GEOPHYSICAL VOID DETECTION DEMONSTRATIONS RIOLA MINE COMPLEX, BLACK BEAUTY COAL COMPANY, NEAR GEORGETOWN, VERMILION COUNTY, ILLINOIS

Contract Number B2532535
Project Number 5006

June 2006

Prepared For:

US Department of Labor
Mine Safety and Health Administration

Prepared by:
ZAPATAENGINEERING, P.A., BLACKHAWK DIVISION
301 Commercial Road, Suite B
Golden, Colorado 80401
(303) 278-8700

Signed________________________________
Kanaan Hanna
Project Manager / Senior Engineer

Signed________________________________
James Hild
Manager / Senior Geophysicist

AUTHORS

Kanaan Hanna	Project Manager / Senior Engineer
Bart Hoekstra	Senior Geophysicist
James Pfeiffer	Senior Geophysicist
Brandy Uphouse	Geologist

COOPERATIVE MINE

Black Beauty Coal Company

ASSOCIATED CONSULTANTS AND SUBCONTRACTORS

Bay Geophysical – Formerly, A Division of Blackhawk
COLOG Borehole Geophysical Services
Magnum Drilling Services, Inc.
Sterling Seismic Services, LTD
Summit Peak Technologies, LLC
Walker Marine Geophysical Company
Workhorse Technologies, LLC

TABLE OF CONTENTS

TABLE

FIGURES

PICTURES

APPENDICES

Acronyms and Abbreviations

2-D	Two Dimensional
3-D	Three Dimensional
AMP	Ampere
ASTM	American Society for Testing and Materials
AVO	Amplitude vs. Offset
Bay	Bay Geophysical – Formerly, A Division of Blackhawk
BGS	Below Ground Surface
BBCC	Black Beauty Coal Company
Blackhawk	Blackhawk GeoServices / ZAPATAENGINEERING P.A., Blackhawk Division
CATscan	Computer Aided Tomography Scan
CDP	Common Depth Point
cm	Centimeter
Conf	Confirmation
dB	Decibel
DC	Direct Current
Dpi	Dots Per Inch
E-Logs	Electrical (Lithological) Logs
Ft	Feet
HRPW	High Resolution Compressional P-wave (3-D)
HRS	High Resolution Seismic
HRSW	High Resolution S-wave (3-D)
Hz	Hertz
In	Inches
ISGS	Illinois State Geological Survey
kHz	Kilohertz
lbs	Pounds
m	Meter
m^3	Cubic Meter
MicroVib	Micro Vibrator
mm	Millimeter
ms	Millisecond
MSHA	Mine Safety and Health Administration
mV	MilliVolt
n/a	Non Applicable
Ωm	Ohm-Meter
PSI	Pounds Per Square Inch
P-wave	Primary or Compressional Wave
PVC	Polyvinyl Chloride
QC	Quality Control
RFP	Request for Proposal
RMC	Riola Mine Complex
RMS	Root of the Mean Square

RVSP	Reverse Vertical Seismic Profiling
SOW	Statement of Work
SP	Spontaneous Potential
SPR	Single Point Resistance
Sterling	Sterling Seismic Services, LTD
S-wave	Shear Wave
USGS	United States Geological Survey
VSP	Vertical Seismic Profiling
XHT	Crosshole Tomography

REPORT ORGANIZATION

The *Executive Summary* provides a synopsis of the geophysical demonstration, results, conclusions, and recommendations contained within this report.

Section One:	Provides a summary of the problem statement, the rationale for the demonstrations, program objectives, and planning, and overview of the geophysical demonstrations.
Section Two:	Provides a description of the approach used in selecting the mine and test-site location. The regional geologic setting and site conditions encountered in the course of the geophysical investigations are also discussed.
Section Three:	Presents the geophysical methods used for the demonstration investigations.
Section Four:	Provides details on the methodology used for the geophysical investigations at the Riola Mine Complex. This includes information on the geophysical methods: high-resolution seismic, crosshole tomography and guided waves methods, and reverse vertical seismic profiling methods. In addition, this section includes geophysical logging and borehole deviation surveys.
Section Five:	Details information on the void confirmations conducted on select boreholes within the investigational area. This section provides the rationale for the void confirmation plan, conventional drilling, borehole deviation, and sonar mapping investigations.
Section Six:	Provides an evaluation of the geophysical technologies used during the investigation. This incorporates results, criteria, and inclusive information on the performance of the following technologies: high resolution compressional P-wave (3-D), high resolution S-wave (3-D), crosshole tomography, guided waves method, reverse vertical seismic profiling, and sonar borehole mapping.
Section Seven:	This section provides a comprehensive discussion of the conclusions and recommendations extrapolated by the results of the geophysical investigation derived for this report.
Section Eight:	The *Certification and Disclaimer* states that all geophysical data analysis, interpretations, conclusions, and recommendations in this document have been prepared under the supervision of and reviewed by Blackhawk, a Division of ZAPATA ENGINEERING, Senior Geophysicists, and Engineers.

Section Nine:	The *Acknowledgement* thanks personnel associated with the compilation of this report.
Section Ten:	The *References* are a listing of documented bibliographies cited within this report.
Section Eleven	The *Glossary* provides a listing of key terms used within this report.
Appendix A:	*Appendix A* contains all tomographic plots generated during this investigation.
Appendix B:	*Appendix B* contains all seismic continuity plots generated during this investigation.
Appendix C:	*Appendix C* contains all geophysical logs generated during this investigation.
Appendix D:	*Appendix D* contains all drill logs generated during this investigation.
Appendix E:	*Appendix E* contains all sonar logs generated during this investigation.
Appendix F:	*Appendix F* contains all daily field logs generated during this investigation.

EXECUTIVE SUMMARY

ZAPATAENGINEERING P.A., Blackhawk Division (Blackhawk) was contracted by the U.S. Department of Labor's Mine Safety and Health Administration (MSHA) to conduct surface and borehole geophysical investigations to locate air- and/or water-filled voids associated with old mine works. The investigations were in support of MSHA's Geophysical Void Detection Demonstrations Program. The main purpose of this program was to advance the current state-of-the-practice geophysical technologies for detecting underground mine voids that could potentially pose health and safety hazards to miners approaching old/abandoned mine works.

As stated by former Assistant Secretary of Labor David D. Lauriski in a news release published in connection with this contract award in Golden, Colorado in October 2004, "The incident at Quecreek shows that the danger of mining coal in the vicinity of poorly mapped, abandoned, and inaccessible coal mines is not uncommon." (Kulczewski, 2004). This incident, along with many other inadvertent excavations into the flooded old works, illustrates the importance of accurately knowing the location of underground works adjacent to, above or below an active mine. Current practice using drilling exploration is expensive, time consuming, and can easily miss targets such as mine entries.

Blackhawk and its consultant team conducted field demonstrations at the known abandoned room-and-pillar underground coal mine adjacent to the active Riola Mine Complex (RMC), owned by Black Beauty Coal Company (BBCC) in Southern Vermilion County in eastern Illinois. The abandoned mine was within the Herrin #6 coal seam averaging six ft in thickness at a depth of approximately 235 ft. The field demonstrations were implemented using three geophysical imaging technologies: 1) surface high-resolution seismic reflection method using both compressional (and primary) and shear wave collected with 3-D techniques; 2) crosshole tomography and guided waves; and 3) reverse vertical seismic profiling methods. In addition, sonar-mapping surveys were implemented to complement the void drilling confirmation plan. The primary objectives of this project were to:

- Demonstrate the effectiveness of the selected geophysical methods to accurately and economically detect the location of the old underground workings;
- Identify the location of the old mine openings/entries, pillars, and anomalous conditions;
- Apply geophysical logging of boreholes to improve the understanding of subsurface conditions and to enhance geophysical data evaluation and interpretation;
- Confirm the locations and boundaries of the imaged anomalies interpreted as voids through vertical drillings, borehole deviation surveys and borehole sonar mapping; and
- Evaluate the performance of the selected methods in determining: a) the boundary of the old mine works; b) vertical and/or lateral extent of voids; and c) void content (air-filled, water-filled, gob-filled, or collapsed structure).

Based on the results and analyses obtained from the geophysical and void confirmation investigations, project engineers and geophysicists developed ranking factors to evaluate the performance of the geophysical technologies deployed at the test site. The performance evaluation was based on seven criteria. Each geophysical method was ranked from excellent to poor based on how well it met each criterion. The cost of each method was ranked from very high to low. These rankings are summarized in the table below.

TABLE EXECUTIVE SUMMARY - 1 PERFORMANCE EVALUATION OF GEOPHYSICAL METHODS

Method / Criterion	HRPW	HRSW	XHT	Guided Wave	RVSP	Sonar Mapping*
Ability to Locate Voids	Fair	Fair	Poor	Poor	Good	n/a
Resolution	Poor	Poor	Poor	Poor	Very Good	Excellent
Depth of Investigation	Good	Poor	Good	Good	Good	Very Good
Anticipated Repeatability	Good	Fair	Good	Fair	Good	Very Good
Robustness Under Various Geologic/Surface Conditions	Fair	Poor	Fair	Fair	Good	Very Good
Cost	High	Very High	Medium	Low	Medium	Medium
Void Content	Poor	Good	Poor	Poor	Good	Good
** Sonar mapping can only be used in a borehole that has intersected a mine void.*						

High Resolution Primary Wave 3-D (HRPW) – The high-resolution primary wave method obtained clear reflections from the Herrin #6 coal seam, and showed consistent data quality throughout the survey. High-amplitude anomalies corresponded to the locations of the old mine works, but also appeared to correlate to rolls in the coal seam roof associated with thinning of the coal seam. This technique only partially met the objective of detecting voids in the Herrin #6 coal seam at the site.

High Resolution Shear Wave 3-D (HRSW) – The high-resolution shear wave method was able to obtain some reflections from the Danville #7 coal horizon overlying the Herrin #6 coal seam. However, little information was obtained form the Herrin #6 coal horizon due to the reflection coefficient of the Danville #7coal that limited the transmission of the S-wave seismic energy below it. Therefore, only limited information could be obtained on the old mine works located in the Herrin #6 coal seam. This technique partially met the objective of detecting voids in the Herrin #6 coal seam at this site.

Crosshole Tomography (XHT) – Multiple XHT panels were acquired between boreholes to produce 2-D and 3-D tomograms. XHT panels were acquired across areas that were believed to contain old mine works and those thought to contain only solid coal within the Herrin #6 coal seam. The tomograms, in both cases, showed similar velocity distributions indicating that the voids were not detected, probably due to high-velocity layers above and below the coal seam and potentially poor velocity contrast between the coal and the water-filled void. This method did not meet the objective of detecting voids in the Herrin #6 coal seam at this site.

Guided Waves – As a low cost addition to the XHT survey, a guided waves seismic continuity analysis was performed. This method is only capable of determining whether a discontinuity exists in the coal seam between two boreholes and has the lowest resolution of all the methods tested. The results from the guided waves analysis for zones with and without old mine works appeared similar. Interpretation of the results proved ambiguous due to a number of mitigating factors, including the presence of water. This method did not meet the objective of detecting voids in the Herrin #6 coal seam at this site.

Reverse Vertical Seismic Profiling (RVSP) – The RVSP method was not in the original scope of this study. However, useable RVSP data could be extracted from a subset of the XHT data. We therefore chose to process the data subset using this method to enhance our geophysical interpretation. In all the RVSP sections that were processed, the boundaries of the mains and submains were detected within the Herrin #6 coal seam. In some cases, the method was able to map individual entries within the mains. The positional error of the RVSP interpretations was on the order of three to five ft. This is notably precise considering the depth of the target horizon is 235 ft and a field geometry that was not optimal for RVSP processing. This method proved to be practical for delineating mine voids at this site and is anticipated to be effective in other areas with or without good historical information. However, it is recommended that additional tests be performed in other topographic, geologic, and cultural settings to evaluate the effectiveness of the RVSP method in various conditions.

Sonar Mapping – Sonar mapping was added under a contract modification to complement the confirmation drilling by mapping the extents of the intersected void adjacent to the borehole. The positional error of this method was on the order of two to six inches when mapping the ribs of the entries. Sonar mapping can only work in water-filled voids; however, alternative instrumentation can work in air-filled voids using a laser-mapping tool. Preliminary information is available in real time, so that decisions can be made regarding new borehole locations while the equipment is in the field.

In summary, the geophysical demonstrations at the abandoned coal mine adjacent to the active RMC have shown the effectiveness of the RVSP as the most viable method to accurately and economically detect the location of old mine works. The RVSP method can be complemented by the use of borehole sonar (or laser) mapping methods to very accurately determine the vertical and lateral extents of the mine voids.

1.0 INTRODUCTION

Blackhawk was contracted by the U.S. Department of Labor's Mine Safety and Health Administration (MSHA) to conduct surface and borehole geophysical investigations to locate air and/or water-filled voids associated with old mine works. The investigation was in support of MSHA's Geophysical Void Detection Demonstrations Program.

The geophysical field investigations, under an Agreement between Blackhawk and the BBCC, were performed at the RMC near Georgetown, in Southern Vermilion County in eastern Illinois. The known adjacent abandoned room-and-pillar mine, formerly the U.S. Steel Mine (1917-1947), was selected for the demonstrations. The study area was located on private property just south of Georgetown Road. The Herrin #6 coal seam was the target zone. The coal seam in this area averages six ft thick at a depth of approximately 235 ft. The old mine works have been identified as being potentially filled with air, water, gob, or collapsed structure.

1.1 PROBLEM DESCRIPTION

Old mine works present major health and safety hazards to our nation's miners. The greatest concern to the Federal and State regulators is the ability to know the location of voids in old/abandoned mines. Since 1995, the MSHA records have indicated over 100 incidents where active mines have inadvertently cut into old mine works creating unexpected hazardous conditions. These health and safety hazards have focused attention on the need for practical geophysical methods to more accurately detect old/abandoned mine works and voids, and thereby reduce the risk of inundation hazards.

As documented in the original Request for Proposal (RFP) # MSHA J53R1011, current mining regulations require that a mine owner/operator accurately identify the location of any adjacent old/abandoned mine works within 1000 ft of the projected works for the active mine. When an active mine approaches within 200 ft of a mine with unknown conditions, the mine operator is required to perform exploratory drilling in advance of mine development. Investigation of recent inundation incidents have indicated that maps of old works have been in error by as much as 3000 ft. Because of the presence of unknown mine works, advanced imaging technologies need to be demonstrated as commercially viable and fiscally practical to detect the location and define the extent of mine voids in advance of mining operations.

1.2 RATIONALE FOR THE DEMONSTRATION

Two major events have focused national attention on the need for mapping underground mine works. These are 1) the failure of the Martin County Coal Corporation tailings impoundment near Inez, Kentucky on October 11, 2000; and, 2) the July 24, 2002 Quecreek Mine inundation that trapped nine miners for 77 hours in Somerset County, Pennsylvania. In both cases, unexpected conditions related to abandoned mines were the sources of the accidents. In the case of the Inez, Kentucky tailings impoundment failure, the overburden between an abandoned mine and the base of a slurry impoundment was too thin and the slurry broke into the mine. In the case of the Quecreek Mine flood, miners excavated into the flooded works of the abandoned Saxman Mine, which they thought was hundreds of feet away. Prior to the inundation, planners of the Quecreek #1 mine believed that their active mine was at least 300 ft from the abandoned mine.

As stated by the former Assistant Secretary of Labor David D. Lauriski in a news release published in connection with this contract award in Golden, Colorado in October 2004, "The incident at Quecreek shows that the danger of mining coal in the vicinity of poorly mapped, abandoned, and inaccessible coal mines is not uncommon". (Kulczewski, 2004). These incidents illustrate the importance of accurately knowing the location of underground works adjacent to, above, or below an active mine. Conventional drilling exploration can easily miss targets such as mine entries. These mined-out areas may be unintentionally penetrated if the necessary information pertaining to their location is inaccurate or unavailable to mine operators.

Many traditional geophysical techniques (e.g., seismic, electrical, electromagnetic) have been around for years and the physics of detecting underground mines has not changed. What has changed is the ability of the geophysicist to gather data in a rapid fashion so that data redundancy and better coverage can be obtained. Increased instrument sensitivity and onboard processing capability have also greatly improved in recent years. New computers and software have revolutionized the means by which data are acquired, stored, processed, and presented, all of which results in improved geophysical interpretations.

Therefore, there is a need for high-resolution geophysical imaging technologies to be implemented both from the surface and in boreholes to delineate the location and extent of old mine works as is described herein.

1.3 PROGRAM OBJECTIVES

The main purpose of the MSHA program as stated in the original RFP was to:

- Conduct demonstrations for advancing the current state-of-the-practice geophysical technologies for detecting underground mine voids.

- Demonstrate the capabilities of selected geophysical technologies that can be confidently and practically applied to void detection in order to eliminate or minimize the risk of inundation hazards to miners approaching old / abandoned mine works.

To meet program objectives, Blackhawk and its consultant team conducted field demonstrations at the known abandoned mine adjacent to the RMC – an active underground room-and-pillar mine - using three geophysical imaging technologies: 1) surface high-resolution seismic (HRS) reflection; 2) XHT and guided waves; and 3) RVSP methods. The overall objectives of this project were to:

- Demonstrate the effectiveness of the selected geophysical methods to accurately and economically detect the location of the old underground workings;
- Identify the location of the old mine openings/entries, pillars, and anomalous conditions;
- Apply geophysical logging of boreholes to improve the understanding of subsurface conditions and to enhance geophysical data evaluation and interpretation;
- Confirm the location and boundary of the imaged anomalies interpreted as voids through vertical drillings, borehole deviation surveys, and borehole sonar mapping; and
- Evaluate the performance of the selected methods in determining: a) the boundary of the old mine works; b) vertical and/or lateral extent of void; c) void content (air-filled, water-filled, gob-filled, or collapsed structure).

1.4 GEOPHYSICAL OVERVIEW

Original Scope of Work

Blackhawk, in coordination with its consultants and subcontractor team as outlined in the original Scope of Work (SOW) dated November 14, 2003, carried out the geophysical field demonstrations and related activities at the selected abandoned mine. The program plan was designed to demonstrate HRS reflection as the primary technology, and XHT and guided wave as the secondary technology. The selected two geophysical methods were implemented at the same site to provide a more comprehensive interpretation. The rationale for the implementation of both of these surface and borehole techniques was that the combination of these techniques would provide the basis for the performance evaluation in order to determine the success and/or limitations for detecting voids as defined in the above objectives.

The HRS and the XHT methods were selected for this demonstration because of their proven ability for locating and imaging subsurface voids with each method having different advantages and limitations. The XHT is less expensive and faster for acquiring data than the HRS method. In addition, the data obtained while drilling the borehole is very useful for "ground truthing". Verification of anomalous conditions and interpretation of voids can be refined and defined in greater detail with the XHT method. The HRS method is more expensive and time-consuming in the field, but it is applicable to a wide range of target depths and geologic conditions and provides greater coverage without the need for boreholes.

For these demonstrations, the justification for choosing surface and borehole geophysical methods over in-mine geophysical methods is as follows:

- On the surface, there are no geometry issues with survey design other than cultural features (e.g., roads, buildings, etc.).
- Survey design is much less complicated. Additionally, because mines (coal mines in particular) have considerably different geologic and surface conditions across this nation and worldwide, demonstrating surface technologies that are less limited by in-seam or underground conditions (including intrinsically safe issues) will have a broader application for MSHA and reducing the safety hazards of encountering old/abandoned mine works.

In conjunction with the geophysical investigations, a conventional vertical drilling program was implemented to confirm the location and lateral extent of the underground air, water, gob, or collapsed structure-filled voids as detected and imaged by the geophysical technologies.

Modifications to the SOW

Contract Modifications: Under contract modification dated October 4, 2005, the name of Blackhawk GeoServices was changed to Blackhawk – A Division of ZAPATA ENGINEERING per the Novation Agreement.

In addition, the sonar mapping and borehole deviation surveys were performed on four confirmation boreholes to:

- Optimize and focus the drilling program;
- Improve the understanding of the void height determined from drilling;
- Determine void locations, geometries, and content; and
- Enhance the geophysical data interpretation to better define the boundary between the old mine works and solid coal.

Additional work performed at no cost to the project: Blackhawk determined that geophysical borehole logging surveys and reverse vertical seismic profiling (RVSP) processing would be critical for achieving the objectives of this program.

Geophysical borehole logging was conducted on the boreholes during the XHT survey to: 1) improve the understanding of the subsurface strata; 2) delineate the geology along the depth of the 300 ft borehole; and 3) augment the geophysical data processing, analysis, and interpretation. The borehole logging involved the following methods:

- Lithological Logs: This log provided the resistivity and natural gamma count to determine the stratigraphic sequences located within a borehole. This survey was conducted on all six of the drilled boreholes. This information was also used for comparison with and validation of the drilling logs.
- Full Waveform Sonic Logging: This log provided primary, or compressional wave (P-wave) velocity [and possible shear wave (S-wave) velocity] and reflectivity, which is used to produce synthetic seismograms that are used for the seismic reflection interpretation. This test was conducted on two boreholes.
- Check Shot: This method was conducted using a sledgehammer as a seismic source and a three-component borehole geophone as the receiver to determine the velocities of the P and S-waves. The results were used for interpretation of the surface HRS reflection data. This test was performed in one borehole.
- Deviation Log: This test provided the deviation of the borehole from vertical for use in crosshole tomography geometry. The borehole deviation survey was performed in all six boreholes.

RVSP processing was conducted on a portion of the data acquired for the XHT survey and used a novel technique developed by Sterling Seismic Services, LTD (Sterling), a Blackhawk consultant, to process the data. The purpose of this additional work was to demonstrate the capabilities of leading-edge processing methods to better define the boundaries of the old mine works using a subset of the XHT data set that had already been acquired.

The advantages of the RVSP method over other methods used in this demonstration include:

- Improved frequency content over surface seismic methods;
- Reduction of survey costs compared with surface seismic methods because of lower requirements for the number of field crew, less expensive seismic sources, and faster field data acquisition; and
- Reduction in the number of required boreholes compared to other borehole geophysical methods.

1.5 PROGRAM PLANNING

Planning required for this program involved a substantial level of effort in organizing, scheduling, and executing the project tasks to ensure the success of this void detection demonstration program. Blackhawk, as the prime contractor for MSHA, assembled a team of highly qualified professional geophysicists, engineers, geologists, and programmers to perform this work. The team included industry leaders for each deployed geophysical technology. Table 1-1 shows the overall program organization and areas of responsibility for the execution of project tasks and related activities.

The execution of the field demonstrations for each of the selected geophysical technologies was carried out at different times between November 2004 and October 2005, as shown in Table 1-2.

TABLE 1-1 OVERALL PROGRAM ORGANIZATION AND AREAS OF RESPONSIBILITIES

Project Tasks and Related Activities		Blackhawk - A Division of ZAPATAENGINEERING	Bay Geophysical - Formerly A Division of Blackhawk	Black Beauty Coal Company	COLOG Borehole Geophysical Services	Magnum Drilling Services, Inc.	Sterling Seismic Services, LTD	Walker Marine Geophysical Company	Workhorse Technologies, LLC	Summit Peak Technologies, LLC
Program Management and Coordination	Management	X								
	Coordination	X								
Land Surveying	Re-Establish Old Mine Coordinates			X						
	HRS Grid Coordinates			X						
	XHT Borehole Coordinates			X						
	Confirmation Borehole Coordinates			X						
HRS Seismic Reflection	HRS Seismic Reflection		X							
XHT	Borehole Drilling					X				
	Geophysical Borehole Logging and Check-Shot Velocity Survey	X								
	XHT and Guided Waves / RVSP	X						X		
Void Confirmation	Borehole Drilling	X				X				
	Borehole Deviation Surveys	X			X					
	Borehole Sonar Mapping	X							X	
Processing and Interpretation	HRS	X	X				X			
	RVSP	X					X			
	XHT	X								X
	Borehole Logging	X								
Report	Draft Report	X	X						X	
	Final Report Integration	X								

TABLE 1-2 OVERALL FIELD PROJECT SCHEDULE

Task	Date Conducted
On-site Kick-off Meeting	October 28, 2004
HRS Reflection	November 12 – November 23, 2004 November 29 – December 3, 2004
XHT, Guided Wave, and RVSP	April 17 – April 30, 2005
Void Confirmation	October 3 – October 7, 2005

2.0 SITE DESCRIPTION

2.1 MINE SELECTION

The RMC, which is an active room-and-pillar coal mine owned by BBCC with a known adjacent abandoned mine, was selected as the test site for the geophysical demonstrations. BBCC made all reasonable efforts to: provide access and land permitting to the mine surface; obtain a suitable surface test site; provide special field scheduling; provide surveying and re-establishment of old mine coordinates; provide on-site technical expertise, and accommodations necessary to conduct the field demonstrations. BBCC also provided information on the mine, local geologic setting, and geologic logs. In addition, the BBCC provided digitized old mine maps along with all available information on the known boundaries of the adjacent abandoned mine.

The adjacent abandoned mine, the former U.S. Steel Mine (1917-1947), was selected for the field investigations. The mine is located near Georgetown in Vermilion County, Illinois in Township 17N, Range 12W, Section 3, just south of Georgetown Road about one-half mile east of Catlin Indianola Road, as shown on Figure 2-1.

FIGURE 2-1 MINE TEST SITE LOCATION

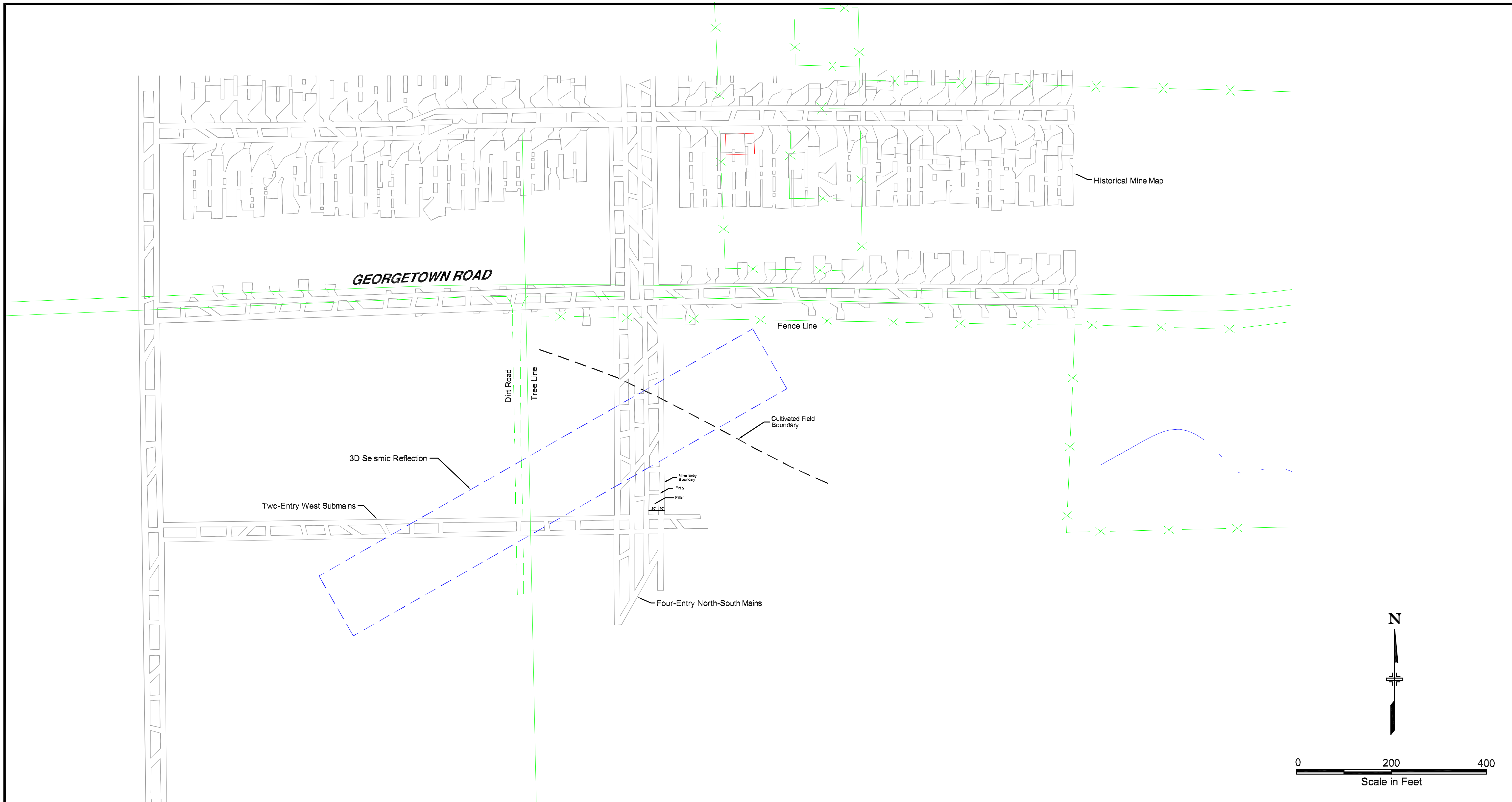
A room-and-pillar method was used to mine the Herrin #6 coal seam, averaging six ft thick at depth of approximately 235 ft. Based on the available historical mine maps, the mine plan consisted of four-entry mains oriented north-south branching to two-entry submains oriented east-west and production rooms. The entries are 10 ft wide, separated by pillars that were 20 ft wide and 40 to 60 ft long. Based on BBCC's exploratory drilling performed previously near the test site, the void conditions of the old mine works were identified as being air-filled, water-filled, and collapsed structure. Since the location of these conditions were outside the test area and can vary considerably from one location to another, no attempts were made to mark their locations on the historical mine map. However, this information was considered during the planning phase of the drilling confirmation program and sonar mapping survey.

2.2 TEST SITE LOCATION

A kick-off project meeting was held on October 28, 2004 at the RMC in Vermilion Grove, Illinois to discuss program planning and site selection. The meeting was comprised of representatives from MSHA, Blackhawk, Bay Geophysical – Formerly, A Division of Blackhawk (Bay), and the BBCC. November 12, 2004 was set as a tentative date for the commencement of the fieldwork.

During this meeting, two potential test sites and an optimal geophysical grid layout were evaluated. One site was located north of Georgetown Road and had extensive mining activities and therefore the multiple boundaries between mined and un-mined areas would have complicated the performance of the geophysical investigations. The other site was located just south of Georgetown Road with no mining activities except the mains and submains entry system oriented north-south and east-west, respectively. This site was preferred because it would allow the geophysical survey to be laid out diagonally across the entries so that the survey grid would overlay both mined and un-mined coal areas. Because this site contains a simplified mine layout with only mains and submains entry, it would allow better performance evaluation of the geophysical methods.

Following the kick-off meeting, the team visited both sites and confirmed that the test site south of Georgetown Road would be used for the field investigations. Figure 2-2 shows the location of the survey grid (150 ft by 1050 ft) outlined with respect to the historical mine map showing the location of the entries system just south of Georgetown Road, and approximately 3.5 miles from Georgetown.



Explanation

3-D Seismic Reflection Survey Boundary

BLACKHAWK
A DIVISION OF ZAPATAENGINEERING

301 Commercial Road, Suite B
Golden, Colorado 80401

Phone: (303) 278-8700
Fax: (303) 278-0789
Web: www.blackhawkgeo.com

US Department of Labor
Mine Safety and Health Administration

General Location Map of the HRS Survey Grid

Riola Mine Complex
Vermilion County, Illinois

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5006	June, 2006	HJV	KH	1" = 200'	2-2

2.3 GEOLOGIC SETTING

The test site is located in the east-central subdivision of the Illinois coalfield. The primary geologic feature of interest within the active underground RMC mine is the Herrin #6 (Herrin) coal seam. This seam is one of the most important strata of coal located near the top of the Pennsylvanian-Period Carbondale Formation. Cyclic changes in sedimentary strata, both above and below the coal seam, are common and show multiple transgressions and regressions from terrestrial (land) depositional environments to more transitional deltaic, fluvial, and swampy depositional environments (marked by the formation of the coal) to marine depositional environments (marked by the limestone and shale deposits). (Wycander, & Monroe, 2000 p. 278). The seam is persistent throughout a large part of the area, with an average thickness varying from six ft to greater than eight ft. The depth and thickness of the coal seams can vary due to such geological features as anticlines, synclines, and monoclines throughout the Illinois Basin.

The stratigraphy in the test area (within a drilling depth of 320 ft) is comprised of sedimentary rocks consisting primarily of shales, sandstones, and siltstones overlain by unconsolidated glacial sand, silt, clay, and gravel deposits. The coal seams in this area consist of the upper Illinois Danville #7 coal, lower Illinois Herrin #6 coal, and the underlying Illinois Springfield #5 coal. The Herrin #6 coal seam was the target zone. The target old mine works within the Herrin #6 coal seam at the investigational site has an average thickness of six ft at a depth of approximately 235 ft. A stratigraphic representation of the lithology of the subsurface obtained from the drill logs is shown in Table 2-1. Estimates of thicknesses and depths of strata overlying and underlying the Herrin #6 coal seam are listed in the table in descending order from the ground surface.

2.4 SITE CONDITIONS

The test site was located on private agriculture property. In general, the terrain is open and relatively flat farmland. The test site is accessed via Georgetown Road to the north and a dirt road to the west. The site was flanked to the west by trees, wire fence, and power lines. Weather conditions during the fieldwork were typically cold with storms and heavy rain. Related to sudden changes in the climatic conditions and the plowing of a portion of the test area, data acquisition was delayed due to mud and excessively wet conditions. In addition, nearby in-mine activities and movement of haul trucks on Georgetown Road were primary sources of ambient noise, which had a measurable impact on data quality. Table 2-2 summarizes the site and climatic conditions and the impacts they had on the investigation. Picture 2-1 is representative of site conditions during data collection. Picture 2-2 illustrates road activities.

TABLE 2-1 GENERALIZED STRATIGRAPHY AT THE TEST SITE

Subsurface Strata Above and Below the Herrin Coal Seam #6			Thickness of Material in Ft
Glacial Material	Overburden Material 233 ft	Unconsolidated Clay with Gravel Tan or Buff	30.00
		Unconsolidated Silt with Gravel Red or Brown	
		Unconsolidated Silt with Gravel Med Gray	
		Unconsolidated Sand with Gravel - Large	
		Unconsolidated Silt with Gravel Med Gray	
		Sandstone - Med. Gray	110.00
		Sandy Shale - Med Gray	
		Shale - Dark Gray	
Danville		**Coal Seam # 7 (No Mining ~ 140 Ft Deep)**	**3.70**
		Sandy Claystone - Med Gray	89.30
		Sandstone- Med Gray	
		Limestone	
		Sandstone- Med Gray	
		Sandstone, Limey Med Gray with Nodules	
		Sandy Shale - Med Gray	
		Shale - Med Gray with Coal Streaks	
Herrin		**Coal Seam # 6 (Target Zone ~ 233-235 Ft Deep)**	**6.80**
	Underlying Material 80.2 ft	Limey Sandy Claystone	13.20
		Sandy Claystone - Med Gray	
		Limey Claystone - Med Gray - Nodules	
		Black Shale with Coal Streaks	
Springfield		**Coal Seam # 5 (No Mining ~ 253 Ft Deep)**	**0.80**
		Limey Claystone - Med Gray - Nodules	66.20
		Sandy Shale - Med Gray	
		Shale - Dark Gray	
		Black Limey Shale	
		Sandy Shale - Med Gray	
		Total Drill Depth	**320.00**

PICTURE 2-1 DATA COLLECTION (DIGGING TO IMPROVE COUPLING OF GEOPHONES AFTER A SECTION OF THE SURVEY GRID WAS PLOWED)

PICTURE 2-2 COAL HAUL TRUCK DRIVING ON GEORGETOWN ROAD

TABLE 2-2 SITE AND CLIMATIC CONDITIONS FOR THE GEOPHYSICAL DEMONSTRATIONS

<table>
<tr><th>Beginning Date</th><th>Ending Date</th><th>Field Methods Employed</th><th>Site Conditions</th><th>Climatic Conditions</th><th>Effects of Site / Climatic Conditions on Investigation</th></tr>
<tr><td>11/12/2004</td><td>12/3/2004</td><td>3-D High Resolution Seismic (HRS) Reflection Survey</td><td>One-third of the survey site was plowed</td><td>Heavy rains</td><td>Plowing one-third of the grid area by the property owner along with rain and mud/ wet conditions made data acquisition more difficult resulting in delays.</td></tr>
<tr><td rowspan="3">4/17/2005</td><td rowspan="3">4/30/2005</td><td>Borehole Drilling</td><td rowspan="3">One-third of the survey site was seeded and fertilized during the survey. Boreholes NS #4, NS #5, NS #6, and EW #2 had to be relocated</td><td rowspan="3">Periodic heavy rains and bad storm weather conditions</td><td rowspan="3">Recent and ongoing plowing, seeding, and fertilizing made data acquisition difficult. Moving boreholes from their original positions to accommodate the property owner caused changes in the planned survey geometry including the spacing between boreholes. The stormy conditions caused delays in data acquisition and the field crews were unable to keep pace with the drilling activities resulting in re-drilling and/or flushing of most boreholes. The drilling crew was maintained on stand-by to ensure that the boreholes were accessible for the XHT surveys.</td></tr>
<tr><td>Geophysical borehole logging / Check-shot Velocity survey / and Borehole deviation survey</td></tr>
<tr><td>XHT/guided wave surveys</td></tr>
<tr><td>10/3/2005</td><td>10/7/2005</td><td>Void drilling confirmation, borehole deviation surveys, and sonar mapping</td><td>Good</td><td>Good weather</td><td>No field delays due to site or climate conditions.</td></tr>
</table>

3.0 GEOPHYSICAL METHODS

To meet the program objectives, Blackhawk, its consultants, and the subcontractor team conducted two field demonstrations at the selected abandoned mine, using three geophysical imaging technologies: 1) surface high-resolution seismic (HRS) reflection; 2) crosshole tomography (XHT) and guided waves; and 3) reverse vertical seismic profiling (RVSP) methods. The program plan was designed to demonstrate HRS reflection as the primary technology, and XHT and guided waves as the secondary technology. As defined in the original RFP, the primary and secondary geophysical technologies referred to the selected methods that yield the most successful and satisfactory results, respectfully. It should be noted that in the XHT survey, data from the surface geophones were also obtained to enhance the XHT data quality and interpretation. As discussed in *Section 1 Introduction,* since the geophysical survey plan did not include RVSP data acquisition, RVSP processing was applied to a subset of the XHT data set (surface geophones and borehole source) to evaluate the ability of the RVSP method to better define the boundaries of the old mine works. It should be emphasized that the RVSP is usually acquired as a stand-alone survey. Determination of the boundaries was critical for selecting the appropriate locations for drilling and sonar mapping to confirm the presence of the imaged voids. The geophysical borehole logging surveys were also conducted to improve the current understanding of the subsurface strata and to enhance the geophysical data evaluation and interpretation.

The selected geophysical methods and related tasks were all implemented at the same survey site to provide a more comprehensive interpretation. The rationale for the implementation of these surface and borehole techniques at one site is that the combination of these techniques should provide the basis for the performance evaluation as discussed in *Section 6 Geophysical Technologies Performance Evaluation* in determining the advantages and limitations of these technologies to accurately and economically detect mine voids, thus achieving the program objectives.

The above selected methods have proven records for locating and imaging subsurface voids. Table 3-1 compares attributes of the surface and borehole geophysical methods used at the site.

The following sections provide a brief description of each method used, including the basic concept, theory, criteria applied, and limitations.

3.1 SEISMIC REFLECTION METHOD

Surface seismic reflection is the predominant subsurface mapping technique employed by the oil and gas exploration industry. The use of this reflection technique for other geophysical applications such as shallow engineering projects has been a relatively recent development, as the formerly high production costs and significant computing requirements were prohibitively expensive for relatively small projects. Advances in seismic instrumentation and PC-based processing software have decreased the costs and increased the range of applications for seismic methods in geotechnical and environmental projects.

TABLE 3-1 GEOPHYSICAL METHODS FEATURE COMPARISON

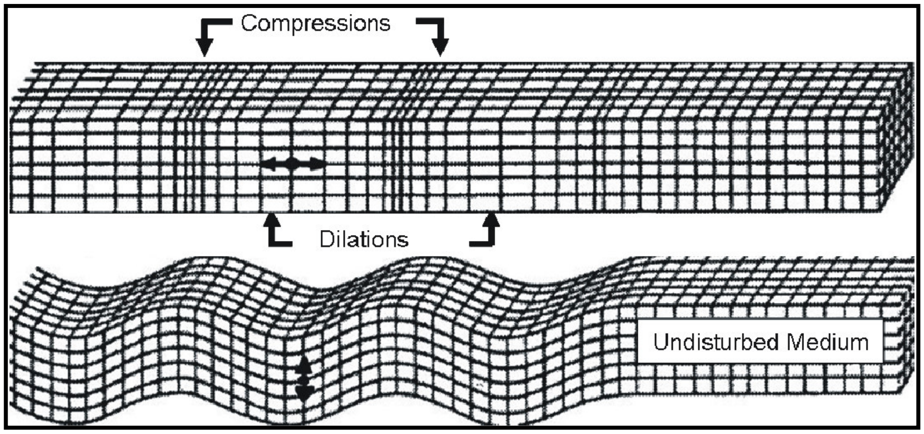
Features	HRS Reflection	XHT and Guided Waves	RVSP
Maximum Imaging Depth	1,000 - 2,000 ft	1,000 ft	1,000 – 2,000 ft
Void Content	Air, water, gob	Cannot differentiate void content	Air, water, gob
Repeatability of Test Results	Statistical sampling 36-72 individual measurements per subsurface point sample	Repeatable Strong air gun source may damage borehole wall and decrease repeatability	Statistical sampling 36-72 individual measurements per subsurface point sample
Safety Features	No explosives No impact devices	Special training for field operator using high-pressure compressive air lines with approx. 2000 psi	Special training for field operator using high-pressure compressive air lines with approx. 2000 psi
Reliability of Data Gathering	Qualified geophysicist/laborers	Qualified geophysicist/laborers	Qualified geophysicist/laborers
Ability to Interpret Data	Qualified geophysicist	Qualified geophysicist	Qualified geophysicist

3.1.1 Basic Concept

Seismic techniques are based on the type of source (or wave) used. For seismic reflection, a type of wave known as a *Body Wave* is utilized. Body waves are comprised of two types of waves. The first wave is a compressional or primary wave, commonly referred to as a P-wave; the second wave is a shear wave, commonly referred to as an S-wave. Both waves are illustrated below in Figure 3-1.

P-waves have the highest velocity of all seismic waves. The particle motion of P-waves is parallel with the direction of the wave. P-waves travel through all media that support seismic waves, including solids, gases, and liquids. Compressional waves in fluids, (e.g. water and air) are commonly referred to as acoustic waves (in air P-waves may be heard). The particle motion of an S-wave is perpendicular to the direction of wave propagation. S-waves travel slower than P-waves in solids; usually at about 60 percent of the speed of P-waves. These transverse waves

FIGURE 3-1 COMPRESSIONAL (P-WAVE) AND SHEAR WAVE (S-WAVE) DIRECTION OF PARTICLE MOTION



P-wave (Compressional)
Longitudinal particle motion

S-wave (Shear)
Transverse particle motion

Direction of Propagation

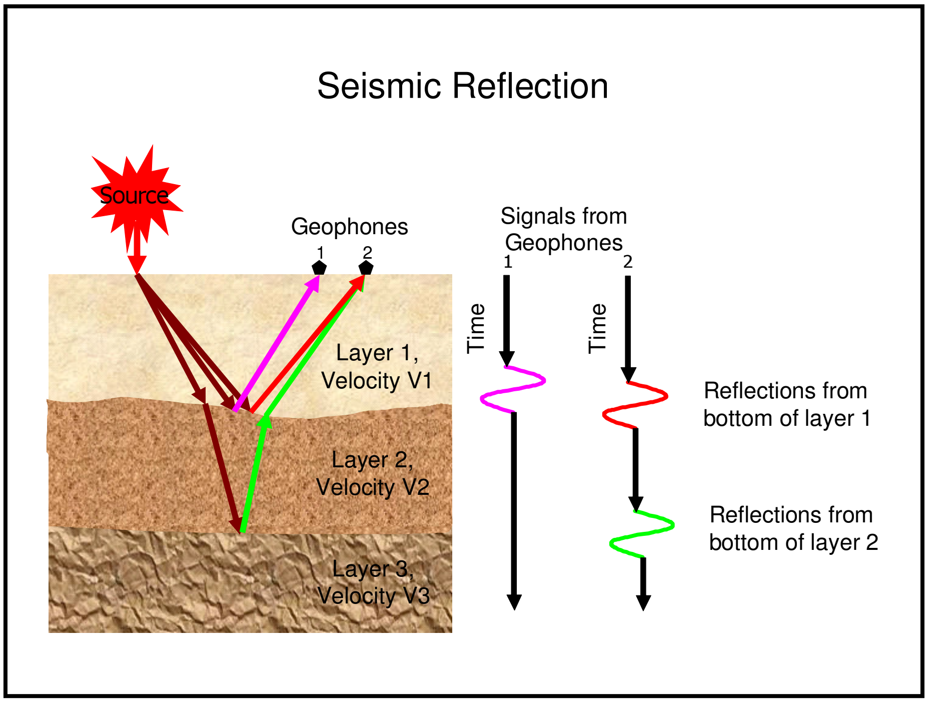
can only travel through materials that have shear strength. S-waves do not propagate through liquids and gases, since these materials have no shear strength.

Shear waves have been used for locating voids primarily for the following two reasons:

- First, for any given frequency, shear waves will have approximately 1/2 to 1/8 the wavelength of the corresponding P-waves. Shear waves often do not propagate as far through the earth as compressional waves. However, when offsets (distance from source to receiver) are short, because of their smaller wavelength, shear waves will provide approximately twice the resolution of that provided by P-waves because of their shorter wavelength.
- Second, S-waves cannot propagate through liquids or gases, as these materials have no shear strength. Thus, S-waves are much more sensitive to separations along discontinuities than their compressional counterparts, making them the more useful tool for finding and delineating fractures and voids.

In a seismic reflection survey, a source, a geophone, and a seismograph are needed to record the data. Seismic waves are generated at or near the ground surface by mechanical impact, explosive or vibratory sources. These seismic waves pass through the subsurface, are received by surface geophones, and are recorded on the seismograph. Seismic ray paths of interest in seismic reflection are illustrated on Figure 3-2. Seismic waves travel down to a subsurface interface that has impedance change (related to velocity and density) and are reflected back at the same angle to the geophones. Subsurface information in reflection surveys are derived by analyzing the travel times of the reflected waves between sources and receivers.

FIGURE 3-2 BASIC PRINCIPLES OF THE HRS REFLECTION TECHNIQUE



The unique advantages of data from the seismic reflection method are that it: 1) permits mapping many horizons, or layers, with each shot; 2) can map reflecting boundaries with spatial resolution five to 10 times greater than refraction; 3) does not require that velocity increase with depth (as is the case for refraction seismic), so that stratigraphy within alluvium and bedrock can be mapped.

3.1.2 Theory

The seismic reflection method involves propagating a wave down from the ground surface, and then recording the returning wave back at the surface as it reflects off formations with contrasting impedances (different velocities and densities) at depth. The seismic energy will also be reflected, refracted, and diffracted at boundaries in the subsurface, in accordance with Snell's Law. (University of Utah, College of Mines and Earth Sciences, 2006).

Snell's Law: $V_2 \sin T_1 = V_1 \sin T_2$

Critical Angle: $\sin i = V_1 / V_2$

Complete Law: $\sin i / V_i = \sin T_{p1} / V_{p1} = \sin T_{s1} / V_{s1} = \sin T_{p2} / V_{p2} = \sin T_{s2} / V_{s2}$

Where,
- i: incident angle
- V_i: velocity of incident wave
- s: Shear wave
- p: Compressional wave
- T: Angle of refraction
- V: Velocity of material
- 1, 2: Layers 1 and 2

The main processing consideration for a successful seismic reflection survey is the ability to separate the reflected energy from other arrivals.

A seismic reflection occurs when an acoustic wave front encounters an impedance boundary in the subsurface. Seismic impedance depends upon both the velocity and density of a subsurface material, and impedance boundaries occur where these material properties change abruptly, usually due to changes in lithology. The reflection coefficient, R_c, across an interface, is expressed by a function relating the acoustic impedance of adjacent layers. R_c determines the relative amplitude of the reflected wavelet.

$$R_c = \frac{\rho_2 V_2 - \rho_1 V_1}{\rho_2 V_2 + \rho_1 V_1}$$

Where, R_c = reflection coefficient,
ρ_1, ρ_2 = mass density of the material on each side of the interface, and
V_1, V_2 = P-wave velocity on each side of the interface

The reflection equation coefficient is valid for all body waves, including P and S waves. The sign of the reflection coefficient determines the polarity of the reflected wave. The magnitude of the reflection coefficient is critical to obtaining usable data. The seismic reflection technique will not work if the acoustic contrast is not sufficient to produce a clear reflection, regardless of the survey parameters or processing techniques employed. The ability of the seismic reflection method to detect an individual sedimentary layer is not only a function of the acoustic impedance at the top and bottom of the bed, but also depends on the layer (bed) thickness. The minimum resolvable layer thickness is often quoted as 1/4 to 1/8 of the wavelength at the target depth. Wavelength is inversely proportional to frequency (i.e. seismic velocity equals wavelength multiplied by frequency).

The reflection coefficients for a sandstone overlying solid coal, water-filled, and air-filled voids are provided in Table 3-2. Because the S-wave velocity for water-filled and air-filled voids is zero, the reflection coefficient for S-wave remains the same for air or water-filled voids.

TABLE 3-2 P-WAVE AND S-WAVE REFLECTION COEFFICIENTS FOR DIFFERENT SUBSURFACE CONDITIONS

	P-Wave Velocity	S-Wave Velocity	Density	P-Wave Reflection Coefficient	S-Wave Reflection Coefficient
Solid Coal	5200	2500	1.346	-0.481525	-0.49645
Air-Filled Void	600	0	0	-1	-1
Water-Filled Void	4900	0	1	-0.606426	-1

The reflection coefficients are computed using the equation above and assume a rock layer with a velocity of 8,000 ft/sec P-wave velocity and a 4,000 ft/sec S-wave velocity and a density of 2.5 g/cm^3. This shows how the void's contents may be predicted using a combination of P and S-wave reflection methods. The change in S-wave reflection amplitude would be the same for either a water or air-filled void, but the change in P-wave reflection amplitude should be significantly higher for air-filled voids.

This assumes that rock above the mined coal seam does not undergo significant collapse. If collapse occurs, the reflection from the coal seam horizon may not occur at all because of the scattering of seismic waves due to the fracturing above the seam.

When a reflecting boundary exists, it is important to optimize the field procedure and acquisition parameters to optimize the quality of the final processed data. Choosing the best field parameters involves determining the relative importance of several competing objectives, such as site constraints, equipment capabilities, and processing needs.

In all geophysical surveys, the objective is to extract the usable data, in reflection seismology; it is desirable to record high frequency, high signal-to-noise ratio reflection events from the boundary of interest. The frequency of a reflection event is largely determined by the source input frequency and the filtering effect of the ground. Often, the target reflector frequency is similar to that commonly recorded for coherent noise (in particular, the noise from ground roll), making it difficult or impossible to selectively filter out noise. Isolation of the reflection events requires careful design of field acquisition parameters, such as the source/receiver geometry, choice of source and receiver types, as well as recording parameters, such as sampling rate and filter settings.

3.1.3 Criteria Applied to HRS

Table 3-3 lists underlying criteria that are necessary to take into account when performing a HRS reflection survey.

TABLE 3-3 HRS REFLECTION CRITERIA

Criteria	
Maximum Imaging Depth	S-wave reflection seismic surveys have produced images at depths of 100 to 400 ft (depending on the surface and subsurface conditions) using the microvibrator. Using the same equipment in P-wave mode, images at depths in excess of 1300 ft have been achieved. Image depths greater than 2000 ft have been achieved using larger vibrators where the upper frequency limits are between 180-200 Hz.
Contents of Detected Voids	P-wave and S-wave seismic techniques are individually unable to determine the contents of detected voids. P-wave reflectivity depends upon the type of fluid in a void space (i.e. air-filled versus water-filled) whereas S-wave reflectivity is very high with any type of fluid, because shear waves are unable to propagate through any type of fluid. Therefore, when both methods are used together, differences in response between P-wave and S-wave reflection as well as the characteristic of the reflective P-wave may provide an indication of the void contents (i.e., air, water, or gob).
Performance Handling Characteristics (Effective frequency range, wave attenuation, and the size and orientation of void)	The selected patented microvibrator source is capable of generating P-waves and S-waves in the frequency range from 20 Hz to 2 kHz. The high-frequency signals are critical for detection of small voids at depth. Generally, the reflection frequencies recovered are site-specific and depend on the type of soil or rock. In general, frequencies recovered for S-waves are on the order of 20-300 Hz and for P-waves 40-400 Hz. Resolving power and resolution are a function of wavelength that is in turn a function of the propagation velocity and the frequency of the seismic signal. Typically, wavelengths are on the order of two to 10 ft for S-waves and five to 40 ft for P-waves. Generally, the frequency of the seismic signal decreases as the depth increases. This means that a void must be relatively larger at depth to be detected.
Repeatability of Test Results	The results from reflection seismic surveys are generally confirmed by invasive methods such as drilling. Because of the expense, the surveys are rarely repeated. The method itself, however, is based on a statistical sampling. The number of repeated measurements is typically referred to as “fold”. Typically, the surveys used to detect voids are on the order of 36 to 72 fold (72 individual measurements per subsurface point sample).
Safety Features and Procedures of Technology	Using the patented microvibrator, neither explosives, nor impacting devices are necessary. The primary hazard is that of lifting the vibrator, which weighs 280 lbs. A dolly, or a two-man lift is used to move the vibrator and because it is used on the surface, it is much safer than working within the mine.

TABLE 3-3 HRS REFLECTION CRITERIA CONTINUED…	
Data Integrity and Interpretation	**Ease and Reliability of Data Gathering** - Data gathering is performed by a crew of highly experienced persons that are supervised by an experienced technician. A geophysicist is typically required at the beginning of a survey to determine the most appropriate data acquisition parameters. Quality control (QC) procedures are in place to allow production data acquisition to be performed by technicians (just as is done with oil and gas seismic surveys). A geophysicist provides quality control of the data on a daily basis.
	Data Processing - Processing is typically done by geophysicists that specialize in seismic processing using computers and software specifically designed for that purpose. These techniques are expensive, but technically robust and good results can be, and usually are, achieved. Close communication between the field geophysicist, processor, and the consumer is essential if the results are to be useful. Well logs, known depths, results from ancillary methods, and the expected results should be furnished to the processor. One important conclusion of the processing is the depth section. The production of depth sections requires conversion of the travel times of the reflections to depths by derivation of a velocity profile. Well logs and check shots are often necessary to confirm the accuracy of this conversion.
	Ability to Interpret Data With Minimal Training -HRS reflection data are not amenable to interpretation by untrained personnel. A qualified geophysicist, experienced in the interpretation of reflection seismic data, must perform interpretation of the seismic sections. However, the procedures for interpretation can be streamlined for specific exploration objectives (i.e., void detection). Typically, within one week of data acquisition, processing can be completed, and another week is required to produce a preliminary interpretation.

3.1.4 Limitations of HRS

Table 3-4 lists the limitations of HRS in various geologic, geographic, and environmental conditions, including data acquisition and processing.

