from the signal wave (the fundamental mode of Rayleigh waves) through diverse seismic attribute analysis.

Henson and Sexton (1991) identified the usefulness of basic high-resolution seismic reflection methods to coal mine planning. They modeled several stratigraphic variations in the roof material overlying the Herrin #6 Coal and sandstone channels that dissect the continuity of the coal. Their study concluded that: "Geological information required for effective coal mine planning is quite often not obtained by traditional drilling practices commonly employed in the coal industry." Silverman et al. (2003) utilized high-resolution seismic data to locate igneous dikes in Saline County, Illinois and to locate abandoned underground mines.

Seismic reflection data has been utilized by the mining industry to provide information on seam occurrence, thicknesses, geometries and structure to guide mining activities. Despite the great success of traditional SH-and P-wave seismic reflections methods in the mining industry, the following factors may limit the functionality of those methods:

1) Data acquisition is slow and expensive.
2) Post acquisition processing requires considerable expertise.
3) Reduced effectiveness in acoustically noisy area.
4) Poor data is recorded within the upper 30 feet (10 m) of the subsurface.

EXPERIMENTAL PROCEDURES

The project was designed to test recent advances in geophysical seismic technology and processing methods to determine their potential usefulness as preliminary coal exploration methods. Several factors were deemed necessary for the project area to be satisfactory.

1) Several coal seams present with various thicknesses.
2) Access for seismic acquisition (good road network, but little traffic or noise).
3) Tectonic structure or faults in the area.
4) Relatively flat topography.
5) Igneous dikes present.
6) Accessability to property for core drilling.

A project area south of Harrisburg, Illinois (Saline County) contained appropriate strata which was confirmed through preliminary core drilling. The project area allowed a seismic streamer to be employed. This streamer is a series of geophones which are strung together at fixed intervals on metal sleds which are towed behind a vehicle (Fig. 4a-c). Fairly well maintained roads are necessary for this streamer to be employed. Furthermore, an area where topography was slight and faults were suspected would be ideal. The project parameters also require coal seams greater than 3 feet (1 meter) to be present within 300 feet (91 m) of the ground surface. A project location southeast of Harrisburg (Appendix 1) was chosen because all of the above criteria were present. Additionally, the western half of the project area was the focus of another geologic mapping study. Therefore, abundant geological information was available concerning this portion of the project area.

<u>Data acquisition</u>

The multi-channel surface wave seismic data was acquired using a 48-channel surface wave land streamer (Fig. 4a-c), built at the Illinois State Geological Survey (ISGS). The geophysical survey parameters of this data are listed in Table 1. Additionally, SH-wave reflection data was acquired using a 24-channel shear wave land streamer also built at ISGS.

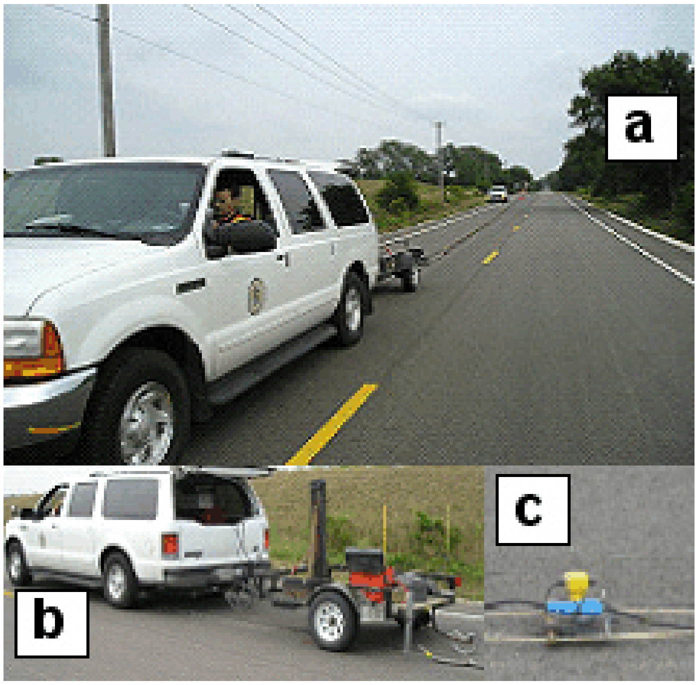

Fig. 4. Data acquisition using the surface land streamer, [a] surface wave land streamer, [b] P-wave weight dropper, and [c] one vertical 4.5 Hz geophone mounted on a sled (land streamer).

Table 1. Geophysical Survey Parameters.

MASW data acquisition		SH-wave data acquisition	
Channels	48	Channels	24
Geophone interval	5 ft. (1.5 m)	Geophone interval	2.5 ft (0.76 m)
Geophone type	Vert. 4.5 Hz	Geophone type	Horiz. 14 Hz
Nearest offset	25 ft. (7.6 m)	Nearest offset	5 ft. (1.5 m)
Shot interval	30 ft. (9.1 m)	Shot interval	5 ft. (1.5 m)
Source	100 lb. (45.36 kg.) weight drop	Source	2 lb (1kg) sledge hammer
Sampling rate	0.5 ms	Sampling rate	0.5 ms
Record length	2 sec.	Record length	1 sec.
Filters	none	Filters	none
Recording system	geode	Recording system	geode
Positioning system	GPS-Trimble DSM212H	Positioning system	GPS-Trimble DSM212H

Data processing

The multi-channel analysis of surface wave (MASW) data was processed using SurfSeis processing software from the Kansas Geological Survey (KGS). Each set of Rayleigh wave data (48 channels data set for each station location) was transformed from the time domain into the frequency domain using Fast Fourier Transform (FFT) techniques. These field-based data were used to generate site-specific dispersion curves (velocity versus frequency) for each station location. The site-specific dispersion curves generated from the field-acquired Rayleigh wave data were then transformed into vertical 1-D shear-wave velocity profiles (MASW shear-wave velocity profile) through an inversion method.

The inversion method uses an initial model before actually beginning to search for the answer in an iterative manner. An initial model consists of several key parameters: S-velocity (Vs), P-velocity (Vp), density (r), and thickness (H) of the layers in the earth model. Using this set of parameters, the program begins searching for a solution, continuously converging on the most probable values. The S-velocity (Vs) is most sensitive and influential to the surface wave phase velocity. Influence of all other types of parameters can usually be neglected as long as they have been reasonably estimated. The initial S-velocity (Vs) model is approximated from the measured dispersion curve. The initial P-velocity (Vp) model is determined using this Vs model and a constant Poisson's ratio of 0.4. A density of 2.0 g/cc is assigned to all layers of the earth model. The maximum depth of investigation is determined from the longest surface wave wavelength measured from the dispersion curve. The thickness or layer model is then created by successively increasing the thickness of each layer as its depth increases, to the maximum depth of investigation. A ten-layer model is initially assigned. The iterative inversion procedure can continue uninterrupted until a minimum root-mean-square error (RMSE) is reached. The obtained 1-D shear-wave velocity profiles for each station then were placed side-by-side and interpolated to generate a 2-D MASW shear-wave velocity profiles consisting of multiple traces (Fig. 5).