TABLE 3-4 LIMITATIONS OF THE HRS REFLECTION

Geologic, Geographic, and Environmental Conditions Limitations	
Diverse Environmental Compatibility	P-wave and S-wave surveys have been performed in a wide variety of environments including: inside a working movie theater, along city streets, muddy farm fields, "swampy" areas with standing water several inches deep, and within working oil and gas refineries. Nevertheless limitations to the recording of good data can occur in the following conditions: standing water more than six inches deep, excessive mud (which would limit access for vehicles and personnel), and underground applications where intrinsically safe equipment is required.
Groundwater Conditions and Saturated Zones	Groundwater has no effect on the results of the S-wave survey and minimal effects on a P-wave survey; however, success is greatly increased if the shots and geophones are near or in the saturated zone.
Presence of Mine Voids Below Unmined Coal Seam	Voids are generally identifiable if they are below an unmined coal seam. However, the presence of an upper coal seam may degrade reflections beneath the coal seam.
Other Subsurface Features	Complex geologic features such as faults and fracture systems can interfere with the ability of the method to image voids within coal. A lenticular sand deposit within a coal seam could possibly be identified as a void in the coal as it may have an appearance similar to that of a void.
Void Contents (i.e. Water, Air/Gas, Slurry, or Gob)	S-wave surveys are unaffected by void contents provided these are liquids or gas (liquids and gasses possess no shear strength); however, P-wave surveys can be affected by the presence of water in the voids. Thus, by using both methods the contents of the void can be categorized.
Data Acquisition and Processing Limitations	
Data Processing	This should be guided by the appearance of the field records and extreme care should be used not to stack refractions or other unwanted artifacts as reflections.
Desired Depth	Variations in field techniques are required depending on depth.
Equipment	Low-cut filters and arrays of a small number (1-5) of geophones are required.
Field Records	Generally, reflections should be visible on the field records after all of the recording parameters are optimized.
Site Preparation	Clearing of brush or trees is required to provide access for the microvibrator. (approximately two to three ft wide path)

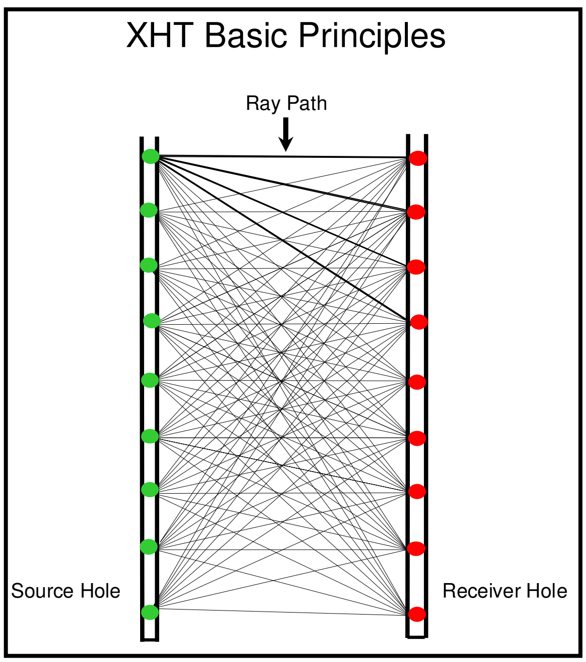
3.2 CROSSHOLE TOMOGRAPHY AND GUIDED WAVES METHODS

3.2.1 Basic Concept

Both two-dimensional (2-D) and three-dimensional (3-D) tomography is used for high-resolution imaging of the subsurface between boreholes. Tomography is an inversion procedure that provides 2-D and 3-D velocity and/or attenuation imaging between boreholes from observation of transmitted first-arrival seismic energy.

Tomography data collection, as shown on Figure 3-3, involves scanning the region of interest with many combinations of source and receiver depth locations, similar to medical Computer Axial Tomography Scan (CATscan). Typical field operation consists of placing a string of receivers (geophones or hydrophones) at the bottom of one borehole and moving the source systematically in the opposite borehole from top to bottom. The receiver string is then moved to the next depth interval and the test procedure is repeated until data from all possible source-receiver combinations are obtained.

FIGURE 3-3 BASIC PRINCIPLES OF THE XHT TECHNIQUE



3.2.2 Theory

The use of tomographic analysis for imaging geological boundaries between boreholes has become a well-established technique for geophysical investigations. It involves imaging the seismic properties from the observation of the transmitted seismic, compressional P-wave or shear S-wave, first arrival energy in either time or amplitude. The relationship between the velocity field v (x, y) and travel time t_i is given by the line integral (for a ray i):

Equation #1) $$t_i = \int_{R_i} ds / v(x,y)$$

Where R_i denotes the curve connecting a source receiver pair, which yields the least possible travel time according to Fermat's principle. Tomography is an attempt to match calculated travel times (model responses) to the observed data by inversion of these line integrals. Initially, the region of interest is divided into a rectangular grid of constant velocity cells (j) and a discrete approximation of the line integral is assumed as:

Equation #2) $$t_i = \sum_j \Delta S_{ij} \cdot n_j$$

Where ΔS_{ij} is the distance traveled by ray i in cell j, and n_j slowness within cell j. Using a first order Taylor expansion and neglecting residual error, Equation #2 can be written in matrix form as:

Equation #3) $$\underline{y} = A\,\underline{x}$$

Where the vector $\underline{y}$ is defined as the difference between computed travel times (from the model) and the observed travel times; vector $\underline{x}$ is the difference between the true and the modeled slowness, and A is the Jacobian matrix. In travel time tomography, Equation #3 is solved using matrix inversion techniques.

The seismic wavefield is initially propagated through a presumed theoretical model and a set of travel times are obtained by ray-tracing (forward modeling). The travel time equations are then inverted iteratively in order to reduce the root mean square (RMS) error between the observed and computed travel times. The inversion results can be used for imaging the velocity (travel time tomography) and attenuation (amplitude tomography) distribution between boreholes.

Two types of seismic tomographic processing are generally used, including:

- Travel Time - Uses time of travel (first-arrival travel times) to derive velocity images using inversion techniques.
- Attenuation – Uses the amplitude of the first arrival energy to derive attenuation images using inversion techniques.

3.2.3 Criteria Applied to XHT

Table 3-5 lists the underlying factors that are necessary to take into account when performing a XHT survey.

TABLE 3-5 XHT CRITERIA

Criteria	
Maximum Imaging Depth and Distance Between Boreholes	XHT surveys have produced images up to 1,000 ft deep depending on subsurface conditions. Distance between boreholes varies between 20 ft to several hundred ft depending on the target size. For close in surveys of 50 ft or less, a downhole vibrator, borehole hammer, or sparker source is used. For larger distances, an air-gun or large downhole vibrator source is used.
Contents of Detected Voids	Voids are suitable targets for tomography; however, the tomography technique is generally unable to determine the content of a void. It must be noted that for water-filled voids in weathered coal (with similar seismic velocity and, therefore, small velocity contrast), only poor tomographic images may be obtained.
Performance Handling Characteristics (Effective frequency range, wave attenuation, and the size and orientation of void)	The measured frequency content of the crosshole signal depends on the type of soil and rock at a site. In general, the frequencies recovered are in the order of 40 to 600 Hz. Resolving power and resolution are a function of wavelength, which is in turn a function of the propagation velocity and frequency of the seismic signal. Typically, wavelengths are on the order of two to 20 ft. Generally, the frequency of the seismic signal decreases as the borehole separation increases. For small target zones on the order of 6.5 to 10 ft in height, the distance between the source and receiver boreholes for crosshole analysis must be kept no more than 33 ft for adequate resolution. For small targets, forward modeling must be performed to compute the magnitude of the expected travel-time anomaly and to determine if the target is resolvable considering survey parameters. Borehole design is also a factor. For proper imaging, the source-receiver borehole pairs must be placed around the suspected mined zone and be drilled to depths equal to twice the borehole separation distance below the expected depth of the mine. In other words, if the separation between source-receiver boreholes is 33 ft and the mine depth is 328 ft, then the boreholes should be drilled to minimum depths of 394 ft. If large horizontal offsets are used between the source and receiver boreholes, low vertical resolution will be obtained in the tomograms, resulting in the velocity images being elongated in the horizontal direction.
Repeatability of Test Results	Tomographic results are generally very repeatable. However, when using a strong air-gun source in open holes or poorly grouted PVC-cased holes, borehole damage may occur giving rise to different shaped seismic signatures (lower frequency) being transmitted when a survey is repeated.
Safety Features and Procedures of Technology	For air-gun sources, special safety procedures must be followed by the field operator when handling high-pressure compressive air-lines (approximately 2000 psi). These pressures pose no danger to existing mine operations and no danger of an explosion is created.

TABLE 3-5 XHT CRITERIA CONTINUED…	
Data Integrity and Interpretation	**Ease and Reliability of Data Gathering -** Data gathering is performed by a crew of highly experienced personnel that are supervised by an experienced technician. A geophysicist is typically required to design the data acquisition parameters. QC procedures are in place to allow production data acquisition to be performed by technicians (just as is done with oil and gas type surveys). A geophysicist may check the data on a daily basis for quality control.
	Data Processing - Processing is typically done by geophysicists that specialize in crosshole seismic tomography processing using special purpose computers and software. These techniques are expensive but technically robust and excellent results can be achieved. Close communication between the field geophysicist, processor, and the consumer is essential if the results are to be useful. Well logs, known depths, results from ancillary methods, and the expected results should be furnished to the processor.
	Data Interpretation - Voids are identified in velocity tomograms. However, proper volumetric imaging of voids must be done by a qualified geophysicist to identify possible image distortions due to velocity anisotropy and presence of artifacts near image boundaries.

3.2.4 Limitations of XHT

Table 3-6 lists the limitations of the XHT in various geologic, geographic, and environmental conditions, including data acquisition and processing.

TABLE 3-6 LIMITATIONS OF THE XHT

Geologic, Geographic, and Environmental Condition Limitations	
Diverse Environmental Compatibility	In general, environmental limitations are related to the drilling operations (e.g., storms) and not the XHT data acquisition or its systems.
Groundwater Conditions and Saturated Zones	If the void is water-filled and the adjacent coal is weathered, the velocity contrast between these two media will be diminished and could be undetectable with P-wave XHT.
Presence of Mine Voids Below Unmined Coal Seam	None. This is XHT's advantage because of the ability to image from above and below the seam(s) and/or voids.
Other Subsurface Features	Vertical features (e.g., high-angle faults, fractures, etc.) between vertical borings are difficult targets to image uniquely if the features do not extend from one boring to the other. In addition, tomographic imaging is unreliable at the top and bottom of the tomogram because of limited ray path coverage, and the algorithms typically place artifacts in these areas of poor coverage.
Void Contents (i.e. Water, Air/Gas, Slurry, or Gob)	The presence of water within the voids can decrease the velocity contrast between the voids and surrounding geology, especially if the surrounding materials have slow velocities (i.e. coal). Other types of void contents such as air or loosely compacted solid material do not affect the velocity contrast. The degree of weathering in the adjacent coal will govern the image resolution between pillars and water-voids.
Acquisition and Processing Limitations	
Data Analysis and Interpretation	Processing of the XHT data requires the use of specialized software, and personnel experienced in the analysis of the seismic data. An understanding of the geology of the site is also required to ensure that the tomogram produced is consistent with the geologic conditions at the site. In the absence of any evidence of a void in the data, an assessment must also be made of the velocities of the layers above and below the coal seam so as to determine if the presence of a void was detectable using this method, because the presence of voids can be masked by nearby high velocity layers. While the presence of the void can be determined by looking for anomalous low velocity zones within the tomogram, determining the extent of the void requires an analysis of the frequency content and the velocities of the surrounding strata.

TABLE 3-6 LIMITATIONS OF THE XHT CONTINUED…	
Disruption of Normal Mining Operations	XHT data acquisition creates a disruption to the mine if mining activities are ongoing in the immediate vicinity of the drilling. Coordination is required to schedule the drilling around the mining activities.
Site Preparation	Boreholes must be drilled with care to minimize horizontal deviation and borehole wall damage. Deviation surveys must be conducted to map deviation of each boring. Borehole completion is a critical step; with poor borehole completion (i.e., improper placement of casing and grout), the seismic data can be rendered useless. American Society of Testing and Materials (ASTM) have a standard (D4428-M91) for completion procedures to be used for crosshole seismic tests. If these procedures are adhered to, the data should provide useful subsurface velocity information. Borehole layout is also a factor. Borehole separation-to-depth ratio should be about 1:2 for seismic tomography imaging.

3.2.5 Guided Waves Criteria and Limitations

In this technique, only a few shot and receiver positions within, immediately above and immediately below the coal seam are required. This makes this technique relatively cost-effective. Guided waves are trapped in low-velocity layers by critical reflections at the upper and lower interfaces of the coal seam. The guided waves will only exist within the coal seam and their frequencies are controlled primarily by the thickness of the coal seam, presence of discontinuities (such as voids, faults, washouts, etc) and any thinning of the coal seam between the boreholes. (Krohn, 1992, pgs. 39-40 & 45). The particle motion of the guided waves has not been well characterized, but they are similar to tube waves, which propagate in boreholes. Because these types of waves have a shear component, they are attenuated when passing through water-filled voids. When the guided waves intersect the receiver borehole, a tube wave is created in the receiver borehole that originates at the coal seam. These tube waves travel up and down the receiver borehole and are recorded by the hydrophones.

The guided waves technique is useful in locating voids within a coal seam. As the guided waves propagate through a coal seam, the waves will be stopped by the coal-void interface and consequently no tube waves are generated in the boreholes and no response is recorded by the receiver. However, the only information obtained with this method is that a discontinuity exists between the boreholes. The horizontal location of this void is unknown.

FIGURE 3-4 BASIC CONCEPT OF THE GUIDED WAVES TECHNIQUE

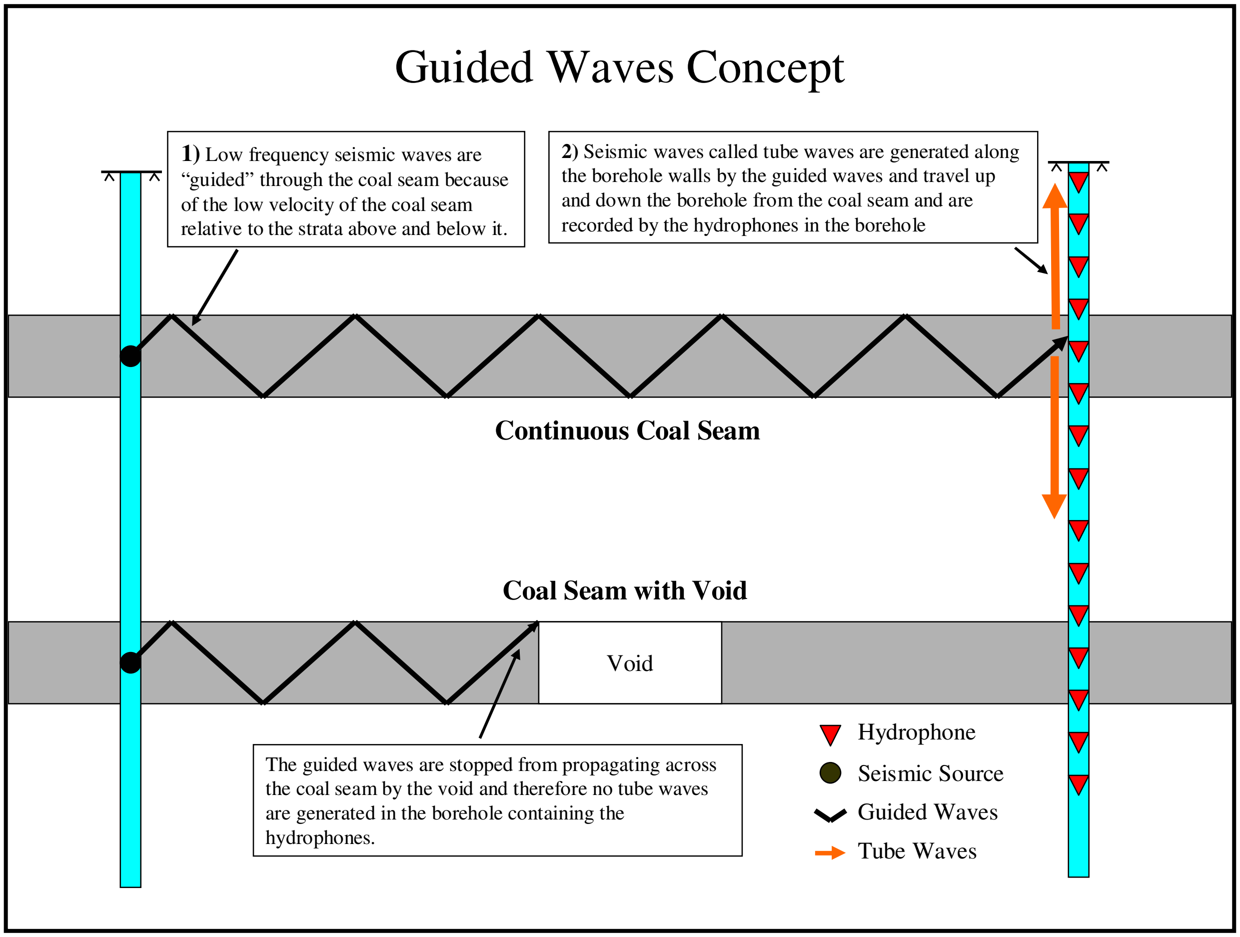


TABLE 3-7 GUIDED WAVES CRITERIA AND LIMITATIONS

Criteria	
Maximum Imaging Depth	The maximum imaging depth depends on the depth of the boreholes used in the survey. Various sources could be used depending on the depth of the survey and the spacing between the boreholes. Sources include: sparkers, air-guns, and vibratory sources.
Contents of Detected Voids	This method provides no information on the contents of the void. In fact, the method is sensitive to other changes in the coal seam besides the presence of a void. These changes could include thinning of the coal seam or faulting that offsets the seam. The presence of water in the void may also reduce the sensitivity of the method.
Performance Handling Characteristics (Effective frequency range, wave attenuation, and the size and orientation of the void)	The frequency of the guided waves is controlled by the thickness of the coal seam and the materials above and below the seam. It is typically much lower than the direct waves received in the XHT survey. However, the advantage of this method is that the attenuation of these waves is very low and they propagate over distances that can exceed one thousand ft. The size of the void that this method can detect can be on the order of several feet horizontally, provided that the void extends over the entire height of the seam and that it is not water-filled. If it is water-filled then the guided waves may not be attenuated enough to be detectable.
Repeatability of Test Results	Guided waves surveys are generally repeatable; however, when using a strong air-gun source in open holes or poorly grouted PVC cased holes, borehole damage may occur giving rise to different seismic signatures. However, the nature of the guided waves makes the recorded signature more sensitive to the nature of the coal seam (primarily thickness) and less sensitive to a damaged borehole.
Safety Features and Procedures of Technology	For air-gun sources, special safety procedures must be followed by the field in handling high-pressure compressive air-lines (approximately 2,000 psi). The pressures pose no danger to existing mine operations and no danger of an explosion is created.
Data Integrity and Interpretation	**Ease and Reliability of Data Gathering** - Data gathering is performed by a crew of experienced personnel that is controlled by an experienced technician. A geophysicist is typically required to design the data acquisition. QC procedures are available to allow production data acquisition to be performed by technicians. A geophysicist may review the data on a daily basis for quality control.
	Data Processing – There is minimal data processing required for this method. Typically, it involves merging different shot records, filtering, and displaying the results. Some information is required from the site, especially well logs and some knowledge of the geologic section.
	Data Interpretation – Interpretation of the presence or absence of a void may require some site knowledge and experience, and must be done by a qualified geophysicist to ensure that the proper waveforms are identified.

Table 3-7 Guided Waves Criteria and Limitations Continued…	
Geologic, Geographic and Environmental Condition Limitations	
Diverse Environmental Capability	In general, environmental limitations are related to the drilling operations (e.g. storms) and not the guided waves data acquisition or its systems.
Groundwater Conditions and Saturated Zones	The guided waves require that a significant amount of the coal seam be intact and have significant velocity contrasts between the coal and surrounding strata. The method may be less sensitive to the presence of water-filled voids than it is to air-filled voids.
Presence of Mine Voids Below Unmined Coal Seam	Provided that borings can be drilled to the level of the coal seam, the presence of other seams does not significantly affect the acquisition, processing, and interpretation of the data.
Other Subsurface Features	The presence of other subsurface features such as faulting, significant coal seam thickening and thinning can cause significant changes in the guided waves response that is independent of any voids present in the media.
Void Contents (i.e. Water, Air/Gas, Slurry or Gob)	The method is more sensitive to the presence of air-filled voids and water-filled voids may not be detectable using this method.
Acquisition and Processing Limitations	
Data Analysis and Interpretation	Cross-well continuity survey data for coal are often straightforward to interpret when the coal seam is a good waveguide. However, certain geological conditions must be met for the propagation of guided waves, and not all guided waves may be easily identified in an unprocessed crosshole data set. Crosshole seismic data with full waveform processing clearly show the presence of guided waves and other modal waves indicative of continuity of the waveguide (coal seam) and by the lack of them the presence of voids is inferred due to attenuation of the seismic energy.
Disruption of Normal Mining Operations	Presents a disruption to the mine if mining activities are ongoing in the immediate vicinity of the drilling. Generally capable of scheduling the mining around the drilling as generally conducted at active mine operations.
Site Preparation	The boreholes used for these surveys can be quickly completed, as only access to the coal seam is required. Furthermore, the spacing between the source and receiver boreholes is not critical to the success of the method. The boreholes can be situated in convenient locations where access for a drill truck is available.

3.3 REVERSE VERTICAL SEISMIC PROFILING (RVSP)

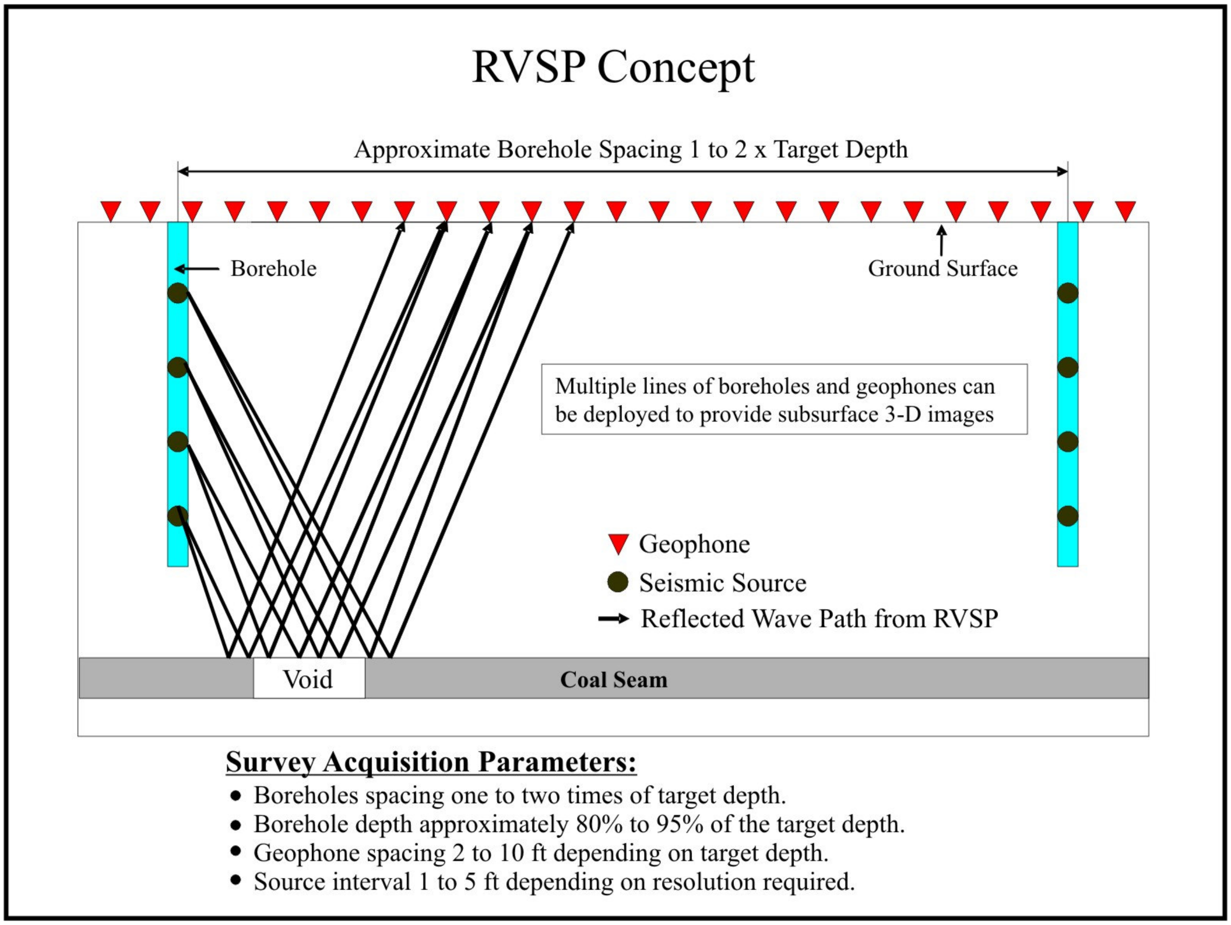
Reverse Vertical Seismic Profiling (RVSP) is a special type of seismic reflection survey and follows the same physical principles as described in *Section 3.1 Seismic Reflection Method*. Vertical Seismic Profiling (VSP) is a method most often used in Oil and Gas surveys when detailed images of complex geologic structures are required (i.e. imaging the flanks of salt domes). VSPs use a seismic source at the surface and clamping geophones in the borehole. A surface source is required in VSP surveys because of the required depth of investigation is often greater than 5,000 ft. For shallow applications where source energy requirements are less, RVSP surveys can be performed. In RVSP surveys, the seismic source is placed in the borehole and surface geophone arrays are used to record the reflected seismic signals. The main advantages of an RVSP over a VSP survey include:

- Significantly faster data acquisition resulting in greatly reduced acquisition costs
- Elimination of interference from tube waves in the borehole
- Use of man-portable seismic sources
- Reduced surface environmental impact
- Ability to conduct surveys in difficult terrain

The design and acquisition geometry for the RVSP (i.e., number of surface geophones and offset, depth of borehole, and source interval), will depend on the amount of information available on the old mine works including void / pillar geometries, target depth, geology, and resolution required. An optimal layout for an RVSP survey along a 2-D line is shown on Figure 3-5. The boreholes should be spaced at a distance approximately equal to twice the depth of the target and drilled to a depth above the target horizon. For shallow targets, up to about 200 ft, the required depth of the source borehole may vary from five to 20 ft above the target horizon. For deeper targets up to 1,000 ft, the borehole depth may vary from 50 to 200 ft above the target horizon depending on the target size being investigated. When multiple coal seams are present, the borehole should be drilled to a depth below the coal seam immediately above the target horizon. Similarly, the geophone spacing may vary from two to 10 ft for shallow and deep targets, respectively. The surface geophones could then be laid out in a line extending between the boreholes and the source deployed in each of the boreholes. This will allow continuous coverage over the entire length of the line between the boreholes. Additional boreholes could be located along a line, depending on the distance that is required for an investigation.

This method could be extended to a 3-D survey around the borehole, although this would require some increase in cost because of additional equipment, field effort, and processing time. Therefore, 3-D surveys should only be performed when very little information is available on the location and orientation of the old mine works.

FIGURE 3-5 SCHEMATIC OF RECOMMENDED RVSP SURVEY TO DETECT OLD MINE WORKINGS



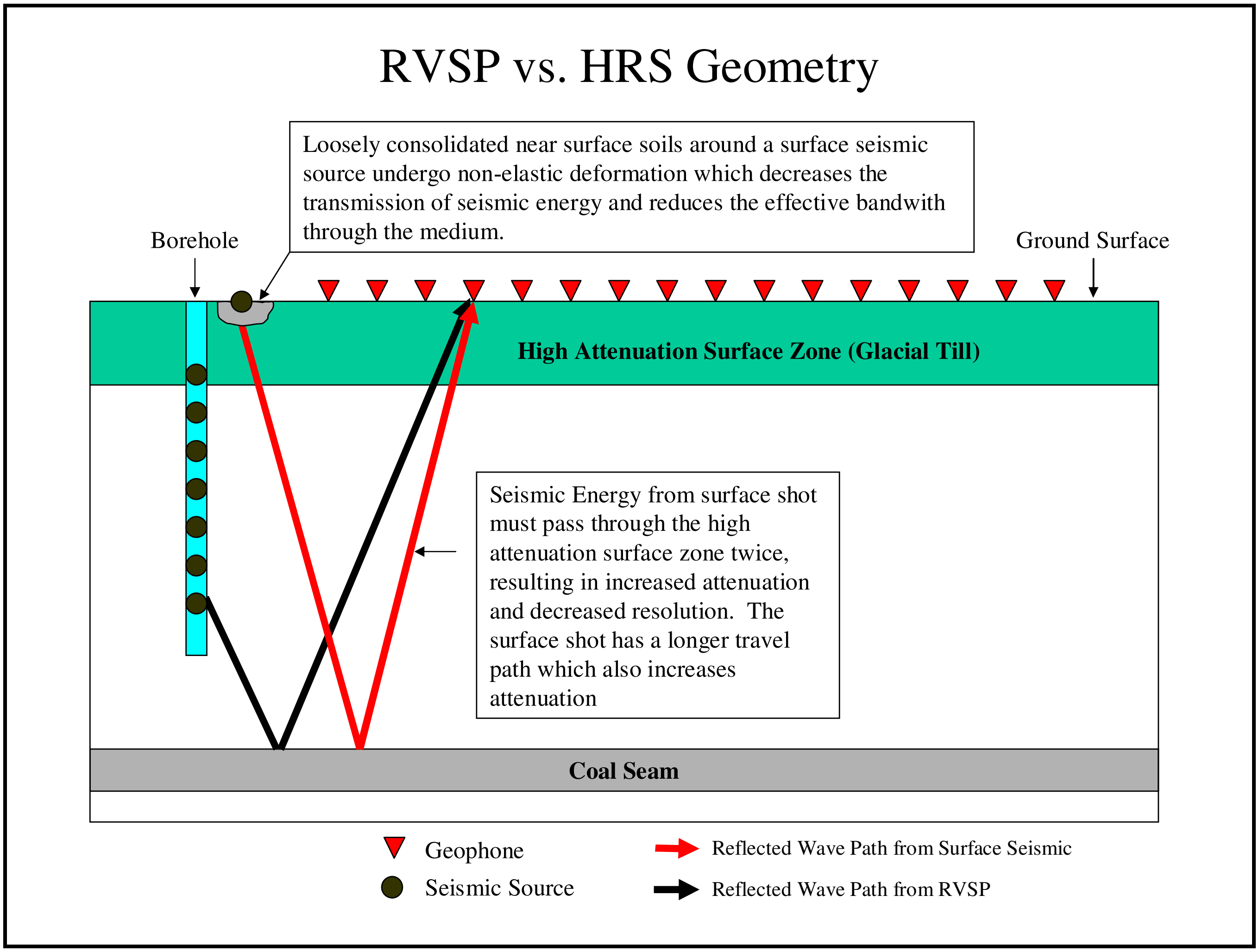
3.3.1 Difference Between RVSP and Surface Reflection (HRS) Surveys

The primary difference between RVSP surveys and surface reflection (HRS) surveys is the requirement for a borehole. A schematic of acquisition geometry for the RVSP and HRS is shown in Figure 3-6. The processed seismic sections for both RVSP and HRS will appear the same because the RVSP reflection points are transposed to simulate a surface reflection survey. The main advantage of a RVSP survey over a traditional HRS survey is greater resolution. Several significant advantages are derived from placing the seismic source in a borehole rather than on the ground surface, including:

- Shortened raypath distances which result in higher recorded frequencies and improved signal-to-noise ratios
- Elimination of ground roll and airblast interference in the seismic record
- Increased high-frequency bandwidth because the signal only has to travel through the soft near surface materials once

- Increased source energy coupling due to a significant reduction in energy loss from non-elastic deformation.

FIGURE 3-6 RVSP VS HRS GEOMETRY



All of these factors lead to improved resolution of the RVSP technique over surface HRS methods. Resolution of an RVSP survey is typically twice that of an equivalent HRS survey. Some disadvantages of the RVSP technique over surface HRS methods include:

- Additional cost of drilling boreholes
- Reduced coverage area constrained to a radius from the borehole equal to approximately the depth of the target horizon.
- Specialized data processing requirement and increased data processing costs

3.3.2 Criteria Applied to RVSP

Table 3-8 lists the underlying factors that must be taken into account when performing an RVSP survey.

TABLE 3-8 RVSP SURVEY CRITERIA AND LIMITATIONS

Criteria	
Maximum Imaging Depth	The maximum imaging depth depends on the distance between the source borehole and the most remote geophone. Provided that an adequate signal-to-noise ratio can be obtained at the far offset geophones then geologic features can be imaged to a depth exceeding 10,000 ft using oil and gas geophysical equipment. Imaging to this depth would require the use of explosive sources and would likely destroy the borehole. To obtain resolution to detect voids 1,000 – 2,000 ft is the anticipated maximum depth of investigation.
Contents of Detected Voids	This method provides no direct information on the contents of the void. However, with high quality data and sophisticated processing methods it may be possible to determine the difference between air and water-filled voids.
Performance Handling Characteristics (Effective frequency range, wave attenuation, and the size and orientation of the void)	The frequency content of the RVSP data is primarily dictated by the seismic source and the geologic conditions. Provided that a high frequency source is used, frequency ranges in excess of 500 Hz are obtainable. The attenuation of the signal is reduced relative to the surface reflection methods with both source and receivers on the surface. In order for the void to be detected, relatively flat lying, layers are beneficial, so that adequate reflections can be obtained.
Repeatability of Test Results	RVSP surveys are generally repeatable and can be used for monitoring purposes.
Safety Features and Procedures of Technology	For air-gun sources, special safety procedures must be followed by the field personnel in handling high-pressure compressive air lines with approximately 2,000 psi pressure. The pressures pose no danger to existing mine operations and no danger of explosion is created.
Acquisition and Processing Limitations	
Data Integrity and Interpretation	**Ease and Reliability of Data Gathering** - Data gathering is performed by a crew of experienced laborers that is supervised by an experienced technician. A geophysicist is typically required to design the data acquisition parameters. The data should be reviewed by a geophysicist on a daily basis to ensure that the data is of sufficient quality.

Table 3-8 RVSP Survey Criteria and Limitations Continued…	
Data Integrity and Interpretation	**Data Processing** – The processing of RVSP data is similar to the processing of HRS data, except that even more specialized knowledge is required by the processor, because of the more specialized software required.
	Data Interpretation – The interpretation of the presence of voids may require some site knowledge and experience, and must be done by a qualified geophysicist to ensure that the proper waveforms are identified. Modeling may be required to fully understand the results obtained.
Geologic, Geographic and Environmental Condition Limitations	
Diverse Environmental Capability	In general, environmental limitations are related to the drilling operations (e.g. storms) and not RVSP acquisition or its systems.
Groundwater Conditions and Saturated Zones	Having high water tables generally produces better results due to decreased attenuation through saturated medium.
Presence of Mine Voids Below Unmined Coal Seams	Provided that borings can be drilled to near the level of the target mine voids the presence of upper seams does not significantly affect the acquisition, processing and interpretation of the data.
Other Subsurface Features	The RVSP method is capable of detecting many other features such as faulting, rolls, and erosional features, and depending on the location of these features, it may make it difficult to distinguish the presence of voids.
Void Contents (i.e. Water, Air/Gas, Slurry or Gob)	The method can detect both the presence of water and air-filled voids and it may be possible in some cases to characterize the contents of the void.
Acquisition and Processing Limitations	
Data Analysis and Interpretation	Should be guided by the appearance of the field records and extreme care should be used to avoid stacking in refractions or other unwanted artifacts as reflections.
Disruption of Normal Mining Operations	Presents a disruption to the mine if mining activities are ongoing in the immediate vicinity of the drilling and the RVSP survey during data acquisition. Generally capable of scheduling the mining around the drilling as generally conducted at active mine operations.
Site Preparation	Boreholes must be drilled with a core to minimize horizontal deviation and borehole wall damage. Boreholes are cased in soft ground and grouted to the surrounding soils. There is flexibility in borehole location, so that they can be placed in areas with existing vehicle access. The surface geophones used for these surveys are hand portable and can generally be carried most places where foot access is available.

4.0 GEOPHYSICAL METHODOLOGY

This section describes the deployment of the HRS, XHT and guided waves, and the RVSP surveys at the site. The survey design, data acquisition, data processing, data analysis, and interpretation are also discussed. A summary of the results with conclusions and recommendations are presented at the end of each method section.

4.1 HRS SURVEY

4.1.1 Survey Design

As outlined in *Section 2.2, Test Site Selection*, we selected an optimum test site to lay out the HRS survey grid. The survey grid, whose size is 150 by 1050 ft (see Figure 2-2), was strategically positioned so that the survey grid would overlay both the mined and un-mined coal areas. This layout allowed the survey grid to cross diagonally over two portions of the old mine entry system; i.e., the four-entry mains in the north-south direction and the two-entry submains in the west direction. The surveys were conducted in an open field partially cultivated and intersected by a tree line and a dirt access road (Picture 4-1). The fieldwork was performed at two different times: November 12-23, 2005 and November 29-December 3, 2005.

PICTURE 4-1 HRS SOURCE AND RECEIVER LOCATIONS

4.1.2 Data Acquisition

The key elements of seismic reflection data acquisition are the seismic source, acquisition geometry and the recording system. Optimal selection and "tuning" of these elements are critical to acquire good quality high-resolution seismic data. Key requirements for this survey include the ability of the source to accomplish the following:

- Generate a broadband signal, so that adequate resolution can be obtained at the target strata.
- Operate with minimum impact on the environment and ongoing site activities.
- Generate sufficient energy to image targets at depths in up to 300 ft.
- Provide the ability to record useful, seismic signals at the geophones with a frequency content that is as high as possible.
- Provide the ability to start the low frequency end of the sweep such that the appropriate depth of penetration is achieved without generating intolerable ground roll.

The key parameters in determining the acquisition geometry are the selection of the minimum and maximum offsets (i.e., distances between the geophones from the source). The key requirement for this project is that the offsets, and geophone spacing, must have the ability to image geologic strata at depths from less than 50 ft to 300 ft and provide sufficient lateral sampling to image the voids. The recording system parameters include the selection of geophones and seismograph that must be capable of sensing and recording seismic signals that have an adequate bandwidth and dynamic range to image the targets of interest. The parameters that were selected, as well as the rationale behind their selection, are discussed in the sections that follow.

4.1.2.1 Instrumentation

This section describes the seismic source, recording system, and acquisition.

Seismic Source

The seismic source selected for this survey is Bay's proprietary Micro Vibrator (MicroVib). The MicroVib is a vibratory source, which is capable of generating seismic energy with frequencies that range from 20 Hertz (Hz) to 2000 Hz with a maximum ground force of 200 pounds (lbs). The MicroVib is coupled to the ground with one-inch spikes or four-inch cones, depending on the surface conditions. It creates a frequency-modulated signal by oscillating two masses through a user-defined range of frequencies, which are then transmitted into the ground. The vibratory source was selected for the following reasons:

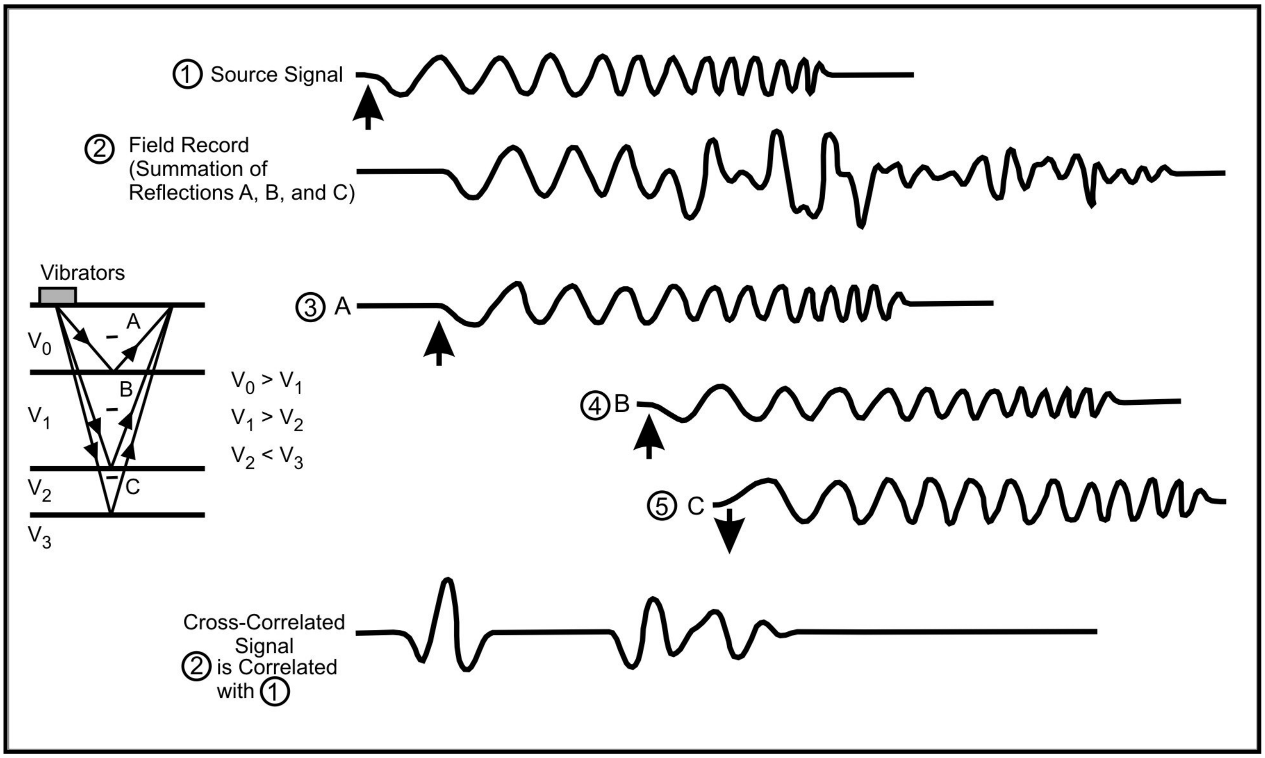
- The ability to generate the high frequencies necessary to image shallow geologic strata as well as attenuate low frequencies, which are the main component of coherent noise events such as ground roll.
- The MicroVib provides cost effective data acquisition because of the ability to acquire a high number of seismic records in a day.

- Lower sensitivity to ambient noise (traffic and facility equipment).
- The MicroVib has a low environmental impact (no discernable noise, shock, or ground disturbance).
- The MicroVib provides the ability to image target horizon depths up to 400 ft below the surface depending on the surface and subsurface conditions.

A vibratory source functions by holding a plate on the ground and vibrating the reaction mass through a user-defined range of frequencies. This is known as a “sweep”. The length of the sweep, peak force and frequency range can be changed in the field. The selection of these parameters is discussed later in this section.

The primary advantage of a vibratory source is that it spreads out the generation of seismic energy over a long period of time. Therefore, more energy can be generated by vibratory sources non-destructively than by other types of seismic sources such as impact or explosive sources with the same energy. However, it requires an additional processing step before the data become useful. This step is referred to as cross-correlation and is shown conceptually on Figure 4-1.

FIGURE 4-1 DIAGRAM OF VIBROSEIS CROSS-CORRELATION OPERATION



The signal received at the geophones (Trace 2 on Figure 4-1) is a sum of a series of source signals from the vibrator (Trace 1 on Figure 4-1) that have been shifted in time. The amount of the shift depends on the depth of the reflecting strata and the velocities of the subsurface. To obtain the output trace (bottom trace on Figure 4-1), a mathematical algorithm called cross-correlation is used. Using knowledge of the input signal, this algorithm compresses each of the source signals summed in Trace 2 into a simple wavelet. Cross-correlation also produces the added benefit of reducing the effects of random ambient noise. Once the cross-correlation is performed, the record is similar to a seismic trace that would be obtained using an impact or explosive source.

Obtaining the input signal from the vibratory source is critical to perform the cross-correlation. This was done in real time using a cable link that sends the signal generated by the signal generator to the seismograph. The seismograph records and uses this signal to correlate with the recorded data received from the geophones. The cross-correlation was performed in real time using SeisNet software by Software Sciences.

To ensure the vibrator source is operating properly, accelerometers are placed on the vibrating reaction mass inside the unit. The purpose of accelerometers is to record and view the motion of the mass. Ideally, the signal generated by the signal generator and the signal from the accelerometer should be "equal" or in phase. This insures that the vibrator's motion matches the signal output of the signal generator.

Vibrator Sweep Testing and Instrument Test Plan

In order to optimize the results from the vibrator, several tests were run to select or adjust the following parameters:

- Sweep starting and ending frequencies;
- Sweep length;
- Number of sweeps;
- Source array and force.

The testing was performed along Inline 30 for both P-wave and S-wave. The following parameters were studied:

- Sweep frequencies from 15 to 400 Hz (high frequency provides high resolution and less depth of penetration);
- Sweep lengths of four and six seconds;
- Four, six, and eight sweeps per station;
- One and two microvibrators.

High-resolution reflection data may be recorded when geophones acquire a wide range of frequencies with a good signal-to-noise ratio. This is because the wider the range of frequencies in which there is good signal-to-noise, the better the resolution to image the subsurface. The frequency content of the recorded signal is a function of several factors including the following:

- Frequencies generated by the seismic source. In the case of the MicroVib, the starting and ending frequencies in the sweep control the range of generated frequencies.
- Attenuation by the subsurface. The Earth tends to attenuate higher frequencies more rapidly than low frequency signals. This means that the Earth acts as a low-pass filter. The result of this is that even though high frequencies may be generated by the source, they may not be received at the geophones, because they have been severely attenuated as they travel through the subsurface.

Another important objective in high-resolution seismic reflection is the minimization of ground roll energy. In surveys for deeper objectives, ground roll energy typically is attenuated by the use of geophone arrays that can extend over 100 ft in length. This is not possible for shallow high-resolution reflection surveys because these geophone arrays would result in an unacceptable degradation of the near-surface reflections. Therefore, a source that minimizes the amount of ground roll energy is important. The primary method of reducing ground roll is to reduce the amount of energy that is generated in the lower frequency bands, typically 60 Hz or less.

Based on in-field analysis of the data, the parameters listed in Table 4-1 were selected for the production of HRPW and the HRSW surveys:

TABLE 4-1 PARAMETERS FOR PRODUCTION OF HRPW AND HRSW SURVEYS

Parameters for Production of HRPW Surveys	
Sweep Frequencies	35 to 300 Hz
Sweep Length	6 seconds
Number of Sweeps Per Station	6
Total Force	200 lbs
Parameters for Production of HRSW Surveys	
Sweep Frequencies	15 to 200 Hz
Sweep Length	6 seconds
Number of Sweeps Per Station	6
Number of Microvibrators	2
Total Force	400 lbs

There were differences in operating the vibrator in HRPW and HRSW data acquisition, including the following:

- The vibrator is oriented vertically to generate the P-waves for the HRPW acquisition with a base plate attached to the bottom end of the vibrator.
- During the HRSW acquisition, the base plate is removed and special cones are added to the side of the vibrator. These cones, when the vibrator is laid horizontally, assist in coupling the vibrator to the ground.

- Two vibrators were needed to perform the HRSW to provide ample energy out to the most distant geophones.
- A source array was used during HRSW acquisition to attenuate (reduce) source noise such as ground roll and spatial aliasing.

Recording Systems

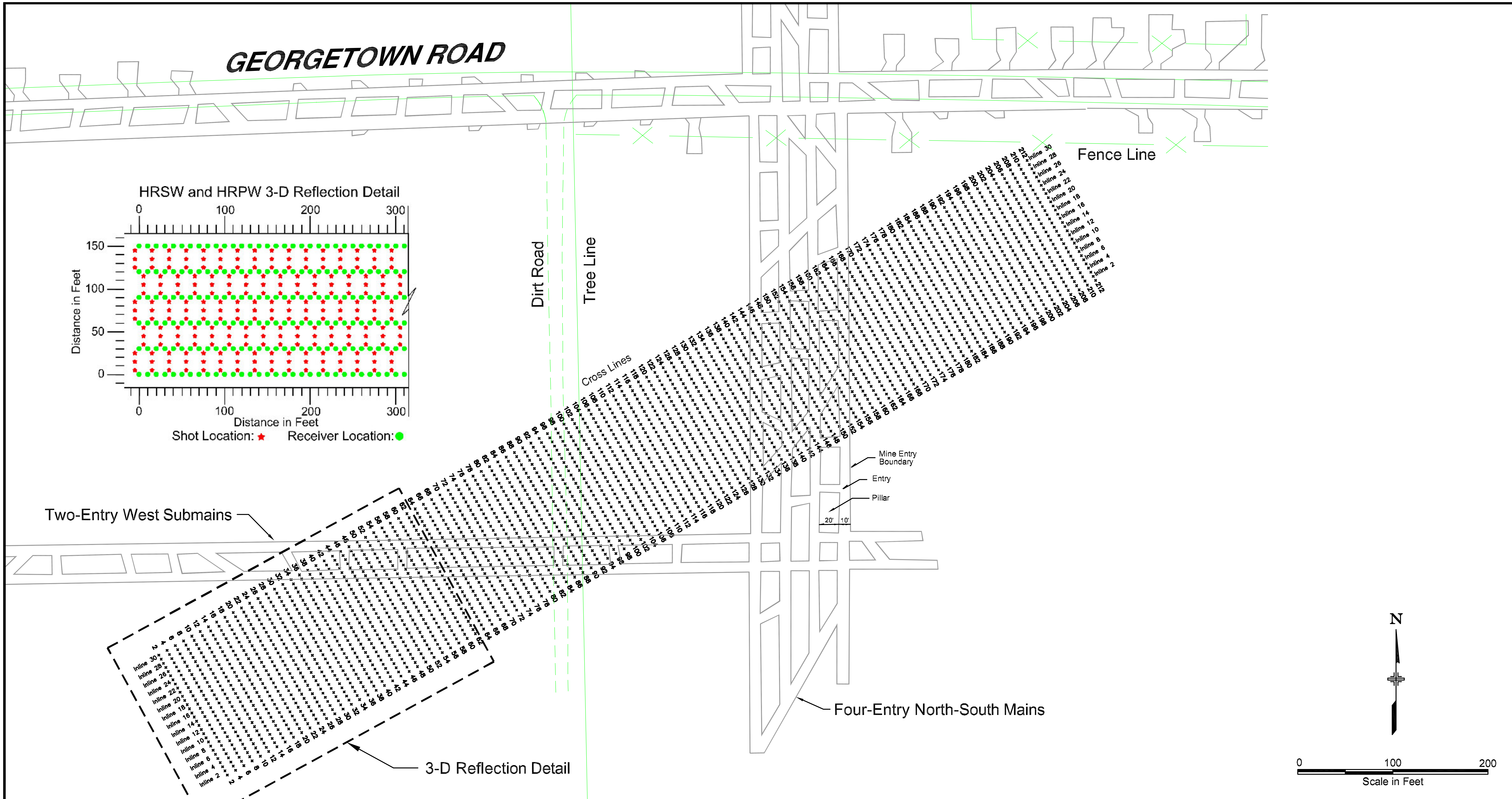
Seismographs: The recording system selected for this survey was two Oyo Geospace DAS-1 seismographs. The DAS is a modern 18-bit sigma-delta engineering seismograph with the following features:

- 144 channel recording (288 channels total in master/slave recording configuration;
- Six auxiliary channel recording;
- A/D converter with 18-bit sigma-delta processor (high dynamic range);
- Sampling rates as fast as 1/8 of a millisecond (ms) (wide recording bandwidth);
- Analog signal/noise ratio: Less than minus 100 decibel (dB), 96-channel;
- Maximum samples per channel: 32,000;
- Plotter: six-inch 600 dots per inch (dpi) internal.

Geophones: The geophones selected for this survey were Oyo Geospace high frequency 40 Hz geophones for both the HRSW and the HRPW. The frequency response of these phones is essentially flat to approximately 780 Hz; therefore, these geophones are suitable for high-resolution surveys.

The geophones were connected to Mark Products CDP cables with 48 pairs of wire so that they could carry the signals of 48 different geophones. The cables had points every 13 ft to connect the geophones. These cables were then connected to two Input/Output 240m roll boxes that allowed the operator to control which subset of the geophone signals would be recorded by the seismograph.

The location of the HRSW and HRPW 3-D reflection surveys is shown on Figure 4-2. The lines were acquired with the nominal acquisition parameters discussed below.



Explanation

HRSW and HRPW 3-D Reflection Surveys

BLACKHAWK A DIVISION OF ZAPATAENGINEERING	US Department of Labor *Mine Safety and Health Administration*		Grid Location of HRSW and HRPW 3-D Reflection Surveys *Riola Mine Complex* *Vermilion County, Illinois*		
301 Commercial Road, Suite B Golden, Colorado 80401 — Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Project No: 5006	Date: June, 2006	Drawn By: HJV	Checked By: KH	Scale: 1" = 100'	Figure: 4-2

4.1.2.2 Data Acquisition Parameters

The primary data acquisition parameters for the HRS surveys are shown in Table 4-2.

TABLE 4-2 NOMINAL ACQUISITION PARAMETERS FOR HRSW AND HRPW

Nominal Acquisition Parameters HRSW and HRPW	
Source Spacing	10 ft (for HRSW, source array was two positions over 10 ft)
Source Line Spacing	10 ft
Receiver Spacing In-line	10 ft
Receiver Line Spacing Crossline	30 ft
Number Active Receivers Per Receiver Line	48
Nominal CDP Fold	72 fold at 235 ft offset
Maximum Offset	235 ft inline, 135 ft crossline
Minimum Offset	5 ft inline, 5 ft crossline
Spread Geometry	3-D Crossline Swath
Seismograph	Oyo Geospace DAS-1
Number of Channels	288 channels, Auxiliary Trace, Vibrator signal input
Sample Rate	0.5 ms
Record Length Uncorrelated	7 seconds, One-second listen
Seismic Source	2 Microvibrators(HRSW), 1 Microvibrator(HRPW)
Receivers	1 x 40 Hz High Fidelity Oyo LMC 70 Geophone

Data Acquisition and Quality Control Procedures were established and adhered to during data collection. Typical field operations were as follows:

- At the beginning of each day, a screen capture was made of the record from an uncorrelated vibrator sweep to ensure that the seismograph triggering and vibrator operation were normal.
- The noise levels were monitored for the spread to ensure that the levels were acceptable and that the number of dead channels was kept to a minimum.
- Prior to beginning the acquisition of each shot, a check was made of the roll box setting, file number on the seismograph, and status of the seismograph. Any anomalies were noted on the observer's notes. The vibrator operator at every vibrator point checked the vibrator position and reported this via radio to the observer (Picture 4-2).
- The vibrator was triggered from the master recording truck, and a sweep was initiated. The record was correlated using SeisNet software, displayed on the screen (every shot location) and every tenth record was printed. The uncorrelated record was stored on hard disk in real time and then on a DVD ROM drive at the end of each day. The first and last file on the disc was played back after move-ups to ensure that the proper location of common depth point (CDP) switch had been used. Additionally, the correlated record

was analyzed on-screen and checked for proper equipment operation and the number of dead channels, if any (Picture 4-3).

- A cable and geophone continuity check was performed each day before the beginning of production. This insured that all of the geophones were connected to the CDP cables during acquisition. A digital voltmeter was placed one position ahead of the CDP roll to ensure that the addition of new geophones for the next shot were live.
- The plowed field on the northeast end of the survey had been tilled prior to data acquisition. This caused coupling inefficiency of the vibrator to ground. Coupling was improved by periodically cleaning the vibrator coupling cones (HRSW) or base plate (HRPW). Additionally, geophones were buried one ft below the plowed field to increase receiver coupling.

PICTURE 4-2 DUAL MICROVIB SOURCE MOVING TO A NEW SHOT LOCATION

4.1.2.3 Data Quality

Coherent Noise

Coherent noise was observed on the field records as ground roll but was minimal. During HRSW, spatial aliasing was tested and observed. This is not considered noise, but rather an acquisition problem associated with the slowness of S-waves and the receiver interval being large. Spatial aliasing was attenuated by using a source array. Three vibrator sweeps were positioned equidistant on each side of the shot location spaced five ft apart. This array assisted in attenuating spatial aliasing and ground roll.

PICTURE 4-3 HRS RECORDING SYSTEM

<u>Ambient Noise</u>

Ambient noise was encountered due to road traffic (heavy trucks) along Georgetown Road. This was avoided by not recording when these trucks were close to the receiver arrays. This was achieved by watching the noise monitoring equipment during data acquisition and communicating with the line crew.

4.1.3 Data Processing

Data processing was performed by Sterling Seismic Services, Ltd. (Sterling). Sterling used Promax-processing software from Landmark Graphics Corporation. Promax is the state-of-the-art seismic processing software designed to process HRPW and HRSW seismic field data in a variety of field formats. The field data, in this case 3,210 field data files, were combined to calculate an acoustical 3-D data set to image previously mined coal seams.

The processing flow for the data is based on a standard CDP 3-D reflection processing flow with several enhancements due to the high resolution required for the survey and specific conditions at the site. Steps one through 16 were performed on either shot records or CDP gathers. The processed shot records (or CDP gathers) from each location along the survey line were then stacked to form the trace record. The final three steps were performed on a CDP stacked section, which resembled the final output.