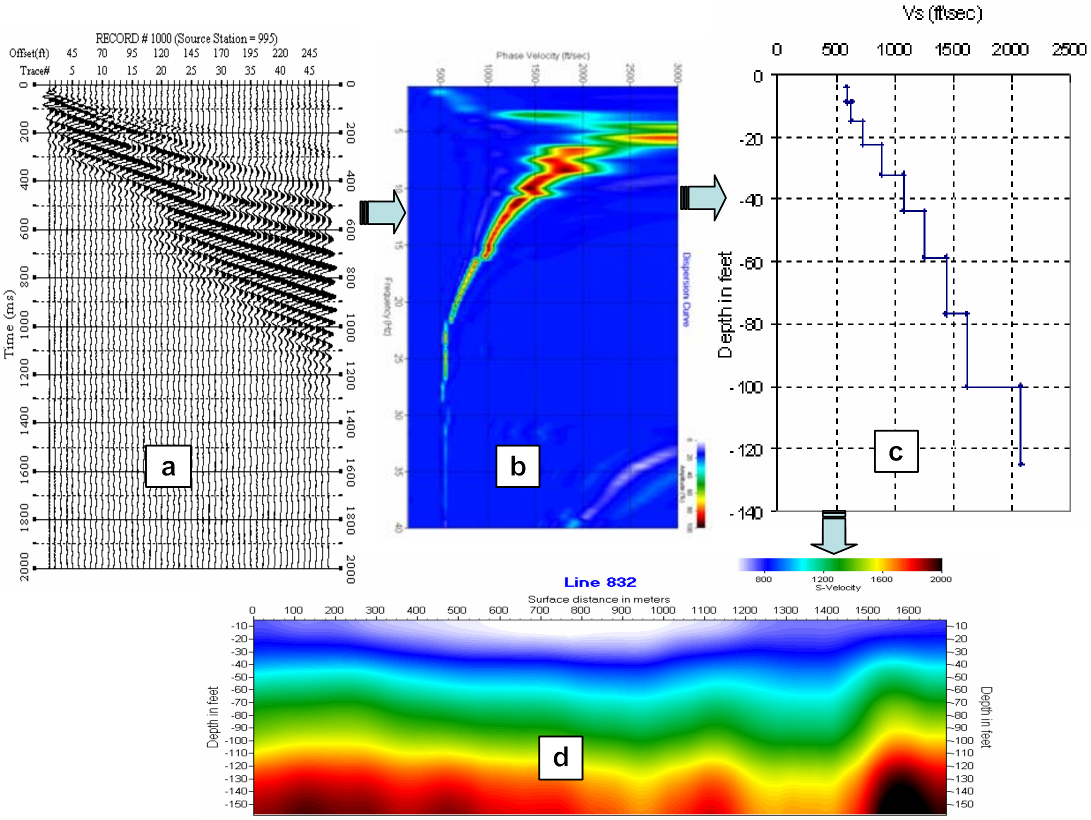

Fig. 5. Processing procedures of MASW data using SurfSeis software, [a] surface wave field record, [b] dispersion curve generated from the field record [c] 1-D shear wave velocity profile generated from inversion of the dispersion curve, and [d] 2-D shear wave velocity section generated from interpolating number of 1-D MASW profiles.

The SH-wave seismic reflection data was processed using WINSEIS Seismic Processing Software also from the Kansas Geological Survey. The data processing steps in Table 2 were applied. The processed data was interpreted and presented as 2-D velocity and depth sections using the Kingdom Suite (SMT) software.

Table 2. Data processing steps.

1	Data conversion SEG2 to KGS-SGY
2	Geometry edit
3	Band pass filter 20-120 Hz
4	Mute air wave
5	First arrival mute
6	Mute ground roll energy
7	AGC scaling 100 ms window
8	CMP sort
9	Velocity analysis (constant velocity stack)
10	NMO correction
11	Stretch mute 20%
12	Stack (divided by the square root of fold)
13	Trace Mix

RESULTS AND DISCUSSION

The procedure and results for Tasks 1 through 4 are described in the following narrative. Coal thickness and immediate roof lithologies are given in Tables 1 through 7. The chemical analyses of coals are given in Tables 8 through 11. Geologic models produced from the seismic surveys, graphic logs, selected photographs of the rock core, photographs of thin sections, and a project location map are included as Appendices.

- Task 1 and Task 3: Core Drilling

Wire-line core drilling obtained a 2.5-inch (6.35 cm) diameter (HQ) core from 6 holes. Cores were transported to the ISGS rock lab on the campus of Southern Illinois University where they were cleaned and lithologic details described by Gary Griffith, Brett Denny, and Joe Devera. Due to their potential for stratigraphic correlation the carbonate rocks from each hole were sampled and thin sections were prepared for petrographic analysis. Lithologically, almost all the carbonates sampled range from wackestone to packstone (Appendices 16A-16G). The carbonates are medium to dark gray in color, argillaceous, and ferrigenous and can vary in thickness from a few inches to a few feet. In many cases, bioclasts in these carbonates become partially pyritized near the base of the unit. There are also occurrences of a gray algal boundstone well above the DeKoven - Davis interval, as well as a green argillaceous bioclastic wackestone lower in the section. The bioclast assemblage of the carbonates display a large diversity of marine invertebrates, including fusulinid, uniserial, and endothyrid Foraminifera; rhomboporoid and fenestrate bryozoans; punctuate, impunctate, and pseudopunctate brachiopods (as well as brachiopod spines); gastropods; pelecypods; echinoid spines and plates; disarticulate trilobites (*Proetid sp.*); ostracodes; unidentified organics possibly resin or amber (Appendix 16G); and a diverse assemblage of algae (including *Asphaltina sp.).*

The surface elevation of the Kent borehole was 362 feet (110 m) and the hole was drilled to a final depth of 325 feet (99 m) below the surface (Appendix 3). Several coals were encountered in this boring (Table 3). Chemical analysis of coals from this hole are given in Table 8.

Table 3. Kent borehole; Sec. 2, T10S-R6E, 1300ft (396 m) EL, 50 ft (15 m) SL)

Coal	thickness ft. (m)	depth to top ft. (m)	roof material rock type \ unit thickness ft. (m)
Colchester	0.5 ft. (0.15 m)	64.8 ft. (19.8 m)	black shale \ 1.9 ft. (0.6 m)
Dekoven	3.5 ft. (1.1 m)	108.5 ft. (33.1 m)	black shale \ 3.3 ft. (1.0 m)
Davis	4.5 ft. (1.4 m)	134.4 ft. (41.0 m)	black shale \ 3.9 ft. (1.2 m)
Unnamed	0.8 ft. (0.2 m)	190.2 ft. (58.0 m)	black shale \ 2.8 ft. (0.9m)
Wise Ridge	1.0 ft. (0.3 m)	211.7 ft .(64.5 m)	black shale \ 5.3 ft. (1.6 m)
Mt. Rorah	1.7 ft. (0.5 m)	237.4 ft. (72.4 m)	siltstone \ 8.6 ft. (2.6 m)

The surface elevation of the Evans borehole was 387 feet (118 m) and the hole was drilled to a final depth of 295 feet (90 m) below the surface (Appendix 4). Several coals were encountered in this boring (Table 4). Chemical analysis of coals from this hole are given in Table 9. A downhole acoustic survey was also completed in this well and is shown in Appendix 17A.

Table 4. Evans boring; Sec. 3, T10S-R6E, 82 ft (25 m) EL, 1345 ft (410 m) SL

Coal	thickness ft. (m)	depth to top ft. (m)	roof material rock type \ unit thickness ft (m)
Colchester	0.3 ft. (0.09 m)	74.3 ft. (22.6 m)	blk. & gray shale \ 7.8 ft. (2.4 m)
Dekoven	3.5 ft. (1.06 m)	118.3 ft. (36.1 m)	sandstone \ 7.8 ft. (2.4 m)
Davis	3.7 ft. (1.12 m)	139.0 ft. (42.4 m)	blk. & gray shale \ 5.8 ft. (1.8 m)
Unnamed	0.7 ft. (0.2 m)	203.1 ft. (61.9 m)	black shale \ 2.8 ft. (0.9 m)
Wise Ridge	0.6 ft. (0.18 m)	220.4 ft. (67.2 m)	black shale \ 2.4 ft. (0.7 m)

The surface elevation of the Fox borehole was 370 feet (113 m) and the hole was drilled to a final depth of 189 feet (58 m) below the surface (Appendix 6). Several coals were encountered in this boring (Table 5). Chemical analysis of coals from this hole are given in Table 10.

Table 5. Fox boring; Sec. 36, T9S-R6E, 870 ft (265 m) EL, 35 ft (11 m) SL

Coal	thickness ft. (m)	depth to top ft. (m)	roof material rock type \ unit thickness ft. (m)
Colchester	0.5 ft. (0.15 m)	105.6 ft. (19.8 m)	black shale \ 5.4 ft. (1.6 m)
Dekoven	3.3 ft. (1.0 m)	159.7 ft. (48.7 m)	black shale \ 2.5 ft. (0.8 m)
Davis	3.8 ft. (1.2 m)	184.3 ft. (56.2 m)	limestone \ 0.4 ft. (0.1 m)

The surface elevation of the Blackman borehole was 410 feet (125 m) and the hole was drilled to a final depth of 145 feet (44.2 m) below the surface (Appendix 5). Several coals were encountered in this boring (Table 6). Chemical analysis of one coal sample from this hole is given in Table 11. A downhole acoustic survey was also completed in this well and is shown in Appendix 17B.