The steps involved in the processing of the seismic data are:

1. SEG-D TO INTERNAL FORMAT CONVERSION
2. VIBROSEIS CORRELATION
3. GEOMETRY AND TRACE EDITING
4. 3-D CDP BINNING 5 X 5 FT BINS
5. TRUE AMPLITUDE GAIN RECOVERY
6. SURFACE CONSISTENT AMPLITUDE ANALYSIS AND COMPENSATION
7. MINIMUM PHASE COMPENSATION FILTER FOR VIBROSEIS DATA
8. SURFACE CONSISTENT DECONVOLUTION
   TYPE: SPIKING OPERATOR LENGTH: 60 MSEC NOISE: 0.1%
9. SPECTRAL WHITENING: 20-200 HZ (S-wave) 40-300 HZ (P-wave)
10. GREEN MOUNTAIN GEOPHYSICS: ELEVATION/REFRACTION/DATUM STATICS
    DATUM: INTERMEDIATE FLOATING/NMO DATUM
    VC: 4000 FT/SEC (S-wave)
    VC: 8000 FT/SEC (P-wave)
11. COMMON MID-POINT GATHERS
    INLINES: 1-30 CROSS-LINES: 1-212
12. PASS 1: VELOCITY AND MUTE ANALYSIS
13. PASS 1: NORMAL MOVEOUT CORRECTIONS AND MUTE APPLICATION
14. PASS 1: SURFACE CONSISTENT AUTOMATIC STATICS APPLICATION
15. PASS 2: VELOCITY AND MUTE ANALYSIS
16. PASS 2: NORMAL MOVEOUT CORRECTIONS AND MUTE APPLICATION
17. PASS 2: SURFACE CONSISTENT AUTOMATIC STATICS APPLICATION
18. LINEAR VELOCITY NOISE ATTENUATION
19. TIME-VARIANT AMPLITUDE SCALING
20. FINAL PASS: VELOCITY AND MUTE ANALYSIS
21. FINAL PASS: NORMAL MOVEOUT CORRECTIONS AND MUTE APPLICATION
22. FINAL PASS: SURFACE CONSISTENT AUTOMATIC STATICS APPLICATION
23. CDP CONSISTENT TRIM STATICS
24. COMMON MID-POINT STACK
25. FINAL DATUM CORRECTION
    DATUM: 900 FT
    VC: 4000 FT/SEC (S-wave)
    VC: 8000 FT/SEC (P-wave)
26. SPECTRAL BALANCING: 20-200 HZ (S-wave) 40-300 HZ (P-wave)
27. FX-Y 3-D PREDICTIVE DECONVOLUTION FILTER

4.1.4 Data Analysis and Interpretation

Depth Calibration

When processing and interpreting seismic data, it is important that the data be correlated with borehole or drill log data. BBCC provided drill log data dated January 26, 2005. This drill log information consisted of identified strata and their respective depths for all the initial boreholes. "Ground truth" is important in the interpretation of seismic reflection data where the reflecting events are mapped in time and need to be correlated to specific geologic strata. To accurately estimate the depth of reflecting strata, detailed knowledge of subsurface velocities is required. While some information can be obtained from stacking velocities estimated during the processing of seismic reflection data, these velocities are only approximations of the true subsurface velocities. Therefore, the seismic data were referenced to drill log data to add confidence to the correlation of reflection events to geologic strata.

Typical P-wave velocities were chosen for changes in lithologies identified by the drill log to generate a vertical incidence model, or synthetic seismogram. Specifically, these velocities were assigned depth values for different lithologic intervals identified in the drill log. Figure 4-3 illustrates this concept on the HRPW data set. The drill log on the left represents the drill log from well 3K1N7W2 showing lithology and elevations above sea level. This well was located approximately 3600 ft to the northwest of the 3-D reflection survey site. The next figure to the right is a sonic log created after the assignment of velocities for selected lithologic units in the drill log. The sonic log is measured in depth below the ground surface (ft) and the velocity in ft per second. This log is then integrated and convolved to a selected wavelet to create a synthetic seismogram. This seismogram correlates to the seismic section on the right. The lithologic units identified on the drill log can then be used to interpret horizons in the seismic section.

Interpretation

Figure 4-4 is a map showing anomalies identified under the 3-D grid from the visual inspection of the inline and crossline seismic P-wave data. These anomalies are shown as blue strips on the map. Inline data are seismic sections that are taken from "profiles" oriented parallel to the receiver lines. Inline profiles were used primarily because their longer length made the interpretation easier to perform than the shorter crossline profiles. The following criteria were used to identify anomalies in the seismic reflections that represented the coal seam:

- Attenuation of the reflection.
- Changes in the character of the reflection. This includes apparent phase changes, conversion of the primary peak/trough to a peak/trough/peak or other changes.
- Changes in attributes associated with the reflection, including instantaneous phase, amplitude envelope, and instantaneous frequency.

A box represented by dashed gray lines drawn inside the boundaries of the 3-D grid (Figure 4-4). This box represents the statistical reliability of the subsurface seismic data. All seismic surveys require some distance from the boundaries of the survey to build up statistics of measurement in the subsurface. This rectangle represents the zone of reliability in the interpreter's opinion. That is, data inside this box have sufficient statistical redundancy (fold) to provide a reliable interpretation. Data outside this box are less reliable due to lower statistical redundancy (lower fold). This reduction in fold toward the edges of the survey occurs with all seismic reflection surveys.

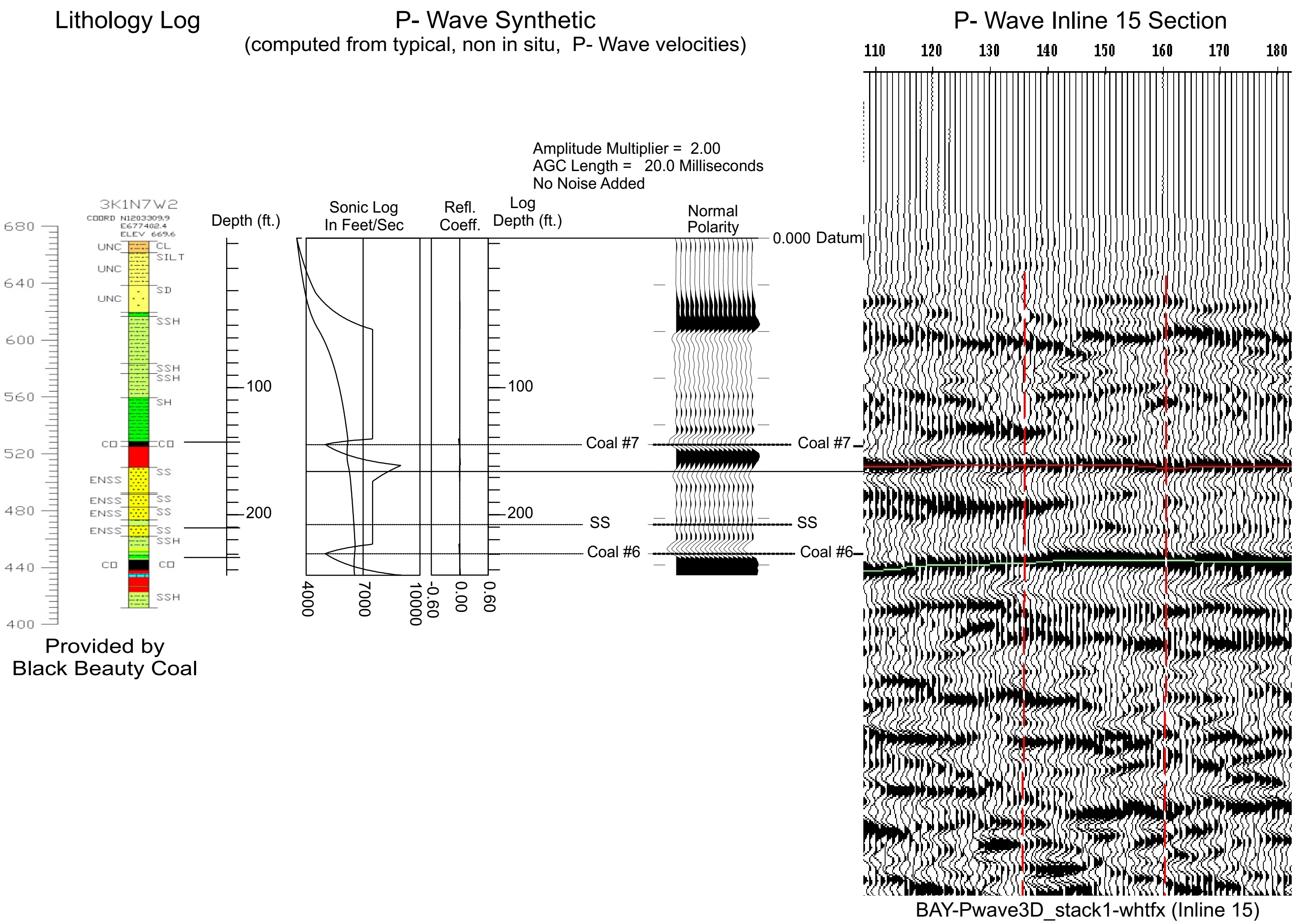
Color bars within the grid represent anomalous areas that were observed on each inline vertical slice based on the character and/or amplitude changes in the reflection that represents the Herrin #6 coal. These anomalous responses are interpreted to represent potential abandoned mine works, as follows:

- Anomaly Group #1 corresponds relatively well to the assumed location of the north-south mains.
- Anomaly Group #2 corresponds to the assumed location of the west submains.
- Anomaly Group #3 is weaker in correlation to the assumed locations of the mains and submains when compared to Anomaly Groups #1 and #2. This may be attributed to geologic features or other anomalies not related to mining.

Three-dimensional data allows additional analysis, which cannot be done with 2-D data. Each subsurface point represents a bin, or pixel, at various points in time. In other words, each pixel represents a cube in space that is centered on coordinates x, y, and time. Thus, it is possible to perform spatial analysis on the data. Maps showing various values of the seismic data can be constructed either as flat horizontal sections of time called time slices or following specific reflection events identified by the seismic interpreter. The difference between theses two types of maps is shown in Figure 4-5. A combination of volumetric/spatial analysis and standard interpretation techniques using vertical slices were employed on the 3-D data sets.

The data can also be interpreted by inspecting vertical slices of the 3-D data set. These vertical slices are displayed the same as any typical data sample: wiggle trace or other attribute format. These displays are cross-sectional type formats, with the exception that the vertical axis is time as opposed to depth. Figure 4-6 shows a vertical slice from the P-wave 3-D data set. Note that vertical slices may be taken in any direction from the 3-D data set.

- A section oriented parallel to the receiver lines on the surface is called an inline profile.
- A section oriented parallel to the source lines on the surface is called a crossline profile.
- A section oriented in any other direction is called an arbitrary profile. Arbitrary profiles do not necessarily have to be straight. They can be "zigzagged" and are similar to a fence diagram in engineering or geologic studies.



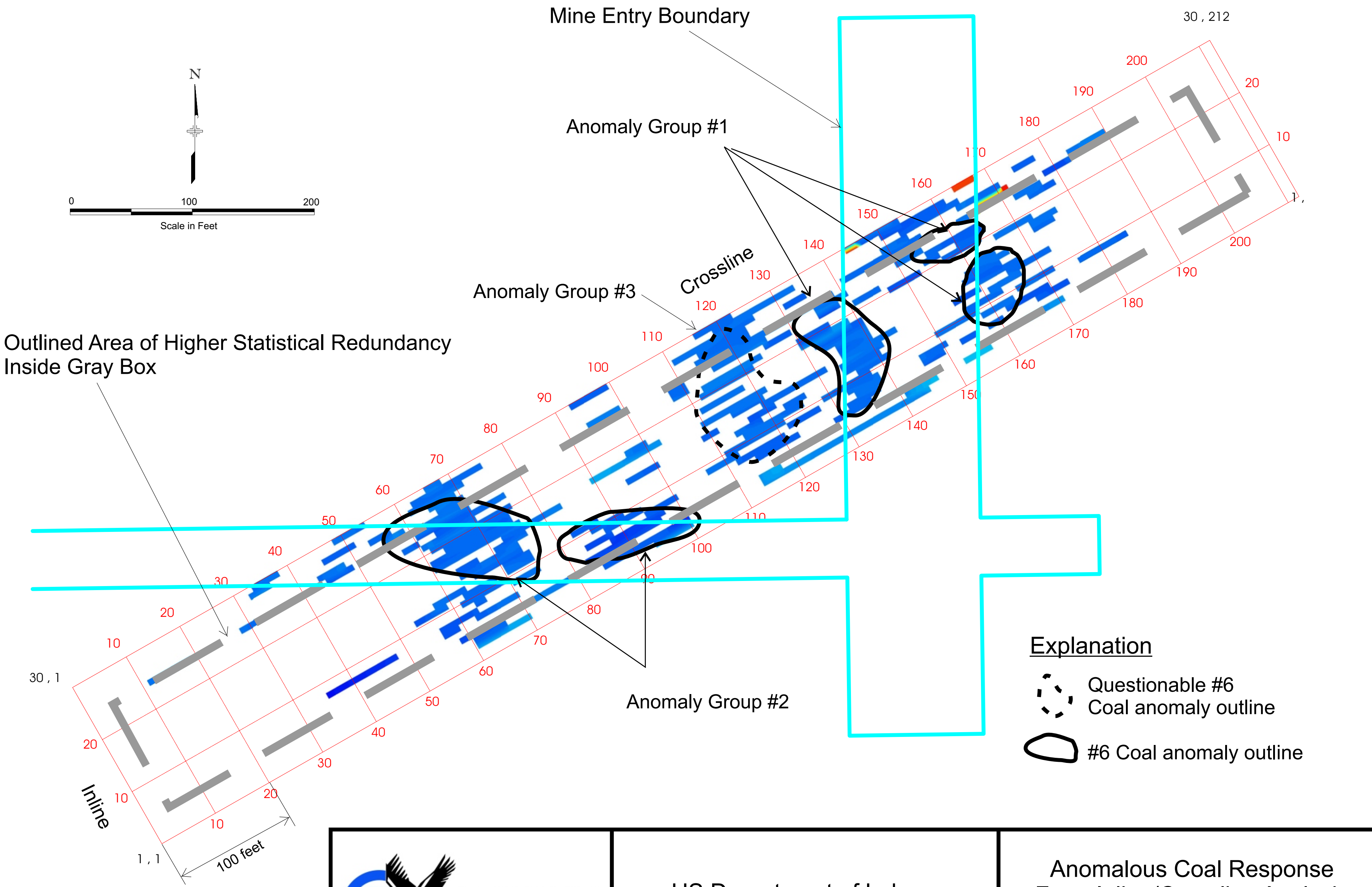
BLACKHAWK
A DIVISION OF ZAPATAENGINEERING

301 Commercial Road, Suite B
Golden, Colorado 80401
Phone: (303) 278-8700
Fax: (303) 278-0789
Web: www.blackhawkgeo.com

US Department of Labor
Mine Safety and Health Administration

Correlation of Lithology Log to P-Wave Seismic
Riola Mine Complex
Vermilion County, Illinois

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5006	June, 2006	HJV	KH	As Shown	4-3



BLACKHAWK
A DIVISION OF ZAPATA ENGINEERING

301 Commercial Road, Suite B
Golden, Colorado 80401
Phone: (303) 278-8700
Fax: (303) 278-0789
Web: www.blackhawkgeo.com

US Department of Labor
Mine Safety and Health Administration

Anomalous Coal Response From Inline/Crossline Analysis
Riola Mine Complex
Vermilion County, Illinois

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5006	June, 2006	HJV	KH	As Shown	4-4

The red and yellow colors on Figure 4-6 are interpreted as the Danville # 7 and Herrin # 6 coal seams, respectively. The seismic signature shows a high-amplitude anomaly in response to the general location of the north-south mains, but does not identify the location of the east-west submains.

FIGURE 4-5 COMPARISON OF TIME SLICE VS REFLECTION HORIZON SLICE

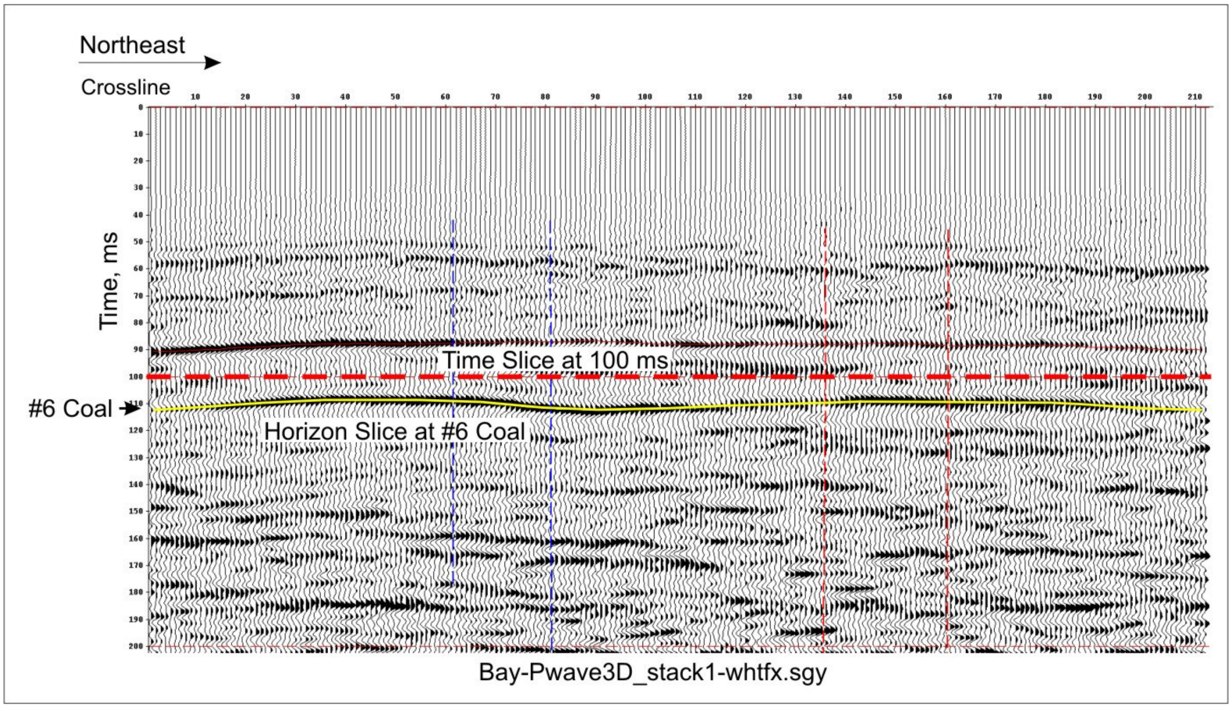


Figure 4-7 is a vertical slice of the S-wave data displayed in trace amplitude mode with a white to black colored transform. The darker (black) areas represent a positive amplitude reflection while the lighter areas represent a negative amplitude reflection. Note that the darker reflection identified in yellow is interpreted as the Herrin coal #6. The reflection of this formation weakens from crossline 140 to the end of the vertical slice at crossline 210. This is caused by poor coupling of the geophones and vibrator source through the recently plowed field along the northeastern portion of the 3-D grid. The loss of the reflection event due to the poor coupling occurs over all the data collected above the north-south mains.

Figure 4-8 is a map of the Herrin #6 coal seam P-wave reflection amplitudes (RMS) as derived from the seismic workstation. This amplitude was calculated by averaging the data values five milliseconds both above and below the reflection picked by the interpreter. A map using the same process was also developed from the S-wave data set and is shown on Figure 4-9. This map has the same features as Figure 4-4 in that a dashed box shows the area of most reliable data based on statistical redundancy. In this case, the anomalies are obvious. Anomalous reflection amplitudes are shown as blue to black regions on the map. Again, the north south mains are relatively well defined (within the statistical box). The submains are somewhat less well-defined. A zone slightly to the north of the west submains also exhibits an anomalous response.

FIGURE 4-6 EXAMPLE OF VERTICAL SLICE FROM P-WAVE DATA 3-D DATA SET

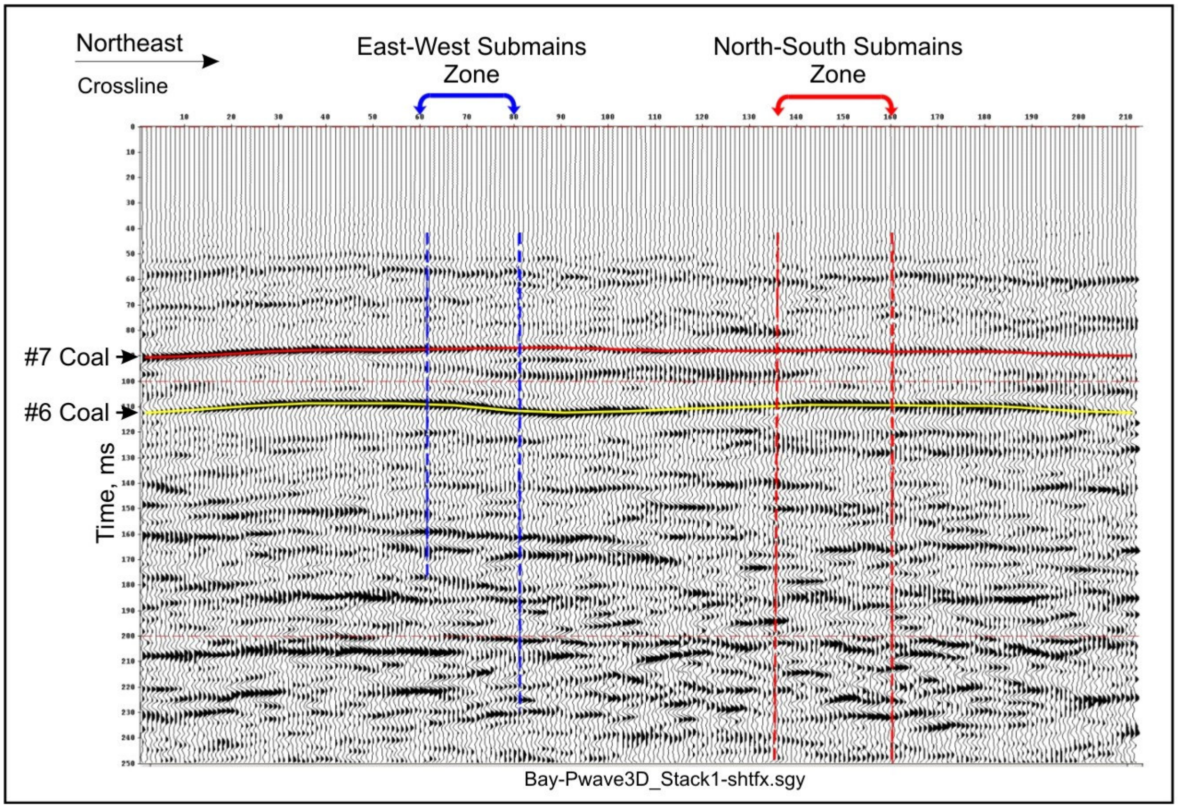
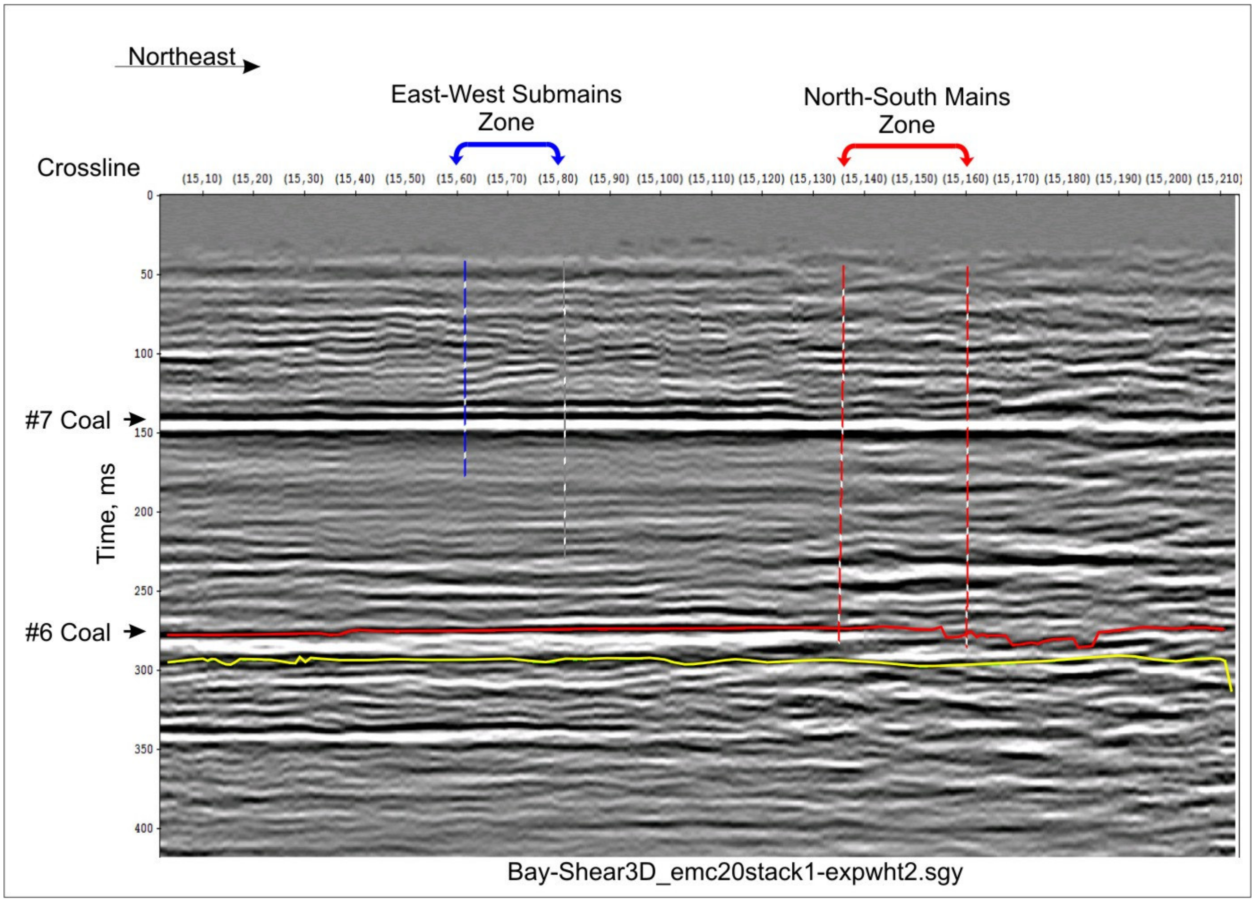


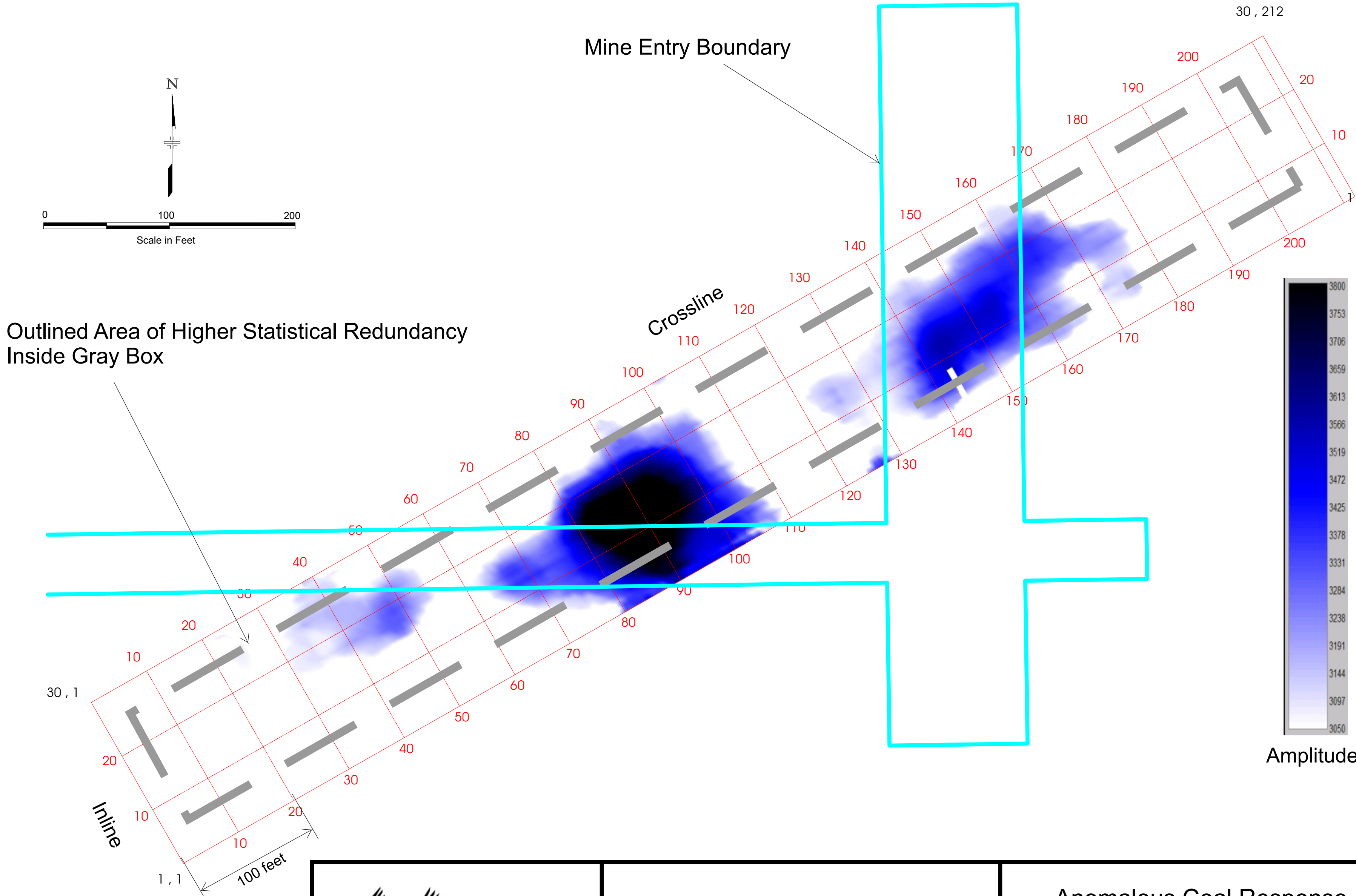
Figure 4-9 is a map of the interpreted Herrin #6 coal S-wave reflection RMS amplitudes. This map resembles the amplitude outline derived from the Herrin #6 P-wave coal reflection in Figure 4-8. The anomalous reflection amplitudes are colored blue to black on Figure 4-9 as well, with the blue to black zones being roughly the same size and having the same locations calculated for the P-wave.

In reviewing Figures 4-6 through 4-9 the P-wave method obtained clear reflection from the upper Danville #7 coal seam and the target Herrin #6 coal horizons with consistent data quality. Amplitude variations are noticed around the old mine works, but also extended out of the area of the old mine works (Figure 4-6 and 4-8). These amplitude anomalies may correspond to old mine works not shown on the historical mine map or to geologic features not related to mining. The S-wave method obtained some reflection data from the Danville #7 coal horizon, but very little information was obtained from the Herrin #6 coal horizon. This is due to the high reflection coefficient of the Danville #7coal that limited the transmission of the S-wave seismic energy below it. A second shear wave MicroVib source was used to increase the source energy output. This increased the signal-to-noise levels of the reflections from the Herrin #6 to produce the amplitude interpretation on Figure 4-9.

It should be noted that the P-wave data, and to a lesser degree the S-wave data, did identify the general area of the old mine works, but neither of the methods identified the location of the individual rooms (voids) and/or pillars. The amplitude response seen in the P and S-waves data is the result of the combined effect of the rooms and pillars. Because of this limited resolution, no attempts were made to use the data set to interpret the void content.

FIGURE 4-7 EXAMPLE OF VERTICAL SLICE FROM S-WAVE DATA 3-D DATA SET





BLACKHAWK
A DIVISION OF ZAPATAENGINEERING

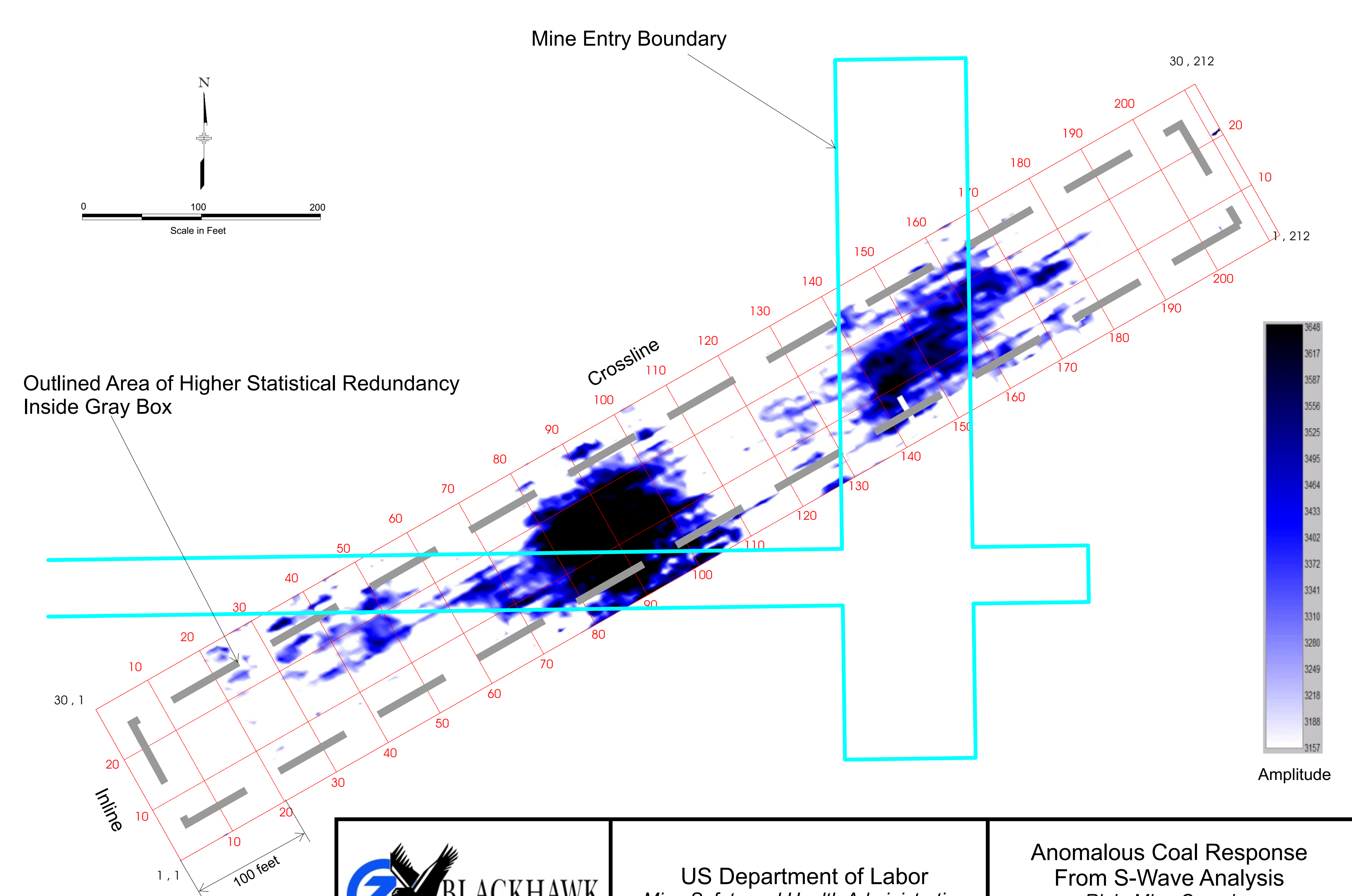
301 Commercial Road,
Suite B
Golden, Colorado 80401

Phone: (303) 278-8700
Fax: (303) 278-0789
Web: www.blackhawkgeo.com

US Department of Labor
Mine Safety and Health Administration

Anomalous Coal Response
From P-Wave Analysis
Riola Mine Complex
Vermilion County, Illinois

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5006	June, 2006	HJV	KH	As Shown	4-8



BLACKHAWK
A DIVISION OF ZAPATAENGINEERING

301 Commercial Road,
Suite B
Golden, Colorado 80401

Phone: (303) 278-8700
Fax: (303) 278-0789
Web: www.blackhawkgeo.com

US Department of Labor
Mine Safety and Health Administration

Anomalous Coal Response From S-Wave Analysis

Riola Mine Complex
Vermilion County, Illinois

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5006	June, 2006	HJV	KH	As Shown	4-9

4.1.5 Conclusions and Recommendations

Conclusions

The P-wave data may have imaged the general area of the old mine works. However, it was not possible to distinguish anomalies caused by the old mine works from other anomalies not related to mining and possibly caused by the thinning of the coal beds, presence of rolls, and / or variations in the vertical and horizontal stresses in the coal seam. The anomaly north of the submains was further investigated during the void confirmation program discussed in *Section 5.0 Void Confirmation*. Boring in this area had confirmed a five ft thin coal seam, being less than seven ft, might be indicative of presence of rolls in the mine roof.

We believe there was narrowly sufficient spatial sampling to identify the abandoned works. A spatial resolution trade-off had to be made in order to obtain 3-D data and in order to fit equipment capabilities and other logistical issues. Therefore, it was necessary to increase the surface receiver interval to 10 ft as opposed to the five ft that was used in a previous 2003 survey, which was performed by Bay Geophysical for BBCC at Vermilion Grove. A bin spacing of five by five ft was obtained, versus the 2.5 ft CDP spacing used on the first data set. When comparing the two data sets, the lateral resolution was adequate to identify the works but not adequate to identify individual rooms and pillars.

The shear wave amplitude anomalies showed less correlation with the old mine works than the compressional wave anomalies. This is likely due to the low signal-to-noise ratios for the reflections recorded from the Herrin #6 coal in the HRSW data.

If reflection seismic is to be used to identify old mine works in a coal seam having this thickness, it must provide bandwidth at a minimum in the 100-300 hertz range. Analysis of the data at frequencies less than 150 hertz did not provide indications of anomalies in the coal seam that can be correlated to known voids.

The S-wave survey imaged the general location of the old mine works but was less successful than that the P-wave survey. The reflection from Herrin #6 coal seam was observed, but was too weak beyond crossline 140 to provide analytical data. It appears that much of the S-wave energy was absorbed by the recently plowed fields in this area. The reflection from the Herrin #6 coal is weaker than the upper Danville #7 coal. Each successive reflection removes energy that propagates downward toward deeper strata. The P-waves experienced much less attenuation because the velocity contrasts at these two interfaces are not nearly as large in magnitude. The reflection coefficient of the soil/bedrock interface for an S-wave is calculated to be 70%, while it is only 50% for a P-wave. The reflection coefficient at this interface is much larger because the Vp / Vs ratio in unconsolidated materials is approximately 5:1 while this ratio in sandstone is only approximately 2.5:1. This implies that the reflection coefficient for S-waves is more than double that for P-waves at the overburden-bedrock boundary. Although two vibrators were deployed during S-wave data acquisition to compensate for this loss of energy, the seismic energy was still insufficient to adequately compensate for the signal loss.

Recommendations

- Borehole confirmation of this method will be necessary because the occurrence of false positives will always be a possibility. The amplitude map shown on Figure 4-7 was used for void confirmation discussed in *Section 5.0 Void Confirmation.*
- Swath acquisition using parallel receiver lines could be used where the coal mine orientation is not known to improve the detection of voids that are parallel to the line orientation.
- The cost of a 3-D survey is nearly five times as much as that of a single 2-D profile. Therefore, it would be as economical to run five 2-D profiles side-by-side, particularly if the approximate orientations of the entries are known.
- Surface reflection methods can be used with more reliability in areas where the coal seam of interest is shallower and preferably the shallowest coal seam in the section.

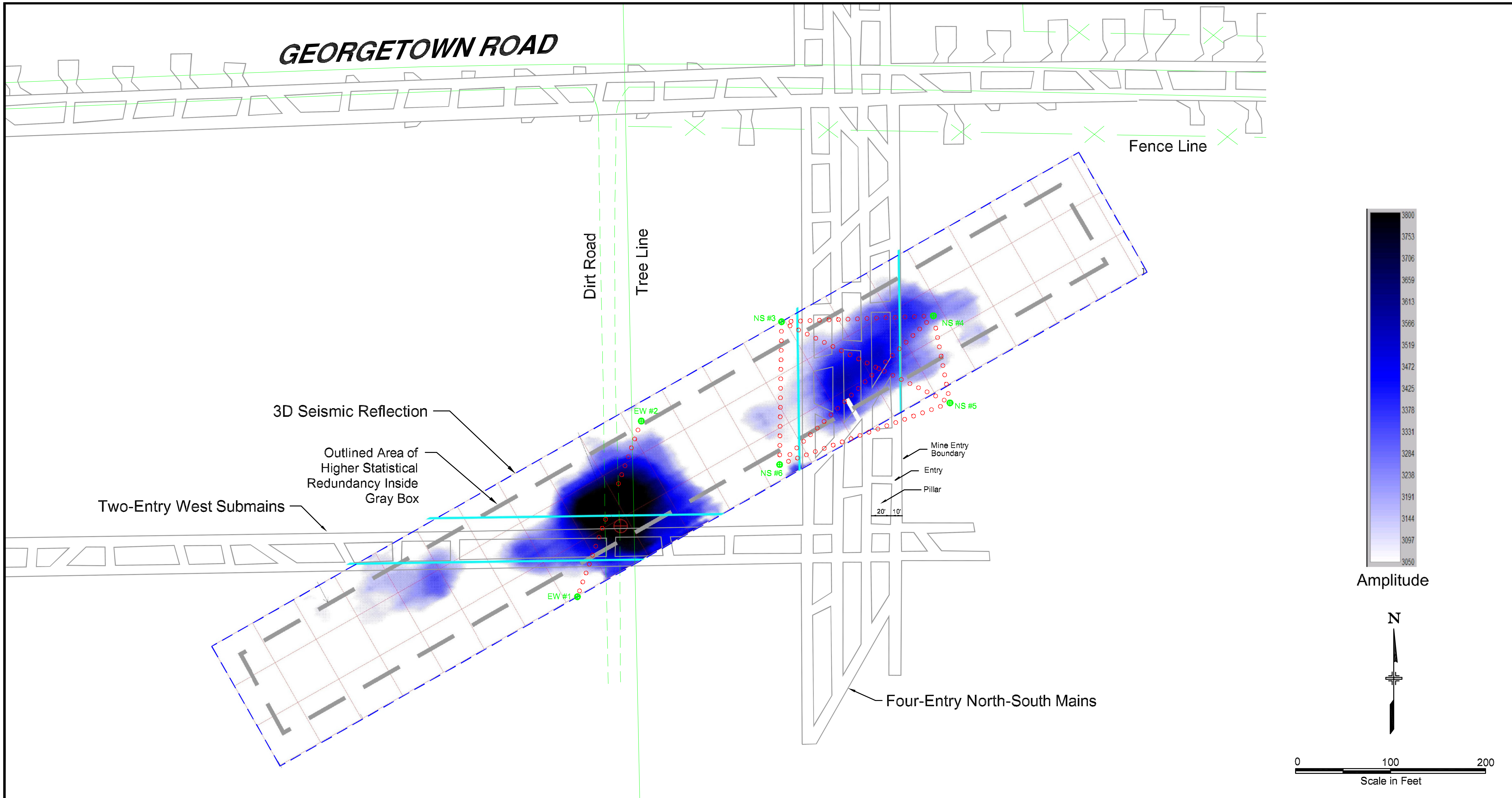
4.2 CROSSHOLE TOMOGRAPHY AND GUIDED WAVES METHODS

4.2.1 Survey Design

The XHT survey design was based on the HRS reflection anomalies and the mapped location of the old mine works relative to the historical mine map. As shown on Figure 4-10, the six boreholes were labeled in accordance with the east-west submains and north-south mains, as EW #1, EW #2, and NS #3, NS #4, NS #5 and NS #6, respectively. In an attempt to avoid drilling into possible void areas, a 25- to 35- ft boundary around the areas that exhibited high anomalies was established on the map as a "safe zone" for drilling. The boreholes were strategically located within this boundary zone, approximately 100 to 225 ft apart. The four boreholes (NS #3 through NS #6) located along the north-south mains were spaced so that a total of six 2-D topographic panels could be acquired and then be combined to create a 3-D tomogram. The other two boreholes (EW #1 and EW #2) were located on either side of the east-west submains and provided only a 2-D tomogram. The fieldwork was conducted April 20 through 28th, 2005, by a combination of crews composed of geophysicists from Blackhawk and Walker Marine, and drilling by Magnum Drilling.

4.2.2 Data Acquisition

As with all seismic methods, the critical components of the seismic surveys are the energy source, the recording device (seismograph), receivers, and the geometry. The following section will highlight the equipment that was used.



BLACKHAWK
A DIVISION OF ZAPATAENGINEERING

301 Commercial Road, Suite B
Golden, Colorado 80401
Phone: (303) 278-8700
Fax: (303) 278-0789
Web: www.blackhawkgeo.com

US Department of Labor
Mine Safety and Health Administration

XHT Borehole Location Map Overlaid on HRS Image
Riola Mine Complex
Vermilion County, Illinois

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5006	June, 2006	HJV	KH	1" = 100'	4-10

4.2.2.1 Instrumentation

Seismic Source

The source used for this survey was a Bolt DHS 5500 airgun with a 2.5 cubic-inch air chamber. The Bolt DHS 5500 air gun is a high frequency impulsive source that creates an energy burst by releasing high-pressure air in a controlled manner. The unit is designed to fit into 4-in diameter boreholes and non-destructively create the energy. The unit can be powered using an air compressor or, as in this case, using bottles of compressed air (three standard 80 cubic-inch scuba tanks.)

Seismograph

The seismograph that was used was a 52-channel system custom built for Walker Marine. It consisted of multiple A/D boards built into a personal-computer-based system. It recorded the signals at a sample rate of 0.1 ms (5,000 Hz Nyquist Frequency) for accurate timing and accurate recording of the seismic waves beyond the maximum frequency generated by the source.

Seismic Sensors

For this survey, two types of seismic sensors were used. For the downhole receivers, a 12-channel hydrophone string with one ft hydrophone spacing was used. Surface geophones were also deployed along a line between the boreholes. The geophones (40 Hz Mark Products) were deployed (where possible) at 10 ft intervals.

4.2.2.2 Data Acquisition Parameters

Data acquisition occurred over a nine-day period, April 20th through 28th, 2005. The data were acquired by locating the hydrophone string within the receiver hole and then acquiring a seismic record for all of the shot locations in the shot borehole. For the tomographic panel between EW #1 and EW #2, a shot spacing of two ft was used, and for all the remaining tomographic panels, a nominal spacing of five ft was used with a one ft source spacing bracketing the three coal seams (Springfield #5, Herrin #6 and Danville #7). The depths were measured from the top of the casing and then later converted to the proper elevations.

A summary of the data acquisition parameters and equipment used is in Table 4-3.

TABLE 4-3 XHT ACQUISITION PARAMETERS AND EQUIPMENT

Seismograph	Custom built 52-channel pc-based system	0.1 ms sample rate
Hydrophones	12-channel	1 foot spacing
Geophones	40 Hz. Mark Products – 1	10 foot spacing
Source	Bolt 550 borehole airgun with 2.5 cubic inch chamber	10 total shots acquired per source depth

The data were recorded onto a hard drive on the seismograph after every seismic shot record and then backed up on a CD at the end of each day.

4.2.2.3 Data Quality

Data quality obtained from the XHT survey was variable, with the first break arrivals clearly visible on many of the records. Because the borehole spacing was relatively wide, up to 225 ft between boreholes, the signal-to-noise ratio was low, especially on traces with high angle offsets and where the signal had to cross multiple coal seams. The problem was compounded by high levels of electronic noise in the equipment due to the presence of power lines at the site.

4.2.3 Data Processing

The XHT data were processed using two separate processors and data processing programs. This provided some comparison between the two processing methods and increased the potential for obtaining optimal results from the data. However, the processing flow was essentially the same for both processes, as follows:

- Import data from the recording system;
- Input geometry information (source and receiver locations);
- Short traces into common shot gathers;
- Filter the data to optimize the picking of arrival times;
- Pick arrival times;
- Input arrival times and geometry information into tomographic inversion program;
- Run iterations of the tomographic program with varying velocities between each iteration until the root mean square (RMS) error between the observed travel times and the computed travel times reaches a minimum.

A Blackhawk geophysicist processed the data using GMA Plus to pick the first arrival times. The first arrival time data were then exported, reformatted and input into TomoSonic software where the final tomograms were generated.

Both 2-D and 3-D tomographic inversions were performed using the TomoSonic software when processing the data from the four boreholes located along the north-south mains (NS #3, NS #4, NS #5 and NS #6). Two-dimensional tomograms were generated between pairs of boreholes and then a 3-D tomogram was generated using all of the data collected from the four boreholes. For the pair of boreholes located on opposite sides of the west submains, only a 2-D tomographic inversion was performed.

Personnel at Summit Peak also processed the first break times data using proprietary programs developed at Summit Peak, but followed approximately the same processing flow as described earlier. Only 3-D tomographic inversions were performed using the four boreholes located along the north-south oriented mains.

4.2.4 Data Analysis and Interpretation

Representative tomographic inversion plots are shown below for both methods of processing. The plots shown below contain color contour representations of the velocities obtained from the tomographic inversions. The plots cannot be compared directly. However, in both representations, the "hotter colors" (reds and yellows) show higher velocity regions, and the "cooler" colors (blues and greens) show regions of lower velocity. Coal seams and voids should be indicated by the lower velocity colors because of their relatively low velocity compared to the surrounding strata.

Figure 4-11 shows the tomographic inversion from the Summit Peak inversion for the panel between the NS #6 and the NS #5 boreholes and Figure 4-12 shows the Blackhawk inversion results for the same location. The lower figure shows the same tomogram with the computed raypaths overlain.

In examining Figures 4-11 and 4-12, there are several features of the tomograms to note.

- The tomograms do not show consistent horizontal stratification as would be expected from the nearly flat-lying geology at the site.
- In general, the location of the low and high velocity zones in the tomograms did not correspond to the presence of coal seams (low velocity) and sandstone (high velocity). There is some indication of a low velocity layer near the Danville #7 coal seam and the low velocity overburden in Figure 4-11 (from Summit Peak processing.)
- There are no low velocity zones within the tomograms that would indicate the presence of voids or old mine workings.

Figure 4-13 is the velocity tomogram obtained from the Blackhawk panel between boreholes NS #3 and NS #4. The lower figure shows the same tomogram with the computed raypaths overlain. Figure 4-14 is a 3-D velocity tomogram (slice) at approximately 232 ft through the Herrin #6 coal seam overlain and aligned with north-south mains (from Blackhawk processing). The tomogram shows no indication of a low velocity zone except near borehole #6 and extending toward borehole #5.

The tomogram obtained from Summit Peak (Figure 4-15) shows a low velocity layer at a depth of approximately 139 ft, which corresponds to the depth of the Danville # 7 coal seam. However, there is no indication of a low velocity zone near the Herrin # 6 coal horizon (235 ft). The tomogram from the Blackhawk processing also shows a low velocity layer near the depth of the Danville #7 coal, but it is not as well defined as the Summit Peak tomogram. Again, no low velocity zone that indicates the presence of the Herrin # 6 coal, or any voids within that layer, is visible in the tomogram.

FIGURE 4-11 VELOCITY TOMOGRAM FOR PANEL BETWEEN BOREHOLES NS #5 AND NS #6

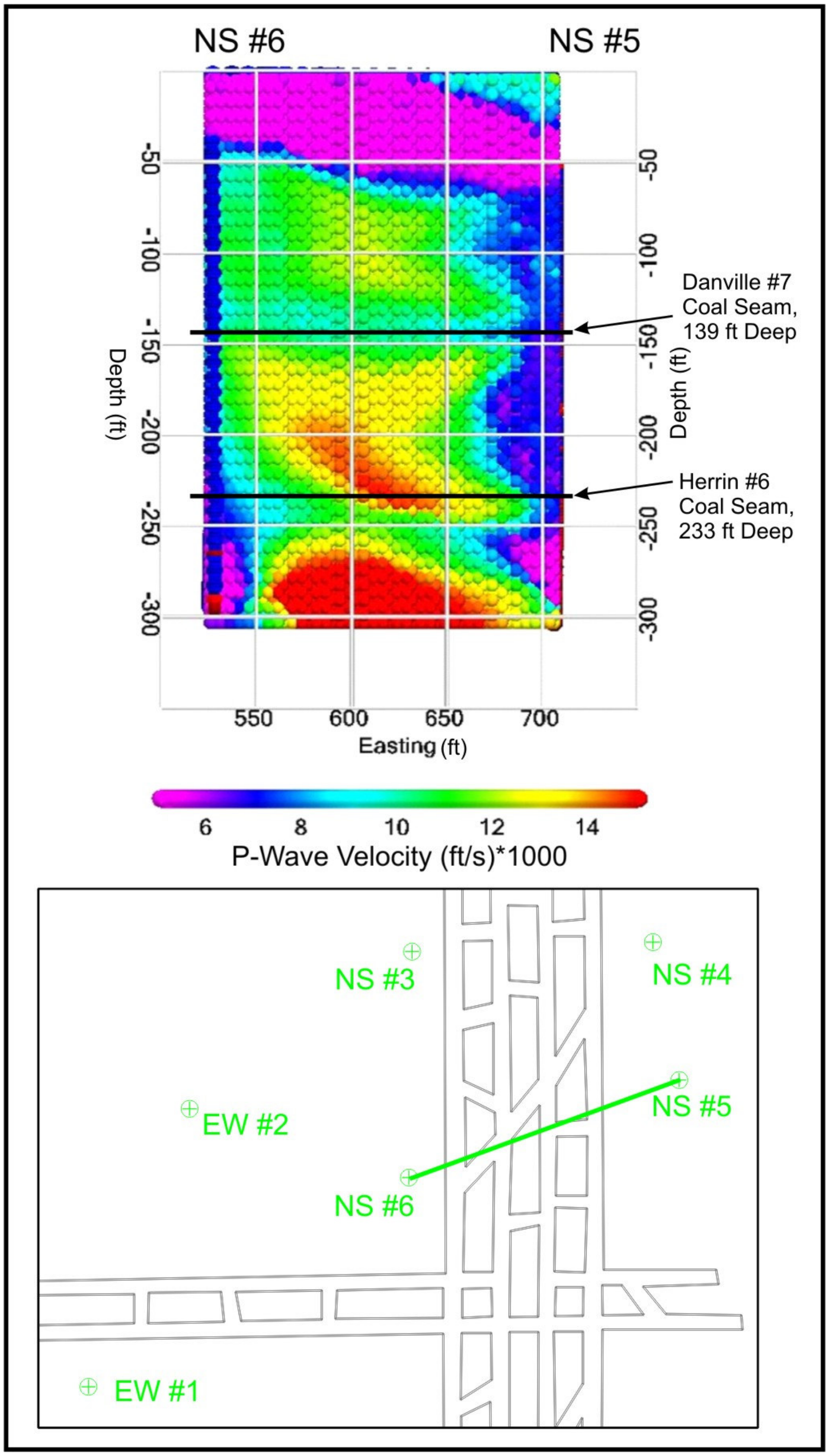


FIGURE 4-12 VELOCITY TOMOGRAM FOR PANEL BETWEEN BOREHOLES NS #5 AND NS #6

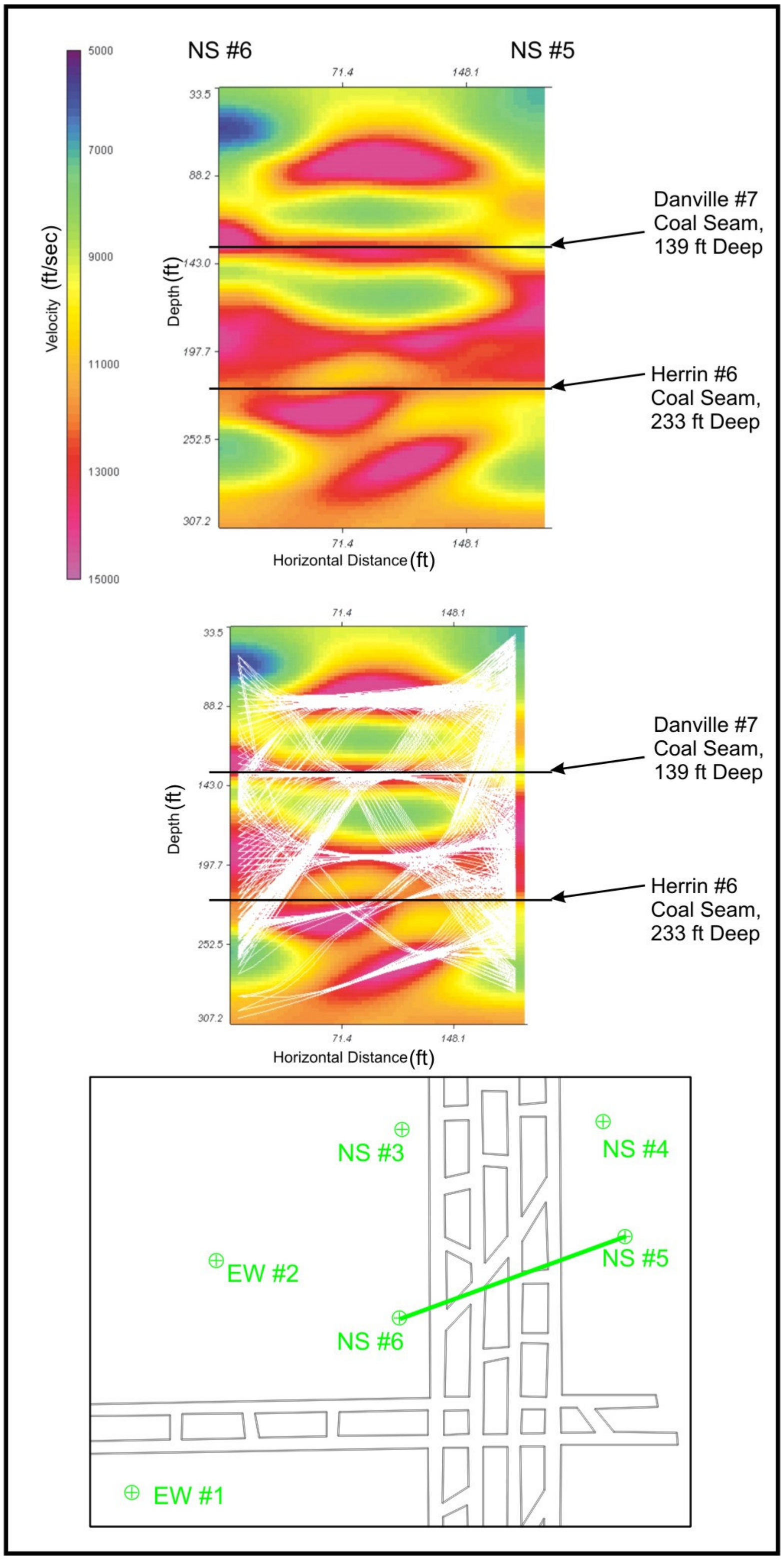


Figure 4-16 shows a perspective view looking from the SW (from the Summit Peak processing) for a slice through the tomographic volume at a depth of 235 ft (Herrin #6 coal seam depth). This figure does not reveal any low velocity zones that appear to correspond to the coal seam or to the north-south oriented mains, which bisects the area.