Table 6. Blackman boring; Sec. 23, T10S-R6E, 800ft (244 m) WL, 1900 ft (579 m) NL

Coal	thickness ft. (m)	depth to top ft. (m)	roof material rock type \ unit thickness ft. (m)
Wise Ridge	1.0 ft. (0.3 m)	50.9 ft.(15.5 m)	blk.and gray shale \ 16.9 ft (5.2 m)
Mt. Rorah	0.3 ft. (0.1 m)	77.2 ft. (23.5 m)	claystone \ 19.8 ft. (6.0 m)
Murphysboro ?	1.4 ft. (0.4 m)	107.1 ft. (32.6 m)	shale \ 27.4 ft. (8.4 m)

The surface elevation of the Rector #1 borehole was 362 feet (110 m) and the hole was drilled to a final depth of 275 feet (84 m) below the surface (Appendix 7). No coal was observed in this boring. The hole encountered over 80 feet (24 m) of Equality clay and encountered the bedrock surface at 85 feet (26 m). The section below the Equality Formation was composed almost completely of sandstone. A few shale breaks were interbedded with the sandstone and a calcareous zone, that may correlate with the Boskydell marine zone, was present at about 150 feet (46 m). This hole flowed groundwater (artesian) from the casing. In order to stop the well from flowing water into the farm field overnight, while not drilling, we put 20 feet (6 m) of casing on the top of the hole. The water rose within the steel casing to about 18 feet (5.5 m) above the ground surface, indicating that hydraulic head on this well was at 380 feet (155 m) above sea-level. We also measured the water flow from this well using a 10-gallon (37.8 liter) bucket. We crudely calculated that the well was free flowing 80 gallons (300 liters) of water per minute from the 4-inch (10 cm) diameter well boring. The water started flowing in the clean sandstone below 125 feet (38 m) and may be coming from the Boskydell marine zone interval. The water appeared to be fresh, but no salinity measurements were conducted. In order to ensure the hole was properly plugged, the steel casing was left in the ground and then a cement grout was pumped (under pressure) into the hole through the casing. The steel casing was then cut off 4 feet (1.2 m) below the ground surface after the cement plug hardened.

The surface elevation of the Rector #2 borehole was 360 feet (120 m) and the hole was drilled to a final depth of 95 feet (29 m) below the surface (Appendix 8). Several coals were encountered in this boring (Table 7). Photographs of thin sections from this boring are included as Appendices 16 (A, B, and G).

Table 7. Rector #2 boring. Sec. 12, T10S-R6E, 3850 ft (1173 m) EL, 500 ft (152 m) SL

Coal	thickness ft. (m)	depth to top ft. (m)	roof material rock type \ unit thickness ft. (m)
Unnamed	0.4 ft. (.12 m)	33.5 ft.(10.2 m)	blk.and gray shale 12.4 ft (3.8 m)
Wise Ridge	1.8 ft. (0.5 m)	61.2 ft. (18.7 m)	black shale \ 4.9 ft. (1.5 m)
Mt. Rorah	0.7 ft. (0.2 m)	85.3 ft. (26 m)	gray shale\ 6.2 ft. (1.9 m)

- <u>Task 2: Seismic data interpretation</u>

The collection of seismic data was supervised by Ahmed Ismail and Steven Sargent. Several teams members assisted with the seismic surveys and down-hole velocity studies. The acoustic survey in the Blackman borehole recorded velocities ranging from 500 to 1600 ft./sec. (152 to 488 m/sec) while velocities in the Evans borehole ranged from 600 to 2100 ft./sec. (183 to 640 m/sec). The shear (SH) wave velocity values were a good match with the lithological descriptions at the two boreholes and they helped to interpret the 2-D surface wave and SH-wave seismic profiles. SH-wave geophysical models and geologic interpretations were constructed by Ahmed Ismail and are included as Appendices 9, 10, 11, 12, and 13. MASW geophysical models are included as Appendices 14 and 15.

- <u>Task 3: (see Task 1)</u>

- <u>Task 4: Chemical analyses</u>

The British Thermal Unit (BTU) analyses were performed by using a Parr 1281 Calorimeter - a microprocessor controlled isoperibol calorimeter. The procedure calls for the sample to be weighed and placed in the bomb head with a cotton fuse. The bomb head is placed into the cylinder and sealed. The weight of the sample is entered into the microprocessor and the analysis is started. The bomb is pressurized with oxygen. The microprocessor monitors the temperatures of the bomb jacket and initiates the firing of the fuse after equilibrium is established. The temperature is monitored and recorded, and at the completion of the analysis the bomb pressure is released. The bomb is then rinsed into a container. The rinsate is titrated for the acid correction. The acid correction and percent total sulfur are inputted into the microprocessor, which then calculates the gross heat of the sample.