The results of the tomograms presented in Figures 4-13 – 4-16 are similar to the results shown in Figures 4-11 and 4-12. None of these figures indicate a low velocity zone near the depth of the Herrin #6 coal seam. Furthermore, there is no indication of the presence of voids.

4.2.5 Conclusions and Recommendations

Additional tomographic plots are provided in Appendix A; however, the figures shown in this section are representative of the results obtained for the overall survey. The results obtained from this survey show that the tomographic method was unable to image the Herrin #6 coal seam and the associated old mine works within the subsurface. This is likely due to several factors including the following:

- Larger than optimal spacing between the boreholes due to site access restrictions;
- High velocity layers above and below the Herrin #6 coal seam that were faster routes of travel than through the coal seam, and therefore masked the low velocity coal seam and related mine workings;
- Low data quality obtained at the depth of the Herrin #6 coal seam due to high levels of electrical noise and reduced data coverage due to the low signal-to-noise ratios in the high angle offset data and reduced depth of the wells due to borehole collapse filling the bottom of the holes.

The results of the XHT data set were not used to design the confirmation drilling. This method is not recommended for imaging small low-velocity targets bounded by high-velocity layers.

4.2.6 Guided Waves Survey

In conjunction with the XHT survey, the data obtained were also used as part of a seismic guided waves survey. A subset of the XHT seismic records, whose source depth corresponded to the depths of the coal seams within the section, was selected and analyzed. The records were analyzed for the presence of tube waves (in the receiver borehole), which, as discussed in *Section 3.2.5 Guided Waves Criteria and Limitations*, indicate that guided waves traveled from the source hole to the receiver borehole. Two example seismic records are shown below. These records were obtained with the seismic source at a depth of 235 ft BGS, which is the depth of the #6 coal seam. Figure 4-17 is the seismic guided waves record between boreholes NS #5 and NS #6, which has the north-south mains running between the two boreholes. Figure 4-18 is the seismic guided waves record between boreholes NS #4 and NS #5, which should have solid coal between the boreholes. The interpreted first arrival waves and tube waves are highlighted on the figures in blue and red, respectively. The tube waves are characterized by a low velocity event with linear moveout that originates at the first arrival.

FIGURE 4-13 VELOCITY TOMOGRAM FOR PANEL BETWEEN BOREHOLES NS #3 AND NS #4

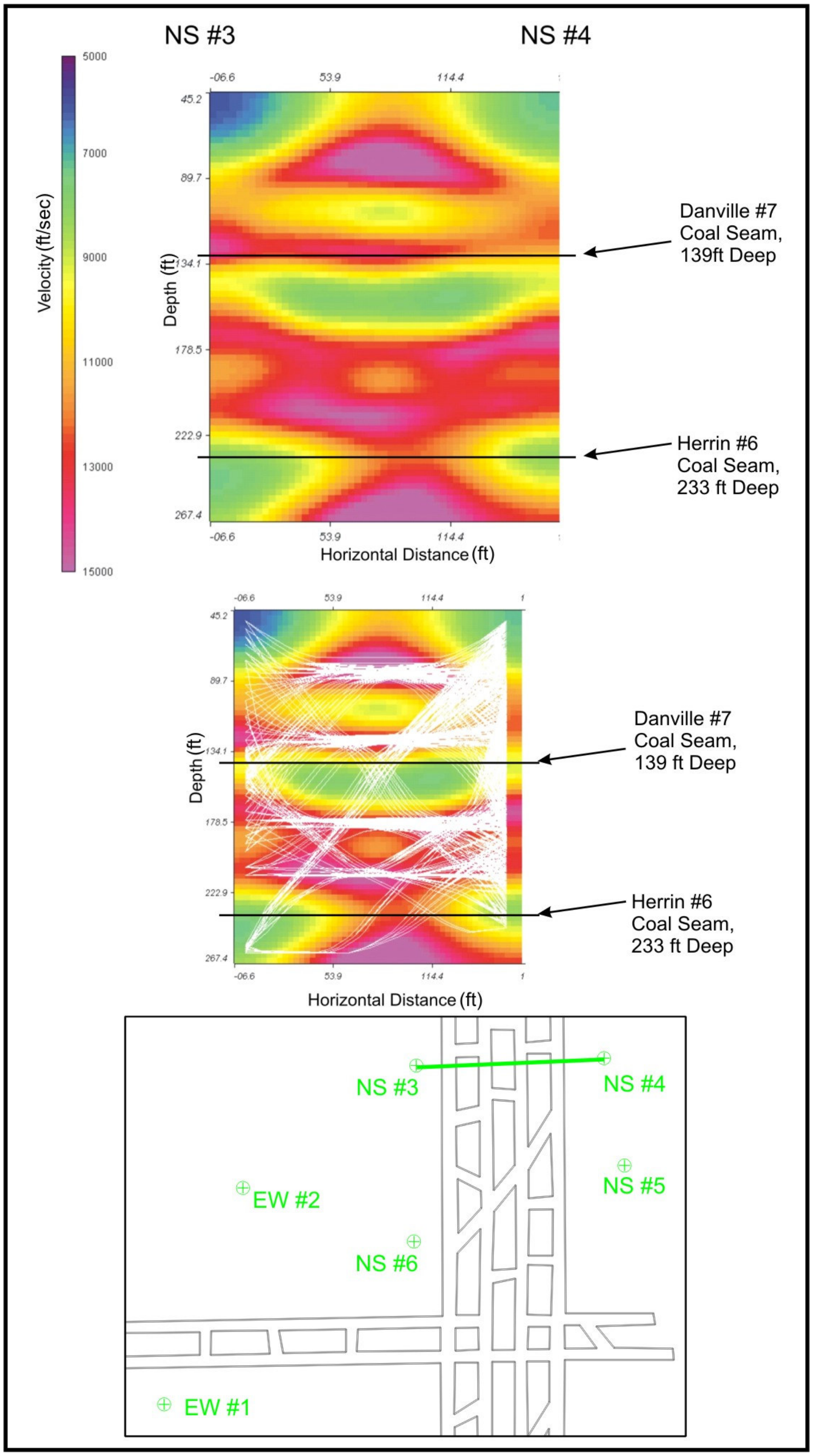


FIGURE 4-14 TOMOGRAPHIC 3-D RESULTS – DEPTH SLICE AT 232 FT THROUGH HERRIN #6 COAL SEAM

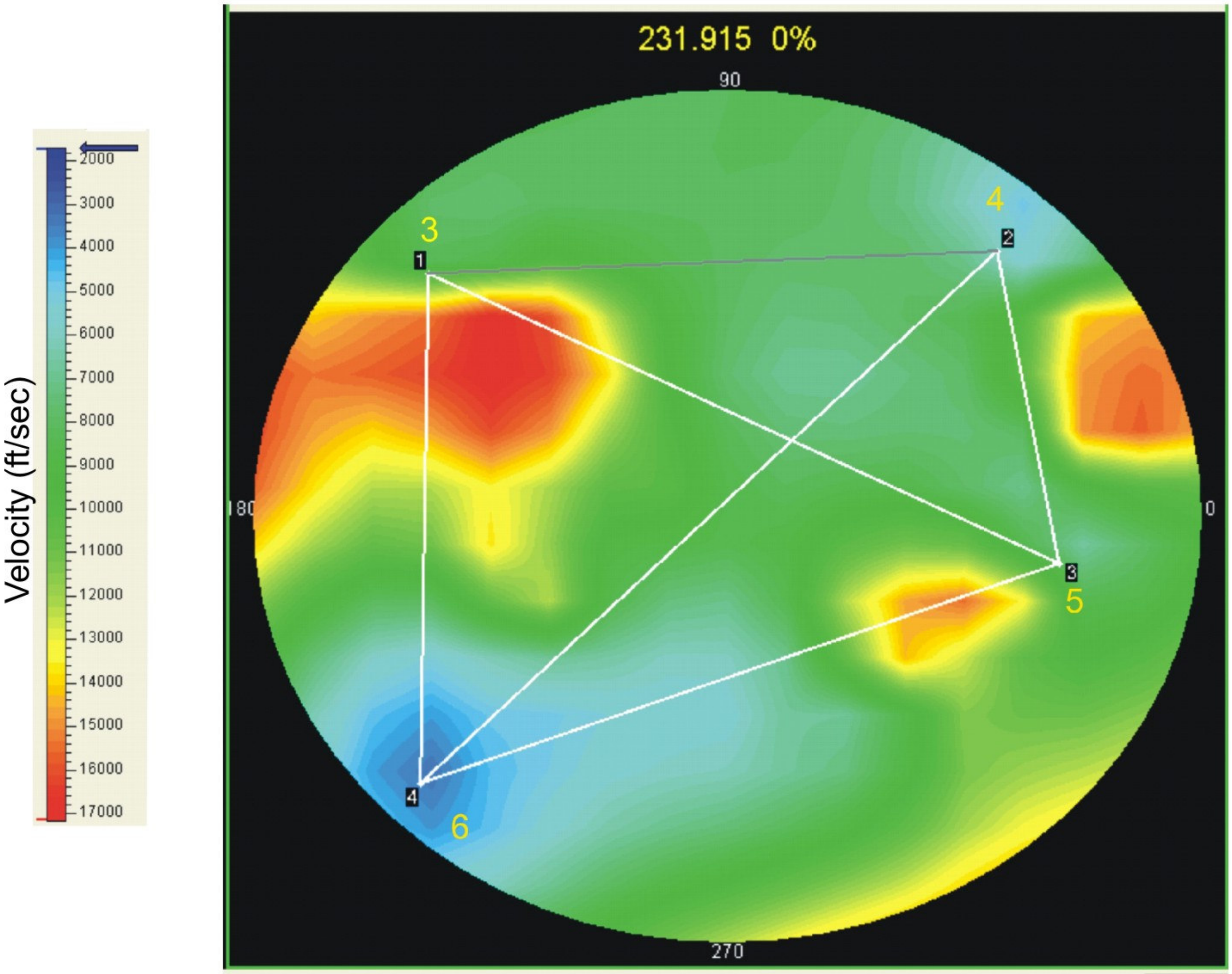


FIGURE 4-15 VELOCITY TOMOGRAM FOR PANEL BETWEEN BOREHOLES NS #3 AND NS #4

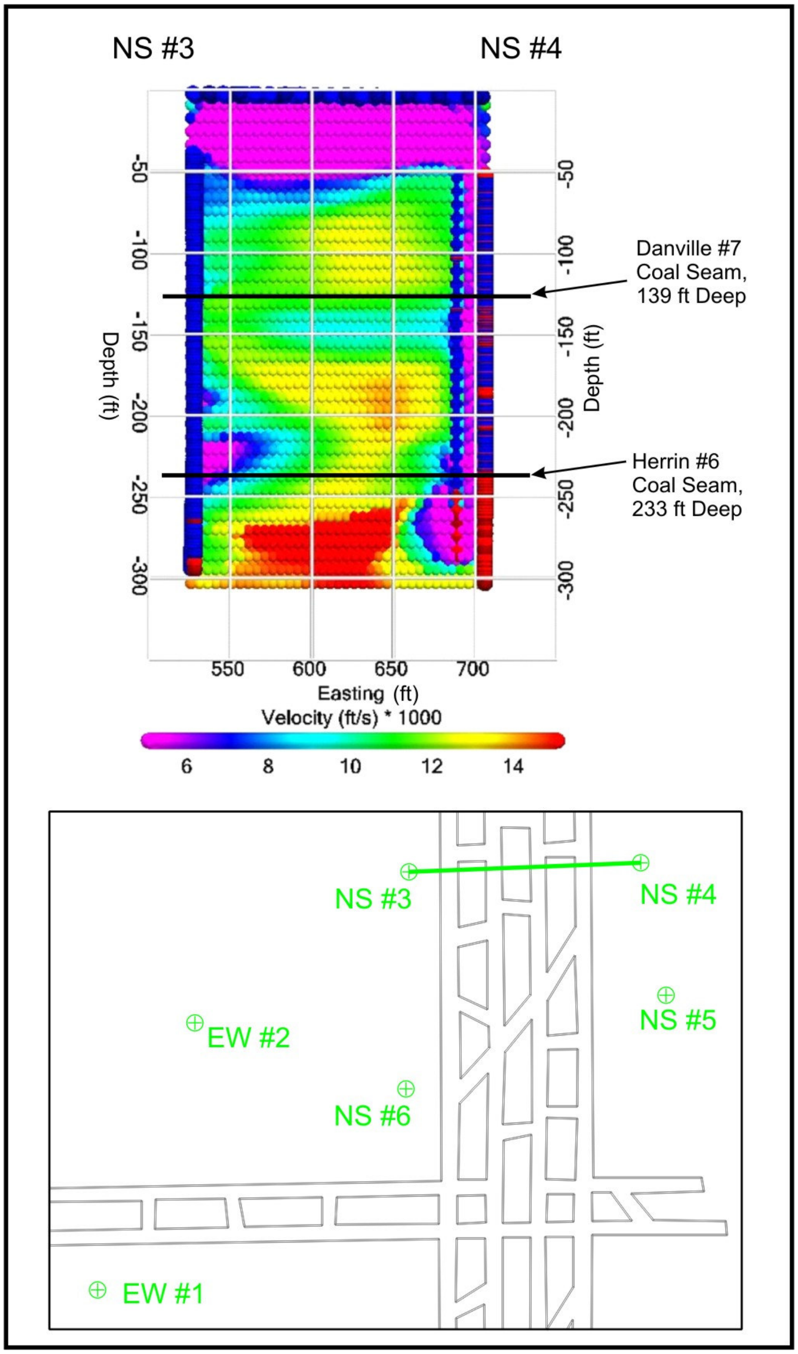


FIGURE 4-16 SW PROSPECTIVE VIEW OF SLICE THROUGH THE TOMOGRAPHIC VOLUME FOR BOREHOLES NS #3, NS #4, NS #5 AND NS #6

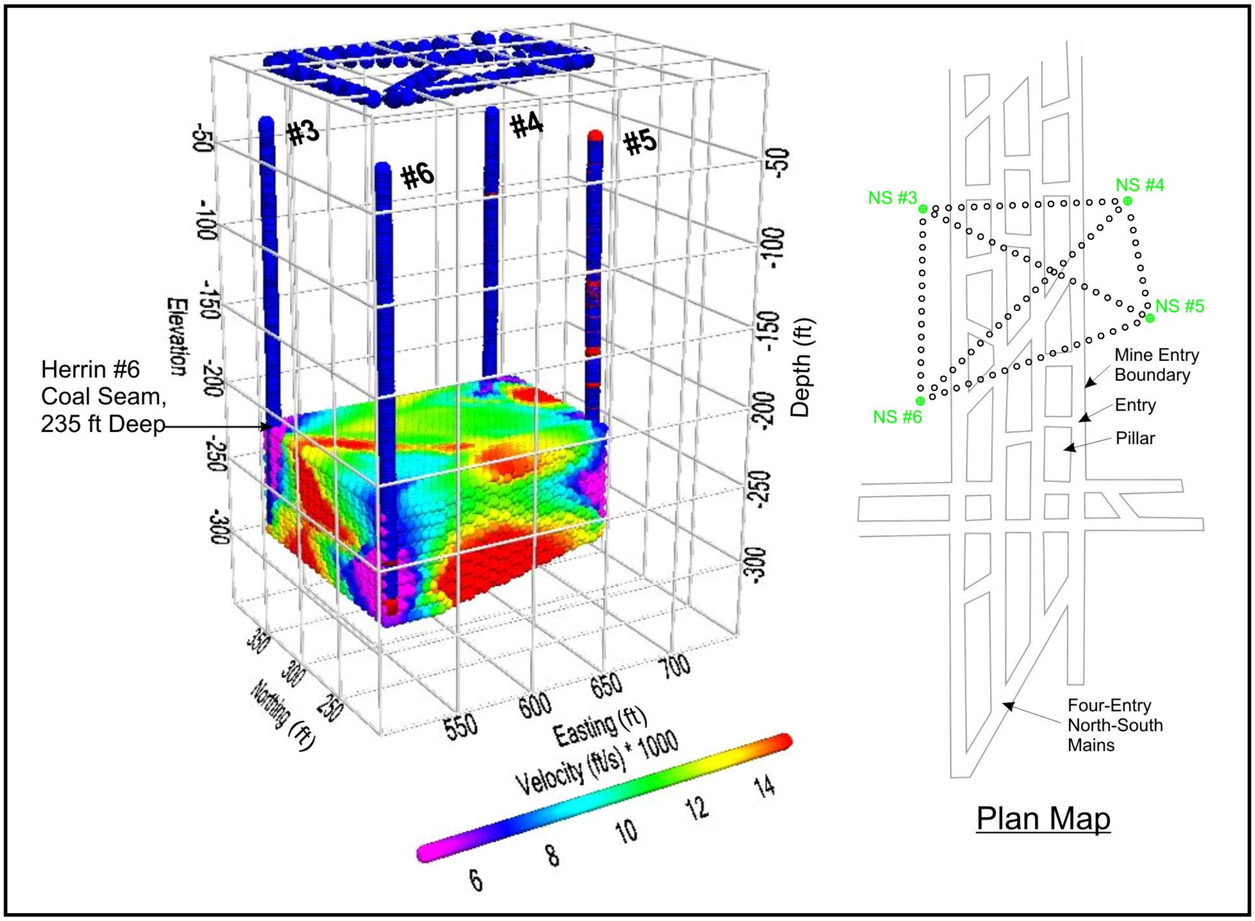
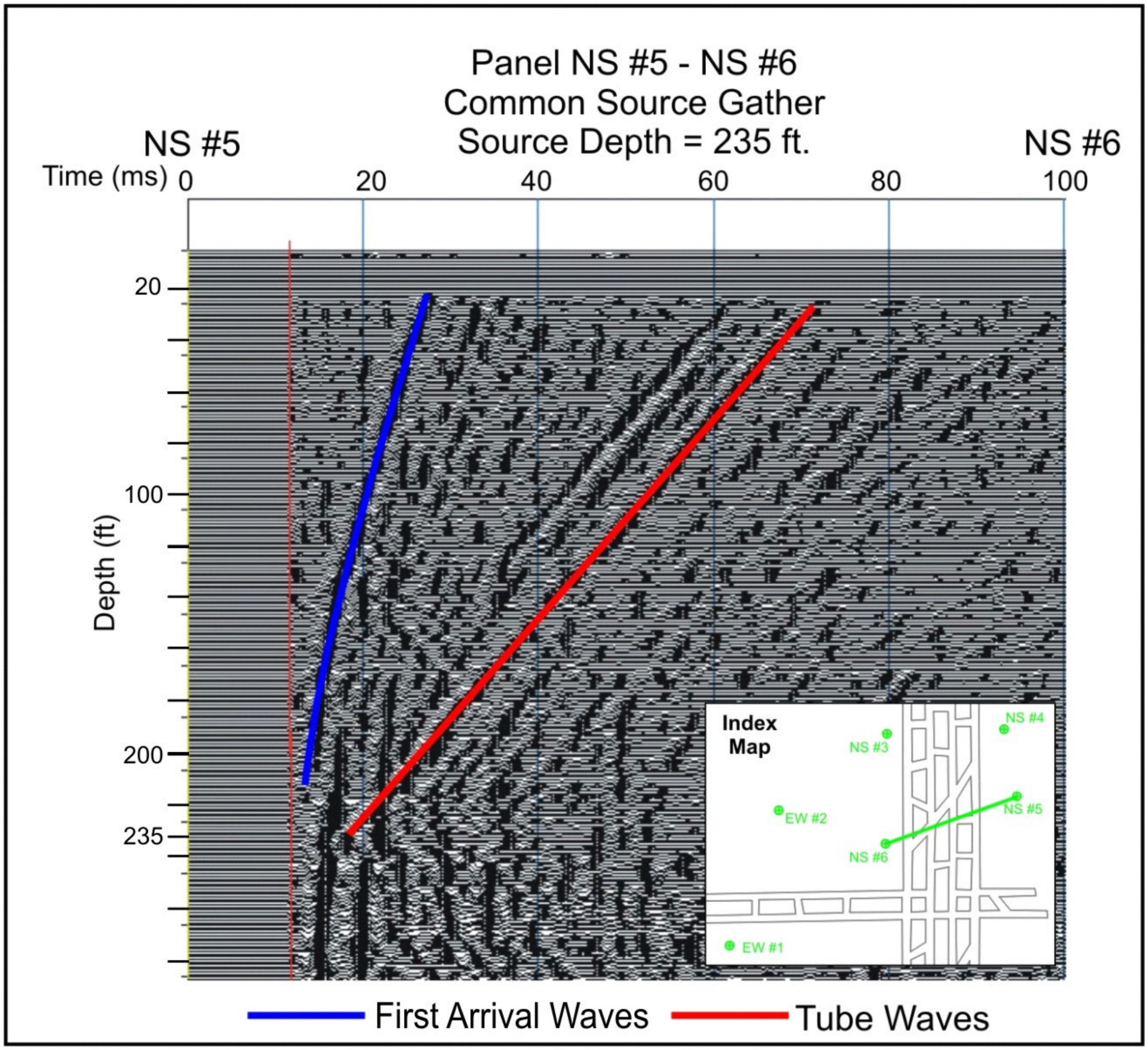


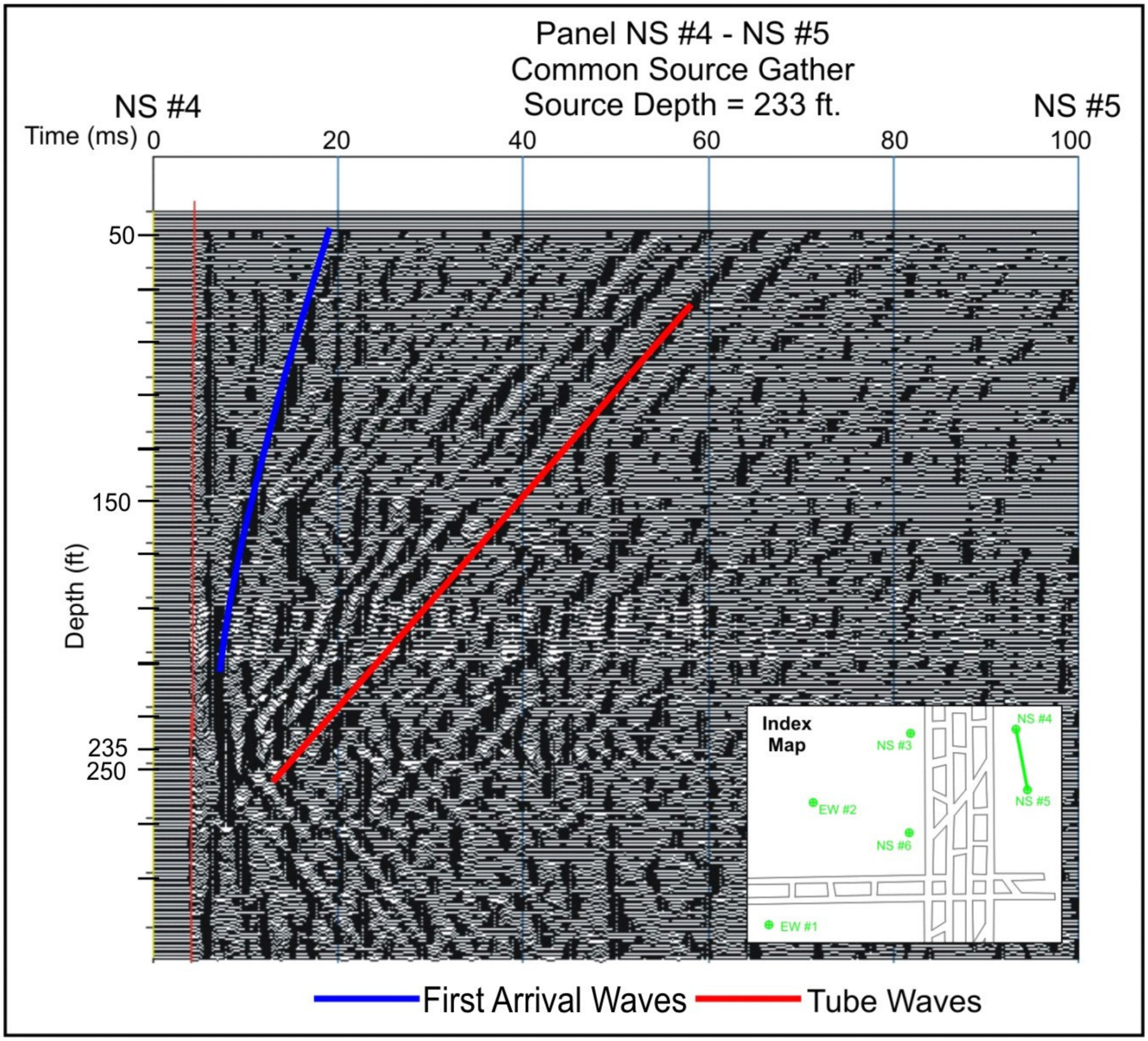
FIGURE 4-17 PANEL NS #5 – NS #6 COMMON SOURCE GATHER



As can be seen from Figures 4-17 and 4-18, there are no discernable differences between the two sets of data despite the fact that the area between boreholes NS #6 and NS #5 contains at least three mine entries. This indicates that the guided waves are propagating through the water-filled voids and thus are not a reliable indicator of the presence of voids at the site.

Other seismic guided waves plots are provided in Appendix B. They show similar results, although several of the records exhibit high levels of electrical noise.

FIGURE 4-18 PANEL NS #4 – NS #5 COMMON SOURCE GATHER



4.2.6.1 Conclusions and Recommendations

The results obtained from the guided waves method were inconclusive at differentiating mined and unmined coal seams due to the presence of the tube waves in both cases. Tube waves are a primary indicator of the presence of guided waves. Tube waves may also have occurred due to the following:

Tube waves are created in the receiver borehole in areas where the borehole diameter had significantly increased due to partial collapse. This enlarged borehole diameter, as detected during the surface to borehole check shots in borehole EW #1, was coincident with the Herrin #6 coal horizon.

- It is possible that the guided waves were propagating through or around the water-filled voids in the coal seam.

In Conclusion:

- The guide waves records for zones with and without old mine works appeared similar at the site.
- This method may not be reliable for locating flooded mine voids.

4.3 REVERSE VERTICAL SEISMIC PROFILING

This section describes the application of the Reverse Vertical Seismic Profiling (RVSP) at the investigational site.

4.3.1 Survey Design

The data used for the RVSP processing was a subset of the data obtained from the XHT survey. Specifically, the RVSP process used only the acquired data from the surface geophones. These geophones were laid out at 10 ft intervals (where possible) in a line between the source and receiver boreholes. It should be noted that, if the RVSP surveys had been in the original proposed work plan, then the surface geophones would have been laid out at a closer spacing (i.e. three to five ft intervals). However, the data was of sufficient quality to determine the ability of the RVSP method to image mine voids.

4.3.2 Data Acquisition

Because the data used for the RVSP processing was a subset of the XHT data, the data acquisition parameters are identical to those of the XHT acquisition and are summarized in the following Table 4-4.

TABLE 4-4 RVSP ACQUISITION PARAMETERS AND EQUIPMENT

Seismograph	Custom-built 52-channel pc-based system	0.1 ms sample rate
Geophones	40 Hz. Mark Products – 1	10 foot spacing
Source	Bolt 5500 Borehole airgun with 2.5 cubic in chamber	10 total shots acquired per source depth

4.3.2.1 Data Quality

The data was of sufficient quality to determine reflectors within the seismic records. However, there was some electrical noise contamination in the data.

4.3.2.2 Data Processing

The data was processed by Sterling Seismic Services, who also processed the HRSW and HRPW data set. The following was the processing flow:

1. Import data from DVD
2. Assign Geometry (input source and receiver locations for each record)
3. Ensemble Predictive Deconvolution (Decon) (25 ms operator, 1.0 ms predictive length, 0.1% white noise)
4. True Amplitude recovery. RMS Trace Balance
5. Wavefield separation to extract upgoing P-Wave reflections
6. Proprietary imaging transforms (US Patent Application 20050174886)
7. Iterative velocity and statics analysis
8. Surface Consistent Predictive Decon (40 ms operator, 5.0 ms predictive length, 0.1% white noise)
9. Iterative velocity and statics analysis
10. Apply statics and velocity corrections and CDP Stack
11. Bandpass filter 25/45/500/600 Hz.
12. Time Variant Spectral Whitening (25/35/500/600 Hz.)
13. FX Decon (7 trace, 75 ms window, 25 ms overlap)
14. Time to Depth Conversion
15. SEGY output at two ft trace interval, 0.5 ft depth interval

4.3.3 Data Analysis and Interpretation

To interpret the RVSP data, the data were imported into GMAPlus 3-D, a PC based seismic interpretation program. The interpretation procedure is similar to that employed for the HRS data. Horizontal reflectors in the section are correlated to geologic horizons. The RVSP sections show two significant reflectors that correspond to the Danville #7 coal and sandstone underlying it and the Herrin #6 coal respectively.

The results of the RVSP processing are shown on Figures 4-19, 4-20, 4-21, respectively, for the sections between boreholes EW #1-EW #2, NS #6-NS #4, and NS #5-NS #3. The plots are displayed in color showing the instantaneous amplitude of the seismic data overlain by the wiggle trace showing the processed RVSP. The amplitude is color coded to show the area of relatively high amplitude. The high amplitudes occur primarily near the Herrin #6 coal seam reflector. The peak that has the line running through it marks the reflection from the Herrin #6 coal horizon. The void locations marked on these figures are based on the historical mine map. It should be noted that the RVSP profiles on the figures expand from the source boreholes to the end of the data. The solid survey line in each of the index map represents the area with data coverage.

There are clear amplitude variations along the peak of the Herrin #6 coal horizons, which would be expected where there are mined voids within the coal. In order to visualize the amplitude variations relationship to the possible mined void locations, the amplitude at the peak of the coal horizon was extracted from each RVSP section. Because each of these sections was processed separately, the amplitudes from one section cannot be compared directly to another section. However, these amplitudes do provide a good representation of the amplitude variation along each seismic section.

The amplitudes for the reflection at the Herrin #6 coal for each trace on the sections were geo-referenced and plotted on the historical mine map. The color representations of the amplitudes along each survey line are overlain on the map, as illustrated on Figure 4-22. The color of each point correlates to the relative amplitude along the line, with the “warmer” colors showing high amplitudes and the “cooler” colors showing the lower amplitudes.

The correlation between the Herrin #6 coal seam reflection amplitude and the presence of voids is very clear along the RVSP profile from NS #6 to NS #4. The amplitudes were extracted and displayed in a graph format on Figure 4-23. On the amplitude graph the locations along the profile where the main entries (from the historical mine map) intersect the profile are shown. The maxima in the amplitudes along the profile all correspond to the presence of voids. Furthermore, the RVSP amplitudes also show the presence of a corner pillar that approaches the profile location on the historical map. The impact of the pillar corner on the amplitude may be due to errors in the geo-referencing of the historical map that were observed in the borehole sonar mapping phase discussed in *Section 5.4.4 Sonar Data Processing and Interpretations* and that a more significant portion of the pillar may actually intersect the profile.

FIGURE 4-19 RVSP SEISMIC AMPLITUDE ALONG HERRIN #6 COAL HORIZON FROM EW#1 TO EW#2

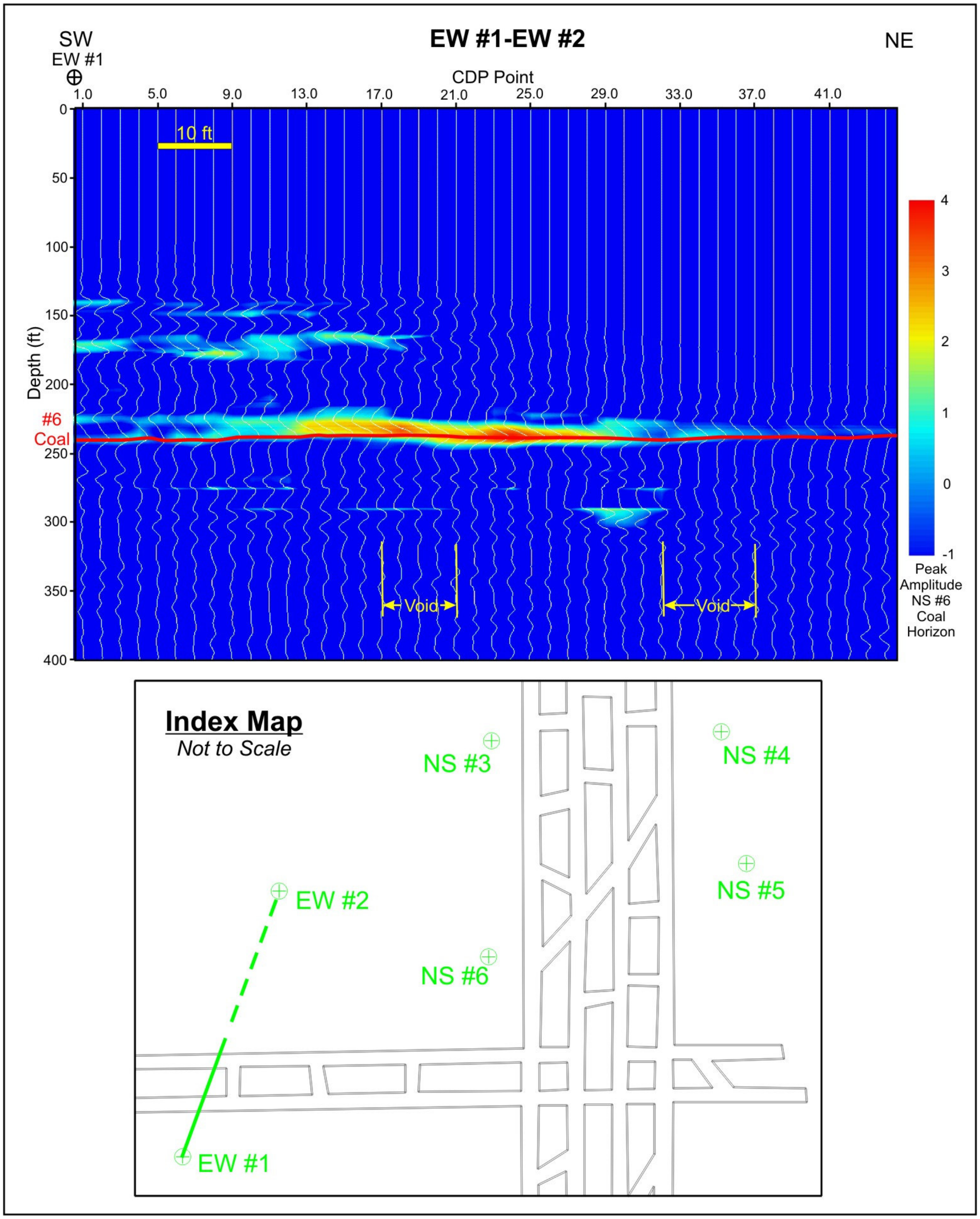


FIGURE 4-20 RVSP SEISMIC AMPLITUDE ALONG HERRIN #6 COAL HORIZON RVSP FROM NS #6 TO NS #4

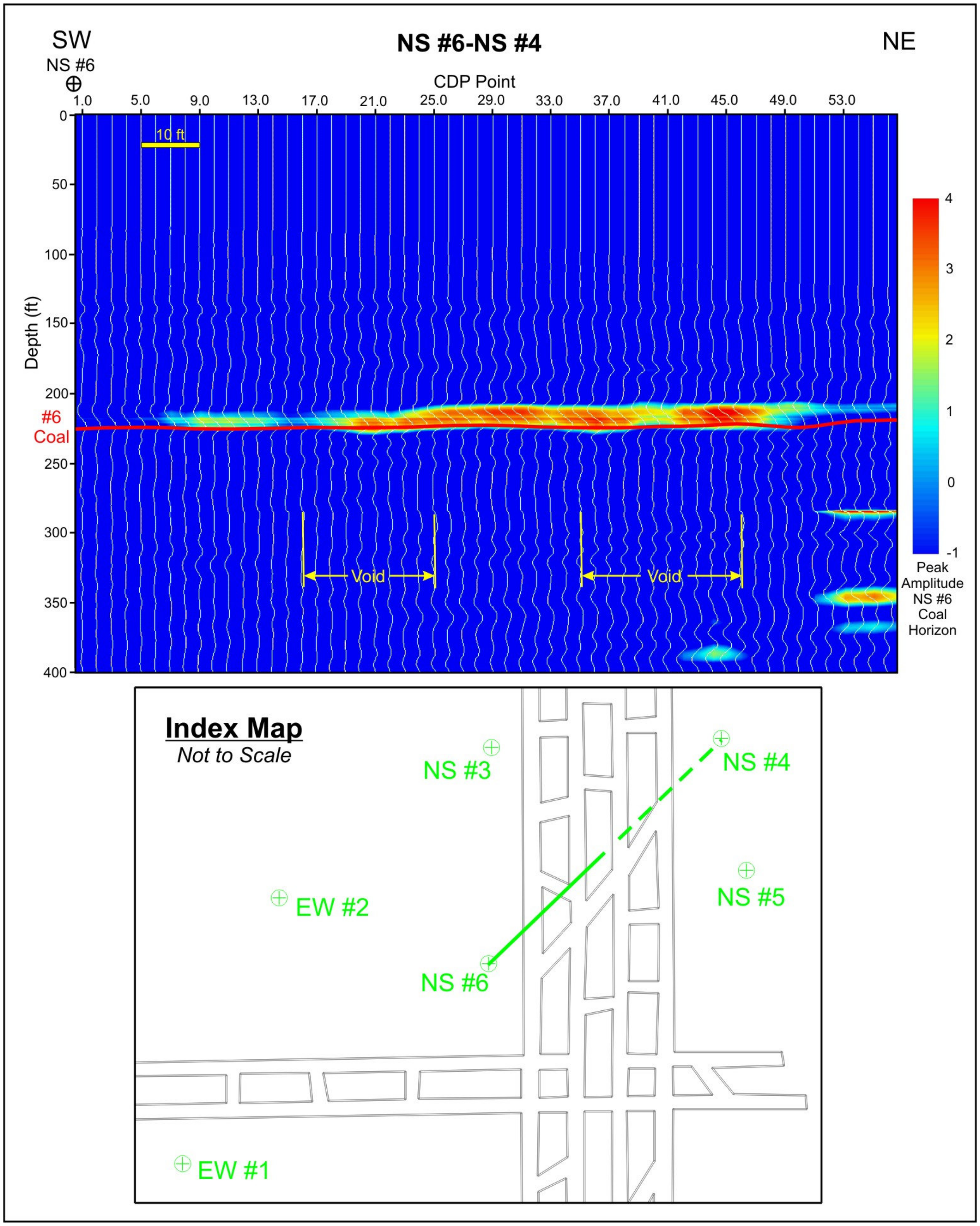
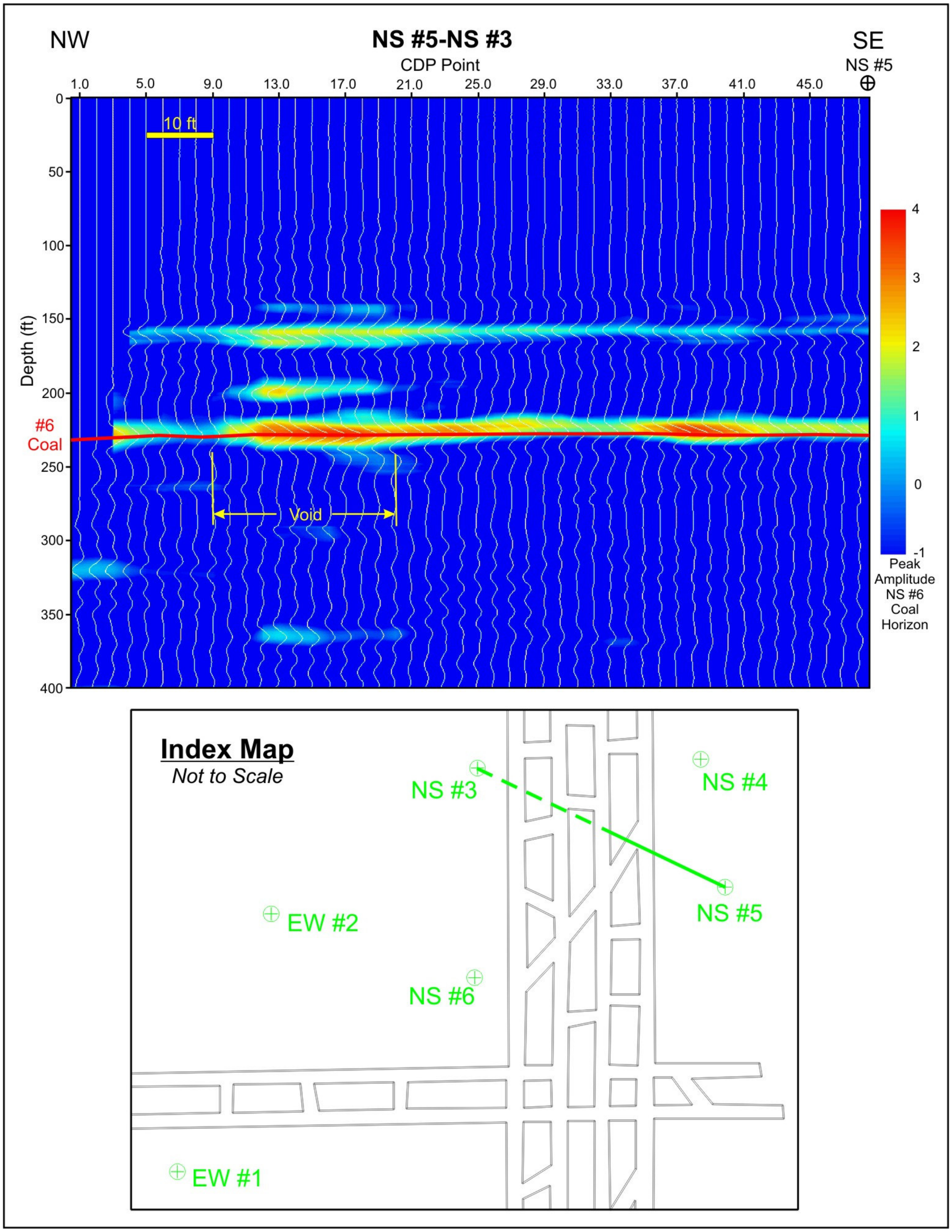
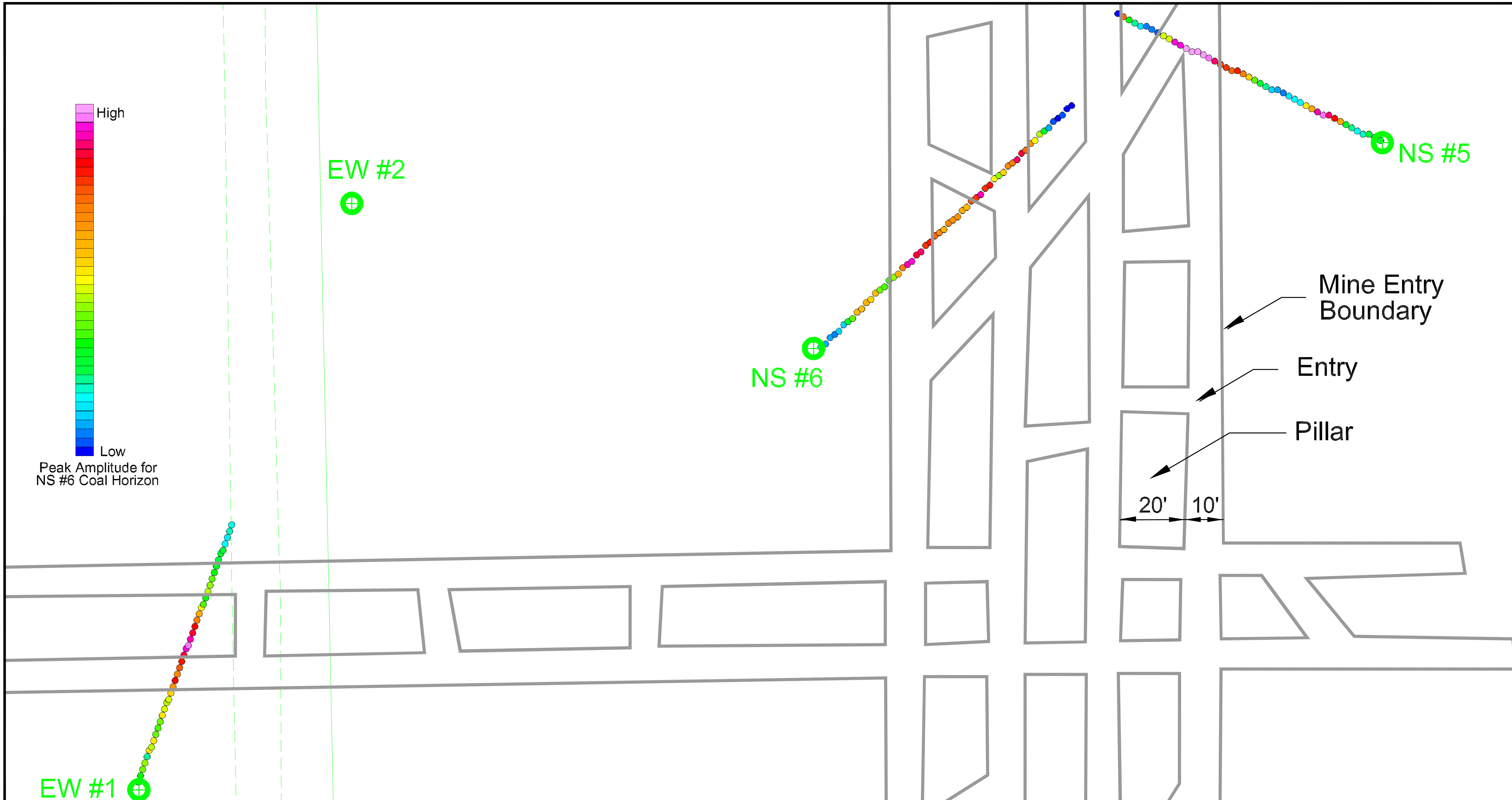


FIGURE 4-21 RVSP SEISMIC AMPLITUDE ALONG HERRIN #6 COAL HORIZON FROM NS #5 TO NS # 3





BLACKHAWK
A DIVISION OF ZAPATAENGINEERING

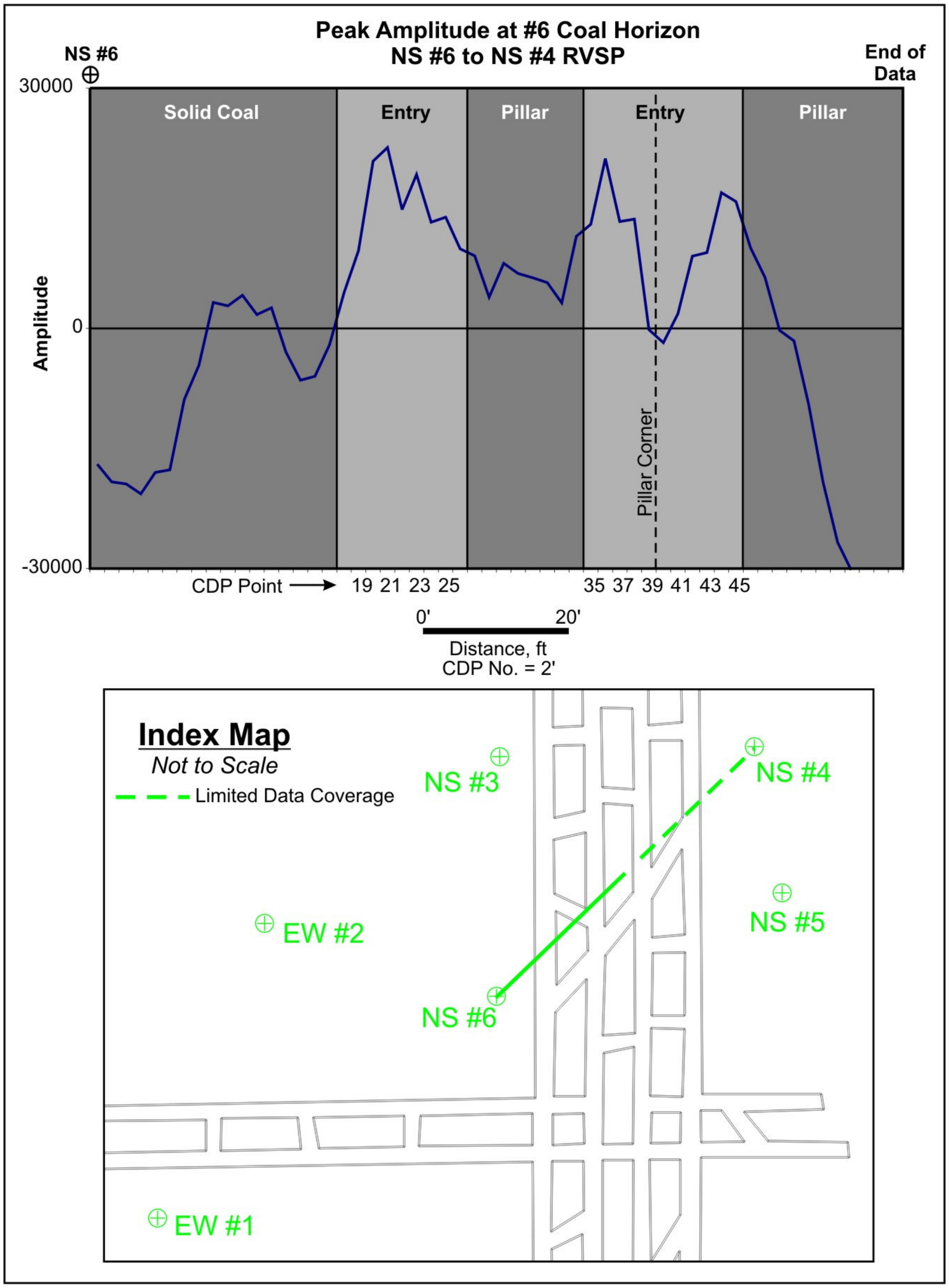
301 Commercial Road, Suite B
Golden, Colorado 80401
Phone: (303) 278-8700
Fax: (303) 278-0789
Web: www.blackhawkgeo.com

US Department of Labor
Mine Safety and Health Administration

Peak Seismic Amplitudes at Herrin #6 Coal Horizon from RVSP Surveys
Riola Mine Complex
Vermilion County, Illinois

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5006	June, 2006	HJV	KH	1" = 30'	4-22

FIGURE 4-23 RVSP PEAK AMPLITUDE AT THE HERRIN #6 COAL HORIZON FROM NS #6 TO NS #4



The correlation between higher amplitudes at the peak of the Herrin #6 coal seam reflection and the presence of mine voids on Figures 4-20 and 4-21 is very good and much better than the correlation with the HRS amplitude anomalies and the voids. This is likely due to the much higher frequency content in the RVSP data. Along the NS #3 to NS #5 section, the correlation with higher amplitude reflections and the presence of mine voids is excellent, with the RVSP amplitude corresponding to individual voids (rooms or entries). It appears that even the crosscuts between the entries is imaged. Figure 4-21 also shows an anomalous zone located east of the mains that has a character similar to the anomalies associated with confined voids. This may indicate a void or disturbed zone within a coal seam.

The NS #6 to NS #4 section (Figure 4-20) also shows a good correlation to the presence of the mine voids with higher amplitude reflections. However, the location of the higher amplitudes is offset to the east from the mapped location. The data from the borehole sonar discussed in *Section 5.4.4 Sonar Data Processing and Interpretations* indicates that the entries are offset to the east from the mine drawings, although not as far as would be interpreted from the RVSP data. Despite this, if a boring were located at the spot of the highest amplitude anomaly, the boring would intersect the voids within the mined areas. There is also a small, isolated high amplitude anomaly to the east of the north-south mains. The origin of this anomaly is unknown.