The total sulfur was run using a LECO SC-32 - a microprocessor controlled instrument. The sample is weighed and the weight entered into the microprocessor. The sample is then combusted in an oxygen atmosphere where the sulfur oxides to SO. The SO is measured by a solid state infrared detector. The microprocessor calculates the sulfur and reports the results as % total sulfur.

Table 8. Chemical analyses of coals from the Kent drill hole.

Coal	% Moisture	% Ash (dry)	% Total Sulfur (dry)	BTU (dry)	Depth below surface (ft.)	Sample Thickness ft (m)
Colchester	2.33	18.64	8.59	11,641	64.85 - 65.45	0.6 ft (0.2 m)
Dekoven	1.82	10.61	3.81	13,202	108.6 - 110.9	2.3 ft (0.7 m)
Dekoven	1.93	9.26	3.31	13,471	110.9 - 112.0	1.1 ft (0.3 m)
Davis	1.89	11.11	3.22	13,279	134.6 - 136.1	1.5 ft (0.5 m)
Davis	2.14	12.22	6.82	12,600	136.1 - 138.3	2.2 ft (0.7 m)
Davis	2.09	8.3	4.97	13,389	138.3 - 139.0	0.7 ft (0.2 m)
unnamed	1.57	16.52	4.85	12,358	190.0 - 191.1	1.1 ft (0.3 m)
Wise Ridge	1.58	15.75	5.25	12,228	211.7 - 212.7	1.0 ft (0.3 m)
Mt. Rorah	2.62	39.04	11.02	7,783	237.4 - 238.0	0.6 ft (0.2 m)
Mt. Rorah	2.03	14.81	5.34	12,866	238.0 - 239.2	1.2 ft (0.4 m)

Table 9. Chemical analyses of coals from the Evans drill hole.

Coal	% Moisture	% Ash (dry)	% Total Sulfur (dry)	BTU (dry)	Depth below surface (ft.)	Sample Thickness feet (m)
Dekoven	2.1	8.96	3.97	13,550	118.3 - 120.3	2.0 ft (0.6 m)
Dekoven	2.55	15.82	9.07	12,058	120.3 - 121.3	1.0 ft (0.3 m)
Dekoven	1.86	11.74	6.81	12,950	121.3 - 121.8	1.5 ft (0.5 m)
Davis	2.73	9.93	4.65	13,389	139.3 - 140.5	1.2 ft (0.4 m)
Davis	3.37	8.03	3.53	13,613	140.5 - 141.5	1.0 ft (0.3 m)
Davis	1.62	15.16	10.77	12,310	141.5 - 142.1	0.6 ft (0.2 m)

Table 10. Chemical analyses of coals from the Fox drill hole.

Coal	% Moisture	% Ash (dry)	% Total Sulfur (dry)	BTU (dry)	Depth below surface (ft.)	Sample Thickness feet (m)
DeKoven	4.2	15.47	6.37	12,238	159.7 - 163.0	3.3 ft (1.0 m)
Davis	3.54	14.86	5.76	11,941	184.3 - 188.1	3.8 ft (1.2 m)

Table 11. Chemical analysis of coal from the Blackman drill hole.

Coal	% Moisture	% Ash (dry)	% Total Sulfur (dry)	BTU (dry)	Depth below surface (ft.)	Sample Thickness feet (m)
Murphysboro or Delwood ?	2.37	12.26	6.82	12,958	107.1 - 108.5	1.4 ft (0.4 m)

CONCLUSIONS AND RECOMMENDATIONS

The multi-channel analysis of surface wave (MASW) method was able to accurately model the Pleistocene-Pennsylvanian interface. This MASW survey predicts the unconsolidated surficial units to be less than 10 feet (3 m) to nearly 100 feet (30 m) thick (Appendices 14 and 15). The geologic models predict the bedrock surface to be of moderate relief. This indicates that the Pleistocene glacial ice sheets stopped their southerly advance north of the project region. There were no glacial tills observed in any of the borings. The Pleistocene units observed during drilling were Wisconsin Episode lake bed deposits (Equality Formation) which were formed as the Wisconsin ice sheet melted approximately 75,000–12,000 years ago. Lacustrine sediment filled the paleo-bedrock valleys up to about 350 feet (107 m) mean-sea-level. Due to the clay content of the Equality Formation it poses issues for surface mining operations. Local coal miners call the Equality Clay "blue mud". The clay will take on water between the layer latices and expand. As the clay expands it increases the spoil load. The loading of the clay caused rotational slumps and spoil-side failures at one surface mine in the region. Thick accumulations of Equality Clay may also create mining difficulties through high-wall instability issues. An unstable highwall creates safety issues and limits the proper placement of explosive blastholes along the edge of the highwall. The improper blasthole location can create poor blasting results and significantly increase overburden removal costs. The MASW provides an excellent source of data to predict the thickness of the unconsolidated material in the region. This data can be valuable to assist surface mine design and planning and to help predict overall explosive cost for the mine. We can image no coal seams in the area based on the MASW data due to poor vertical resolution and limited depth of penetration of the method.