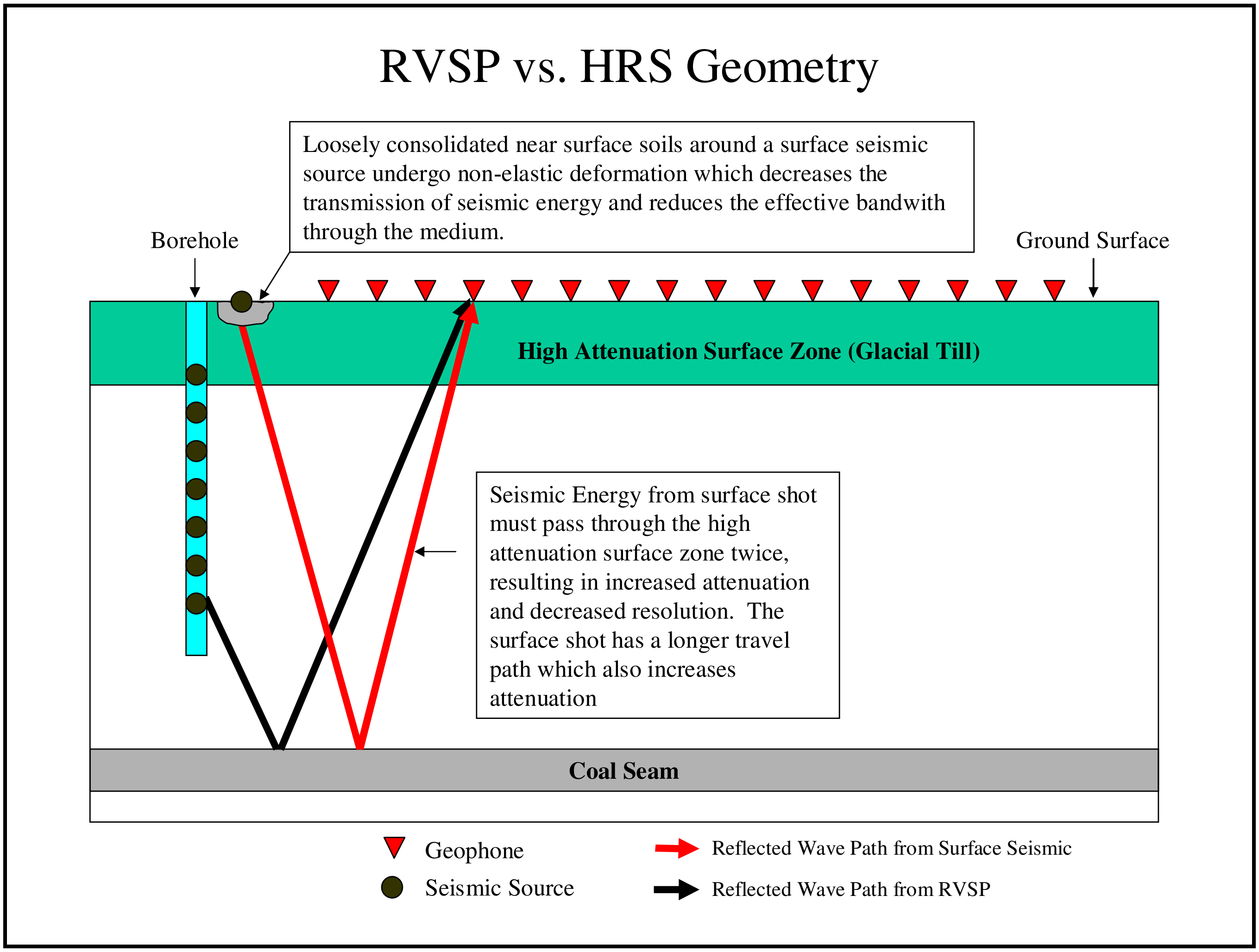
The EW #1 to EW #2 RVSP section (Figure 4-19) located across the west submains does not show as strong a correlation with the presence of mine workings with peak amplitude. The southern edge of the mined area correlates well with the onset of high amplitudes. However, the highest amplitude from the EW #1 to EW #2 RVSP section corresponds to a pillar in between the two entries. The reason for the high reflection amplitudes over a pillar (solid coal) is likely due to insufficient geophone coverage. The access dirt road north of the submains prevented the installation of five of the potential 24 surface geophones. Therefore, there was significant gap in the data coverage. The amplitudes from the coal seam horizon were then spread out by the processing algorithms because of the gap in the data coverage.

It is clear from a comparison between the HRS data and the RVSP data that the RVSP interpretation provided a much better correlation with the presence of mine voids. This is due to the broader bandwidth (higher frequency) and improved signal obtained with the RVSP geometry. A schematic detailing this advantage is shown on Figure 4-24. Moving the source in the borehole below the near surface layer offers two clear advantages, as presented below:

- The source is moved below the area of highest attenuation; i.e., the near surface. This reduces the number of times the seismic energy has to travel through the higher attenuation areas by one-half. This <u>decreases</u> the attenuation of the higher seismic frequencies and results in improved resolution.
- The effects of inelastic attenuation of the seismic signal near the source are reduced. When seismic sources such as impact devices, vibratory devices, and explosives are used at the surface, a large fraction of the energy is lost to the inelastic behavior of the soils. Inelastic behavior is when the soil particles do not return to their original position after being moved. This occurs when the soil is compacted, crushed, and moved. The

inelastic attenuation preferentially attenuates higher frequencies. When the seismic source is moved below the surface, and primarily deployed in areas of consolidated rock, the inelastic behavior around the source is significantly reduced and wider bandwidth signal is generated from the source.

FIGURE 4-24 RVSP VS HRS GEOMETRY



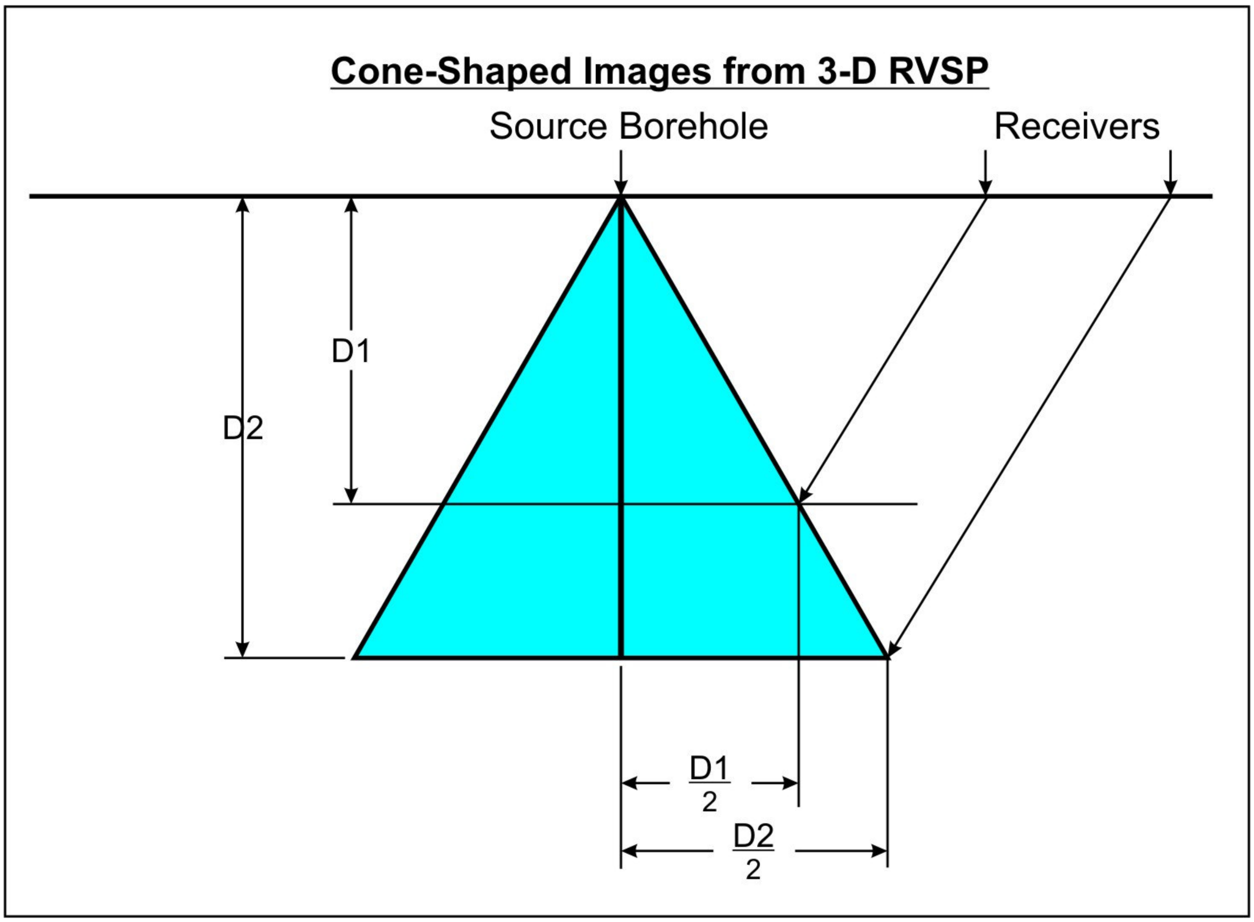
There are also other advantages to the RVSP data acquisition over HRS data acquisition. In general, the amount of fieldwork for the geophysical portion of the work is much less. Once the geophones are emplaced on the surface, acquiring the data by moving the source up and down the hole requires very little effort compared to moving surface seismic sources. Furthermore, the geometry of the layout is more flexible than HRS. If a borehole can be placed somewhere along a line, then the only other surface access required is for geophones to be placed along the remainder of the line. This only requires foot access to the line and therefore the RVSP can be deployed in terrain that would be inaccessible to HRS surveys.

The distance (radius) from the drill borehole that useful RVSP data can be obtained about the target horizon is approximately equal to one-half of the depth of the target or one-half of the distance between the borehole and the furthest geophone, whichever is smaller. In the case of the demonstration site, the target coal horizon was approximately 235 ft below the surface. This would require a surface geophone to be placed at a three to five ft spacing. The geophone array will extend 235 ft from the borehole to obtain subsurface coverage to a distance approximately 117 ft from each borehole, as illustrated on Figure 4-25.

Contents of Detected Voids

As indicated in Table 3-8, the RVSP method provides no direct information on the contents of the voids. However, with sufficient data and sophisticated processing methods it may be possible to determine void contents. Since only a subset of the XHT data were used for the RVSP processing, no attempts were made to interpret the void contents.

FIGURE 4-25 CONE SHAPED IMAGE FROM 3-D RVSP



4.3.4 Conclusions and Recommendations

The results obtained from the data acquired during the XHT acquisition clearly demonstrates the potential of the RVSP method to detect the presence of old mine workings. This was accomplished using a data set that was not acquired optimally for RVSP processing. In all the RVSP sections that were processed, the boundaries of the mains and submains were detected with horizontal accuracy of three to five ft. This method appears to contain significant promise for the imaging of voids within coal seams.

Further enhancements to the method would include:

- Use of more geophones at closer spacing, and extending the geophone array line further from the source hole;
- Laying out lines so that no significant gaps in the geophones occur;
- Emplacing the geophones in shallow (6-12 in) holes to further reduce near surface attenuation;
- Laying out the acquisition geometry so that lines were oriented perpendicular to the expected orientation of the mine workings;
- Use a larger air chamber (five cubic inch) in the airgun source to increase the seismic signal.

If the orientation of the mine workings is not known, then the RVSP geometry could be extended to a 3-D area of interest at the cost of deploying more geophones and increased processing cost.

4.4 SEISMIC MODELING

A modeling study of the seismic reflection was also performed as part of the data analysis. This was done to evaluate whether the features that were observed in the RVSP and HRS data could reasonably be assumed to be the result of voids in the coal seam. The modeling analysis was also made to determine the frequency content necessary for imaging the void.

A simplified model was made of a water-filled void in the coal seam, which extended over the entire thickness of the seam. The modeled void was approximately 15 m in width. Simulated seismic data were then collected over the void in a manner that mirrored the acquisition of both the RVSP data set as well as the HRS data set. Because the geology surrounding the coal seam is complex with several different geologic formations in close proximity to the coal seam, the modeling did not attempt to directly recreate the entire complexity of the overlying stratigraphic sequence. The goal was to determine if the amplitude variations observed in the acquired data could be reasonably correlated to the presence of voids.

The modeling was performed using the SUEA2DF program from the Seismic Unix package developed by the Center for Wave Phenomena at the Colorado School of Mines. The code uses a 2-D anelastic finite difference forward modeling to simulate the expected seismic reflection created by a single source and a line of geophones. Multiple runs were conducted with varying source locations to create a data set that had a similar geometry to the actual data collected at the demonstration site. The simulated data were then processed in a similar manner to the actual data to create seismic sections.

The results from the modeling are shown on Figure 4-26 A and B. These plots are similar to the plots in *Section 4-3 Reverse Vertical Seismic Profiling,* and show the instantaneous amplitude in color, overlain by a wiggle trace of the actual seismic data. The amplitudes are displayed so that the higher amplitudes correspond to a warmer color. Figure 4-26 A shows the results of the modeling for the simulated RVSP data set. The amplitude of the seismic reflection from the top of the simulated coal seam shows an increase over the area of the void as well as a small phase shift, that shifts the peak of the instantaneous amplitude downward in time. This is very similar to the features observed from the seismic reflection originating from the Herrin #6 coal seam over the voids in the acquired RVSP data.

Figure 4-26 B shows the simulated results from an HRPW survey acquired across a void in the coal seam. The lower frequency content of the HRPW data (40-300 Hz for HRPW vs. 40-500 Hz for the RVSP data) significantly decreased the resolution of the data, making the void marginally detectable even under noise-free conditions.

The results of the modeling indicate that the variations in the RVSP amplitudes observed in the Herrin #6 coal seam reflection in the area of old mine works are similar in phase and amplitude to what would be expected from a water-filled void within the coal seam.

4.5 GEOPHYSICAL LOGGING AND BOREHOLE DEVIATION SURVEYS

Borehole logging surveys were implemented to provide detailed in-situ property information around the borehole walls. However, the subsurface strata between the boreholes can be extrapolated by correlating multiple borehole logs within a set area.

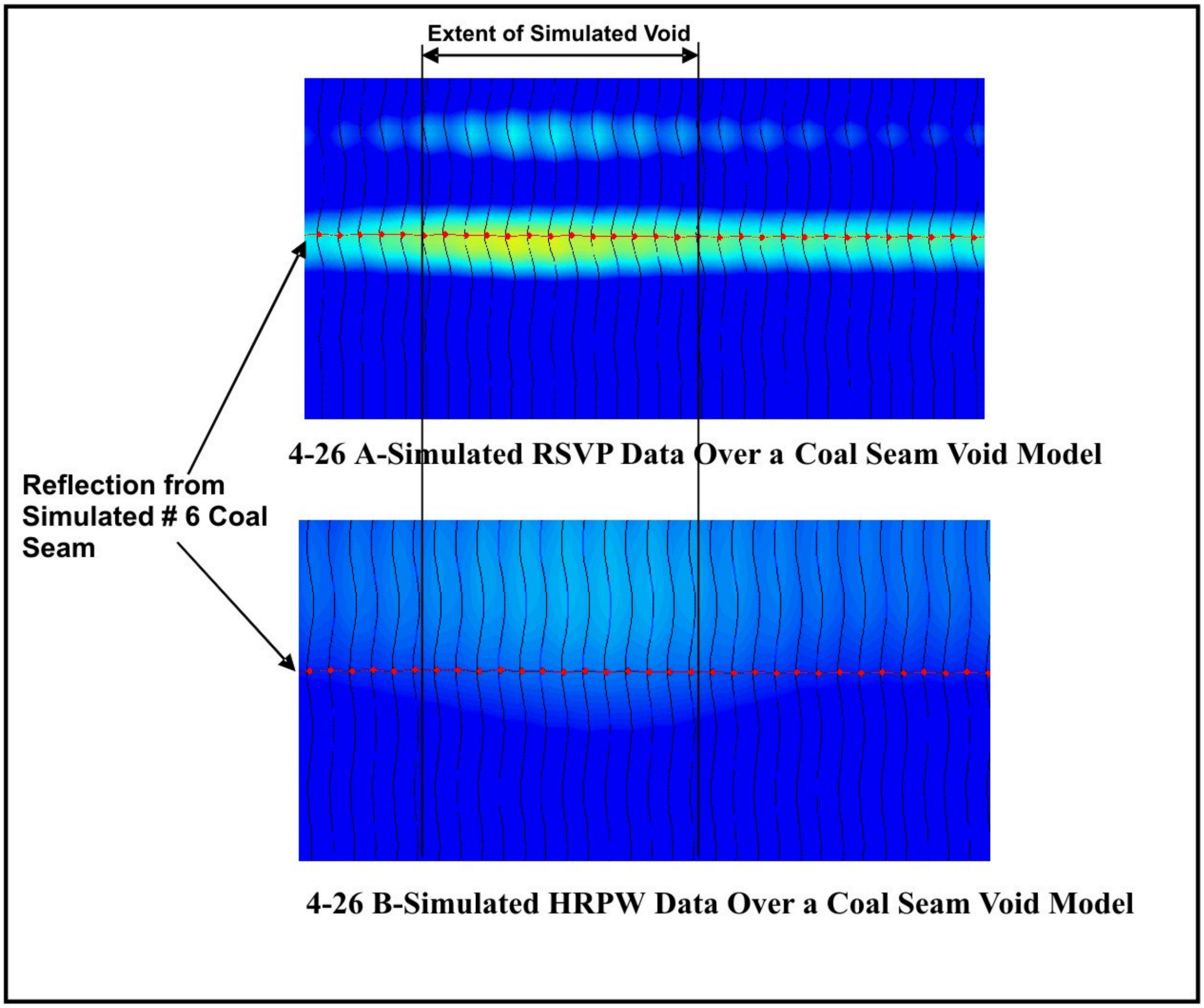
Geophysical logging was conducted on the boreholes during the XHT survey to: 1) improve the understanding of the subsurface strata; 2) delineate geology along the depth of the 300 ft borehole; and 3) augment the geophysical data processing, analysis, and interpretation.

Subsurface strata information was obtained using the following logging techniques described below.

4.5.1 Lithological Logs

This test provided resistivity, natural gamma, spontaneous potential (SP), and single point resistance (SPR) to determine the stratigraphic sequences located within a borehole. This survey was conducted on all of the six drilled boreholes. This information was used for comparison and validation with the drill logs. The lithological logging tool is shown in Picture 4-4.

FIGURE 4-26 MODEL OF COAL SEAM VOID FROM THE RVSP AND HRS DATA



4-26 A-Simulated RSVP Data Over a Coal Seam Void Model

4-26 B-Simulated HRPW Data Over a Coal Seam Void Model

By the use of multiple logs within the investigational area, correlations between the logs were made by examining strata, particularly the shale sections and major sands common to two logs. These can be seen best by using the SP and Natural Gamma logs.

The left hand tracks contain the Natural Gamma Logs, SP Logs, and SPR Logs. The right hand tracks show Normal Resistivity Logs for 8-inch, 16-inch, 32-inch, and 64-inch electrode spacing. The driller's log is indicated on the vertical depth axis.

Figure 4-27 indicates that three coal seams are clearly identified in the lithological logs. In descending order these are: the Danville # 7 which is nearest to the surface, the Herrin #6 which is in the center (seam of interest), and the Springfield # 5. Interpretations of the resistivity logs were found to coincide with drill logs of the boreholes. Specific details regarding the coal seams are presented below.

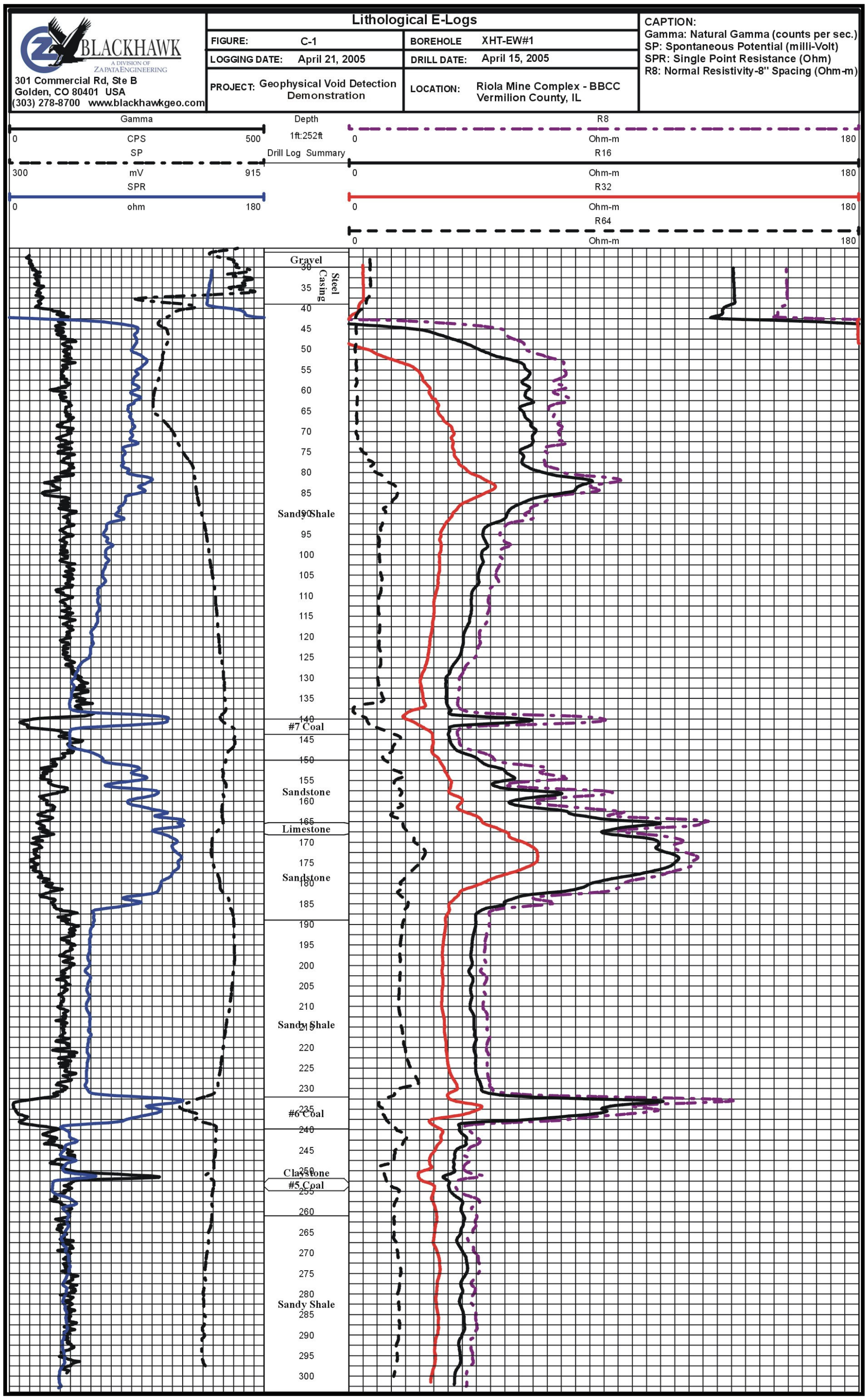
PICTURE 4-4 LITHOLOGICAL LOG SURVEY TOOL

1. **Danville # 7 Coal Seam**: Observed at depths between approximately 139.0 and 142.5 ft with an average thickness of 3.5 ft. The Danville is overlain by gravel (unconsolidated glacial material) and sandstone, sandy shale, and shale.

2. **Herrin # 6 Coal Seam**: Observed at depths between approximately 232.5 and 239.0 ft with an average thickness of 6.5 ft. The Herrin is overlain by multiple layers comprised of sandstone, limestone, and sandy shale. In log XHT-EW #6, the Herrin coal seam is interbedded with a thin sandy shale inclusion within the coal bed at this location.

3. **Springfield # 5 Coal Seam**: Observed at depths between approximately 252.2 and 253.2 ft with an average thickness of 1 ft. The Springfield exhibited high natural gamma counts; therefore, the interpretations are not as “clean” as coal seams #6 and 7. This was primarily due to the presence of a claystone cap directly overlying the Springfield coal seam #5. In log XHT-EW #5, this coal seam was missing entirely from the log. This was confirmed in the drill log where only a section of black shale with coal streaks and a thickness of 0.80 ft were found at depths between 251 and 251.8 ft in lieu of the Springfield coal seam.

FIGURE 4-27 LITHOLOGICAL E-LOG FOR EW #1



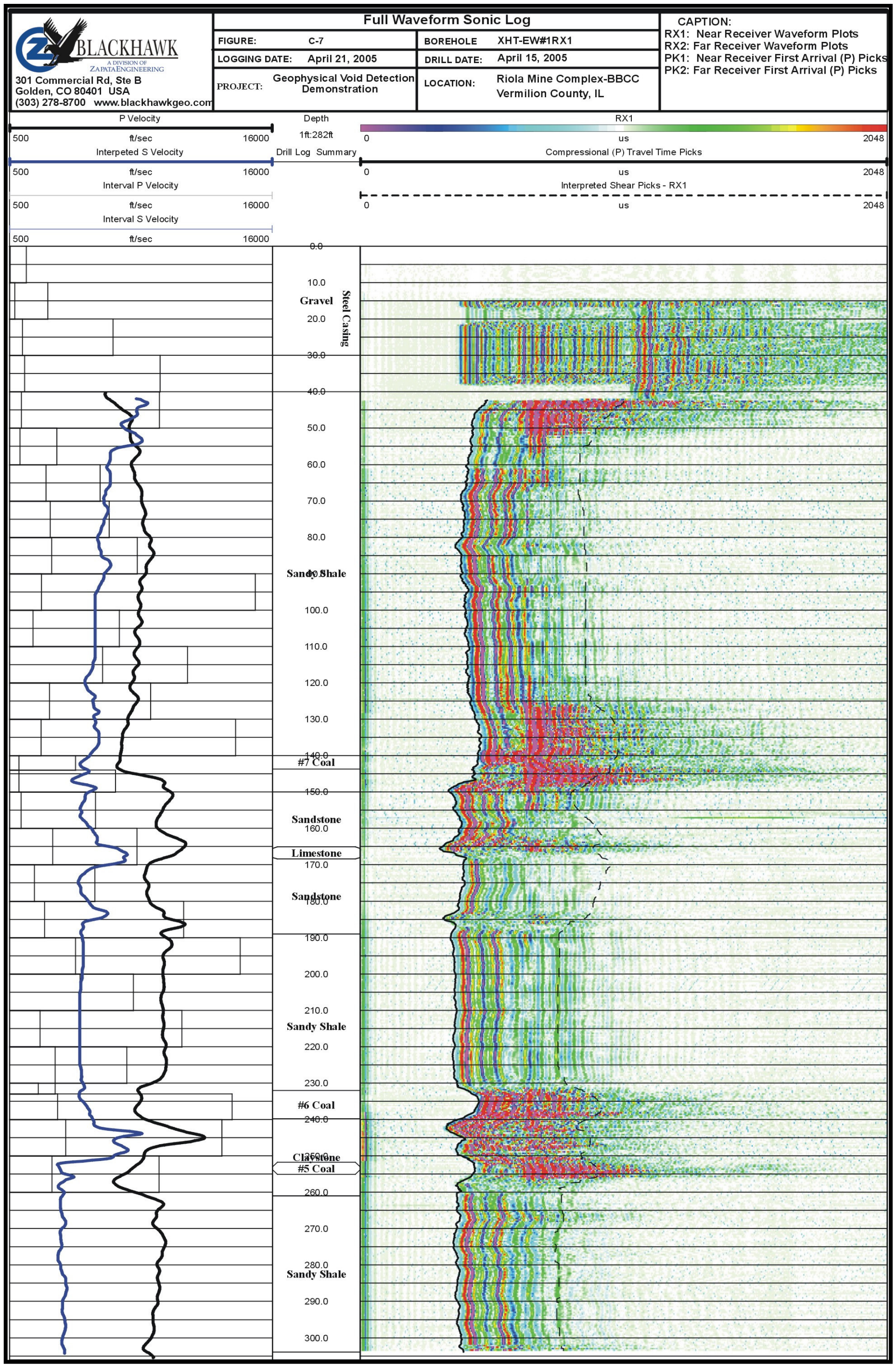
4.5.2 Full Waveform Sonic Logging

This test provided the P-wave velocity and interpreted S-wave and reflectivity, which was used to produce synthetic seismograms for the interpretation of the reflection data. This test was conducted on boreholes XHT-EW #1 and XHT-NS #6 (Picture 4-5). The elastic properties of rocks can be calculated from the velocities of the P and S-waves and from corrected bulk density using a gamma-gamma log. The elastic properties or constants that can be determined are shear modulus, Poisson's ratio, Young's modulus and bulk modulus (Yearsley & Crowder, 1990).

PICTURE 4-5 FULL WAVEFORM SONIC LOGGING SURVEY TOOL

As shown on Figure 4-28, the full waveform sonic log for the near receiver (borehole XHT-EW #1) is shown in the right hand track along with the compressional first arrival and interpreted shear first arrival picks. In the left hand track, the compressional and interpreted shear velocities are plotted along with interval velocities obtained from a downhole seismic (check shot) survey. The driller's log is indicated on the vertical depth axis. The three coal seams (Danville #7, Herrin #6, and Springfield #5) are clearly indicated as low velocity (high travel-time) intervals in the sonic logs. In addition, the coal characteristically exhibited a high amplitude signal return in the full-waveform sonic logs. Appendix C contains all full waveform sonic logs created by the investigation.

FIGURE 4-28 FULL WAVEFORM SONIC LOG FOR EW #1



Note: Due to software limitations, unable to keep the words in the middle column from overriding the numbers.

4.5.3 Deviation Logs

Borehole deviation surveys (Picture 4-6) were performed on all of the boreholes to determine the degree to which the holes deviated from vertical for the XHT method. The data obtained from the deviation surveys were used as input for the XHT geometry.

PICTURE 4-6 BOREHOLE DEVIATION SURVEY TOOL

Examples of some of the borehole deviation plots are shown on Figures 4-29, 4-30, and 4-31. In these figures, negative northing (from the zero mark) means borehole deviation is tending towards the south and negative easting implies borehole deviation tending towards the west. Appendix C contains all deviation logs obtained from the surveys.

The following conclusions are observed in the data:

- Minimal deviation was observed in all of the boreholes. The largest observed was about a six ft borehole deviation to the south in boreholes EW #2 and NS #5 in about 300 ft total borehole depth (or 2%) and 3.6 ft to the west in borehole NS #3 (or about 1.2%).
- With the exception of borehole EW #1, the rest of boreholes deviated mostly to the south.

FIGURE 4-29 BOREHOLE DEVIATION PLOT XHT-NS #2

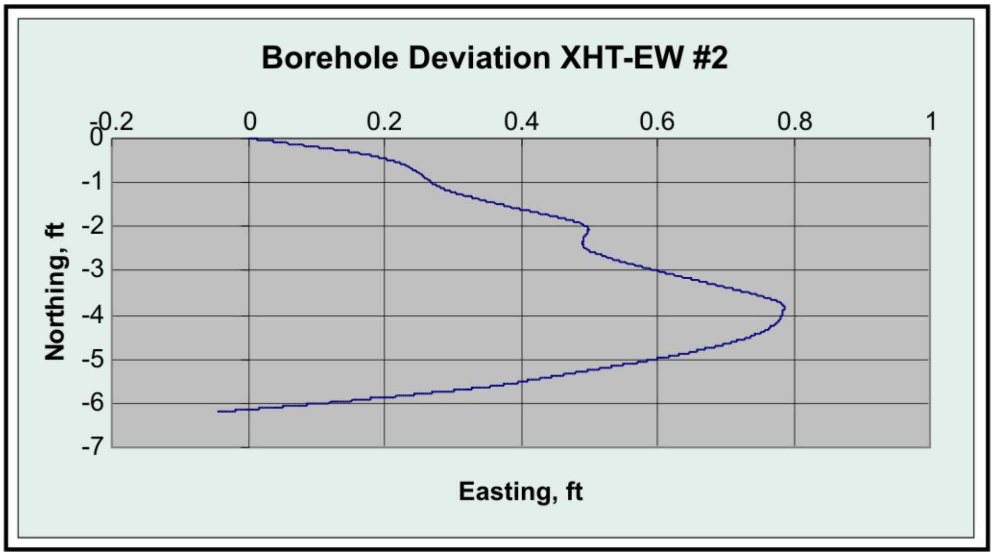


FIGURE 4-30 BOREHOLE DEVIATION PLOT XHT-NS #3

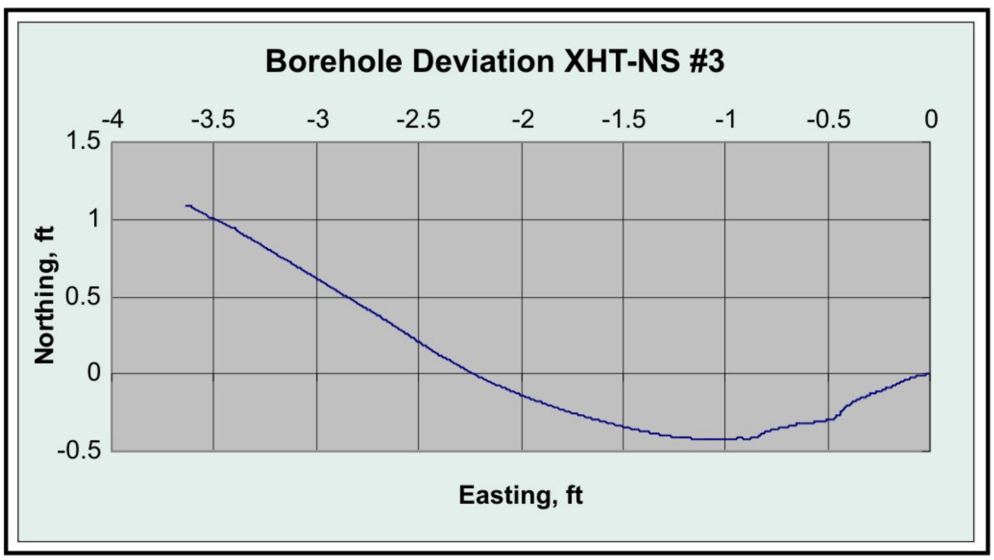
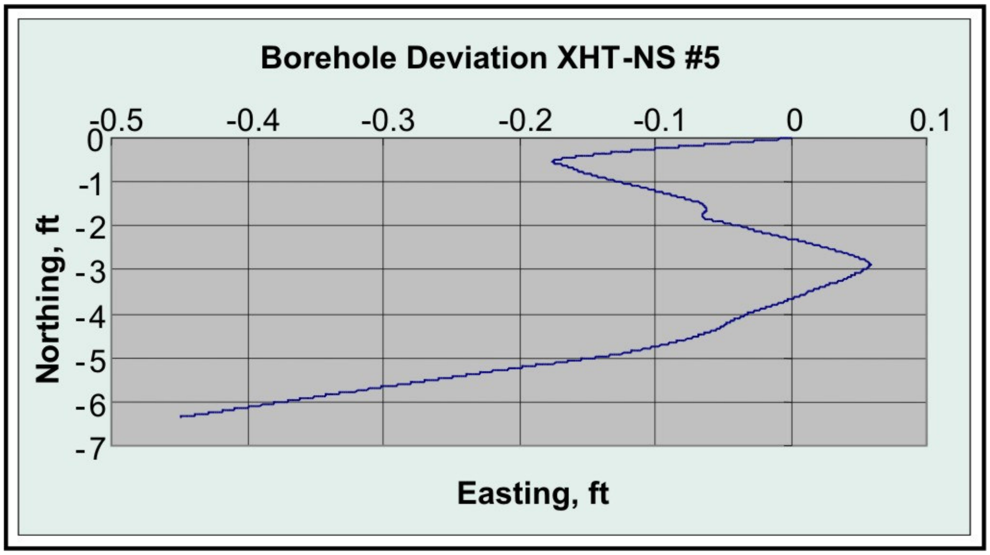
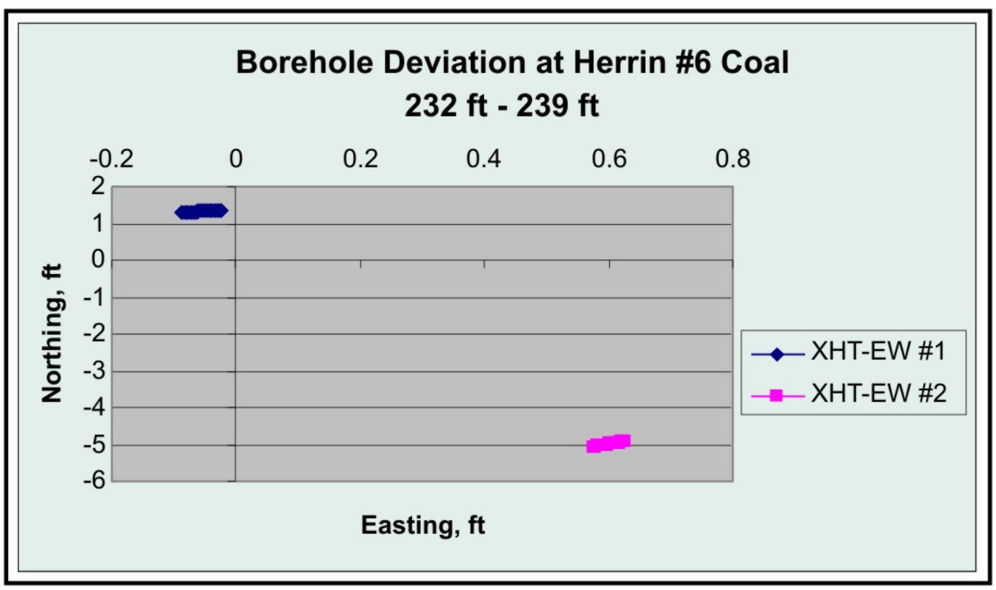


FIGURE 4-31 BOREHOLE DEVIATION PLOT XHT-NS #5



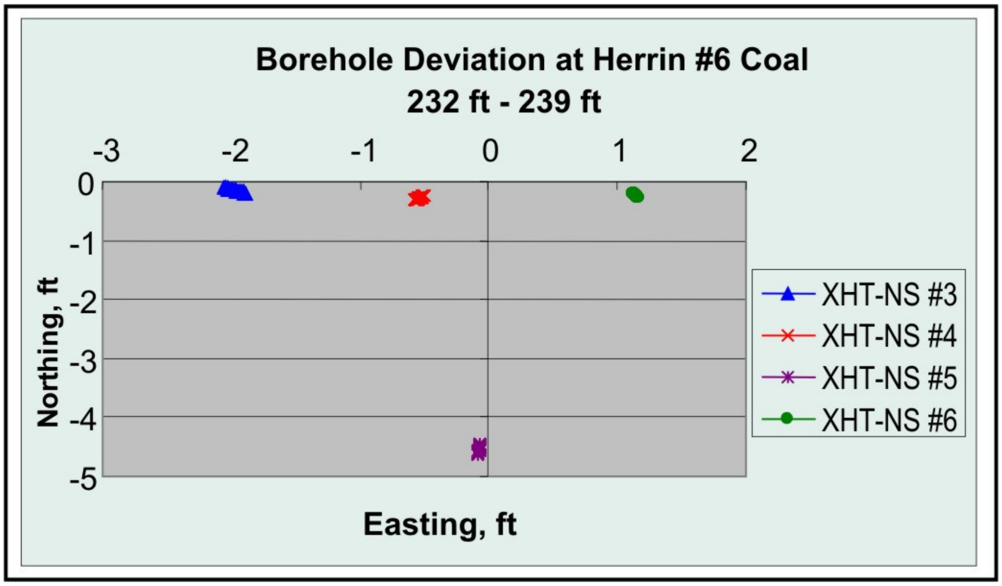
A comparative deviation plot at the Herrin #6 coal seam level between boreholes EW #1 and 2 is shown on Figure 4-32 indicating up to about five ft of deviation at borehole XHT-EW #2.

FIGURE 4-32 COMPARATIVE BOREHOLE DEVIATION PLOT XHT-EW #1 AND #2



A comparative deviation plot at the Herrin #6 coal seam level between boreholes NS #3, NS #4 and NS #5 and NS #6 is shown on Figure 4-33. The largest deviation, about five ft, occurred between boreholes NS #5 and NS #3 and between boreholes NS #5 and NS #6.

FIGURE 4-33 COMPARATIVE BOREHOLE DEVIATION PLOT XHT-NS #3, #4, #5, AND NS #6



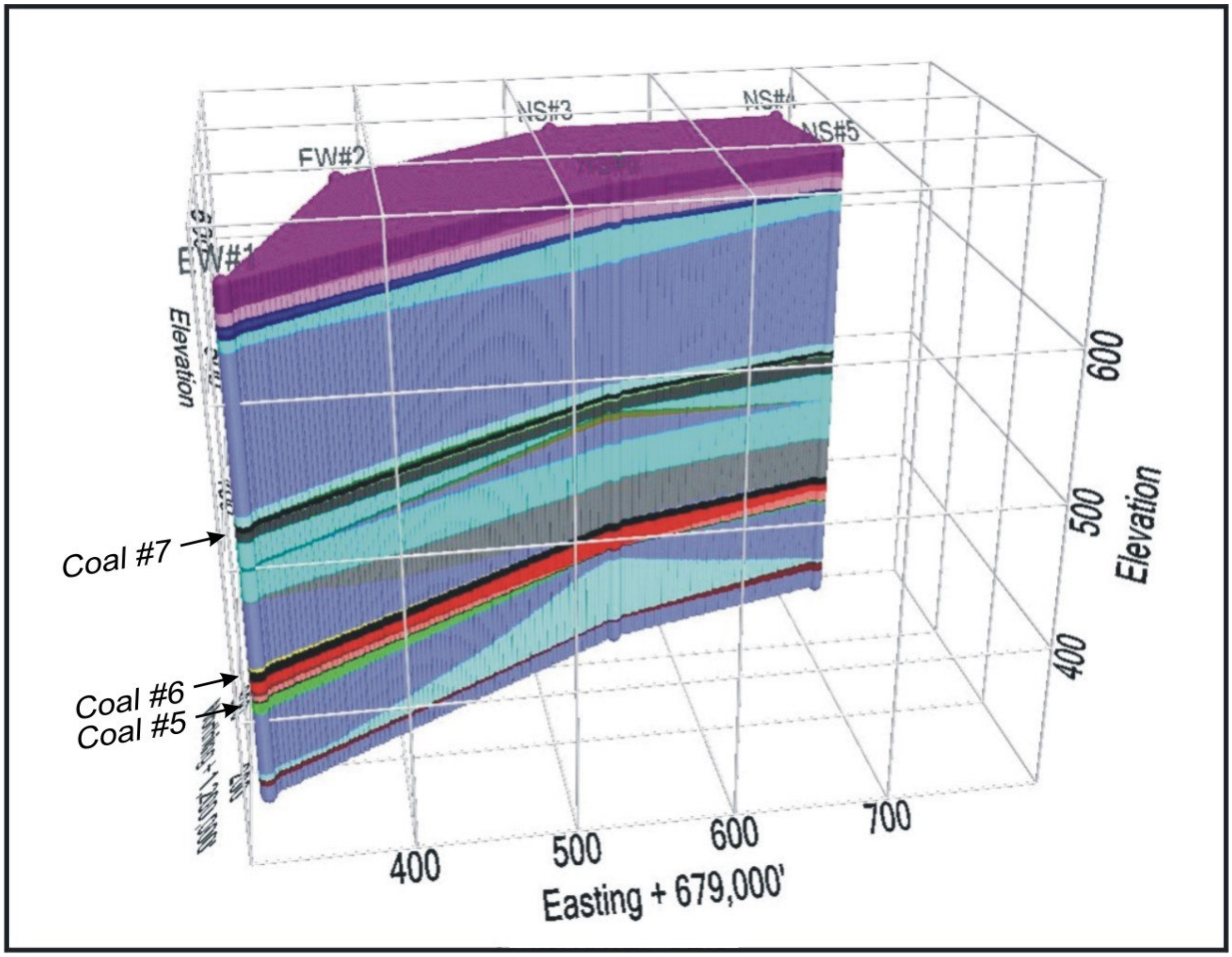
4.5.4 Drill Logs

Drill logs recorded physical lithological information from a borehole, including formation depths, formation thicknesses, lithology codes, beds, descriptions of the stratigraphy, hydrological data, general drill log data, and geographical location. These logs were obtained by the drill crews for use on-site during the geophysical investigation. Table 4-5 is an example of the information listed on a drill log. The information listed was used in tandem with lithological and full waveform sonic logs to illustrate a more detailed history of the lithology around the borehole location. The Drill Log in Table 4-5 correlates to the XHT-EW #1 E-Log and Full Waveform Sonic Log, respectively, on Figures 4-27 and 4-28. The information obtained from the drill logs were used to generate a 3-D stratigraphic model shown in Figure 4-34. The information depicted on this figure was used to aid in data interpretation and analysis. Appendix D contains all drill logs used in the investigation.

TABLE 4-5 FROM MAGNUM DRILLING DRILL LOG FOR BOREHOLE EW #1

Drill Log EW #1 from Magnum Drilling Services, Inc. Dated 04/18/05				
Material		**Thickness in Ft**	**Depth in Ft (Top to Basal)**	
Glacial Material	Unconsolidated Clay with Gravel Tan or Buff	15.00	0.00	15.00
	Unconsolidated Silt with Gravel Red or Brown	7.00	15.00	22.00
	Unconsolidated Silt with Gravel Med Gray	2.00	22.00	24.00
	Unconsolidated Sand with Gravel - Large	3.00	24.00	27.00
	Unconsolidated Silt with Gravel Med Gray	3.00	27.00	30.00
	Sandstone - Med. Gray	7.00	30.00	37.00
	Sandy Shale - Med Gray	97.00	37.00	134.00
	Shale - Dark Gray	6.00	134.00	140.00
Danville	**Coal Seam # 7**	**3.70**	**140.00**	**143.70**
	Sandy Claystone - Med Gray	6.30	143.70	150.00
	Sandstone - Med Gray	15.50	150.00	165.50
	Limestone	2.50	165.50	168.00
	Sandstone - Med Gray	19.00	168.00	187.00
	Sandstone, Limey Med Gray with Nodules	2.00	187.00	189.00
	Sandy Shale - Med Gray	42.00	189.00	231.00
	Shale - Med Gray with Coal Streaks	2.00	231.00	233.00
Herrin	**Coal Seam # 6**	**6.80**	**233.00**	**239.80**
	Limey Sandy Claystone	7.20	239.80	247.00
	Sandy Claystone - Med Gray	2.00	247.00	249.00
	Limey Claystone - Med Gray - Nodules	3.50	249.00	252.50
	Black Shale with Coal Streaks	0.50	252.50	253.00
Springfield	**Coal Seam # 5**	**0.80**	**253.00**	**253.80**
	Limey Claystone - Med Gray - Nodules	7.20	253.80	261.00
	Sandy Shale - Med Gray	42.00	261.00	303.00
	Shale - Dark Gray	4.00	303.00	307.00
	Black Limey Shale	4.00	307.00	311.00
	Sandy Shale - Med Gray	9.00	311.00	320.00
	Total Depth	**320.00**		

FIGURE 4-34 3-D STRATIGRAPHIC DISPLAY OF DRILL LOG INFORMATION



5.0 VOID CONFIRMATION

5.1 RATIONALE FOR VOID CONFIRMATION PLAN

A conventional vertical drilling program, combined with on-site observations, borehole deviation surveys, and sonar mapping, were implemented to confirm the presence of the imaged geophysical anomalies interpreted as voids. The design of the borehole drilling program was based on the results obtained from the geophysical surveys described in *Section 4.0 Geophysical Methodology*, including:

- HRS interpreted voids;
- XHT and guided waves interpreted voids;
- RVSP interpreted voids and mine entry boundary.

The HRS indicated anomalies from which general outlines of the old mine works were interpreted. However, the anomalous regions from the HRS data extended out over a significantly larger area north of the west submains than was expected from the historical mine map. The results of the XHT and guided waves were inconclusive; therefore, the survey results were not used in the planning of the void confirmation boreholes. The RVSP provided detailed outlines of the mains and submains boundary. The borehole confirmation layout was primarily designed based on the RVSP interpretation and the large HRS anomaly north of the submains with reference to the historical mine map. The interpretation of the RVSP amplitudes (Figure 4-22) correlated very well with the locations of the mains and submains as derived from the georeferenced mine map. Based on this, a level of confidence was developed that the historical map could be used as a basis for the placement of the confirmation boreholes in areas not covered by the RVSP survey.

The preliminary void confirmation plan was designed such that four to five uncased boreholes would be drilled at sites that exhibit the most significant anomalies. The borings would be drilled to the depth of the coal horizon (Herrin #6, about 234 ft deep) to confirm the voids within the main and submain entries system.

Because of the importance of this task in achieving the overall program objectives, a meeting was held with Mr. George Gardner and Mr. Steven Vamossy of MSHA on September 23, 2005, at the Blackhawk, Golden office to discuss the void confirmation plan and determine the optimum layout for the borings. We agreed that two additional field tasks -sonar mapping and borehole deviation surveys - be conducted in conjunction with drilling to enhance the void confirmation program. This modified approach would provide benefits as follows:

- Optimize and focus the drilling program along one entry rather than drilling along a line crossing various entries (voids) and solid (pillar) areas.
- Enhance the geophysical data interpretation.
- Place three boreholes along the right entry of the mains to determine the location of the voids and pillars within this entry.

- Use sonar mapping to better define the ribline boundary between the right entry and the solid coal along the north-south mains by having overlapping regions of investigation. Areas overlapped between the data from two-sonar mapping data sets acquired in different boreholes could be analyzed for the difference in the location of the ribline.
- Determine the location of the additional one to two boreholes depending upon the success of the other three boreholes in intersecting a void.

As a result of this meeting, the borings layout consisted of: a) three boreholes to be positioned in the center of three-way intersections in the right entry along the north-south mains and spaced approximately 50 to 70 ft apart; b) one borehole in a three-way intersection in the west submains to verify that the submains were accurately located on the map and assess the ability of the sonar mapping in locating the ribline boundary from a single borehole; and c) one borehole in the area that exhibits a high amplitude geophysical anomaly located north of the west submains. Figure 5-1 shows the mine entries and boreholes confirmation plan.

The void confirmation fieldwork was performed from October 3 to 7, 2005, and included: 1) conventional drilling by Magnum Drilling; 2) borehole deviation surveys by Colog; 3) sonar mapping by Workhorse Technologies; and 4) borehole coordinates surveying by BBCC.

To maintain the field work activities on schedule and minimize stand-by time, a timetable was implemented as follows:

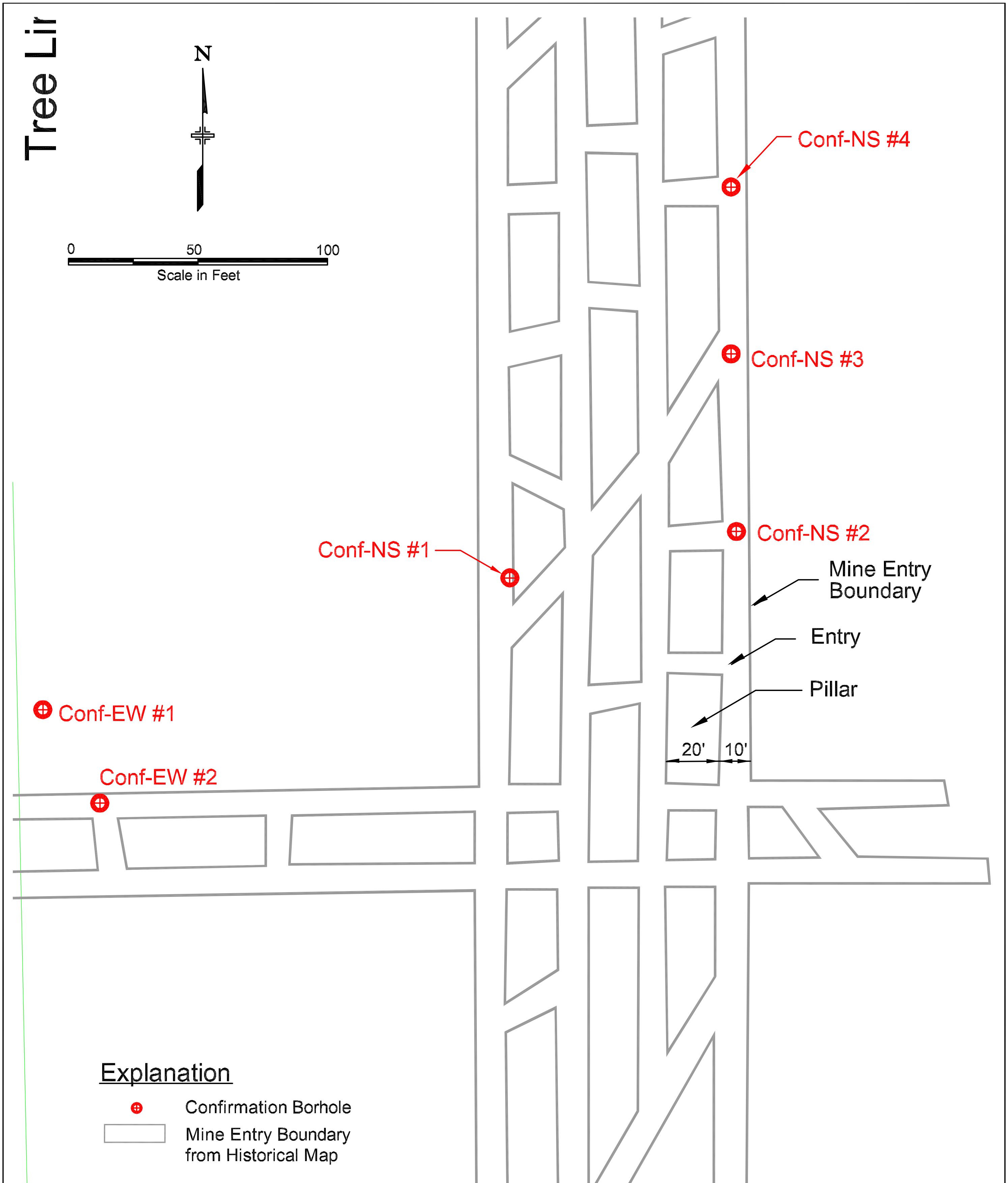
- Borehole drilling to begin Monday, October 3, 2005;
- Borehole deviation surveys to begin Wednesday, October 5, 2005;
- Sonar mapping to begin Thursday, October 6, 2005;
- Completion of fieldwork by Friday, October 7, 2005.

A summary of the void confirmation activities and related field tasks are discussed in the sections below.

5.2 CONVENTIONAL DRILLING

Locations of the five confirmation boreholes were designated with coordinates in accordance with the old mine coordinate system consisting of a north-south and east-west grid. As shown on Figure 5-1, the entries located in these areas are 10 ft wide and separated by 20 ft wide and 40 to 60 ft long pillars. The boreholes were spaced approximately 64 to 68 ft apart, with the spacing based upon the three-way intersections and pillar geometry and spacing.

The three boreholes located in the easternmost entry of the north-south mains were labeled as: Confirmation (Conf) NS #2, Conf NS #3, and Conf NS #4. It should be noted that the Conf NS #1 was drilled during the XHT survey. This borehole was positioned near the westernmost entry of the north-south mains, which was thought to be solid based on the HRPW results. However, borehole Conf NS #1 intersected a seven ft void and was abandoned and used as part of the void confirmation task.



BLACKHAWK
A DIVISION OF
ZAPATA ENGINEERING

US Department of Labor
Mine Safety and Health Administration

Mine Entry Map with
Borehole Confirmation Plan

Riola Mine Complex
Vermilion County, Illinois

301 Commercial Road,
Suite B
Golden, Colorado 80401

Phone: (303) 278-8700
Fax: (303) 278-0789
Web: www.blackhawkgeo.com

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5006	June, 2006	HJV	KH	1" = 50'	5-1

The two boreholes in the west area of the submains were labeled Conf EW #1 and Conf EW #2. Boreholes Conf NS #2 through #4 was positioned in the center of the three-way intersections in-line along the easternmost entry of the north-south mains. The location of borehole Conf NS #3 was about one ft west of the centerline alignment, which was determined after drilling had commenced.

All of the boreholes were 5 1/8-inches in diameter and drilled to a depth of the target zone at about 231 to 245 ft. The upper 30 to 40 ft of each borehole were drilled to a diameter of nine inches and cased with six-inch diameter Schedule 40 steel pipe to prevent borehole collapse in the cased interval. The remaining depth of the boreholes was left uncased. All of the boreholes were visually logged by the drilling crew and abandoned by grouting once the borehole deviation and sonar surveys were completed. During grouting, a borehole packer was used to prevent loosing grout into the void.

Drilling was planned to begin with the Conf NS #2 borehole, followed by the deviation survey and sonar mapping within the borehole. The results obtained from the drilling and sonar mapping would be used to determine if the planned locations or design of the remaining boreholes would need modifications. The drill rig was mobilized on Monday, October 3, 2005, as scheduled, and began drilling borehole Conf NS # 2 (Picture 5-1). On Tuesday morning, the drilling encountered a 7.8 ft void at a depth of 230 ft to the top of the void. To minimize drill crew stand-by time, we decided to begin drilling borehole Conf NS #3. We also determined that, if borehole Conf NS #3 was successful in intersecting a void, then borehole Conf NS #4 would be drilled at the planned location. If borehole Conf NS #3 did not encounter a void, the driller would await instructions before proceeding to borehole Conf NS #4.

The three confirmation boreholes along the north-south entry (Conf NS #2, #3, and #4) confirmed the presence of voids, as described in Table 5-1.

As a result of the successful void confirmation, it was decided that a borehole would be drilled outside to the north of the submains area to achieve the following:

- Evaluate the HRS geophysical anomaly that extends north of the west submains;
- Determine the causes of this anomaly;
- Determine the possible presence of an old mine area not shown on the mine map.

Borehole Conf EW #1 was drilled in the middle of the HRS anomaly approximately 36 ft north of the west submains near the tree line, as shown in Picture 5-2. The drilling confirmed the presence of five ft of solid coal at a depth of 236 ft. We determined that Conf EW #2 would be drilled in the center of the three-way intersection of the northernmost entry in the west submains (see Figure 5-1).

The two confirmation boreholes, Conf EW #1 and #2 in the west submains area, confirmed the presence of a void/solid, as described in Table 5-2.

PICTURE 5-1 BOREHOLES DRILLING LOCATIONS ALONG THE RIGHT ENTRY OF THE NORTH-SOUTH MAINS

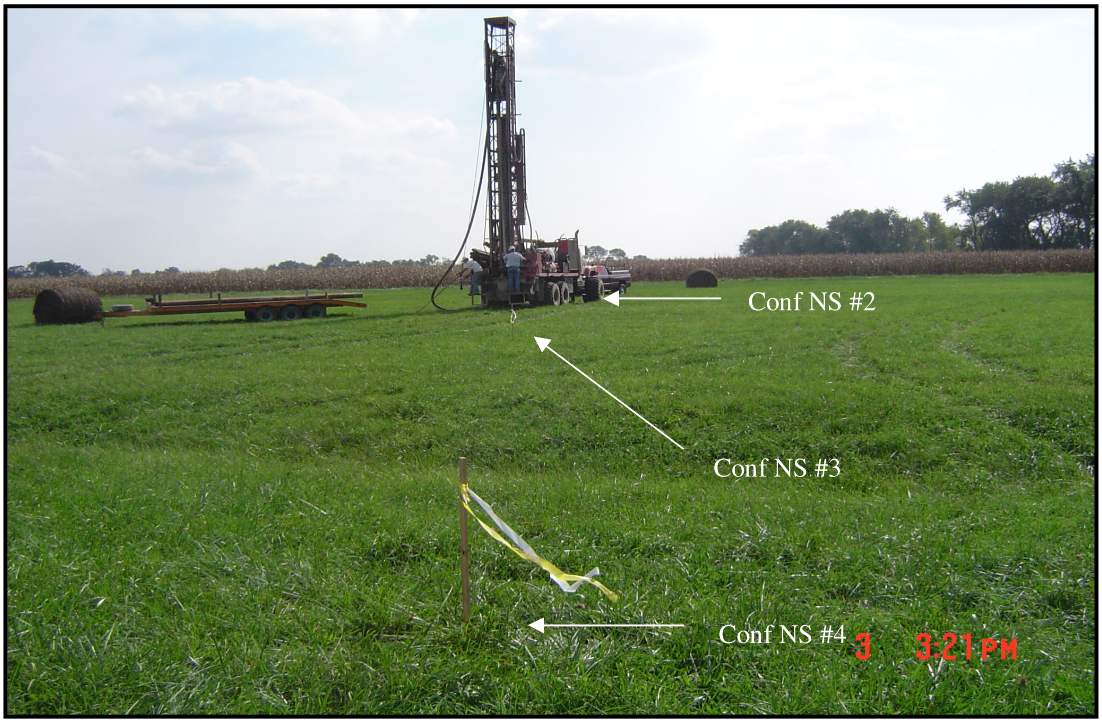


TABLE 5-1 RESULTS OF BOREHOLE DRILLING CONFIRMATION ALONG NS ENTRY

Borehole Number	Results
Borehole Conf NS #2	Void depth 230 ft to its top; void height 7.8 ft. Drill rod showed a sudden drop all the way through the void, indicating no obstructions.
Borehole Conf NS #3	Void depth 231 ft to its top; void height seven ft. Drill rod showed a sudden drop during the first three ft and exhibited dragging as the drill rod was pushed downward during the remaining 4 ft, indicating a possible collapsed zone or gob materials.
Borehole Conf NS #4	Void depth 229 ft to its top; void height 7.3 ft. Drill rod showed a sudden drop all the way through the void, indicating no obstructions.
North-South Mains Void Contents - Air-Filled / Water-Filled Voids	The drilling crew was unable to determine the presence of water in the mine voids. A plastic bottle filled with water was lowered down the borehole to check the water level. The water level in all the boreholes was about 58 ft above the mine roof, or at depth of about 172 ft below ground surface (BGS), confirming flooded mine voids.

PICTURE 5-2 REPRESENTATIVE BOREHOLE DRILLING AT CONF EW #1 NEAR TREE LINE

TABLE 5-2 RESULTS OF BOREHOLE DRILLING CONFIRMATION IN THE WEST SUBMAINS

Borehole Number	Results
Borehole Conf EW #1	The drilling confirmed the presence of five ft of solid coal at depth of 236 ft to its top. The borehole was drilled to a total depth of 245 ft to ensure that no other voids were present.
Borehole Conf EW #2	The borehole was drilled in the center of a three-way intersection. The borehole encountered a 6 ft high void at a depth of 230 ft to its top.

We discussed with Mr. Phil Ames of BBCC that the five ft thick coal seam encountered in borehole Conf EW#1, being less than seven ft, might indicate the presence of roll in the mine roof. As discussed in *Section 4.1.5 Conclusions and Recommendations*, the HRS anomaly to the north of the submains may be the result of the coal seam thinning, which suggests the presence of a roll. At the frequencies obtainable with HRS, the amplitude differences in the reflection from the coal horizon between mined voids and areas of thinner coal seams may not be distinguishable.

5.3 Borehole Deviation

Borehole deviation surveys were performed along all boreholes immediately following the drilling (Picture 5-3). Generally, the field data showed minimal deviation in all boreholes. The deviation survey in borehole Conf NS #3 exhibited similar "dragging action" as noted during the drilling. This phenomenon is discussed in Table 5-1. At this point, the deviation probe was lowered slowly down the void and a sudden change in the vertical alignment occurred. This may indicate that the probe was resting on collapsed material within the void. The data obtained from the deviation surveys were used in processing the sonar data described below.

Picture 5-3 Borehole Deviation Survey Probe

5.4 Sonar Mapping

As stated in *Section 1.4 Geophysical Overview*, the sonar mapping and borehole deviation surveys were not in the original work plan. These tasks were added to the SOW under Contract Modification #2 as supplements to the confirmation drilling program in order to enhance our understanding of: a) the presence of the confirmed voids; b) the contents of the voids; c) the geometries of the voids; and d) the alignment of the entries with respect to the original mine map.

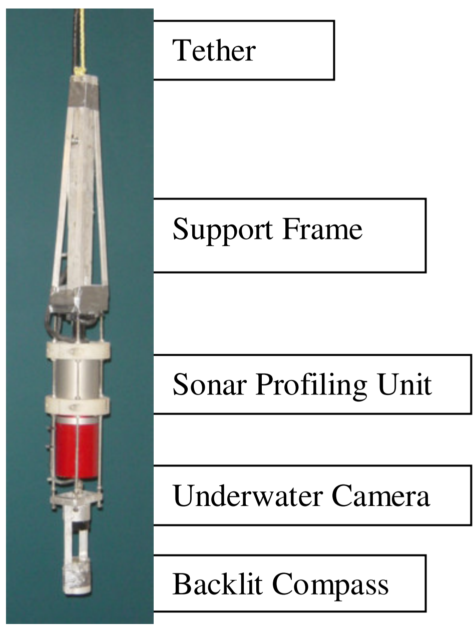
The sonar mapping and modeling were conducted by Blackhawk's consultant team member, Workhorse Technologies. On-site field observations were made and results were documented by

Blackhawk's Project Manager. During the two days of fieldwork, the four boreholes that had encountered voids (Conf NS #2, #3, #4, and EW #2, Figure 5-1) were used to map the flooded voids using a device called a Wet Ferret.

5.4.1 Instrumentation

As shown in Picture 5-4, the Wet Ferret consists of a profiling sonar unit, color underwater camera, backlit magnetic compass, support frame, and tether. The Wet Ferret uses the profiling sonar unit to take range measurements up to 300 ft in 360-degree horizontal planes referred to as scans. Scans are referenced using the depth from the ground surface, borehole surface coordinates, and the camera view of the magnetic compass. By taking enough scans at different elevations, a 360-degree 3-D model of the void can be produced. The scanned void can be geo-referenced to correlate with the magnetic compass and underwater camera integrated into the device.

PICTURE 5-4 WET FERRET SONAR MAPPING TOOL



5.4.2 Data Acquisition

The Wet Ferret unit measures 4 7/8 inches in diameter, which allowed the unit to experience little or no problems in negotiating the 5 1/8 in diameter boreholes. The sonar mapping began at borehole NS #2 and continued sequentially until all of the boreholes were completed. The surface elevation and coordinates of each borehole were used to reference the raw data. At each borehole location, the unit was lowered manually to the top of the flooded void (mine roof). At this depth, raw data were acquired at 12-inch vertical intervals until it reached the mine floor, or the unit was in a mud-like area preventing data acquisition. Data collection was then repeated from the mine floor to the roof. Horizontal 360-degree scans were acquired at different range resolutions to gather as much detail as possible for each interval. This approach allows 3-D sonar images to be produced. Sonar scans gave range-reading returns from distances of over 100 ft in the confined spaces of the coalmine voids. Picture 5-5 shows the Wet Ferret sonar data acquisition device.

PICTURE 5-5 DATA ACQUISITION USING WET FERRET TOOL

5.4.2.1 Survey of Borehole Locations

Table 5-3 lists the borehole coordinates and elevations used in the data analysis. The borehole coordinates were obtained by BBCC surveying crew.

TABLE 5-3 BOREHOLE COORDINATES

Location ID #	Coordinates		
	Easting, ft	Northing, ft	Elevation, ft*
NS #2	679,650.73	1,200,275.41	666.68
NS #3	679,648.66	1,200,343.94	665.92
NS #4	679,648.66	1,200,408.31	665.55
EW #2	679,405.10	1,200,170.60	668.42
**Ground Surface*			

5.4.2.2 Field Data Reference Table

Table 5-4 lists the sonar scans with their depths and elevations. The listed elevations are referenced to the top of the casing. Compass references of the elevation and sonar scan associated with the photo of the magnetic compass were used to align the model. “Magnetic” and “Map” refer to the angular offset applied to the associated scan. “Map” represents the final analyzed angular offset used to align the scan and the model with north.

TABLE 5-4 SONAR SCANS

NS #2	Surface Elev. Plus Offsets	668.18 ft			
Scan ID	Depth in ft	Note	Elevation, ft*	Angular Offsets (degrees)	
				Magnetic	Map
	175.1	Water Level	492.08		
	230.6	Roof	436.58		
231	230.6	Compass	436.58	236	250
231v2	231.66		435.52		
232	232.75		434.43		
233	232.9		434.28		
234	235.1		432.08		
235	236		431.18		
236	237.5		429.68		
*Top of Casing					

NS #3	Surface Elev. Plus Offsets	667.72 ft			
Scan ID	Depth in Ft	Note	Elevation (ft)*	Angular Offsets (degrees)	
				Magnetic	Map
	174.25	Water Level	492.47		
	232	Roof	434.72		
			666.72		
00	232.75	Compass	433.97	277	287
01	234		432.72		
02	234.8		431.92		
03	233.5		433.22		
04	233		433.72		
* Top of Casing					

5.4.3 Field Observation Results

Figures 5-2 through 5-5 show a screen capture of a raw sonar scan at a single elevation at each of the four boreholes (Conf NS #2, #3, #4, and EW #2). By examining these data in the field, informed decisions were made on additional scans needed to completely map a void or plan the location of the next borehole. Table 5-5 provides a summary of the field observations. In general, the sonar field results showed that the scanned locations of the Conf NS #2, #3, and #4 boreholes were near the south corners of the pillars.

Table 5.4 SONAR SCANS CONTINUED…

NS #4	Surface Elev. Plus Offsets	666.80 ft			
Scan ID	Depth in Ft	Note	Elevation (ft)*	Angular Offsets (degrees)	
				Magnetic	Map
	174	Water Level	492.80		
	230	Roof	435.80		
00	232.5	Compass	433.30	232	241
01	230.33		435.47		
02	231.4		434.40		
03	232.5		433.30		
04	234		431.80		
05	235		430.80		
06	233.1		432.70		
07	232		433.80		
08	231		434.80		
** Top of Casing*					

EW #2	Surface Elev. Plus Offsets	669.32 ft			
Scan ID	Depth in Ft	Note	Elevation (ft)*	Angular Offsets (degrees)	
				Magnetic	Map
	172	Water Level	496.32		
	232	Roof	436.32		
00	232		436.32		
01	233		435.32		
02	234		434.32		
03	235		433.32		
04	236		432.32		
05	233.5		434.82		
06	234.5		433.82		
07	233		435.32		
08	234	Compass	434.32	153	165
** Top of Casing*					

The scan from the Conf EW #2 confirmed the center of the three-way intersection location. These scans suggested that there is an offset in the historical (old) mine map relative to the geo-referenced boreholes, as shown on Figure 5-6. The figure illustrates that the geo-referenced mine is offset approximately five to ten ft south and three ft east of that shown on the historical (old) mine map. This offset indicates that the boundary of the original four-entry mains along the north-south rib line is east of that shown on the existing historical mine map. *Section 5.4.4*

Sonar Data Processing and Interpretations, provides detailed information from the sonar data analysis and models used to determine the mine map offset.

FIGURE 5-2 VIEW OF A SONAR SCAN FOR A SINGLE ELEVATION AT CONF NS #2

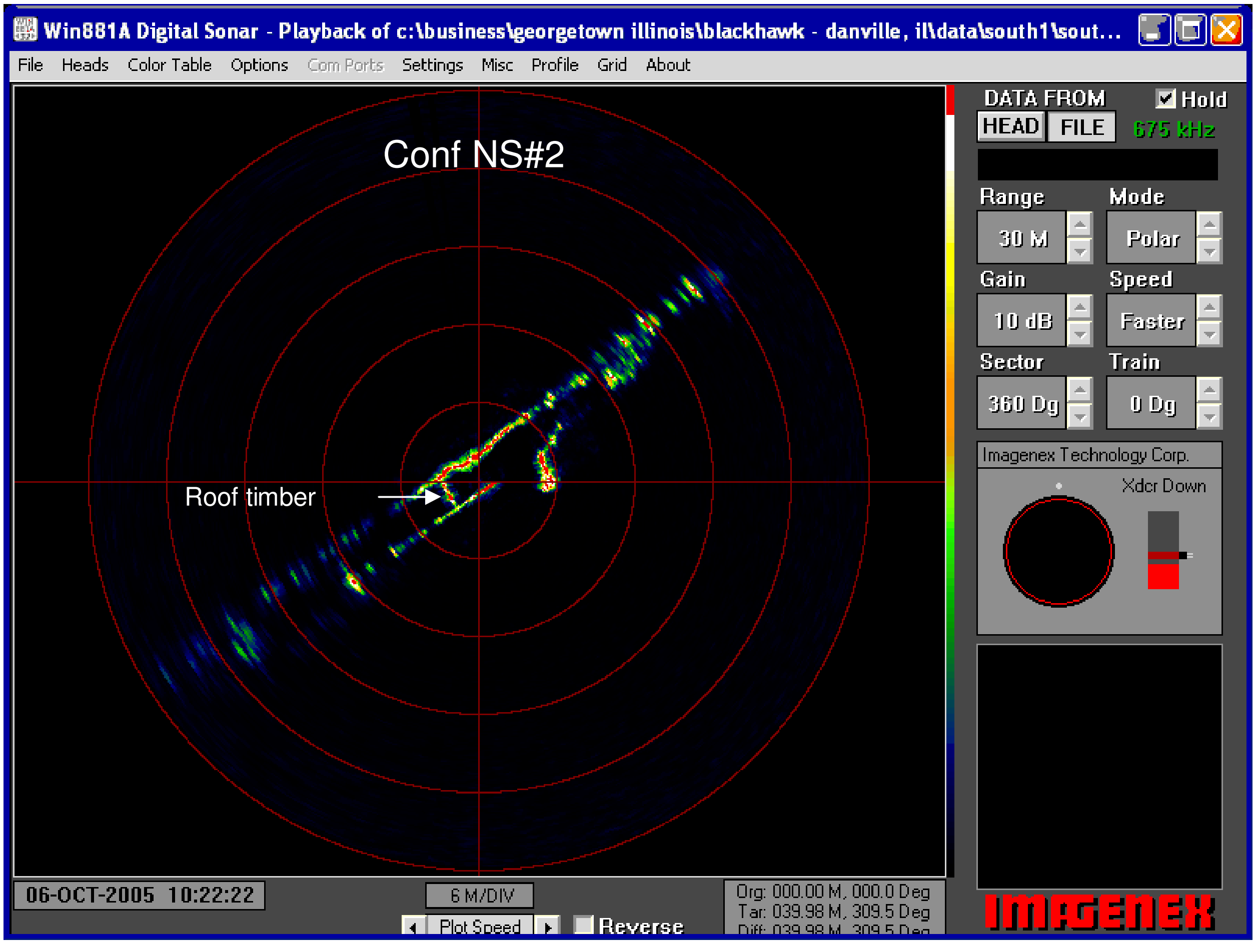


FIGURE 5-3 VIEW OF A SONAR SCAN FOR A SINGLE ELEVATION AT CONF NS #3

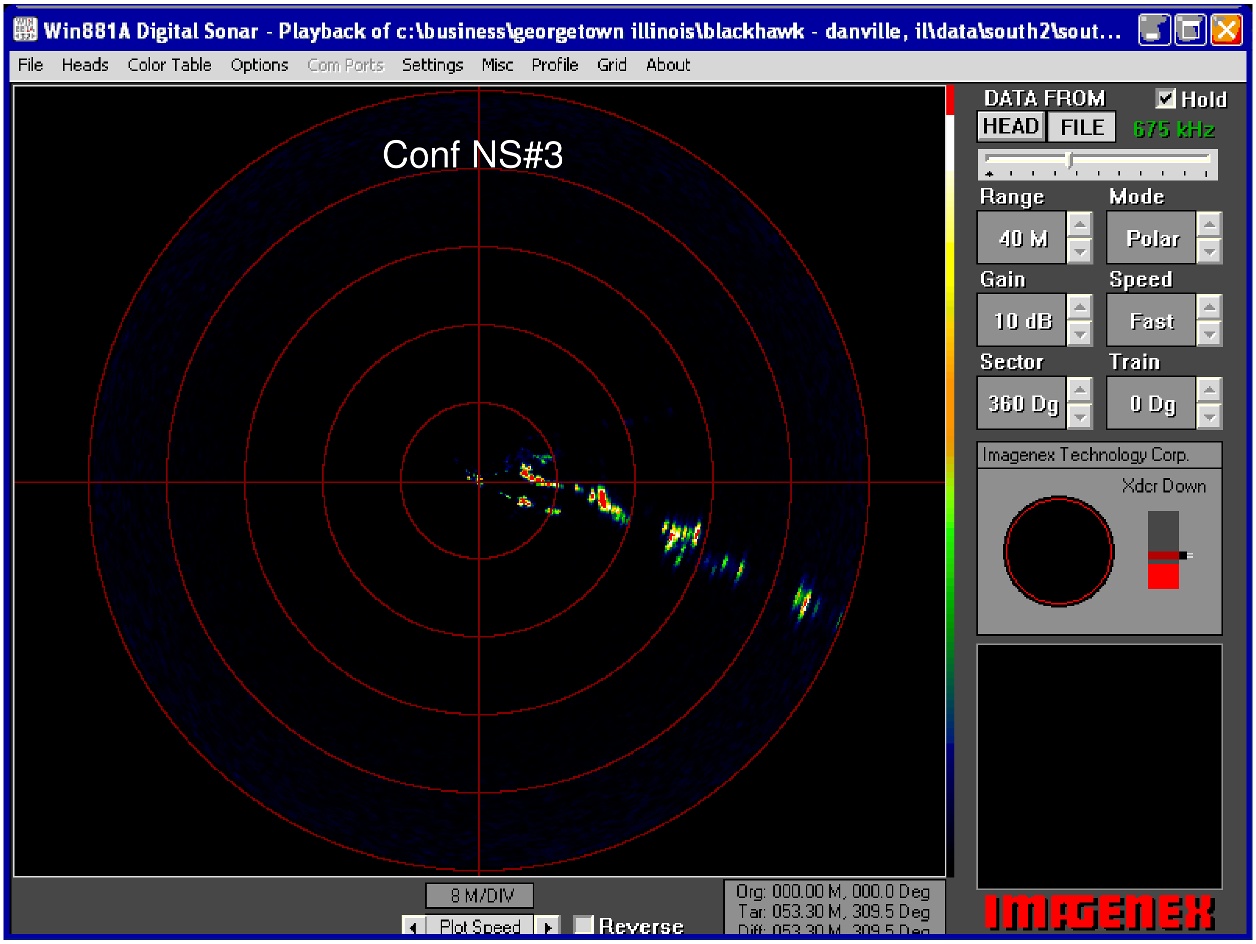


FIGURE 5-4 VIEW OF A SONAR SCAN FOR A SINGLE ELEVATION AT CONF NS #4

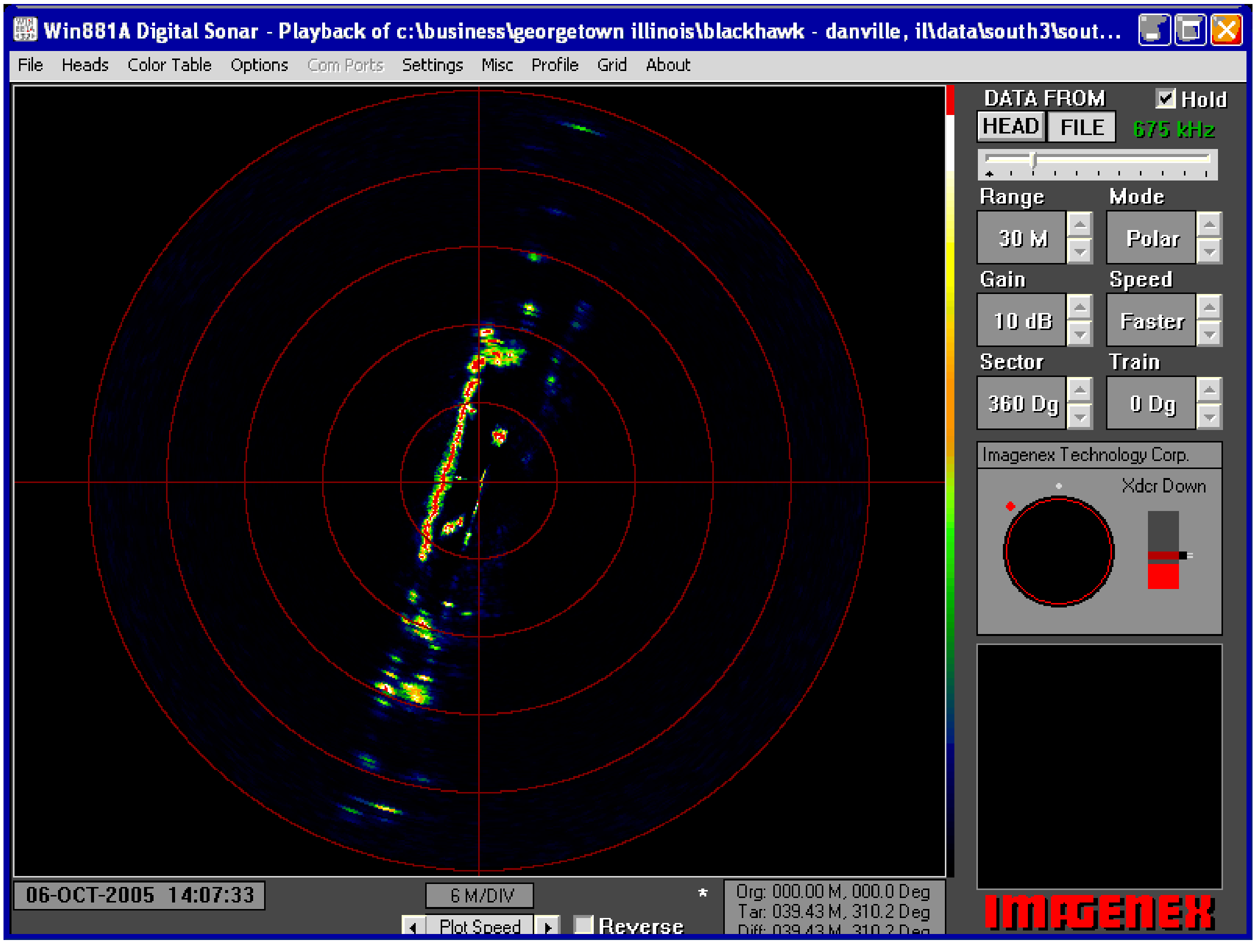


FIGURE 5-5 VIEW OF A SONAR SCAN FOR A SINGLE ELEVATION AT EW #2

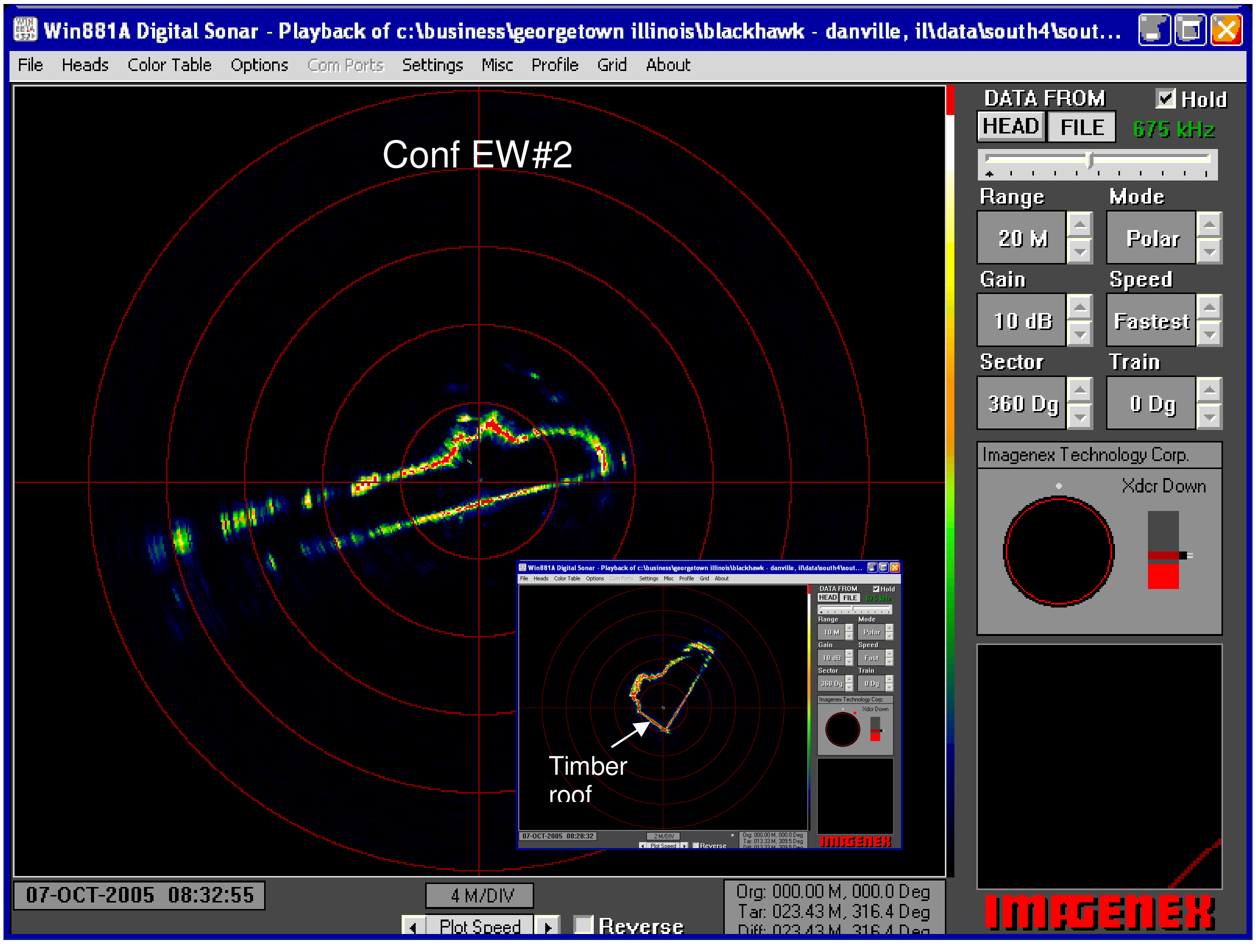
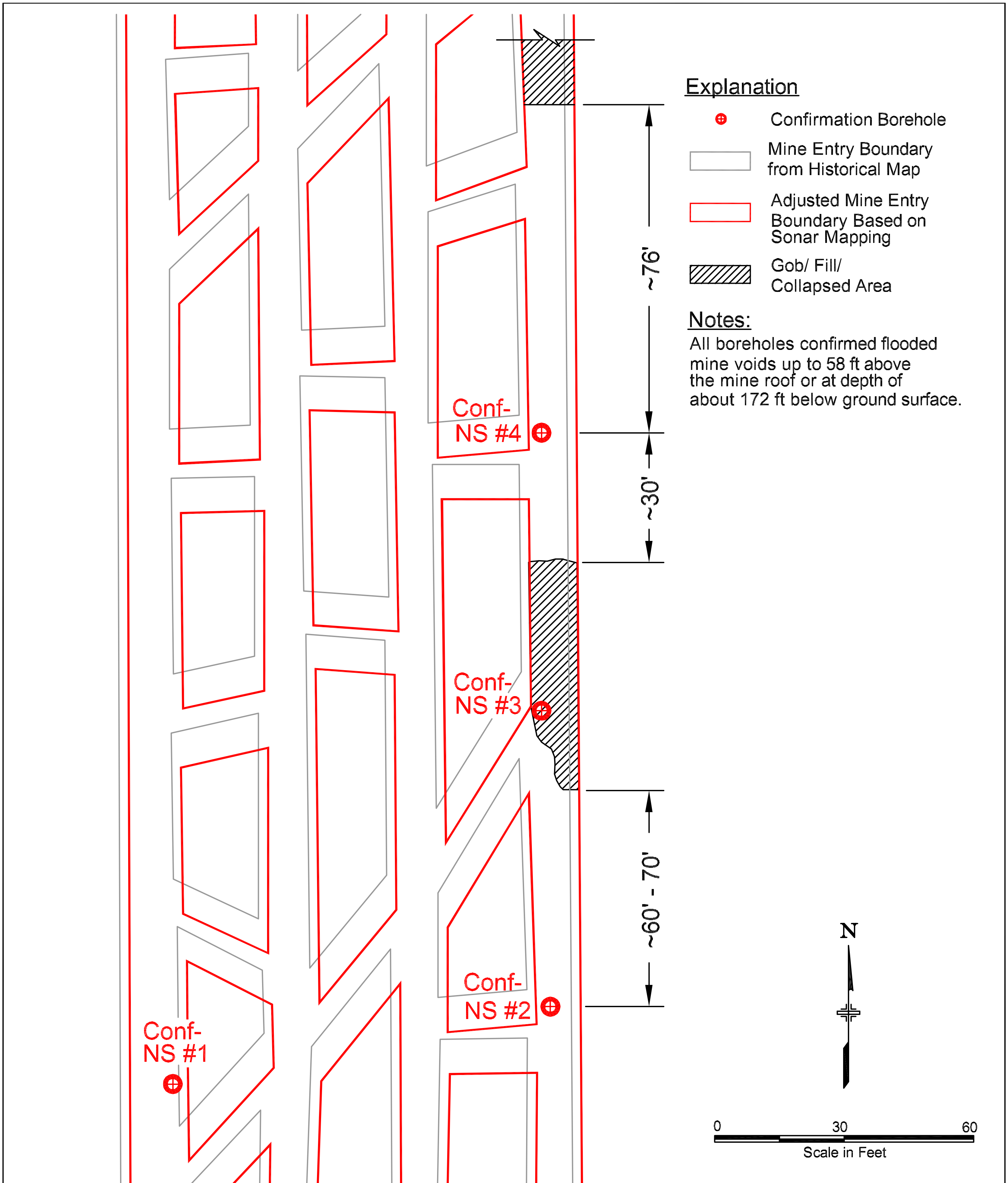


TABLE 5-5 SONAR MAPPING FIELD OBSERVATIONS FOR BOREHOLES IN THE MAINS AND SUBMAINS

Borehole Number	Results
Borehole Conf NS #2	The rib line was visible to a distance of about 75 ft in both north and south directions. The 90-degree crosscut was visible, confirming the three-way intersection. The south corner of the pillar was partially visible. Straight lines perpendicular to the entry were noticed in the sonar scans near the roofline indicating the location of the timber roof support. No obstructions such as gob/fill-like materials were noticed in the vicinity of the three-way intersection area. **The sonar survey in this borehole confirmed the void height as 7.8 ft and the relative accuracy of the entry/pillar layout.**
Borehole Conf NS #3	The rib line was visible to a distance of about 75 ft *only* in the south direction (toward borehole NS #2). The 45-degree diagonal crosscut was visible, confirming the three-way intersection. The south corner of the pillar was partially visible. Obstructions were noticed in the vicinity of the three-way intersection area north of the borehole location, which made it difficult to survey the entire height of the void. **The sonar survey in this borehole confirmed the unfilled void height of about three to four ft, which supports the observations made during drilling and the deviation survey, where the drill rod and the deviation instrument were noticed to drag along a sloped pile of possible solid/rubblized or loose materials. The survey also confirmed the relative accuracy of the entry/pillar layout.**
Borehole Conf NS #4	The rib line was visible to a distance of about 76 ft in the north direction and about 30 ft in the south direction of the borehole. This limited site distance to the south supported the presence of a possible gob or otherwise filled zone between boreholes NS #3 and #4, starting in the vicinity of borehole NS #3 and extending about 25 to 30 ft north of the borehole. The 90-degree crosscut was visible, confirming the three-way intersection. The south corner of the pillar north of the borehole location was partially visible. Straight lines perpendicular to the entry were also noticed near the roofline indicating the location of the timber roof support. No obstructions of gob or other materials were noticed at the three-way intersection or north of the borehole. **The sonar survey in this borehole confirmed void height as 7.3 ft and the relative accuracy of the entry/pillar layout.**
Borehole Conf EW #2	The rib line was visible to a distance of about 65 ft in both east and west directions. **The 90-degree crosscut was visible.** The sonar survey in this borehole confirmed void height as six ft **and relative accuracy of the entry/pillar layout.**



BLACKHAWK
A DIVISION OF ZAPATAENGINEERING

US Department of Labor
Mine Safety and Health Administration

Plan View of Adjusted Mine Entry with Old Mine Map

Riola Mine Complex
Vermilion County, Illinois

301 Commercial Road, Suite B
Golden, Colorado 80401
Phone: (303) 278-8700
Fax: (303) 278-0789
Web: www.blackhawkgeo.com

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5006	June, 2006	HJV	KH	1" = 30'	5-6

5.4.4 Sonar Data Processing and Interpretations

As discussed above, for each scanned interval, raw sonar data were collected at several range resolutions to offer a wide range of modeling information. All of the horizontal scans for a void location were statistically aligned to create a 3-D model of the mine void surrounding the borehole. The 3-D model was then aligned with the mine map using the following strategy:

- Determine initial entry point into the void from borehole coordinates and deviation data;
- Establish initial orientation based on magnetic compass data;
- Distinguish the lines and features from the model;
- Maximize the fit of the dense data lines to edges on the map;
- Minimize the points overlying pillars;
- Maximize the points of data overlaying rooms (voids);
- Iterate.

The existing historical mine plan map shown on Figure 5-1 was of good quality for the investigated locations and the alignments of the models correlated well with the mine map. The map was properly scaled and dimensionally accurate, as verified by the sonar investigation. The individual models from each hole needed only rotation for orienting north. Once rotationally aligned, all of the points in the model were transformed into grid coordinates.

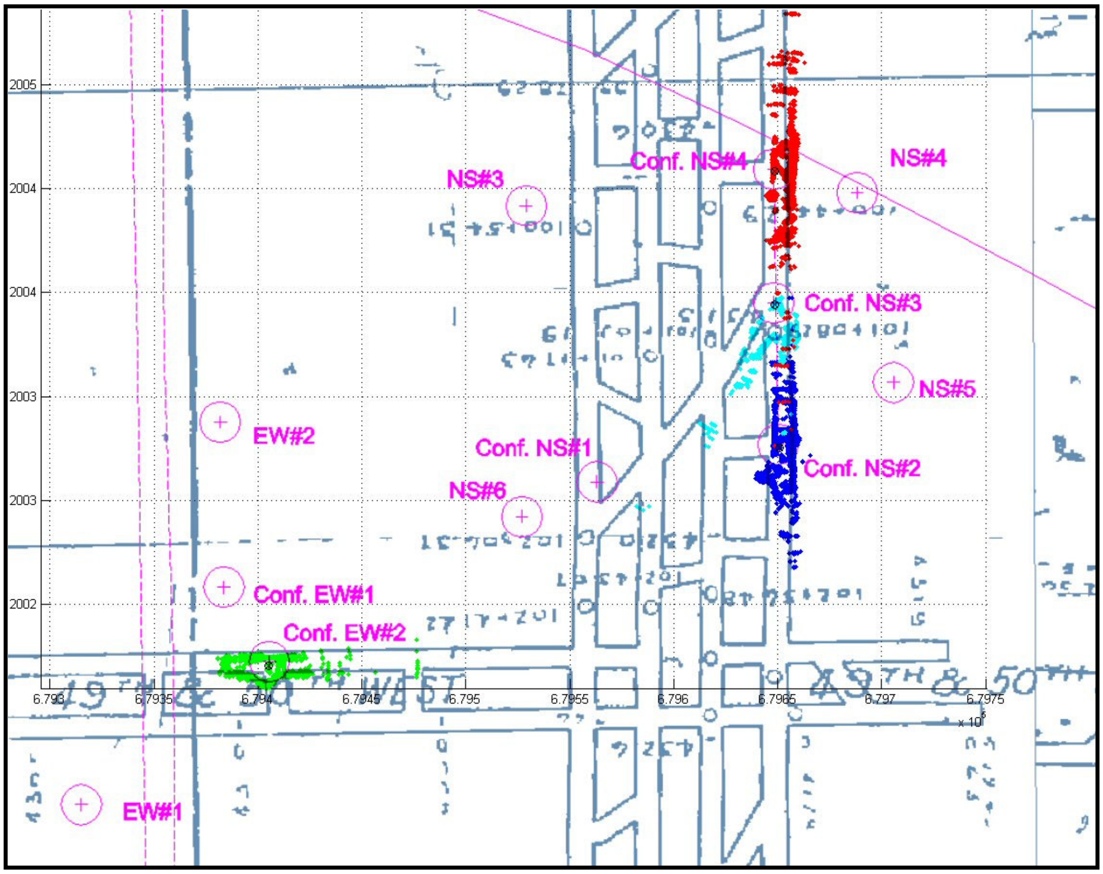
Figure 5-7 shows the plan view of the composite model using sonar scan results from boreholes Conf NS #2 (dark blue), NS #3 (light blue), NS #4 (red) and EW #2 (green) overlaid and aligned with the historical mine map. The composite model generally overlays well with the historical mine map. The individual models from Conf NS #2, #3, and #4 have overlapping points. Each of the four models reveals characteristics of three-way intersections identified on the map. The scan from Conf NS #3 shows sonar returns clearly identifying the crossing entries along the diagonal crosscut extending to the southwest. The model from Conf EW #2, located to the west and away from the other scans, dimensionally scales to the crosscut location on the map.

Figure 5-7 also shows the displacement of the historical mine map relative to the geo-referenced model. Figure 5-8 indicates the displacement and rotation of the model that matches the mine map versus the geo-referenced model. The historical mine map is offset ten ft north and three ft west of the geo-referenced Conf NS #3 and three ft north of geo-referenced Conf EW #2.

5.4.4.1 Borehole and Data Plots

Using the geo-referenced model, orthogonal and cross-section plots were generated to provide additional perspectives of the mine. Figures 5-9 through 5-12 illustrate model information from boreholes NS #2, #3, and #4, and EW #2, respectively. Appendix E contains the processed orthogonal and cross-section plots generated.

FIGURE 5-7 PLAN VIEW OF MINE VOID MODELS FROM FOUR HOLES ALIGNED WITH HISTORICAL MINE MAP



5.5 CONCLUSIONS

Based on the results obtained from the void confirmation, the following summarizes the conclusions of the drilling and sonar mapping combined with on-site field observations in detecting and locating mine voids:

- The design and location of the confirmation boreholes were based primarily on the RVSP survey results and the use of the historical mine map.
- The HRS data were not used for planning the confirmation boreholes except in the area that showed some anomalous amplitude north of the west submains.
- The XHT and the guided waves seismic surveys were not used for planning the void confirmation boreholes, because they were unsuccessful in mapping the old mine works.
- The borings along the easternmost entry in the north-south mains and in the west submains confirmed the presence of voids. The voids' height in the submains was 6.0 ft, and ranged from 7.0 to 7.8 ft in the mains. All of the boreholes showed water level at about 58 ft above the mine roof, confirming flooded mine voids.

- The boring (Conf EW #1) in the area north of the submains which exhibited a high amplitude geophysical anomaly confirmed a five ft thick solid coal seam. The HRS anomaly in this area may be the result of the coal seam thinning and not old mine works. Thinning of the coal seam in the vicinity of this area was also apparent in previously drilled XHT boreholes.
- The sonar mapping successfully imaged the entries in the mains and submains and accurately determined the rib line boundary between right entry and solid coal along the NS mains.
- The observed sonar results in the vicinity of the confirmation borehole Conf NS #3 indicate that the historical mine map is offset 10 ft north and three ft west relative to the geo-referenced sonar mapping results. This offset indicates that the boundary of the original four-entry mains along the north-south rib line is east of the historical mine map. Near the borehole Conf EW #2, the geo-referenced mine map from the borehole sonar mapping data is offset three ft south relative to the historical mine map.

FIGURE 5-8 MAP MATCHED MODEL AND GEO-REFERENCED MODEL

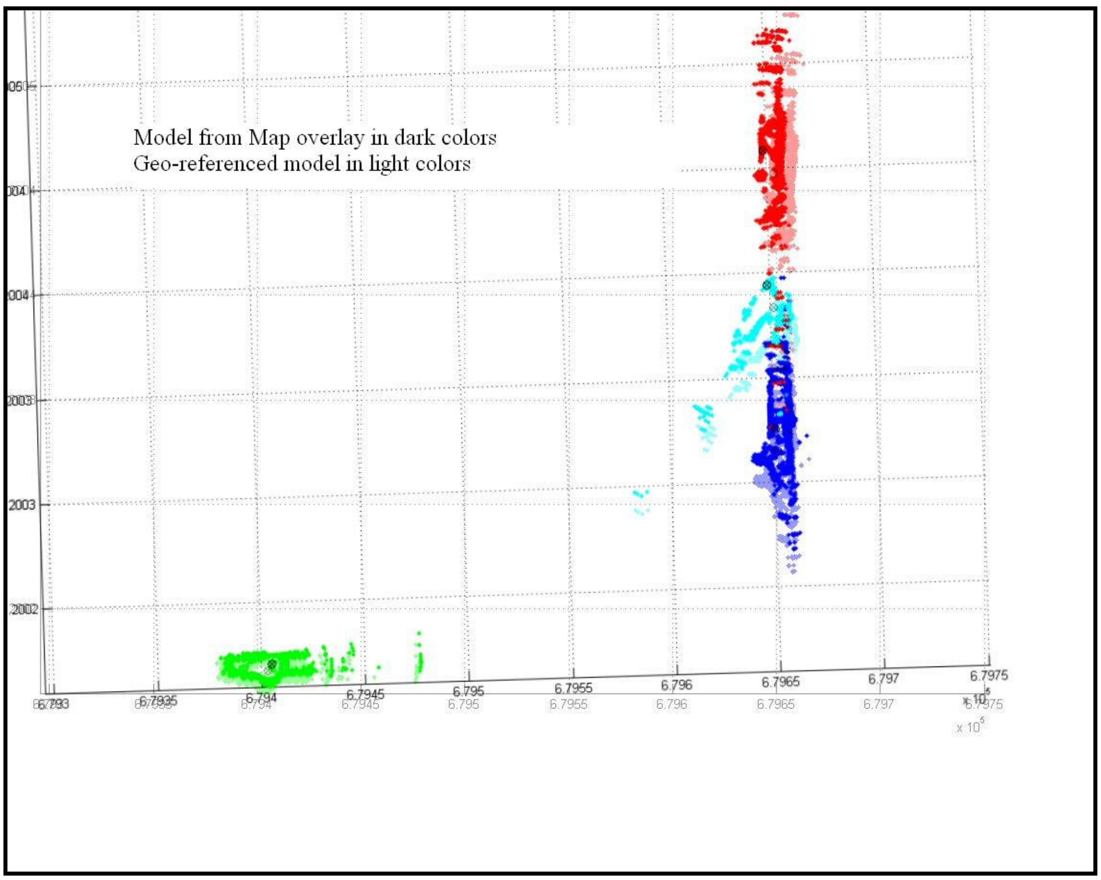


FIGURE 5-9 ORTHOGRAPHIC PLOT OF BOREHOLES CONF NS #2, #3, AND #4

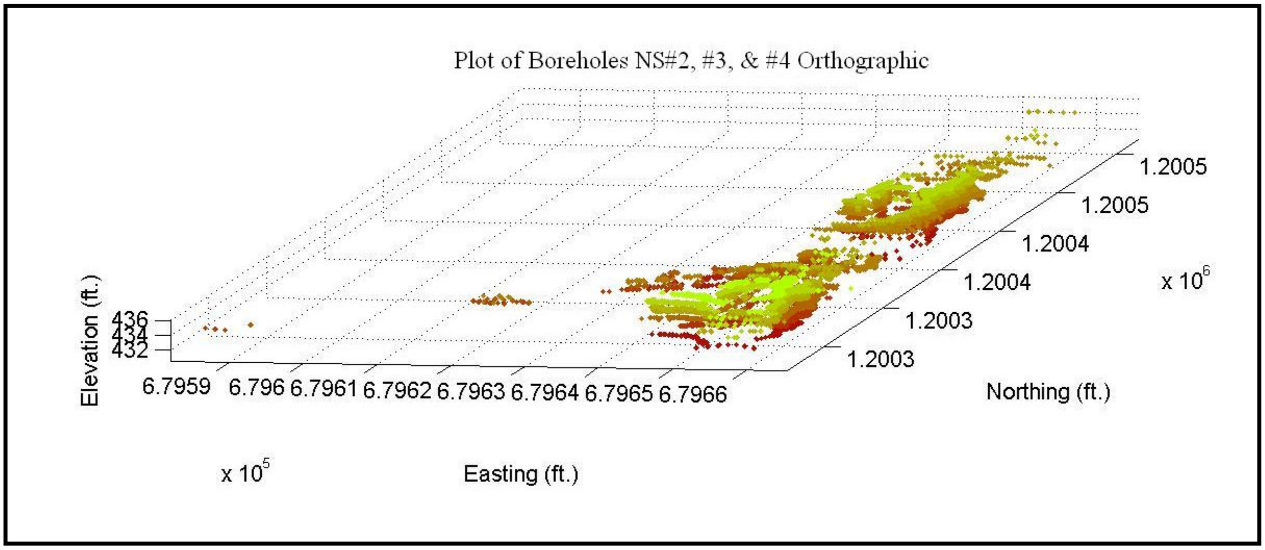


FIGURE 5-10 REFERENCE PLOT OF CONF NS #2, #3, AND #4

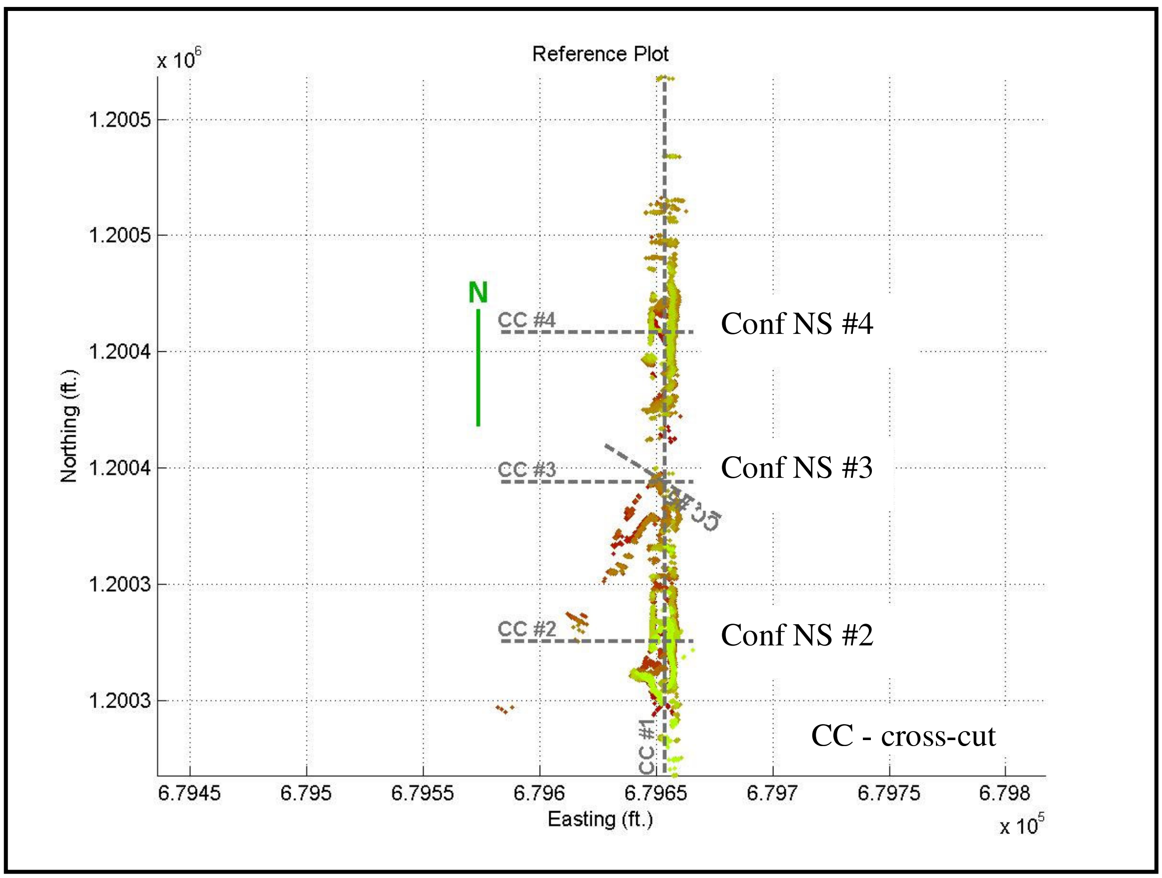


FIGURE 5-11 ORTHOGRAPHIC PLOT OF BOREHOLES CONF EW #2 ORTHOGRAPHIC

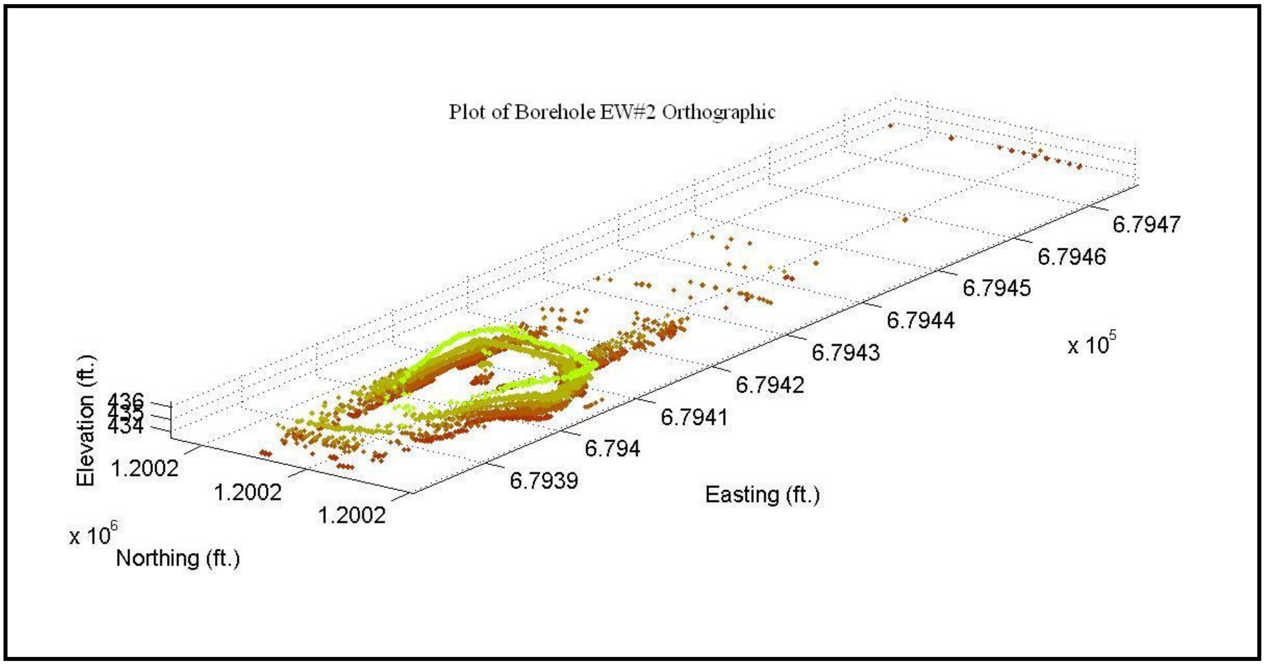
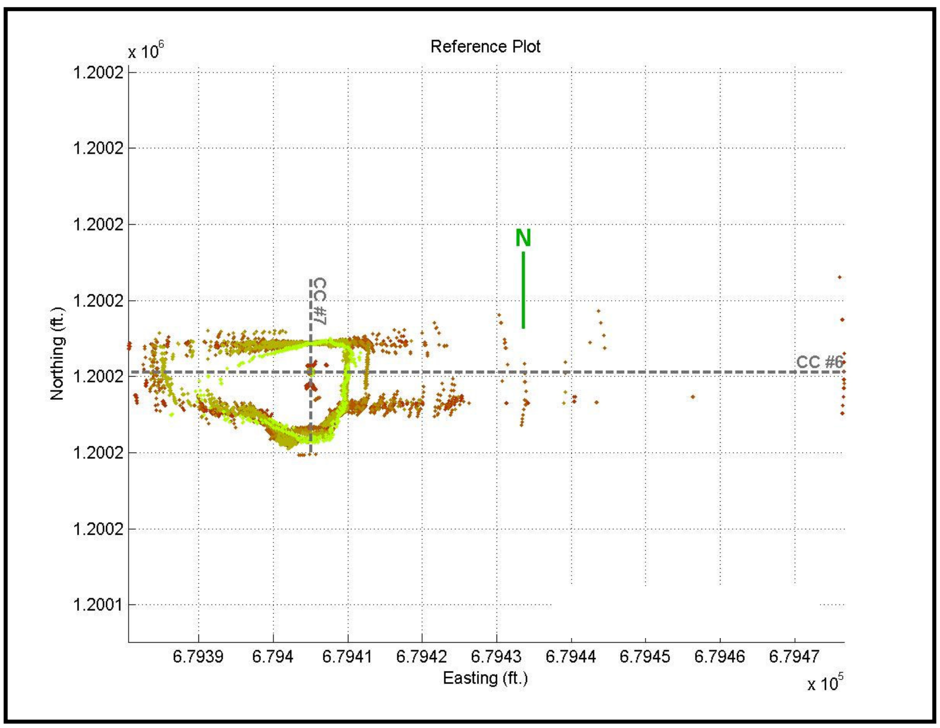


FIGURE 5-12 REFERENCE PLOT OF CONF EW # 2



6.0 GEOPHYSICAL TECHNOLOGIES PERFORMANCE EVALUATION

We evaluated each of the tested geophysical methodologies based on the results of the geophysical demonstrations at the known abandoned underground mine adjacent to the active RMC including the following criteria:

- Ability to Image Old Mine Works – This is the primary criterion by which the methods were evaluated, and is based on each method's ability to detect and map the presence of the old mine works at this demonstration site under these particular site-specific conditions.
- Resolution – The evaluation of this criterion is based on how well each of the methods was able to image details of the old mine works and accurately map the rib lines of the entries.
- Depth of Investigation – This criterion is a measure of the method's sensitivity to the depth of the target. It considers what the relative limits are for the depth of investigation.
- Anticipated Repeatability – Repeatability is defined herein as conducting the survey over again. Due to the scope of work and associated budget, repeated surveys were not obtained at the site except during daily equipment checks. However, based on our experience at the demonstration site and other sites, we estimated how sensitive each method would be to changes in site conditions and other typically encountered field variations.
- Robustness under Various Geologic/Surface Conditions – Based on the results and experience at the demonstration site, this criterion is a measure of how adaptable the method is to differing terrain and geologic conditions while still accomplishing the primary criterion of imaging the old mine works.
- Cost – This criterion is evaluated based on the cost of the equipment, the amount of field effort required to collect the data and the processing and interpretation effort to provide the information required to meet the survey objectives.
- Sensitivity to Void Contents – The old mine workings at the demonstration site was completely flooded with some isolated areas possibly containing loose fill material or collapsed structure. Therefore, no direct comparison can be made to determine each method's sensitivities to void contents. However, based on the theory involved and experience at other sites, an estimate was made of how each method would be affected by the contents of the void (water, air, fill materials, or gob).