The SH-wave analysis was able to accurately model bedrock down to approximately 150 feet to 200 feet (45 to 61 meters) below the surface. The SH-wave lines run for this project confirmed the location of several know faults in the region and detected several small unknown subsidiary faults (Appendices 9, 10, 11, 12, and 13). The rock core from the Evans hole shows moderate fracturing in places and micro-faulting was observed at several intervals in the core (Appendix 18). This data is in agreement with the models which predict faults in this region. The Winkleman Fault Zone was readily observable on line 844000 (Appendix 13). The faulting is normal down on the northwest side. The models seem to exaggerate the dips of the beds and probably are modeling the dips of the beds within the faulted zones. When examining the dips on these models the user should also examine the vertical exaggeration of the model which may increase the apparent dip angle. The models indicate the rocks of the region are dipping into the center of a slight depression or syncline which parallels the fault boundaries. The complexities of this tectonic activity are currently being studied. An apparent horst block , modeled on line 841000 (Appendix 9), may be the structural control for productive oil wells near Mitchellsville, Illinois. More than 29,000 barrels of oil have been produced from Mississippian Age (Chesterian Series) units in this field. Research concerning this tectonic structure as a potential oil and gas trap is on-going.

The 2-D shear wave velocity profiles generated from SH-wave seismic reflection lines provided good correlation to the nearby boreholes and helped to locate coal seams (Lines 841000 and 842000). At other sites, the SH-wave seismic profiles were not able to resolve coal seems that have been shown to be present in nearby boreholes. Although the coals have large impedance contrasts with respect to the host strata, seismic reflectivity is diminished because individual coal seams are so thin or located at depth greater than the penetration depth of the SH-wave (Line 843000 and 844000). We conclude that the SH-wave survey is able to model coal seams but maximum depths and thicknesses will vary depending upon the velocity contrasts of the strata directly above and below the individual coal seam. According to the *"Rayleigh Criterion"*, in order for two nearby reflective interfaces to be distinguished, they have to be about 1/4 wavelength in thickness. For smaller thicknesses than 1/4 wavelength we rely on the amplitude to judge the bed thickness. For thicknesses larger than 1/4 wavelength we can use the wave shape to judge the bed thickness. When the thickness of a bed is at about 1/8 of the dominant wavelength, constructive interference of those reflections from the top and the bottom of the bed builds up the amplitude to large values. Applying all these concepts on the current study, a seismic wave of a velocity of 1400ft/sec (427 m/sec.) and a dominant frequency of 70Hz will have an average wavelength of 20 ft (6 m). One fourth of this wavelength, 5 ft (1.5 m), will be the minimum thickness to be resolved on the current shear wave reflection data. For that reason, we relied on the amplitude change or the tuning effect to image the existing thin coal layers less than 5 ft (1.5 m) thick. More research concerning the maximum depth of penetration and the minimum bed thickness resolution through the use of various vibration point sources may be warranted.

The location of an igneous intrusion was predicted through SH-wave analysis on line 482000 at 1740 feet (Appendix 10). A second igneous intrusion may be present on this profile at 120 feet but this also may be related to nosie. Unfortunately, the location of these dikes and the inability to gain land owner permission to drill precluded any confirmation of the igneous material through core drilling.

The data compiled for this research will be incorporated into a Illinois Geologic Quadrangle (IGQ) map of the Harrisburg 7.5 minute quadrangle to be published in late 2007 or early 2008. Further studies concerning the tectonics, stratigraphy, and oil and gas potential of this region are being conducted and will be included in the report that accompanies the IGQ.

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