Our geophysicists and mining engineers evaluated the results obtained at the abandoned mine site and ranked each method using the above criteria. This is summarized in Table 6-1. A more detailed discussion of the evaluation of each of the methods is provided below.

TABLE 6-1 PERFORMANCE EVALUATION OF GEOPHYSICAL METHODS

Criterion	HRPW	HRSW	XHT	Guided Waves	RVSP	Sonar Mapping*
Ability to Locate Voids	Fair	Fair	Poor	Poor	Good	n/a
Resolution	Poor	Poor	Poor	Very Poor	Very Good	Excellent
Depth of Investigation	Good	Poor	Good	Good	Good	Very Good
Anticipated Repeatability	Good	Fair	Good	Fair	Good	Very Good
Robustness under Various Geologic/Surface Conditions	Fair	Poor	Fair	Fair	Good	Very Good
Cost	High	Very High	Medium	Low	Medium	Medium
Void Contents	Poor	Good	Poor	Poor	Good	Very Good

*Sonar mapping can only be used in a borehole that has intersected a water-filled void in the mine.

HRPW

The high-resolution P-wave method obtained clear reflections from the Danville #7 and Herrin #6 coal horizons, and showed consistent data quality throughout the survey. Noticeable amplitude variations were seen in the reflection from the Herrin #6 coal seam in the vicinity of the old mine works. These amplitude variations are clustered around the existing old mine works, but also extending out beyond the mapped area of the historical mine works (see Figure 4-7). Confirmation borehole EW#1 as described in *Section 5.0 Void Confirmation,* was drilled based on the locations of these amplitude anomalies. The presence of these amplitude anomalies, which thought to correspond to the location of the voids, but appeared to correlate to, rolls in the coal seam roof and thinning of the coal seam. The survey was unable to detect the location of the rooms (voids) and pillars. The cost of conducting and processing the 3-D survey for this demonstration program was relatively high and the survey only partially met the objectives. This was partially due to the lack of high frequency reflections from the Herrin #6 coal seam. Therefore, this method may be feasible to use in situations where the target is shallower and near-surface conditions provide better transmission of the seismic energy. Because the compressional-wave velocities of water and coal are very similar, improved results may also be obtained if the voids are air-filled.

A significant cost reduction could be obtained if 2-D or 3-D swath acquisition was used, as opposed to a full 3-D survey. This would also have the benefit of improving the signal quality and resolution along the profile from increased data redundancy and reduced sensor spacing.

Performing 2-D or 3-D swaths would require some knowledge of the orientation of the old mine works.

HRSW

The high-resolution shear wave method obtained some reflection data from the Danville #7 coal horizon, but very little information was obtained from the Herrin #6 coal horizon. This was mainly due to the high reflection coefficient of the overlying Danville #7 coal horizon that limited the transmission of the shear wave seismic energy below this coal horizon. Therefore, only limited information could be obtained on the old mine works located in the Herrin #6 coal seam. Acquisition of shear wave data was also hindered by the soft soils in the near surface. A second shear wave source was used during the survey to increase the source energy output. This increased the signal-to-noise levels of the reflections from the Herrin #6 coal seam to produce the amplitude interpretation on Figure 4-9. The distribution of the amplitude anomalies interpreted in the HRSW data match well with the distribution of the amplitude anomalies shown in the HRPW data (Figure 4-8). The survey was unable to detect the location of the rooms (voids) and pillars.

The HRSW survey was originally selected because of the high impendence contrast between coal and both air-filled voids and water-filled voids. Shear waves have an advantage over P-waves for void detection because shear waves do not propagate through water or air, such that the void contents (water-filled or air-filled) should not affect the ability of shear waves to detect a void. This method potentially could be used in areas where the uppermost coal seam is the target, because no overlying coal seam would prevent the transmission of the shear wave energy. The cost of an HRSW reflection survey could also be significantly reduced by using 2-D or 3-D swath geometry with the same benefits of improved signal-to-noise ratio and resolution.

XHT

Multiple XHT panels were acquired at the demonstration site. The boreholes were located so that different panels were acquired across areas that were believed to contain old mine works and those thought to contain only solid coal at the Herrin #6 horizon. In both cases, the XHT provided similar results, indicating that the voids were not detected by the method. This is likely attributable to several factors including low velocity contrast between the coal and water-filled voids, higher than desired spacing between boreholes, and the high velocity of the layers immediately above and below the Herrin #6 coal seam. There were low velocity zones located at the same depths as some of the coal seams within the section, particularly the Danville #7 coal seam at approximately 135 ft.

The method may have application in areas where the boreholes can be spaced significantly closer and where the coal seams are not directly adjacent to high-velocity lithologic layers. However, closer borehole spacing would increase the cost. The sensitivity of XHT to lithologic units surrounding the coal seam makes it unsuitable for a wide range of sites. The cost for performing an XHT survey is less than that for a surface 3-D HRS survey, but the results were not suitable for siting confirmation boreholes.

Guided Waves

As a low cost addition to the XHT survey, a guided waves seismic continuity analysis was performed. When it works, this method is only capable of determining whether a discontinuity exists in the coal seam between two boreholes. Therefore, it has the lowest resolution of all the methods tested, and is also sensitive to a variety of other geologic conditions such as washouts and faults/fractures.

When comparing the data for the guided waves analysis for zones with and without old mine works, the responses often appeared very similar. This may be due to the water within the voids that transmitted the guided waves even though coal was not present. Nevertheless, this method does not appear to be suitable for a number of cases even though it was one of the least expensive methods tested.

RVSP

RVSP data were acquired using a subset of the data from the XHT survey, namely the data from the surface receivers. In all three RVSP processed sections, the boundaries of the mains and submains were detected. It appeared to accurately image the boundary of the old workings as well as the individual entries and pillars within the mains, but was not able to image individual entries in the submains. However, this may have been due to a gap in the geophone array where it crossed the access road. This success in imaging the old mine was despite the fact that the survey geometry was not optimal for RVSP processing. The positional accuracy of the RVSP interpretations for mapping the boundaries of the old mine works was on the order of three to five ft. This is notable considering the depth of the target horizon is 235 ft and that the survey geometry was not optimal for RVSP.

As can be seen on Figures 4-21 and 4-26, the RVSP method is capable of obtaining significantly higher frequency bandwidth than surface methods and therefore has much better resolution for mapping old mine works. This is likely because of 1) decreased non-elastic behavior around the seismic source when the source is located in the borehole and 2) decreased attenuation in the near surface, because the seismic energy only has to pass through the high attenuation near surface materials once.

The RVSP method also offers some cost advantages over the HRS (HRPW and HRSW) methods, because vehicular access is only required in the vicinity of the borehole. The seismic geophones are man portable and can easily be placed where seismic sources would require a significant effort to position. This makes the RVSP less expensive than HRS in many situations. The RVSP method can be extended to 3-D acquisition in cases where little is known about the orientation of the old mine workings. The borehole does not have to be drilled into the target coal seam, so the cost of drilling can be reduced, especially if there is concern about drilling into a void at the target horizon. The information from an optimally acquired RVSP survey can extend out from the borehole for a distance approximately equivalent to the depth of the target.

Sonar Mapping

Sonar mapping was able to accurately map the extent of the old mine entries at the demonstration site. The positional accuracy of this method was on the order of two to six inches when mapping the distance from the borehole to the ribs of the entries. The only drawback to this method is that a borehole must exist that intersects the old mine workings; i.e., this method is unable to map old mine workings without access to the interior of a void. Once the instrumentation is placed within the void, the method offers accuracy and reliability unobtainable from any other remote method in almost all geologic conditions and at depths up to 800 ft below ground surface. Although sonar mapping can only work in water-filled voids, alternative instrumentation can work in air-filled voids (e.g., laser mapping). If the void is filled with thick mud or gob, sonar mapping will be unable to acquire useful data.

The data for these surveys can be acquired rapidly once the borehole has intersected the old mine workings. At the demonstration site, data from four boreholes were acquired in less than two days on site. Preliminary information is available in real time, so that decisions can be made regarding new borehole locations while the equipment is in the field. This can significantly reduce the cost of mobilizing drilling crews and geophysical crews.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Performance evaluation of the geophysical methods used for the mine void detection at the site showed that the RVSP method can detect the boundary of the old mine works with horizontal accuracy of three to five ft and detect the location of the voids (entries) and pillars. The borehole sonar can map water-filled voids within a line of site (sonar path). In the case of air-filled voids, a borehole laser should be used to map mine voids. The RVSP methods when combined with the borehole mapping tools offer significantly better performance than the other evaluated methods in terms of their ability to:

- Detect the mine voids, and to
- Accurately map the boundaries of the entries.

These two methods are complementary. The RVSP method provides initial information on the location of the old mine works. It can be relatively inexpensively deployed in a variety of geologic and surface conditions. The main requirement for the method is access to a borehole that can be drilled within a maximum distance approximately equal to the target depth. The borehole does not have to be drilled into the target horizon (coal seam) and the construction of the borehole is not as critical as with the XHT survey.

Of the other geophysical methods that were demonstrated, the HRS methods (HRPW and HRSW) provided the general location of the old mine works but did not have sufficient detail for the location of the confirmation boreholes. XHT and guided waves (seismic continuity) surveys did not provide adequate information on the location of old mine works.

Based on these results, we recommend the following steps for deployment of the RVSP and sonar mapping for the detection and mapping of old mine works:

1) Acquire RVSP with optimal geometry to map the location of the old mine works. Optimizing the layout includes increasing the number of channels so that the spacing between the geophones can be decreased and the length of the geophone array can be increased. Other improvements can be made in the emplacement of the phones, including burying the geophones below the softer near-surface material and using multiple geophones per receiver location.

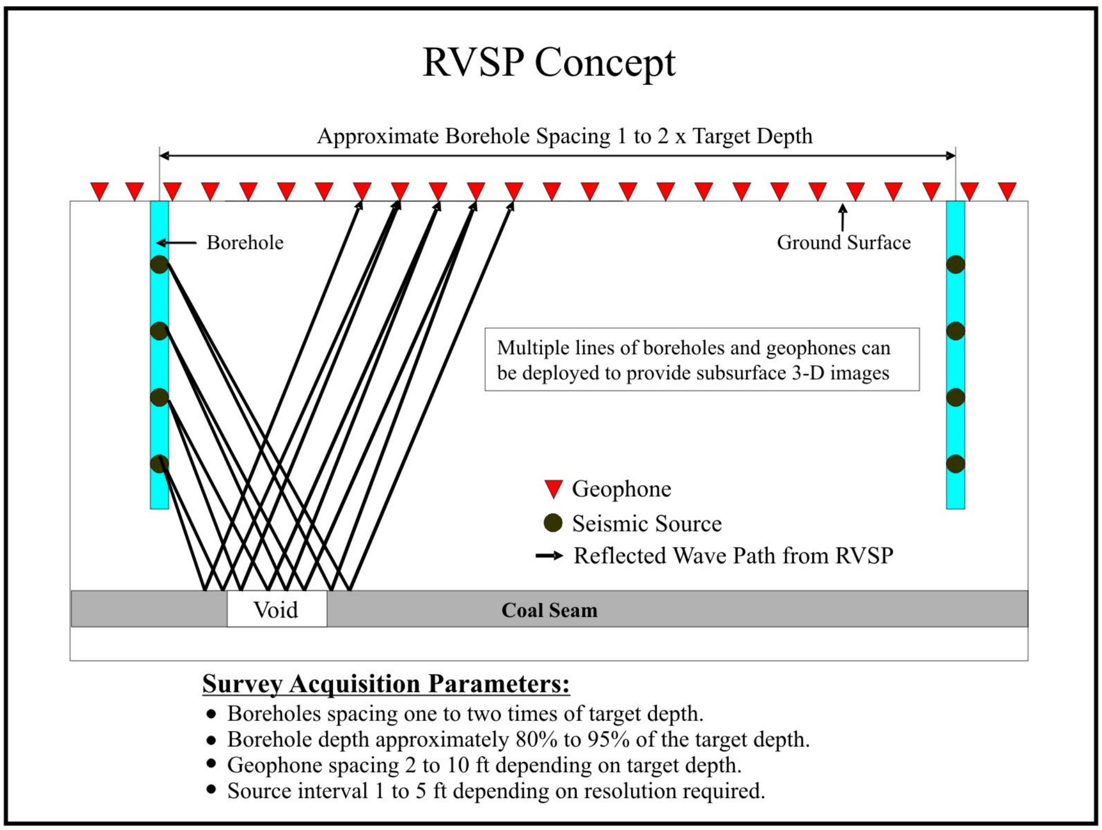
2) The number and layout of the RVSP surveys will depend upon several factors, including the amount of information available on the location of the old mine works and the level of confidence in that information. A proposed optimal layout for an RVSP survey along a 2-D line is shown on Figure 7-1. The boreholes should be spaced at a distance approximately equal to once or twice the depth of the target depending on the target size, depth, and resolution required. The boreholes should be drilled to a depth above the target horizon. The surface geophones could then be laid out in a line extending between the boreholes and

the source deployed in each of the boreholes. This will allow continuous coverage over the entire length of the line between the boreholes. Additional boreholes could be located along a line, depending on the distance that is required to be investigated.

This method could be extended to a 3-D survey around the borehole, although this would require some increase in cost because of additional equipment, field effort, and processing time. Therefore, 3-D surveys should only be performed when very little information is available on the location and orientation of the old mine works.

A further improvement on the RVSP method may be possible with the use of Amplitude vs. Offset (AVO) analysis of the data. AVO has been used successfully in the hydrocarbon exploration industry for determining the oil/gas contacts in reservoirs. If high quality data are obtained with an optimized RVSP survey, this type of analysis could be useful for mapping the difference between water-filled and air-filled voids as well as improving the overall detection of voids.

FIGURE 7-1 SCHEMATIC OF RECOMMENDED RVSP SURVEY TO DETECT OLD MINE WORKINGS



3) Once the location of the old mine works has been established, a confirmation borehole should be drilled to intersect the suspected void in the old mine works and to determine the contents of the void. This will guide the selection of the borehole mapping tool to be used; i.e., a sonar system in water-filled voids or a laser system in air-filled voids, and a borehole camera to identify the content of the void. These borehole mapping tools can provide results in real time, so that the basic geometry of the voids can be determined in the field. This information can then be used to plan the location of additional borings to investigate the conditions and extent of the voids. This results in cost savings because additional mobilization would not be required.

It is recommended that additional tests be performed in other topographic, geologic, and cultural settings to evaluate the effectiveness of the RVSP method in various conditions. In the case of the target horizon being less than 50 ft deep, the surface geophysical methods such as surface reflection and DC-resistivity should be used. The RVSP may not be feasible in steep terrain due to difficulty in drill borehole locations.

In summary, the geophysical demonstrations at the known abandoned mine adjacent to active underground RMC using HRS, XHT, guided waves and RVSP have shown the effectiveness of the RVSP as the most viable method to accurately and economically detect the location of old mine works. The RVSP method can be complemented by the use of borehole mapping tools (sonar, laser, or borehole camera) to accurately determine the vertical and lateral extents of mine voids and their conditions.

8.0 CERTIFICATION AND DISCLAIMER

All geophysical data analysis, interpretations, conclusions, and recommendations in this document have been prepared under the supervision of and reviewed by Blackhawk, a Division of ZAPATA ENGINEERING, Senior Geophysicists, and Engineers.

This geophysical investigation was conducted using sound scientific principles and state-of-the-art technology. A high degree of professionalism was maintained during all aspects of the project from the field investigation and data acquisition, through data processing, interpretation, and reporting. All original field data files, field notes and observations, and other pertinent information are maintained in the project files and are available for the client to review.

A geophysicist's certification of interpreted geophysical conditions comprises a declaration of his/her professional judgment. It does not constitute a warranty or guarantee, expressed or implied, nor does it relieve any other party of its responsibility to abide by contract documents, applicable codes, standards, regulations, or ordinances.

Kanaan Hanna

Project Manager / Senior Engineer
ZAPTATAENGINEERING, P.A.
Blackhawk Division

James Hild

Manager / Senior Geophysicist
ZAPTATAENGINEERING, P.A.
Blackhawk Division

9.0 ACKNOWLEDGEMENT

The authors would like to express their appreciation to Mr. Steven Vamossy, COTR and Mr. George Gardner, Program Manager of MSHA, for their undivided attention in guiding and directing this project, and providing valuable technical assistance during the field demonstrations and review during the preparation of this report. The authors would also like to thank MSHA's reviewer team who provided a technical review of this report:

- Greg Hasenfus, Senior Geochemical Engineer, Consol Energy, Pittsburgh, PA
- Peter Michael, Geologist, Office of Surface Mining, Pittsburgh, PA
- Dr. Dayakar Penumadu, Professor, University of Tennessee, Knoxville, TN
- Jon Peterson, Mine Engineer, General Chemical (Soda Ash) Partners, Green River, WY

Special thanks are given to BBCC and to Mr. R. Eric Quam, Mine Superintendent for their cooperation and contributions in making the RMC available for the field investigations. Thanks are extended to Mr. Philip Ames, Director of Geology & Exploration, for his assistance in organizing and planning the fieldwork, and providing technical assistance during the course of the investigations, and to Mr. Richard Reisinger, Mine Engineer, for his assistance in providing mine maps and scheduling the surveying crew.

The authors would like to thank the following senior reviewers for providing helpful technical comments and review of the report:

- Neil J. Gilbert, Vice President Technical Resources, ZAPATAENGINEERING
- W. Ed Wightman, Ph.D., Geophysical Consulting Services, LLC
- Jim Hild, Manager/Senior Geophysicist, ZAPATAENGINEERING, P.A., Blackhawk Division

Finally, the authors would like to thank Blackhawk's staff, Ms. Brandy Uphouse and Ms. Cynthia Hoeppner, for word processing, layout, and editing of the report, and Mr. Herman Vialpando for drafting and artwork.

10.0 REFERENCES

Krohn, Christine E. (1992, July). Cross-well continuity logging using guided seismic waves. Geophysics: the leading edge of exploration.

University of Utah, College of Mines and Earth Sciences (CMES). (2006). Snell's law. Retrieved January 24, 2006, from http://www.mines.utah.edu/~ggapps/snell/snell.html .

Kulczewski, Richard. (2004, October 22). Nearly $600,000 in mine safety and health contracts awarded in colorado colorado school of mines, blackhawk geoservices to conduct seismic testing. *US Department of Labor, Office of Public Affairs, Denver, Colorado*.

Wycander, R., & Monroe, J. (2000). Historical geology evolution of earth life through time. (3rd Ed.). Brooks Coal / Thompson Learning.

Yearsley, E. N., & Crowder R., (1990). Acoustic spectrum analysis of borehole sonic logs for engineering properties and fracture characterization: a case history. Proceedings of 1990 Annual Symposium on Engineering Geology and Geotechnical Engineering, No. 26.

11.0 GLOSSARY

Accuracy. Refers to closeness of a measurement to the true value.

Acoustic Impedance. Reflects the ability of a boundary to reflect seismic energy. It is the contrast of density multiplied by velocity across the boundary. A measure of the seismic inertia of the medium.

Acoustic Log. Also called sonic log; a record of changes in the character of sound waves as they are transmitted through liquid-filled rock; a record of the transit time (t) is the most common; amplitude and the full acoustic-wave form also are recorded.

Amplitude. The maximum departure of a wave from the average value.

Amplitude Envelope. A set range in which the maximum departure of a wave from an average value in located.

Anomaly. Refers to deviation from uniformity in a physical property.

Attenuation, Attenuate. A reduction in energy or amplitude caused by the physical characteristics of a transmitting system.

Automatic Gain Control (AGC). A process for increasing the amplitude of a trace with time, thus making all events on the trace appear to be of approximately the same amplitude. Note that this process will expand the amplitudes even if no data are present. Various window lengths are used; the appearance of the data may be greatly affected by the window used in the calculation.

Bandpass Filter. The procedure of accepting frequencies within a set range and rejecting (attenuates) frequencies outside the set range. This can be accomplished by combining high and low pass filters. *Retrieved:* *http://en.wikipedia.org/wiki/Bandpass_filter*

Common Depth Point (CDP). In multi-channel seismic acquisition on horizontal strata, the common reflecting point at depth on a reflector, or the halfway point when a wave travels from a source to a reflector to a receiver. Horizontal strata have a CDP located vertically below the common midpoint. With dipping strata, the CDP point shared by multiple sources and receivers is nonexistent. *Retrieved:* *http://www.glossary.oilfield.slb.com/*

Common Depth Point Gather (CDP Gatherer). Process displaying traces that share a common acquisition parameter such as a common depth point. Used commonly to display seismic data. *Retrieved:* *http://www.glossary.oilfield.slb.com/*

Common Depth Point Fold (CDP Fold). A factor created when data (such as common depth points) are reduced during processing by stacking. Additionally, folding refers to the number of traces that have been combined for correlation. *Retrieved:* http://www.glossary.oilfield.slb.com/

Common Midpoint. In multi-channel seismic acquisition, the point on the surface halfway between the source and receiver that is shared by numerous source-receiver pairs. The use of multiple source receivers enhances the quality of stacked data. The common midpoint is located vertically above the common depth point, or common reflection point. *Retrieved:* http://www.glossary.oilfield.slb.com/

Common Midpoint Gather. Process displaying traces that share a common acquisition parameter such as a common midpoint. Used commonly to display seismic data. *Retrieved:* http://www.glossary.oilfield.slb.com/

Common Mid-Point Stack. The process used in conjunction with common mid gathers to combine processed records traces to reduce noise and improve overall quality. Used commonly to display seismic data. *Retrieved:* http://www.glossary.oilfield.slb.com/

Compressional Wave. Compressional acoustic waves (P) are propagated in the same direction as particle displacement; they are faster than shear waves and are used for measuring acoustic velocity or transit

Crosshole. Geophysical methods carried out between boreholes (*also see tomography*).

Dead Channels. When collecting data, channels that contain valueless noise, usually due to breaks within the wiring of the geophones or cables.

Deconvolution. A data processing technique applied to seismic reflection data to improve the detection and resolution of reflected events. The process reverses the effect of linear filtering processes (convolution) that have been applied to the data by recording instruments or other processes, such as propagating through the earth.

Depth of Investigation. Maximum depth that is effectively imaged.

Depth Section. A cross section to which a velocity function has been applied, thus converting arrival times of reflections to depths.

Deviation. The departure in degrees between the drill hole or probe axis and vertical.

Differential Log. A log that records the rate of change of some logged value as a function of depth; the differential log is sensitive to very small changes in absolute value.

Electrical Log. Provide information on porosity, hydraulic conductivity, and fluid content of formations drilled in fluid-filled boreholes. This record is based on the dielectric properties (e.g., electrical resistivity) of the aquifer materials measured by geophysical devices lowered down boreholes or wells.

F-K Filtering. As frequency filtering removes components of a signal with particular time variations (low-frequency cut, etc.), F-K filtering removes components of seismic records with particular variations in both time (frequency) and space (K or wave number). As an example, ground roll will often be of low frequency and, due to the low velocity, have short wavelengths (high wave number). Thus, a low frequency, high-wave number cut filter will attenuate ground roll.

Filtering. a) The attenuation of a signal's components based on a measurable property (usually frequency). Filtering usually involves a numerical operation that enhances only a portion of the signal. b) Fluid passage through a material that retains particles or colloids above a certain size.

Fold. A factor created when data is reduced during processing by stacking. Additionally, folding refers to the number of traces that have been combined for correlation. *Retrieved: http://www.glossary.oilfield.slb.com/*

Formation. Used in well logging literature in a general sense to refer to all material penetrated by a drill hole without regard to its lithology or structure; used in a stratigraphic sense, formation refers to a named body of rock strata with unifying lithologic features.

Frequency Domain. In geophysics, refers to measurements analyzed according to their constituent frequencies. The usual alternative is time domain measurements.

Gamma Log. Also called gamma-ray log or natural-gamma log; log of the natural radioactivity of the rocks penetrated by a drill hole; also will detect gamma-emitting artificial radioisotopes (see spectral-gamma log).

Gather. Process displaying traces that share a common acquisition parameter. Used commonly to display seismic data. *Retrieved: http://www.glossary.oilfield.slb.com/*

Geophones. Receivers used to record the seismic energy arriving from a source, in seismic geophysical methods.

Instantaneous Frequency. Used in signal processing, instantaneous frequency (Hz) is expressed as $f(t) + (1/2\pi)\theta(t)$. In the unwrapped phase of processing instantaneous frequency is often defined as the derivative of the phase with respect to t, and in this case it is important that continuity of the phase is preserved and the unwrapped phase is used. *(See Instantaneous Phase). Retrieved: http://en.wikipedia.org/wiki/Instantaneous_frequency*

Instantaneous Phase. Used in signal processing, the instantaneous phase of a signal s(t) is a function $\varphi(t)$ defined as: $\varphi(t) = \arg(sa(t))$ where sa(t) is the analytic signal of s(t). In general, sa(t) is a complex-valued function and the phase is the argument of that value seen as a function of t. *(See Instantaneous Frequency*). *Retrieved:* *http://en.wikipedia.org/wiki/Instantaneous _phase*

Interpretation. Transforming geophysical measurements into subsurface structure. More general term than inversion.

Inversion, Inverting. The process of deriving a model of the subsurface that is consistent with the geophysical data obtained. Generally refers to a more specific methodology than interpretation, and usually involving a mathematical algorithm.

Matrix. The solid framework of rock or mineral grains that surrounds the pore spaces.

Move-Ups. The repositioning of the geophysical source to the next shot point. May also involve selecting different geophones to record from.

Noise. Any unwanted signal and / or a disturbance that is not part of signal from a specified source. In electrical or induced polarization (IP) surveys, noise may result from interference of power lines, motor-generators, atmospheric electrical discharges, (i.e. cultural noise) etc. During seismic acquisition, noise can derive from vehicles or vibratory sources.

Normal Log. A quantitative-resistivity log, made with four electrodes, which employs spacings between 4 and 64 in. to investigate different volumes of material around the borehole; see also long-normal log and short-normal log.

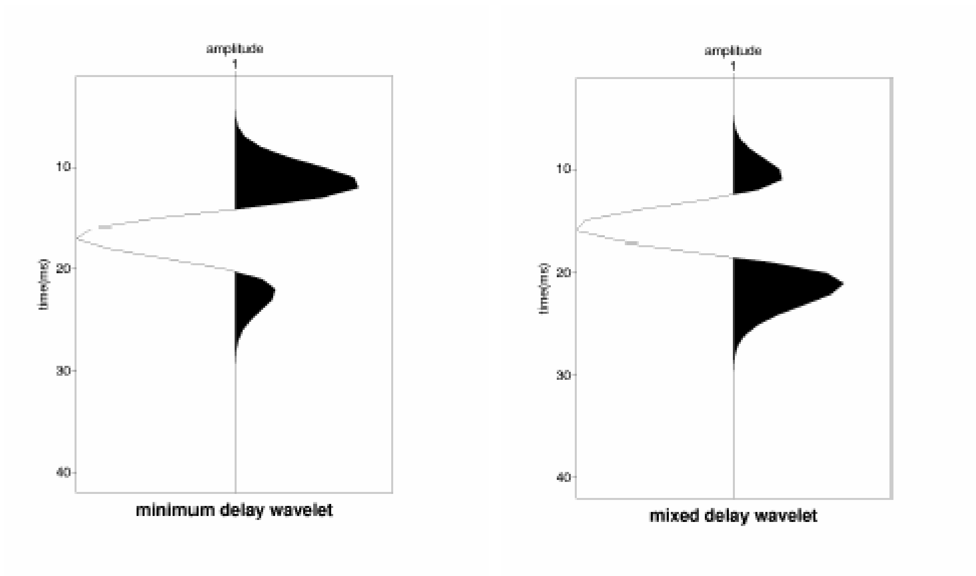
Nyquist Frequency aka Nyquist Limit. The highest frequency that can be coded at a given sampling rate in order to be able to fully reconstruct the signal.

The Nyquist frequency, named after the Nyquist-Shannon sampling theorem, is half the sampling frequency for a signal. It is sometimes called the critical frequency. The sampling theorem tells us that aliasing can be avoided if the Nyquist frequency is greater than the bandwidth of the signal being sampled (or the maximum frequency if the signal is a baseband signal). *Retrieved:* *http://en.wikipedia.org/wiki/ Nyquist_frequency*

Offset (Common). In geophysics, offset pertains to traces, which have the equivalent distance between source and receiver. *Retrieved* *http://www.glossary.oilfield.slb.com/*

Optimum Offset. Seismic reflection technique employing optimum window. Optimum window is an offset where the reflection event can be seen between refraction and ground roll events.

Phase Shift. A measure of the offset between two periodic signals of the same frequency. Measured in degrees or radians/milliradians. An example of two wavelets with the same amplitude but different phases is shown below.



Probe. Also called sonde or tool; downhole well-logging instrument package.

Processing. Geophysically, to change data to emphasize certain aspects or correct for known influences, thereby facilitating interpretation.

Profiling. In geophysics, a survey method whereby an array of sensors is moved along the Earth's surface without change in its configuration, in order to detect lateral changes in the properties of the subsurface (faults, buried channels, etc.) The alternative is usually a sounding.

Receiver. The part of an acquisition system that senses the information signal.

Resistivity Log. Any of a large group of logs that are designed to make quantitative measurements of the specific resistance of a material to the flow of electric current; calibrated in ohm-meters.

Shear Wave, S-Wave. An acoustic body wave with direction of propagation at right angles to the direction of particle vibration (S-wave). Also known as secondary or shear wave.

SEG Y. Established by the Society of Exploration Geophysicists, SEG Y is a data exchange format used widely in the geophysical industry. *Retrieved:* *http://www.seg.org/publications/tech-stand/seg_y_rev1.doc* *(and)* *http://www.passcal.nmt.edu/software/segy.html* \

Seismic Reflection. A surface geophysical method recording seismic waves reflected from geologic strata, giving an estimate of their depth and thickness.

Seismic Refraction. A surface geophysical method recording seismic waves refracted by geological strata.

Sort. Data in shot record form are sorted for display as common offset records, common shot records, common receiver records, or common depth point records.

Spacing. The distance between sources or transmitters and detectors or receivers on a logging probe.

Spectral-Gamma Log. A log of gamma radiation as a function of its energy that permits the identification of the radioisotopes present.

Spontaneous Potential Log. A log of the difference in DC voltage between an electrode in a well and one at the surface; most of the voltage results from electrochemical potentials that develop between dissimilar borehole and formation fluids.

Stack. The process of combining processed records traces to reduce noise and improve overall quality. Used commonly to display seismic data. *Retrieved:* *http://www.glossary.oilfield .slb.com/*

Stacking. Adding together two or more signals. This process is often used in geophysics to improve the signal to noise ratio. A common application is stacking seismic signals in seismic refraction data recording.

Statics. Time shift corrections to individual traces to compensate for the effects of variations in elevation, surface layer thickness or velocity, or datum references.

3-D Crossline Swath. A three-dimensional section (area) of interest during a geophysical investigation.

Target. The object at which a survey sighting is aimed.

Time Variant Spectral Whitening. A processing technique that provides correction for seismic frequency losses. *Retrieved:* *http://www.cseg.ca/conferences/2002/2002abstracts/Somerville_R_A_Fast_and_accurate_Q-inverse_VSP-2.pdf*

Tomography. A method for determining the distribution of physical properties within the earth by inverting the results of a large number of measurements made in three dimensions (e.g. seismic, radar, resistivity, EM) between different source and receiver locations.

Tube Wave. A Stoneley wave that occurs at the low frequencies of seismic data.

Well log. A record describing geologic formations and well testing or development techniques used during well construction. Often refers to a geophysical well log in which the physical properties of the formations are measured by geophysical tools, E-logs, neutron logs, etc

APPENDIX A TOMOGRAPHIC PLOTS

TABLE OF CONTENTS

FIGURE A - 1 TOMOGRAPHIC RESULTS BETWEEN BOREHOLES EW #1- #2

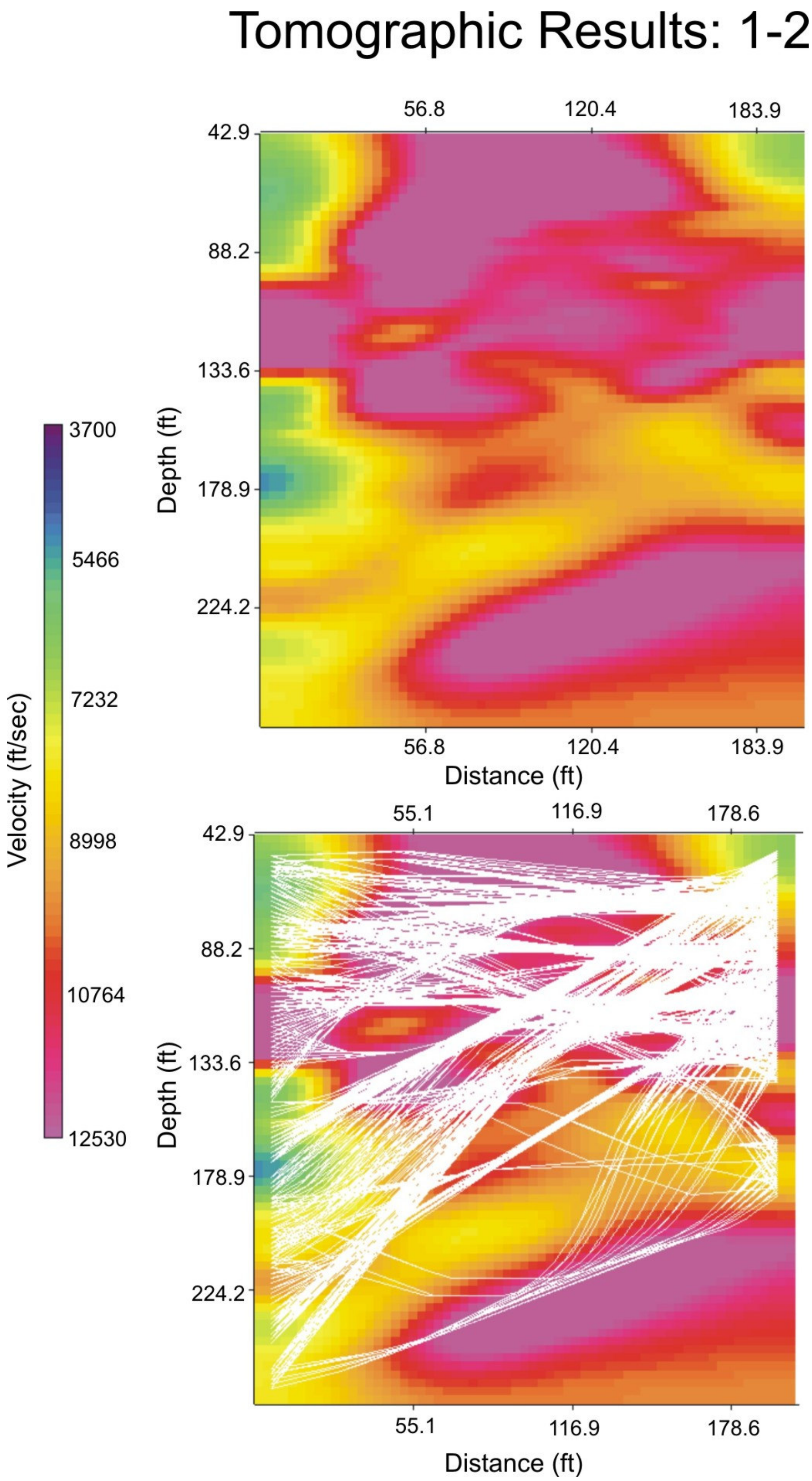


FIGURE A - 2 TOMOGRAPHIC RESULTS BETWEEN BOREHOLES NS #3- #4

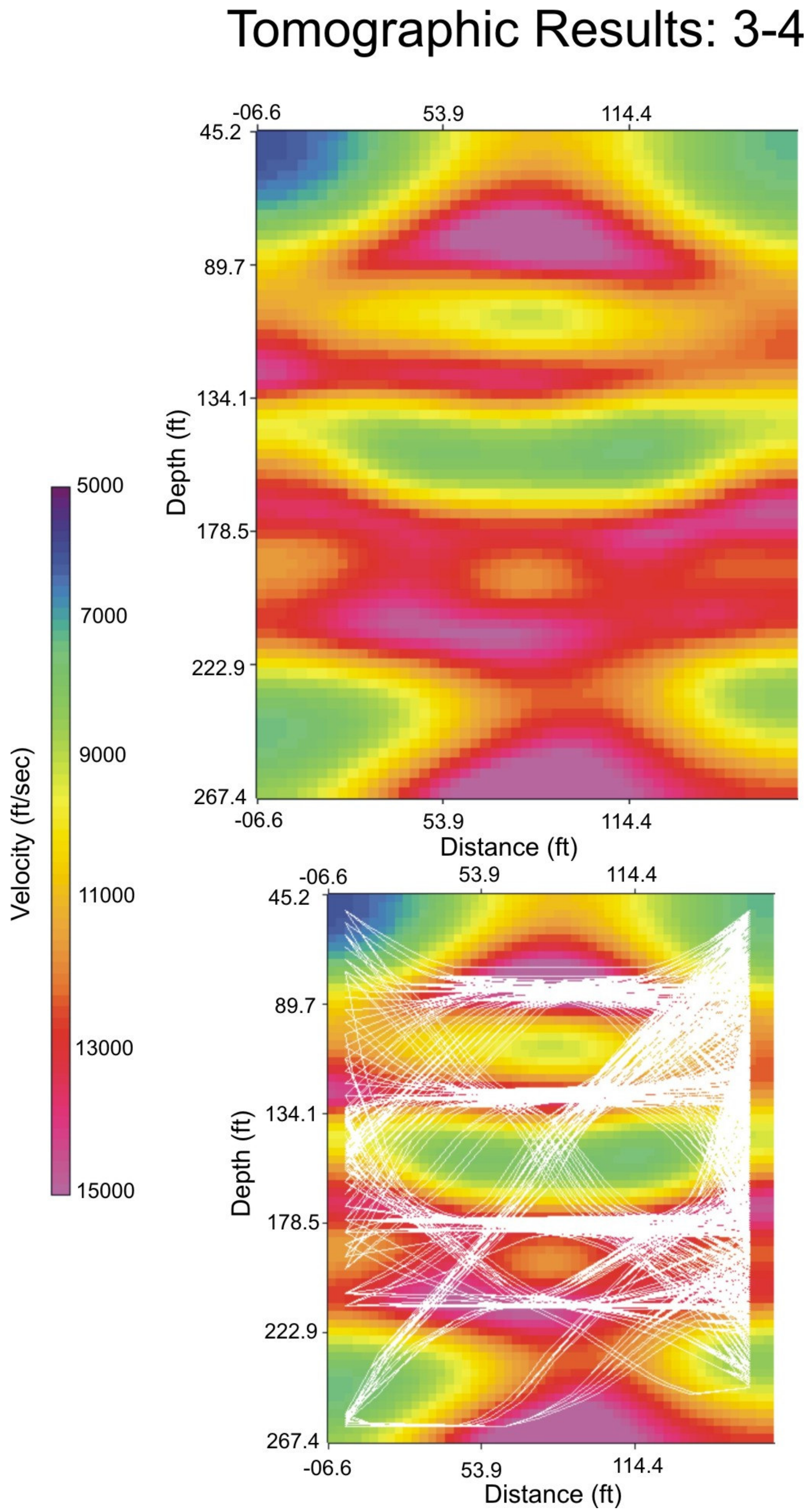


FIGURE A - 3 TOMOGRAPHIC RESULTS BETWEEN BOREHOLES NS #4- #5

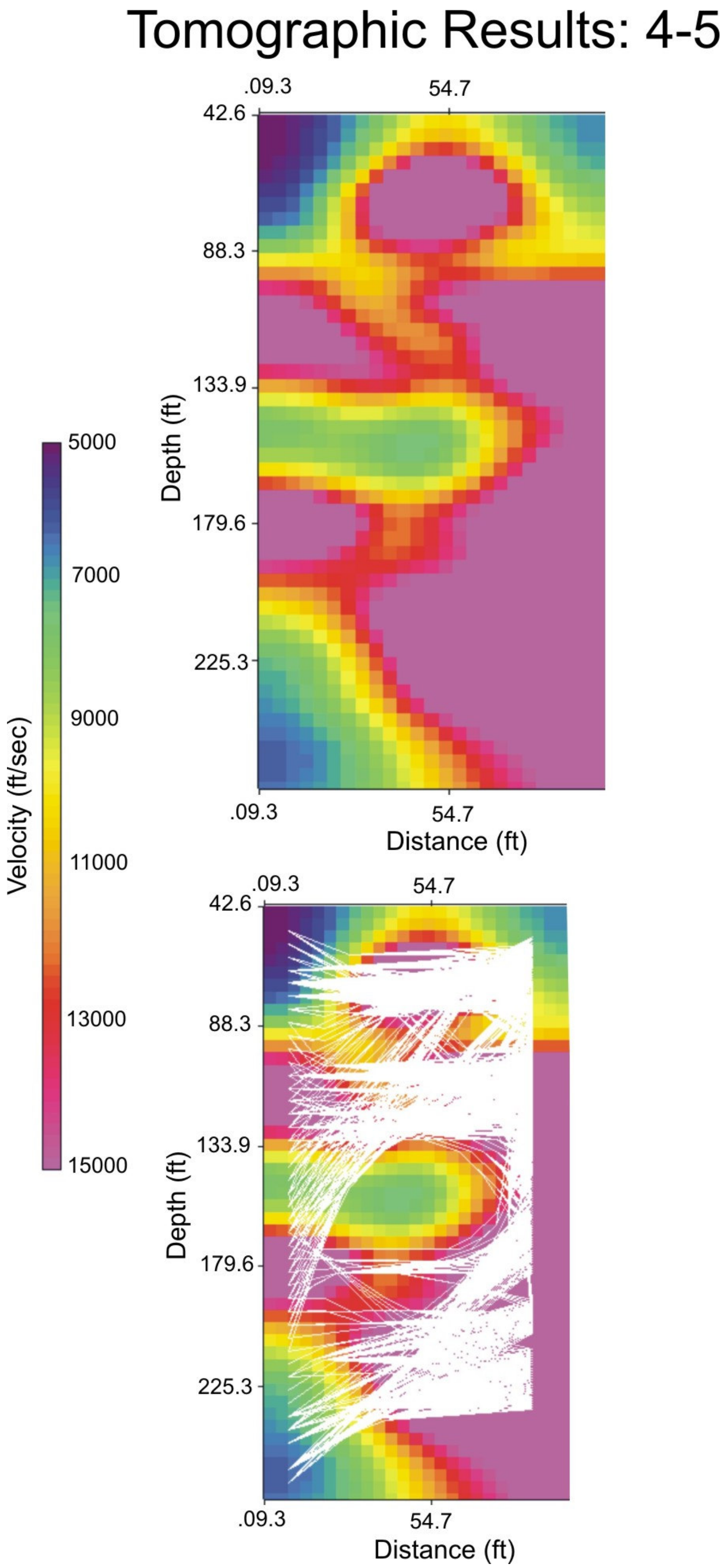


FIGURE A - 4 TOMOGRAPHIC RESULTS BETWEEN BOREHOLES NS #5- #3

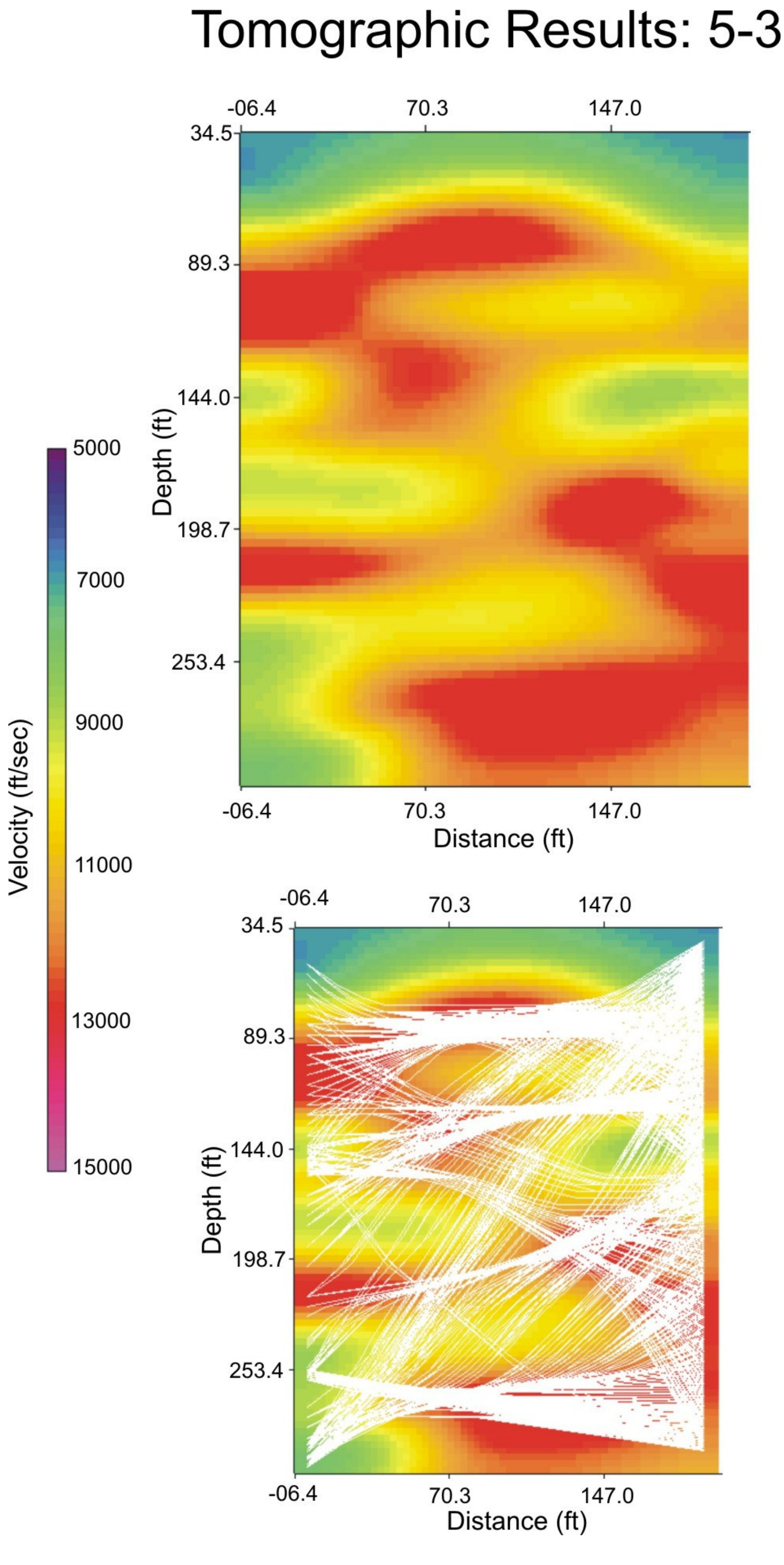


FIGURE A - 5 TOMOGRAPHIC RESULTS BETWEEN BOREHOLES NS #5- #6

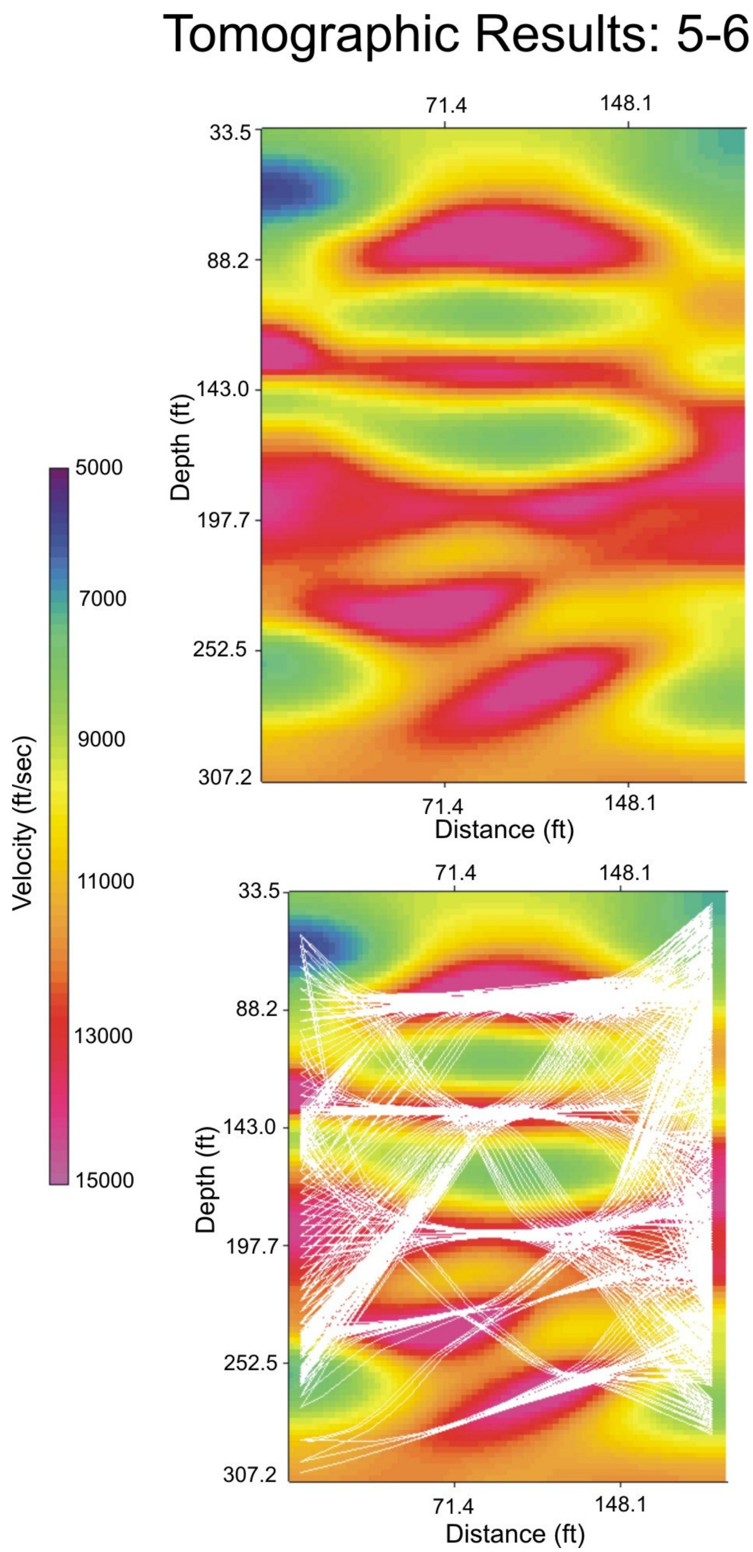


FIGURE A - 6 TOMOGRAPHIC RESULTS BETWEEN BOREHOLES NS #6- #3

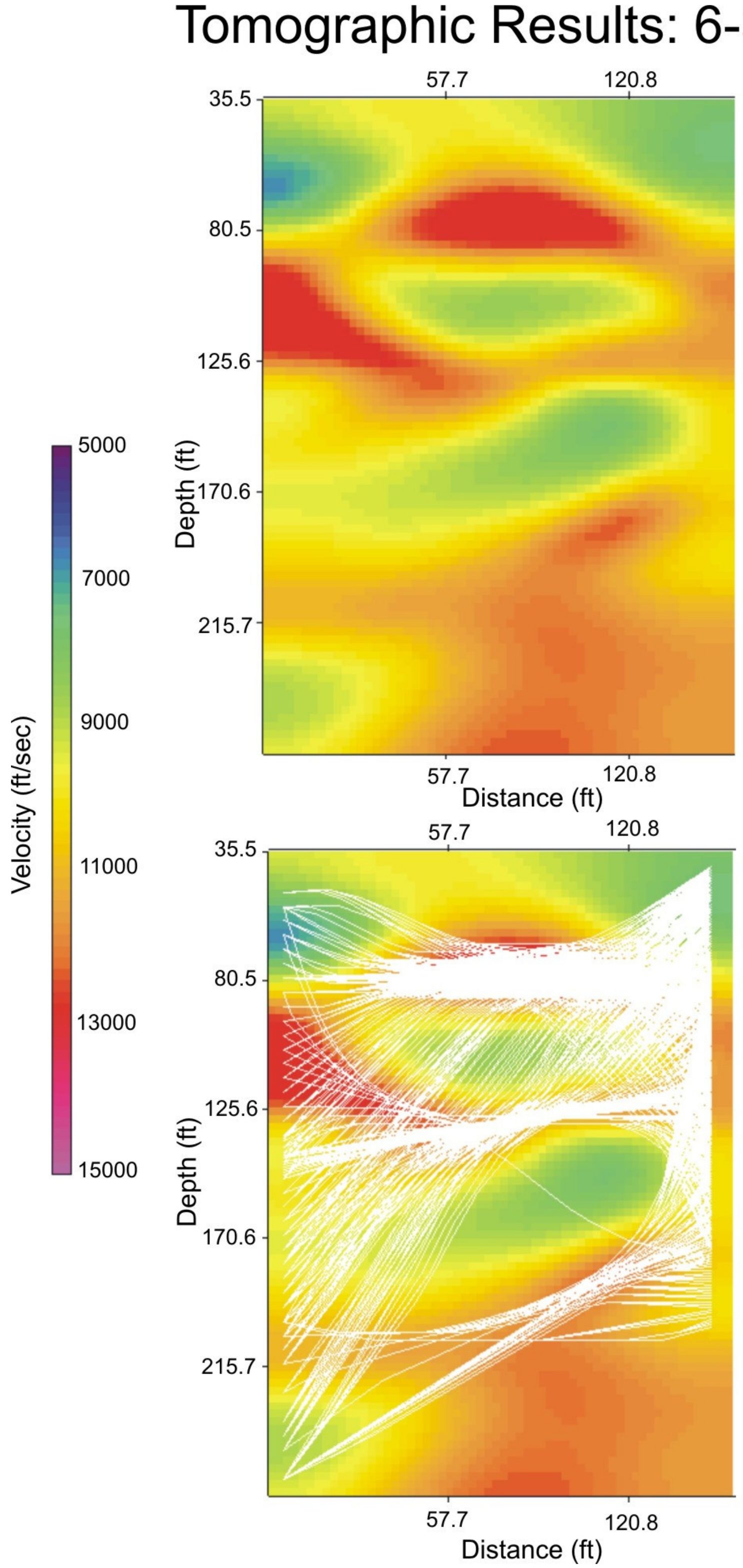


FIGURE A - 7 TOMOGRAPHIC RESULTS BETWEEN BOREHOLES NS #6- #4

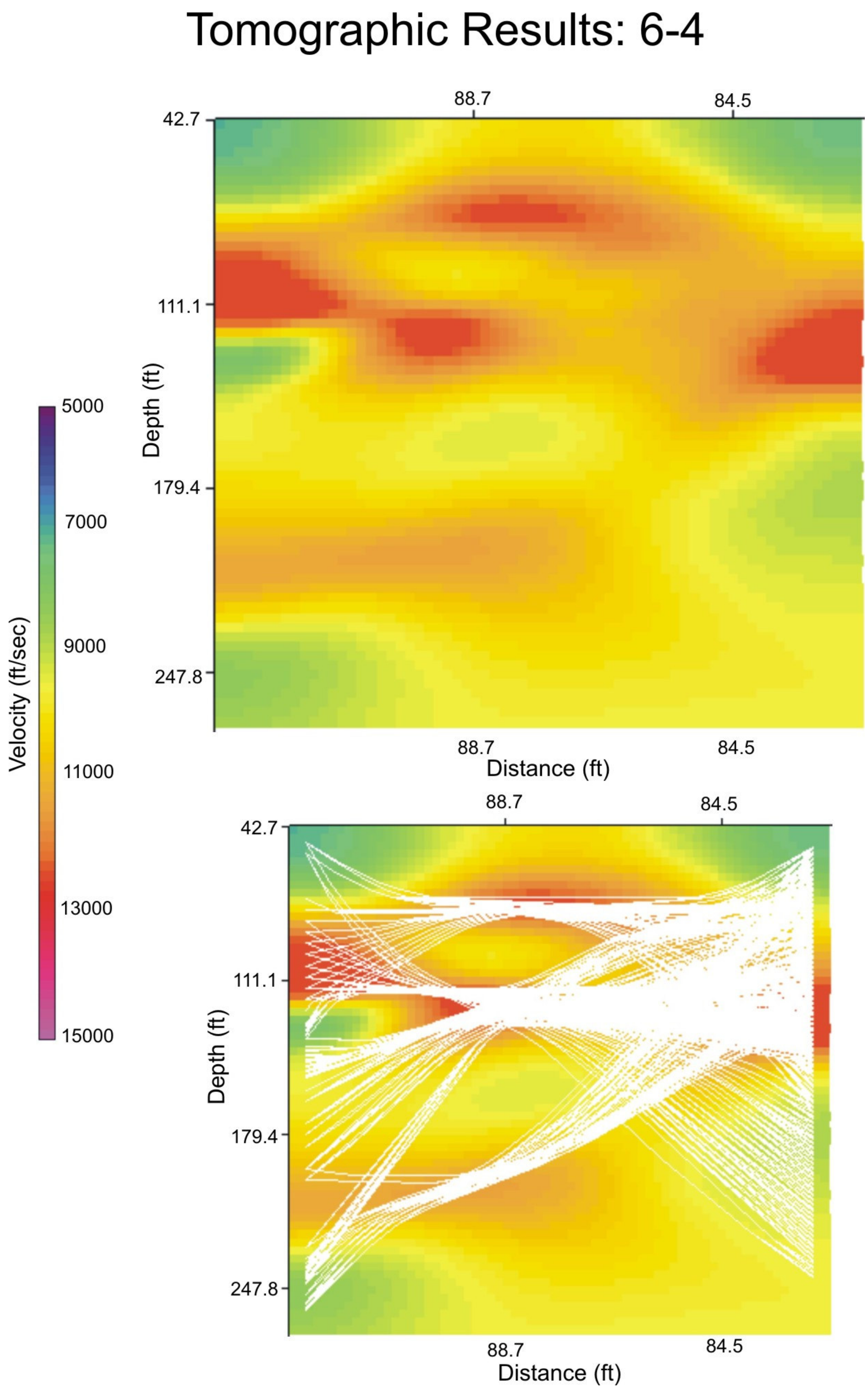


FIGURE A - 8 TOMOGRAPHIC 3-D RESULT – DEPTH SLICE AT 252 FT THROUGH SPRINGFIELD #5 COAL SEAM

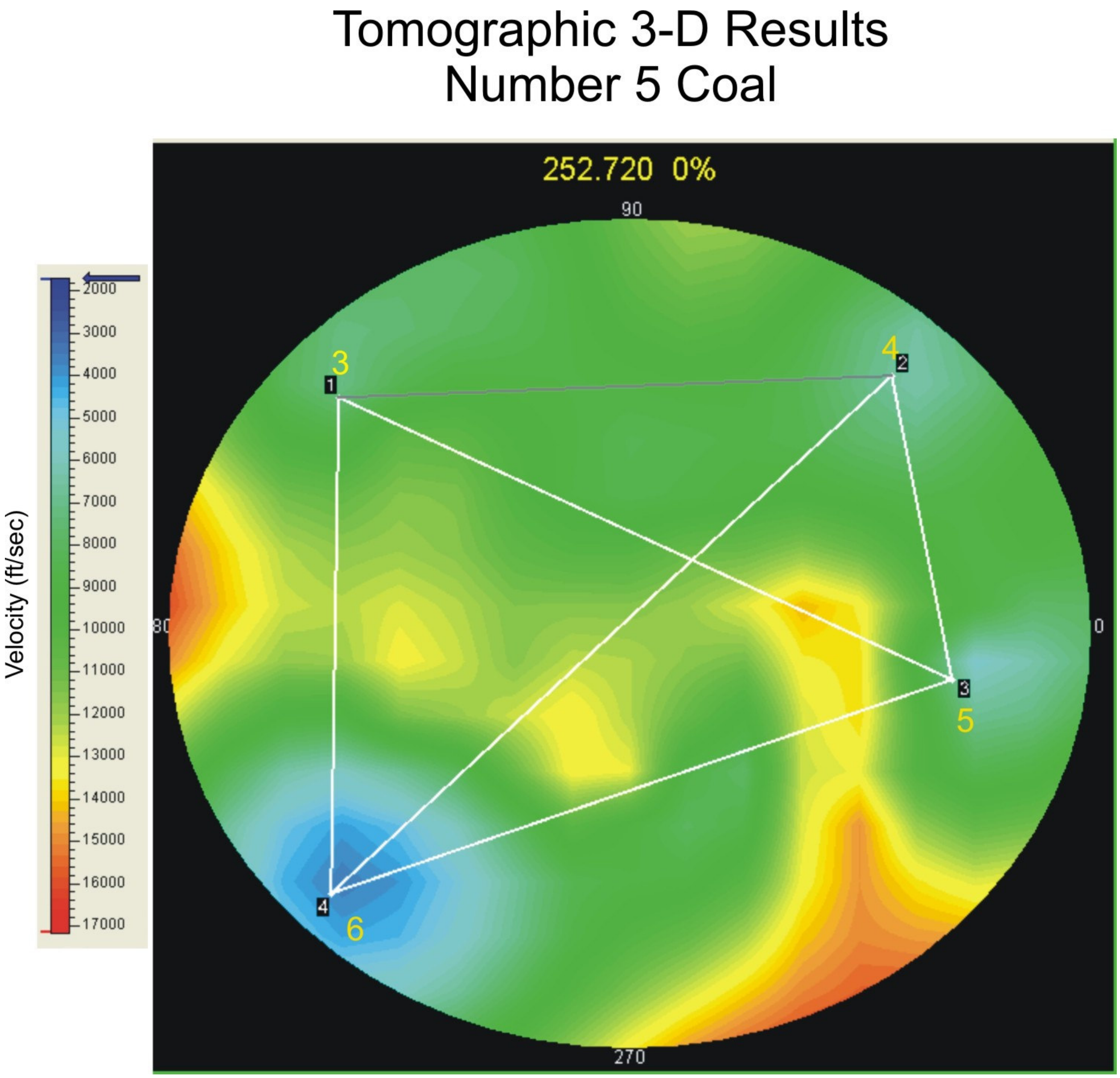


FIGURE A - 9 TOMOGRAPHIC 3-D RESULTS – DEPTH SLICE AT 232 FT THROUGH HERRIN #6 COAL SEAM

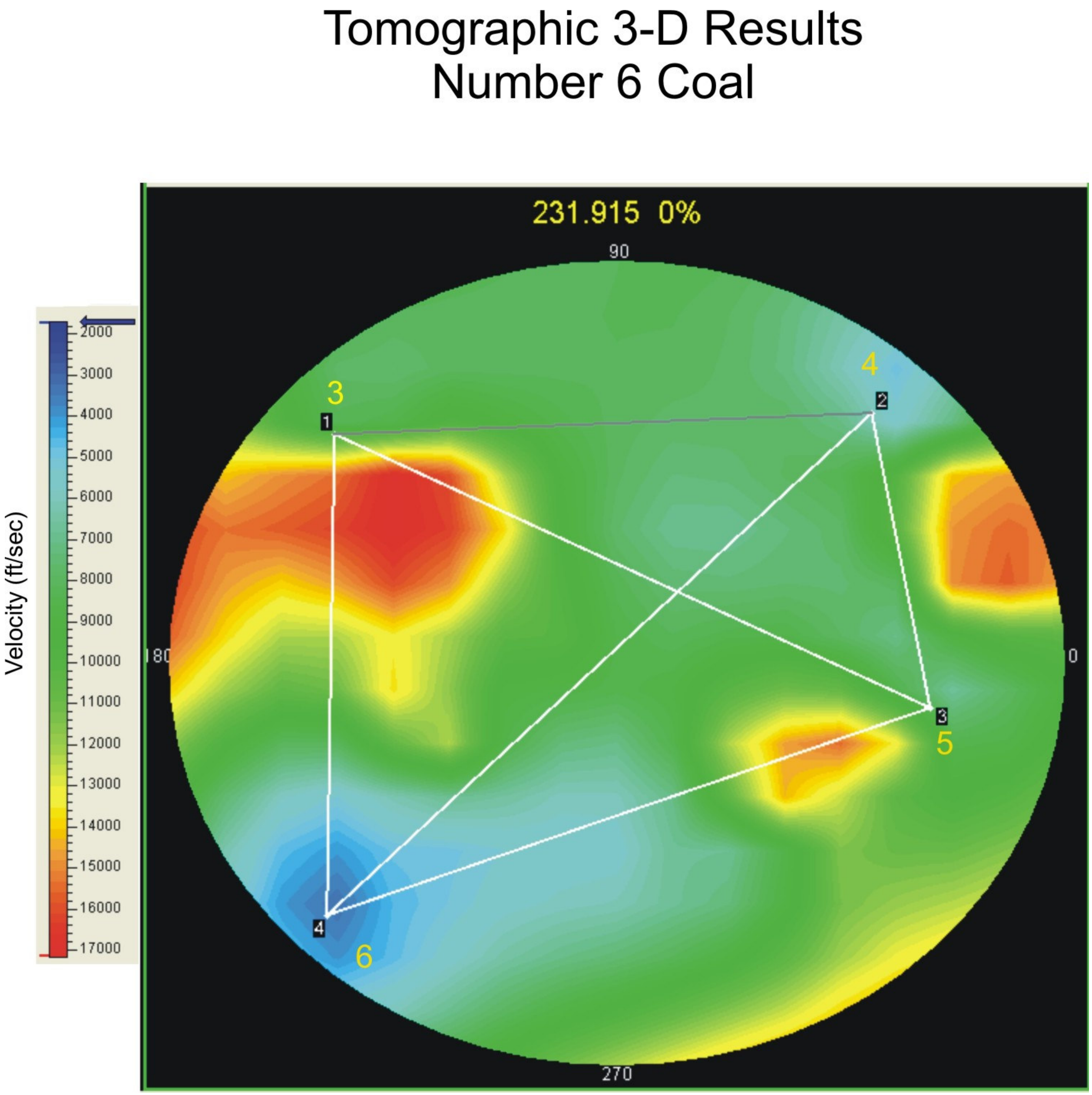
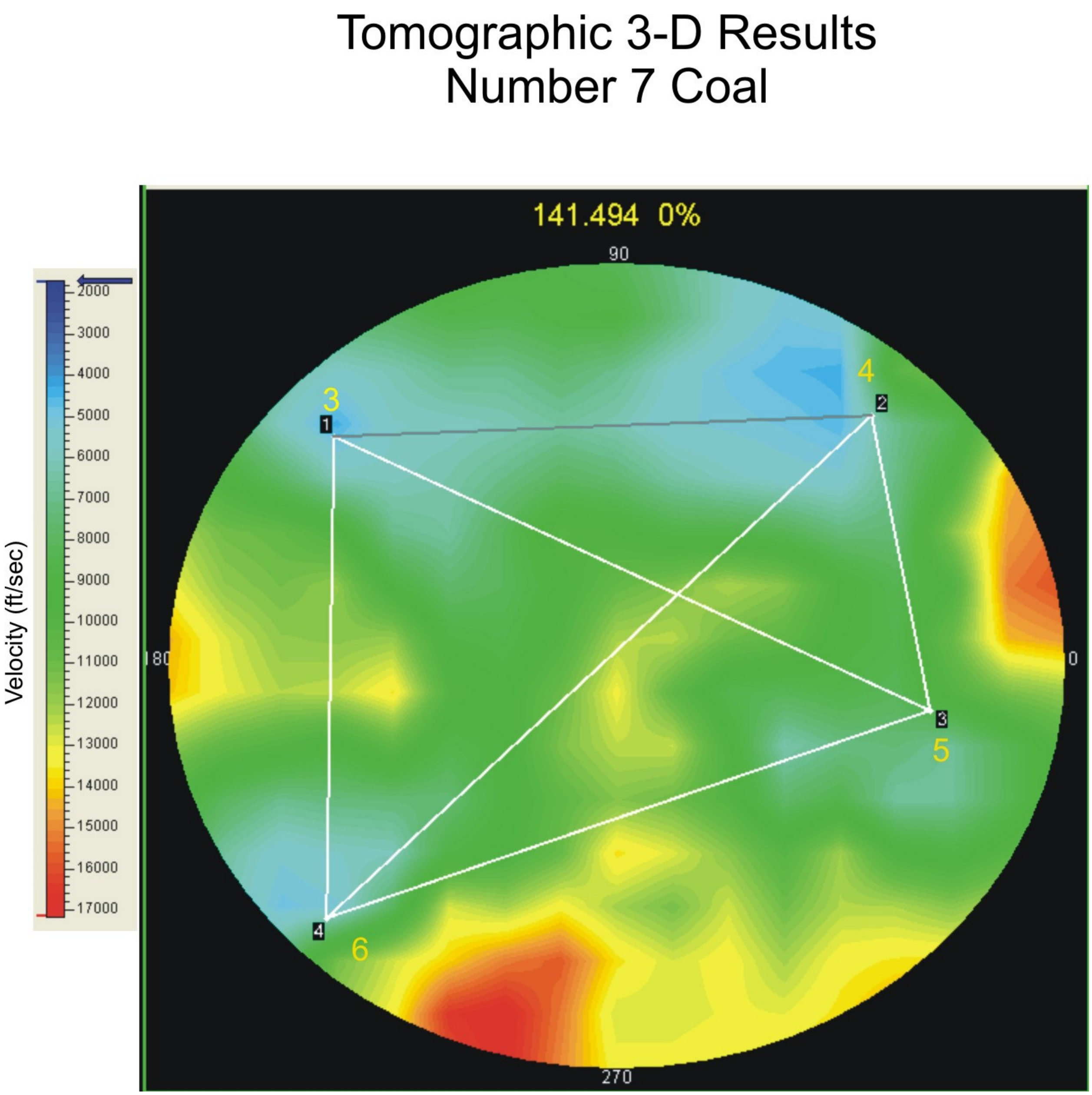


FIGURE A - 10 TOMOGRAPHIC 3-D RESULTS – DEPTH SLICE AT 142 FT THROUGH DANVILLE #7 COAL SEAM



APPENDIX B SEISMIC CONTINUITY PLOTS

TABLE OF CONTENTS

FIGURE B - 1 PANEL EW #1- #2 COMMON SOURCE GATHER SOURCE DEPTH 141 FT

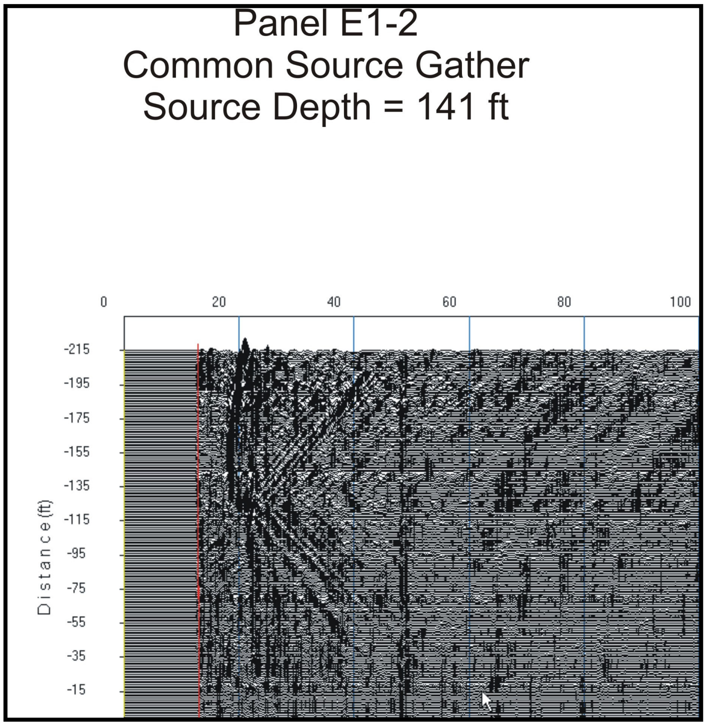


FIGURE B - 2 PANEL EW #1- #2 COMMON SOURCE GATHER SOURCE DEPTH 190 FT

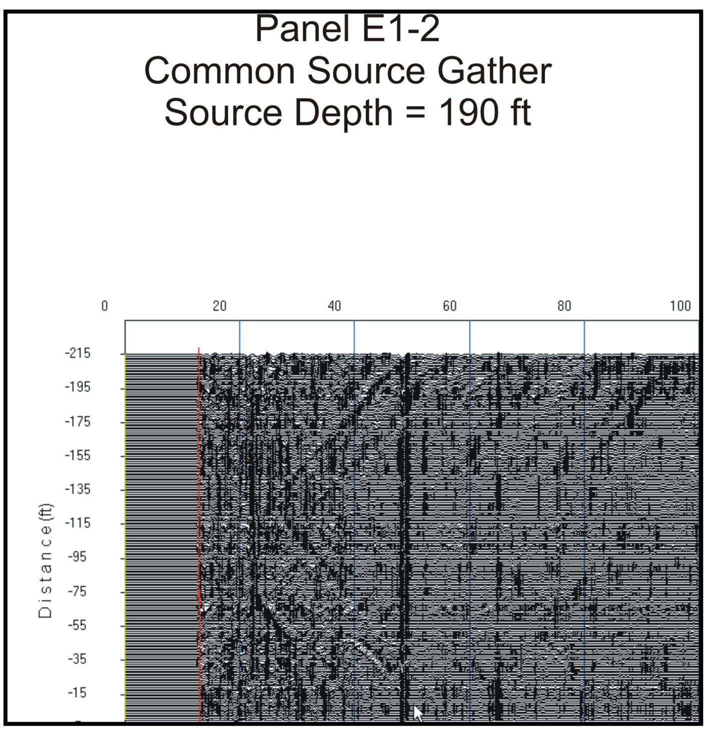


FIGURE B - 3 PANEL EW #1- #2 COMMON SOURCE GATHER SOURCE DEPTH 236 FT

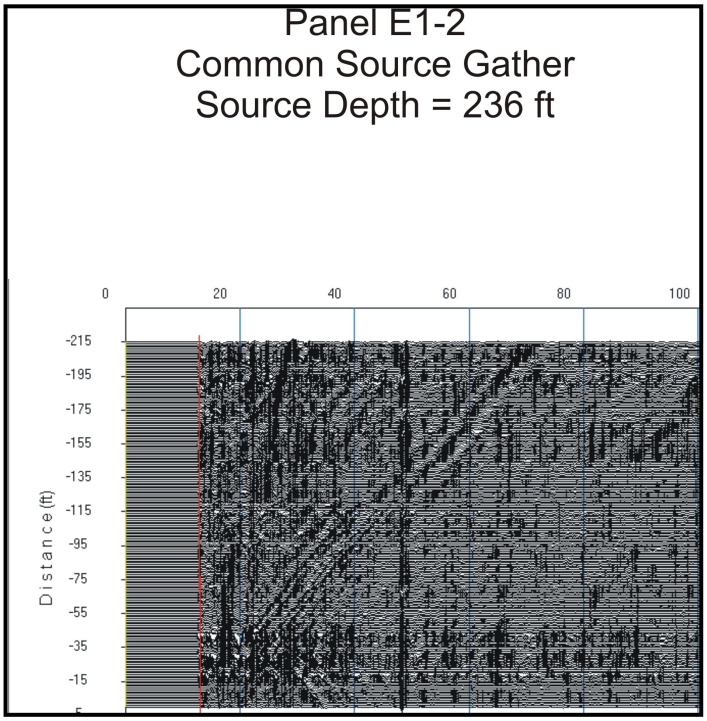


FIGURE B - 4 PANEL EW #1- #2 COMMON SOURCE GATHER SOURCE DEPTH 253 FT

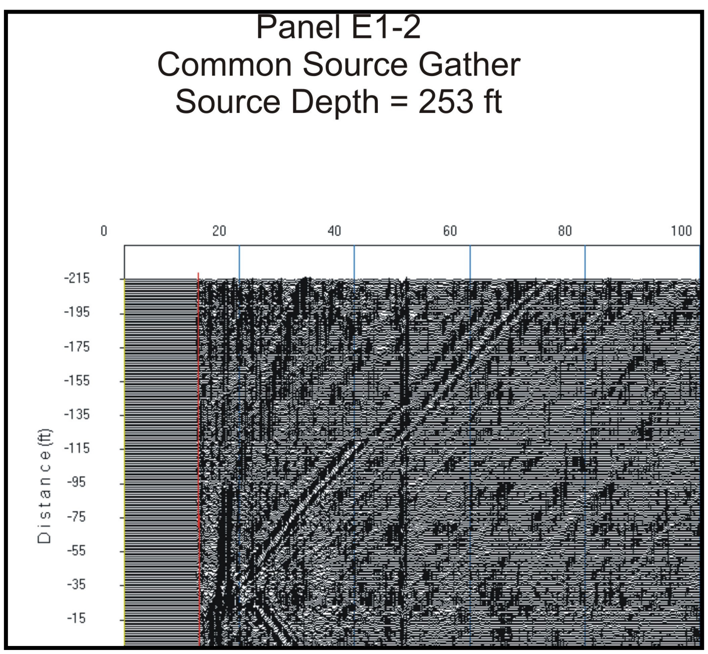


FIGURE B - 5 PANEL EW #1- #2 COMMON SOURCE GATHER SOURCE DEPTH 60 FT

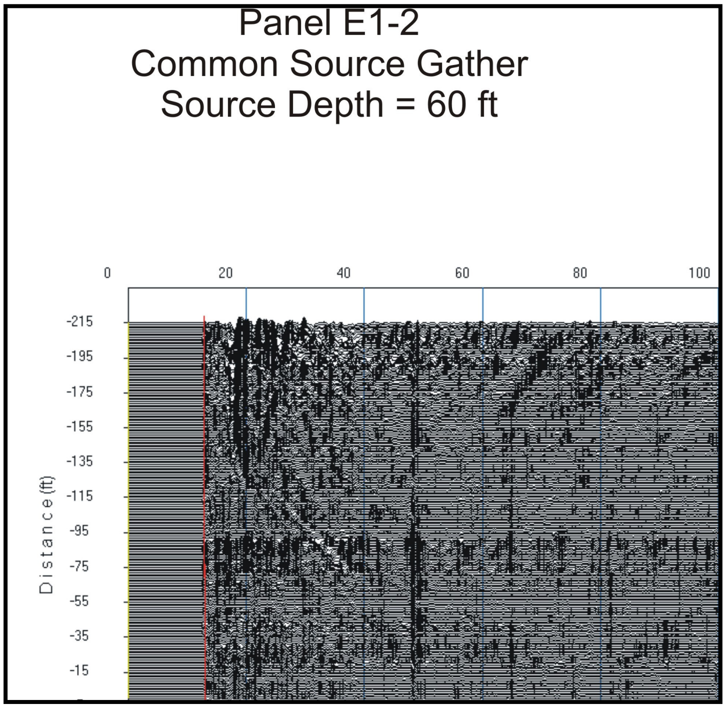


FIGURE B - 6 PANEL NS #3- #4 COMMON SOURCE GATHER SOURCE DEPTH 144 FT

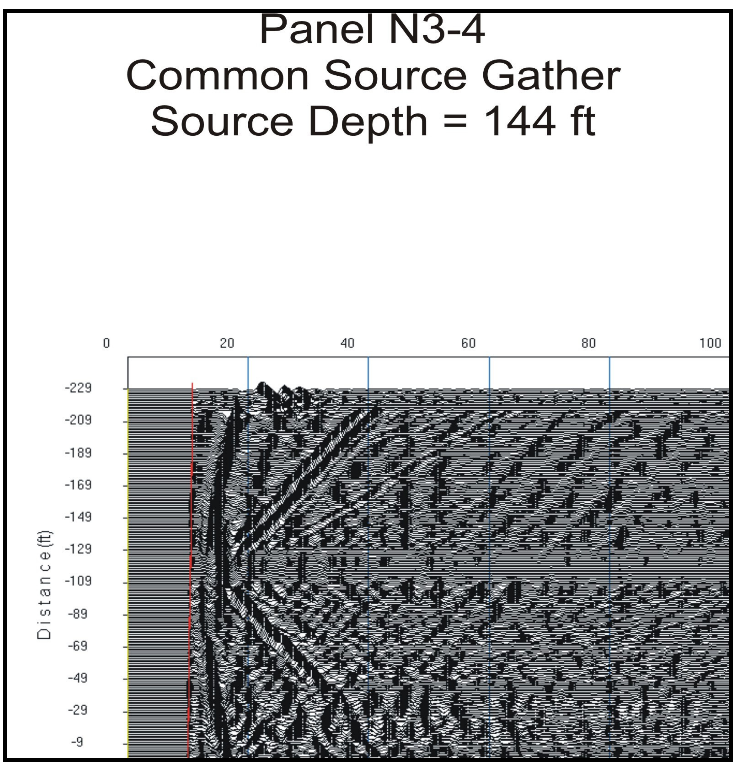


FIGURE B - 7 PANEL NS #3- #4 COMMON SOURCE GATHER SOURCE DEPTH 188 FT

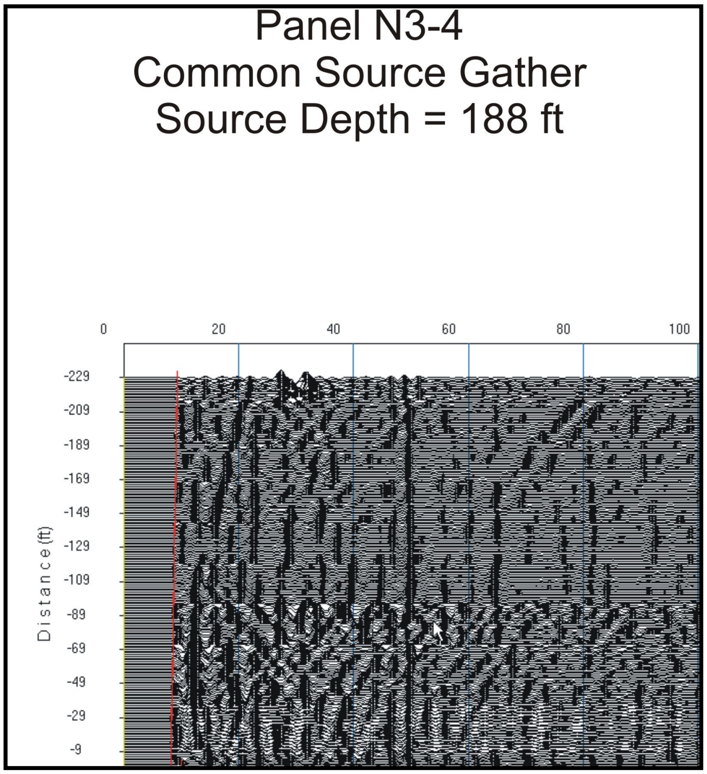


FIGURE B - 8 PANEL NS #3- #4 COMMON SOURCE GATHER SOURCE DEPTH 239 FT

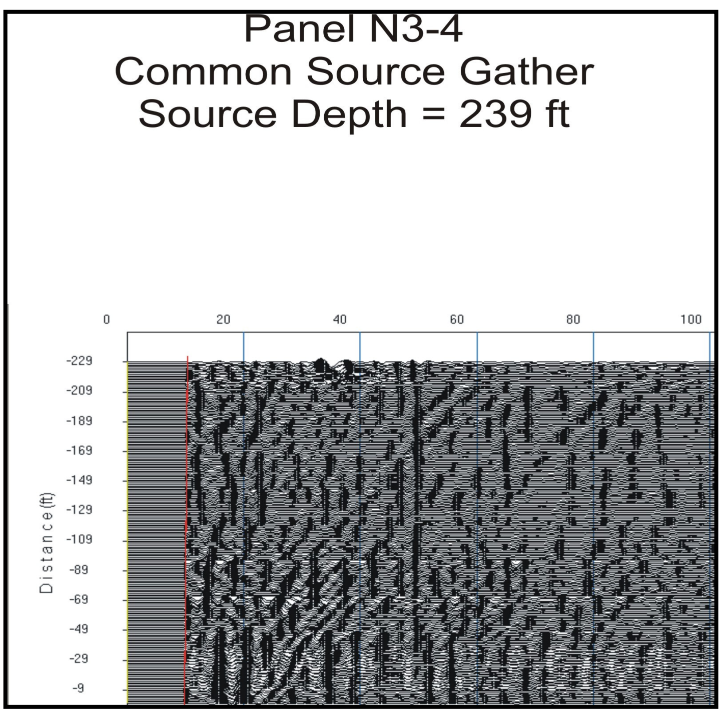


FIGURE B - 9 PANEL NS #3- #4 COMMON SOURCE GATHER SOURCE DEPTH 254 FT

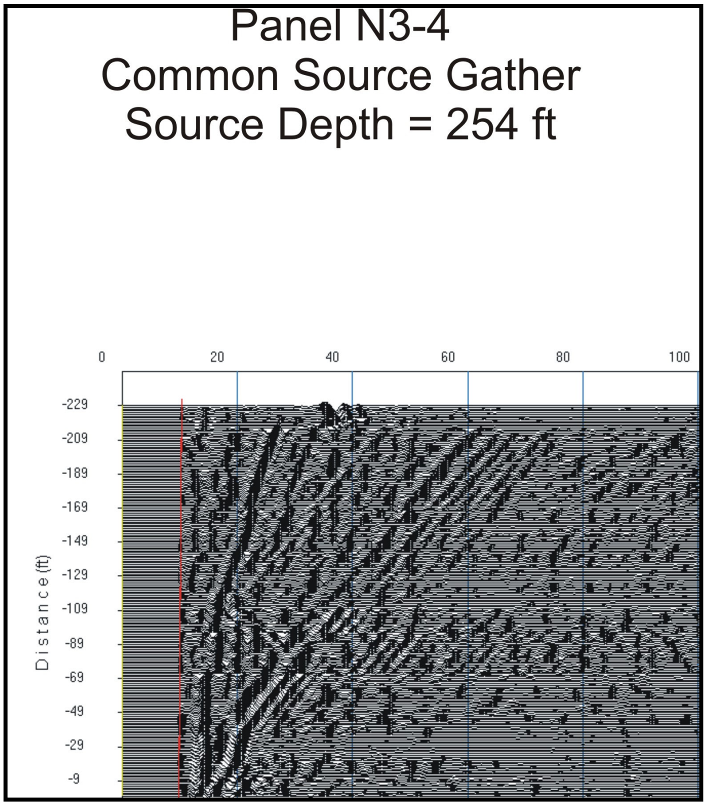


FIGURE B - 10 PANEL NS #3- #4 COMMON SOURCE GATHER SOURCE DEPTH 63 FT

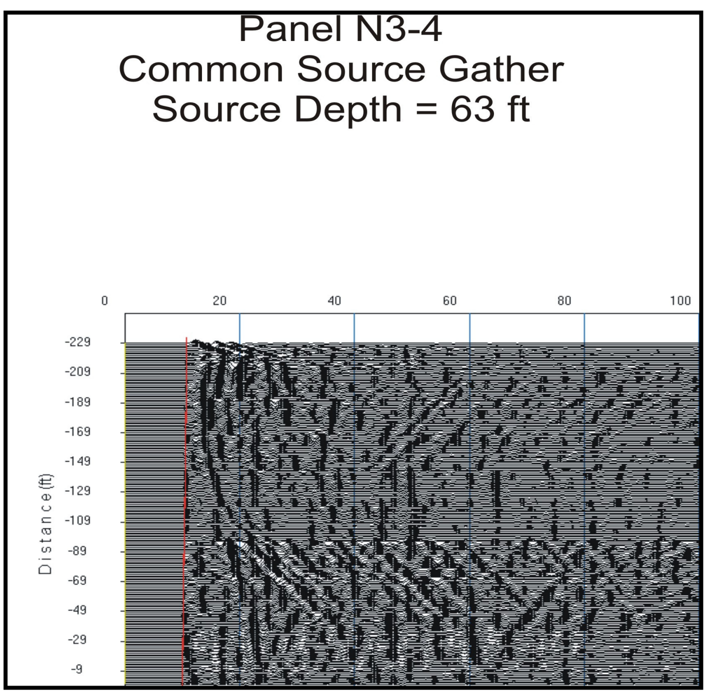


FIGURE B - 11 PANEL NS #3-EW #2 COMMON SOURCE GATHER SOURCE DEPTH 236 FT

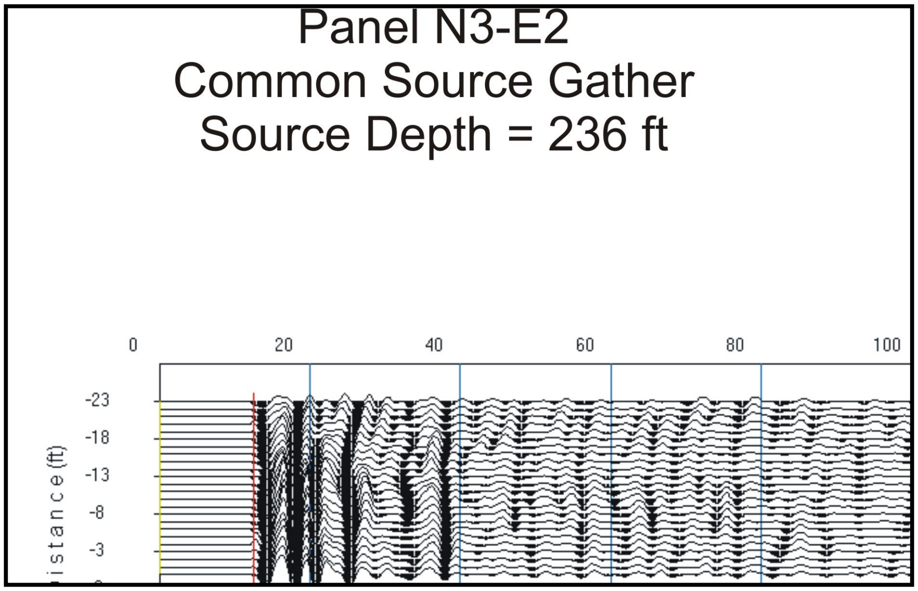


FIGURE B - 12 PANEL NS #4- #5 COMMON SOURCE GATHER SOURCE DEPTH 138 FT

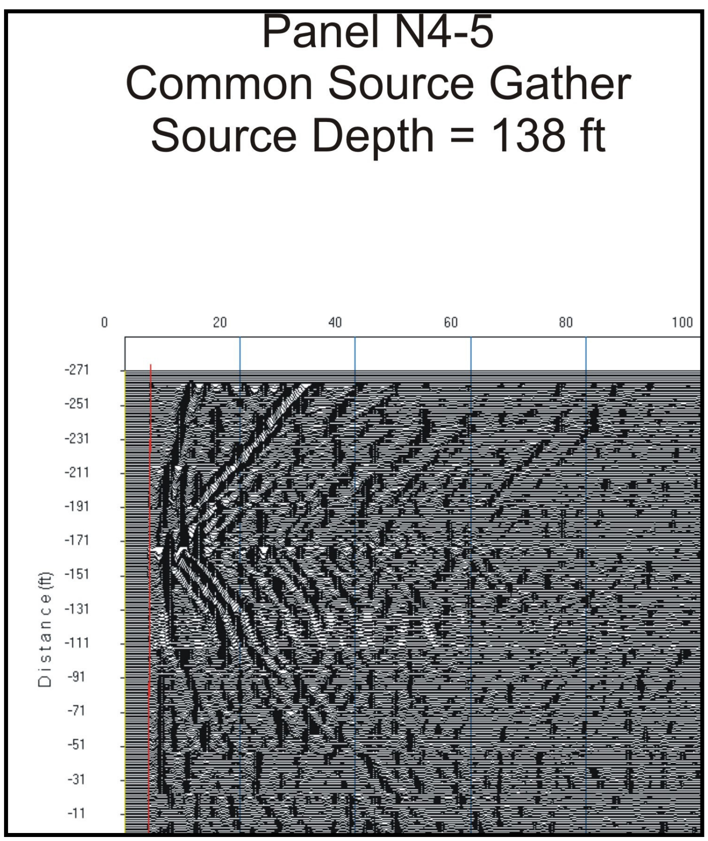


FIGURE B - 13 PANEL NS #4- #5 COMMON SOURCE GATHER SOURCE DEPTH 188 FT

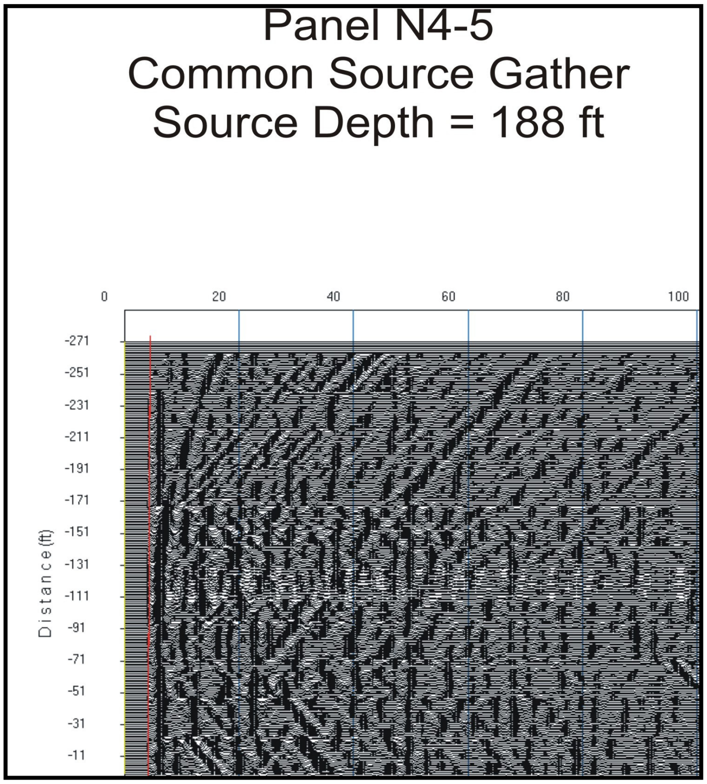


FIGURE B - 14 PANEL NS #4- #5 COMMON SOURCE GATHER SOURCE DEPTH 233 FT

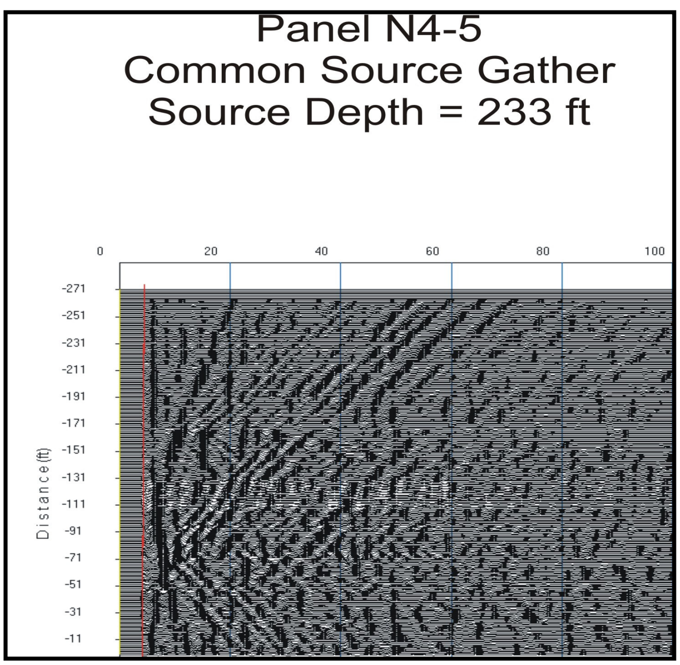


FIGURE B - 15 PANEL NS #4- #5 COMMON SOURCE GATHER SOURCE DEPTH 253 FT

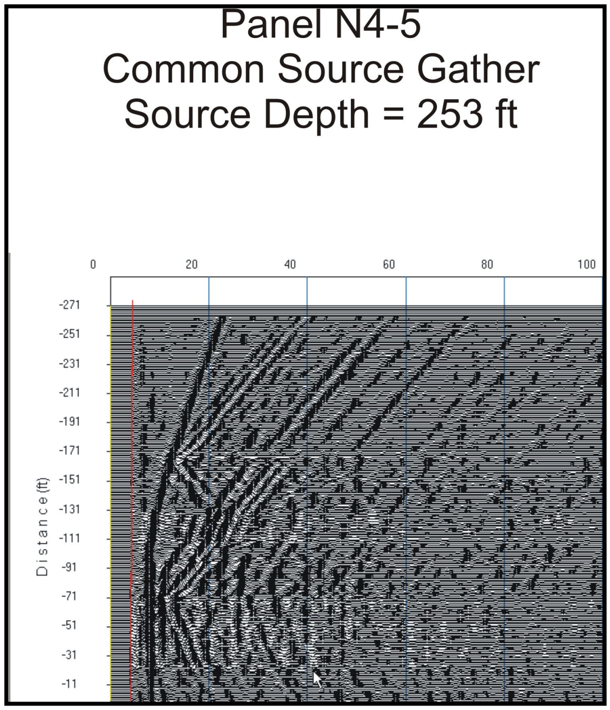


FIGURE B - 16 PANEL NS #4- #5 COMMON SOURCE GATHER SOURCE DEPTH 63 FT

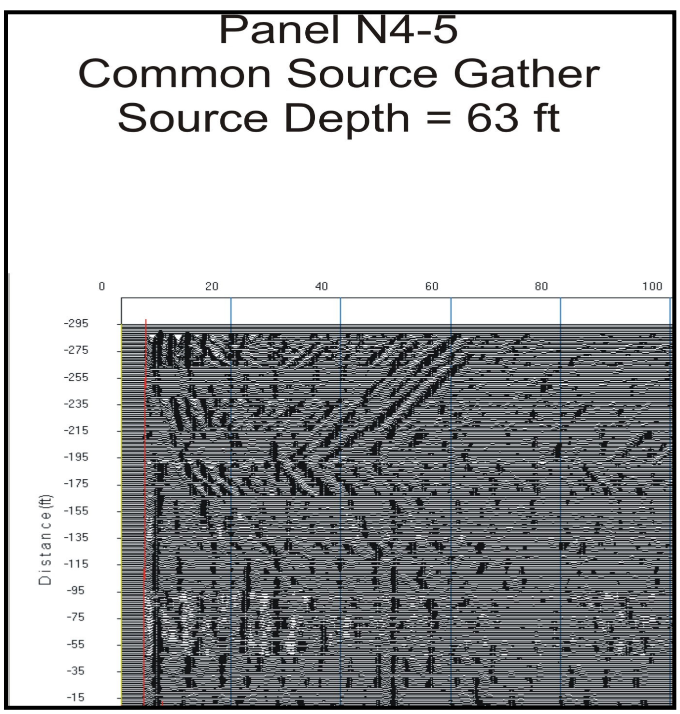


FIGURE B - 17 PANEL NS #5- #3 COMMON SOURCE GATHER SOURCE DEPTH 142 FT

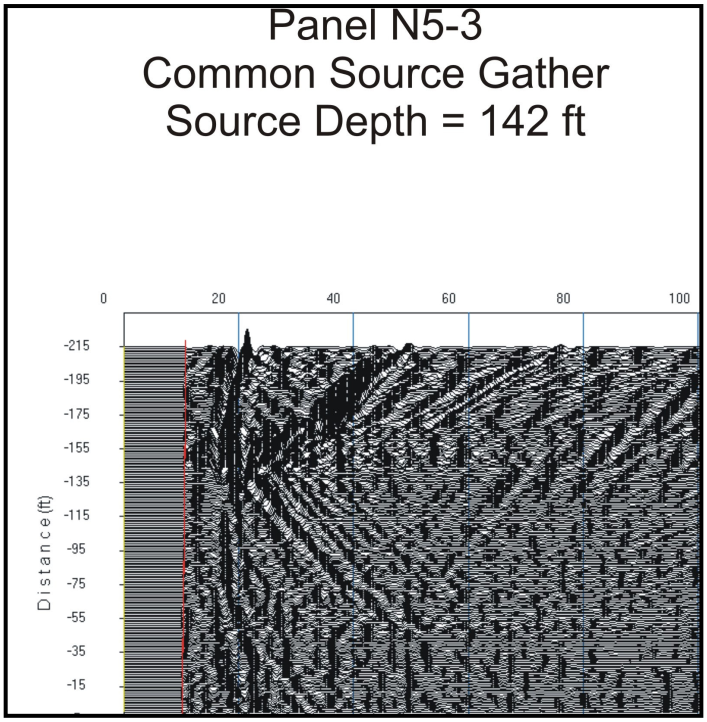


FIGURE B - 18 PANEL NS #5- #3 COMMON SOURCE GATHER SOURCE DEPTH 193 FT

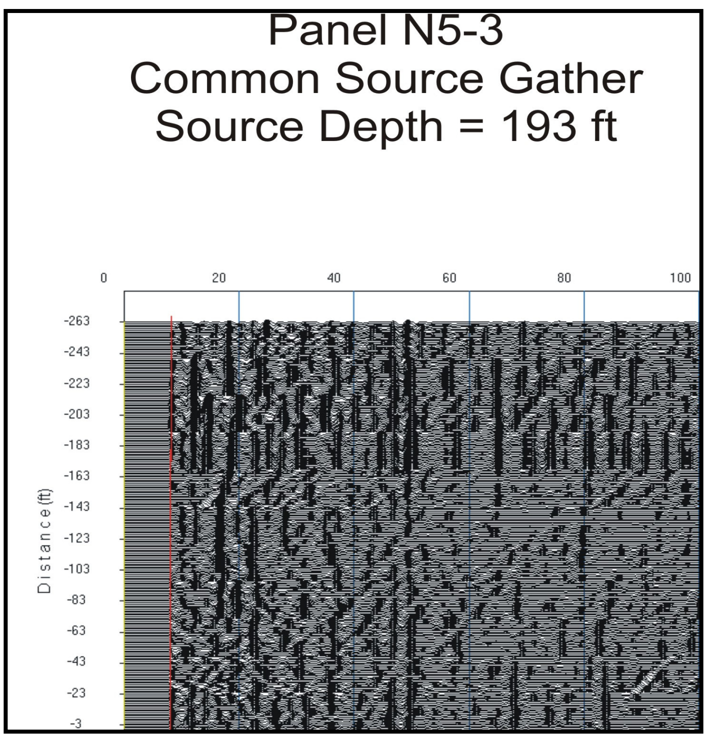


FIGURE B - 19 PANEL NS #5- #3 COMMON SOURCE GATHER SOURCE DEPTH 236 FT

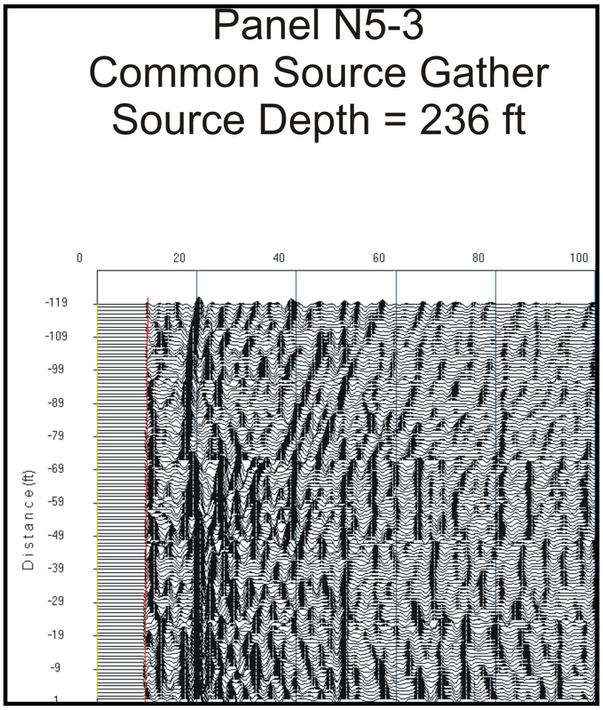


FIGURE B - 20 PANEL NS #5- #3 COMMON SOURCE GATHER SOURCE DEPTH 254 FT

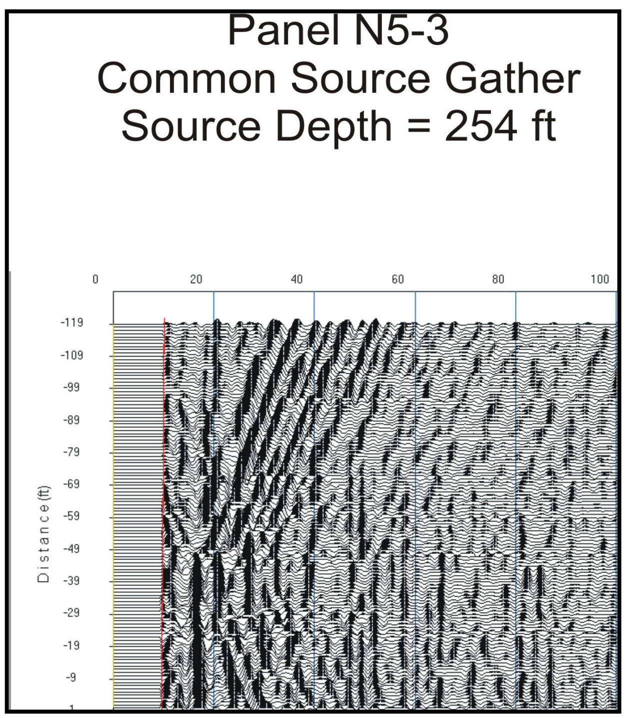


FIGURE B - 21 PANEL NS #5- #3 COMMON SOURCE GATHER SOURCE DEPTH 63 FT

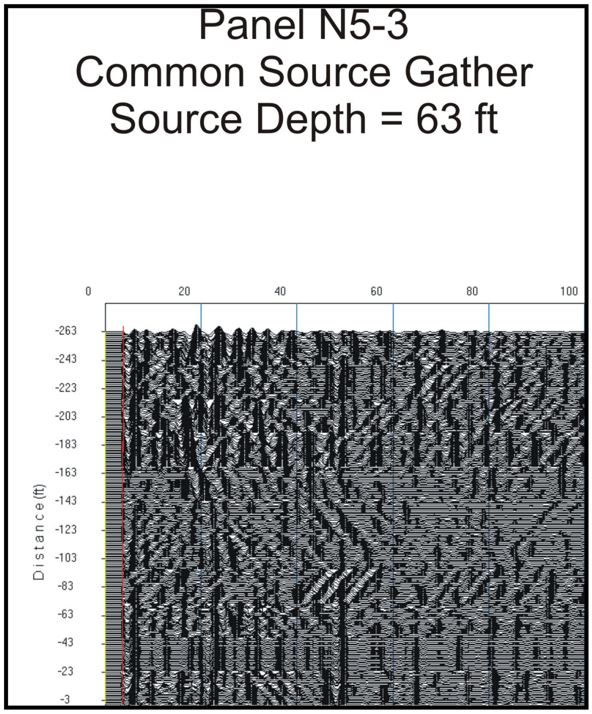


FIGURE B - 22 PANEL NS #5- #6 COMMON SOURCE GATHER SOURCE DEPTH 141 FT

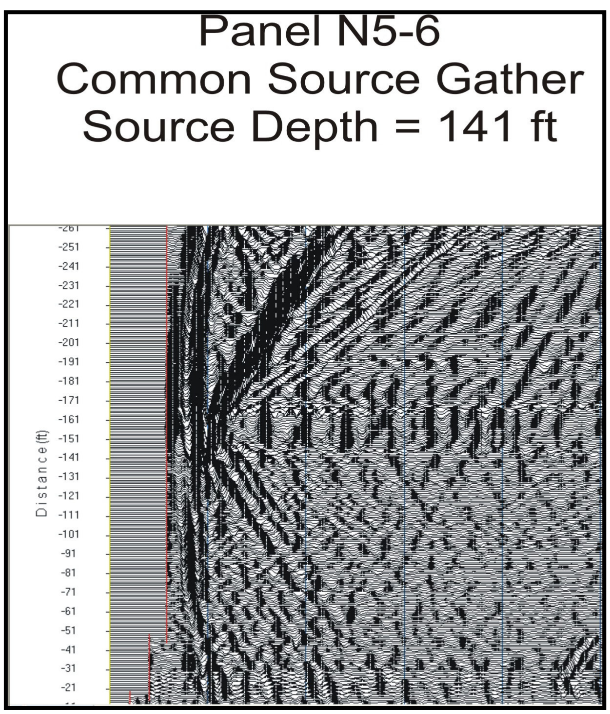


FIGURE B - 23 PANEL NS #5- #6 COMMON SOURCE GATHER SOURCE DEPTH 189 FT

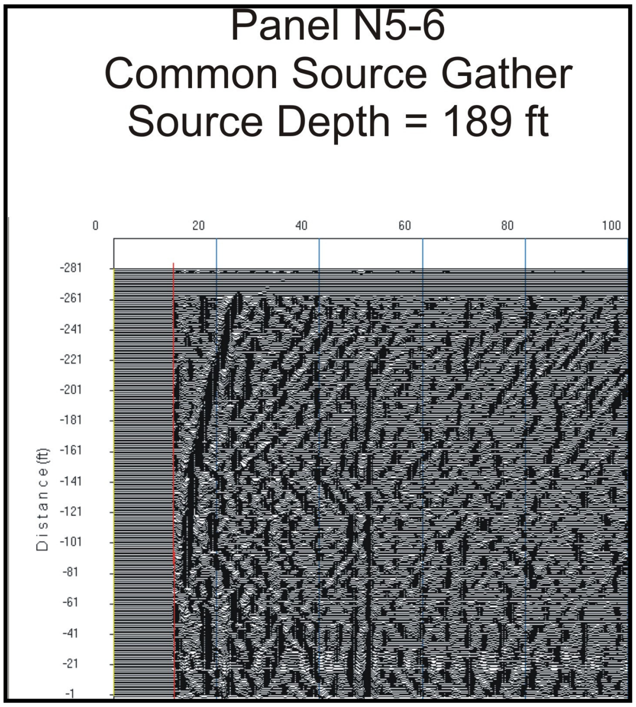


FIGURE B - 24 PANEL NS #5- #6 COMMON SOURCE GATHER SOURCE DEPTH 235 FT

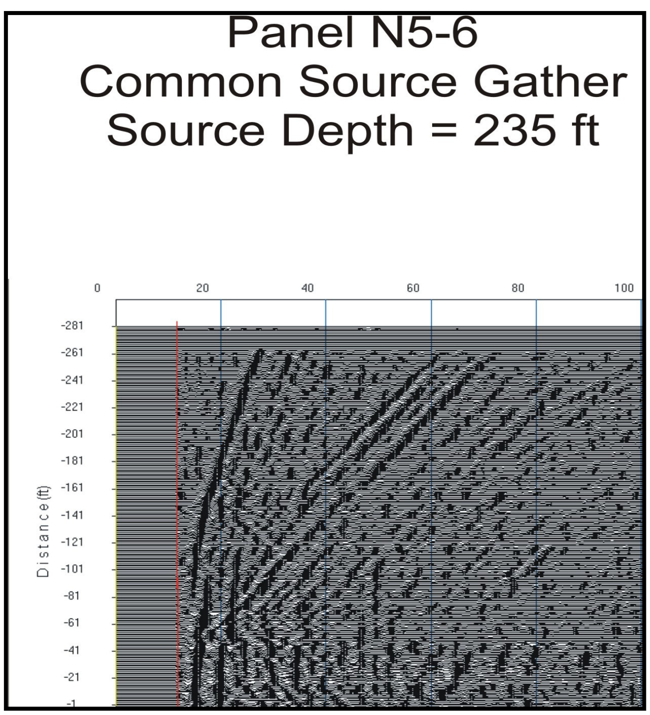


FIGURE B - 25 PANEL NS #5- #6 COMMON SOURCE GATHER SOURCE DEPTH 254 FT

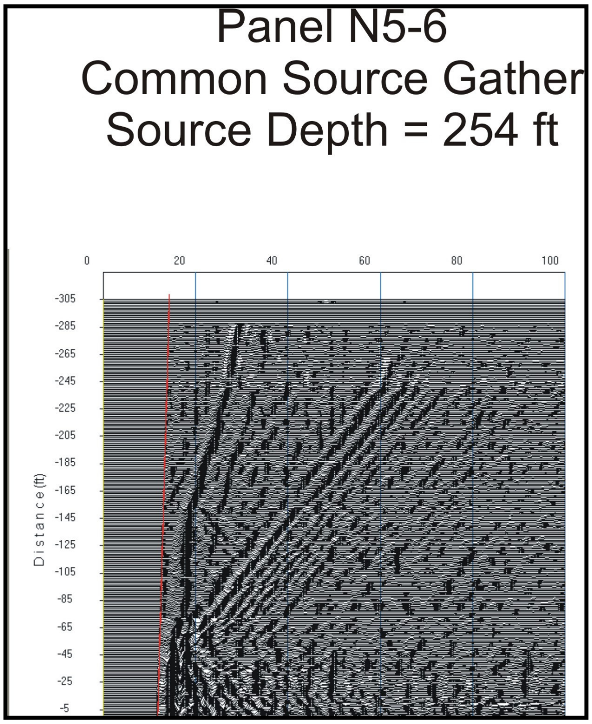


FIGURE B - 26 PANEL NS #5- #6 COMMON SOURCE GATHER SOURCE DEPTH 59 FT

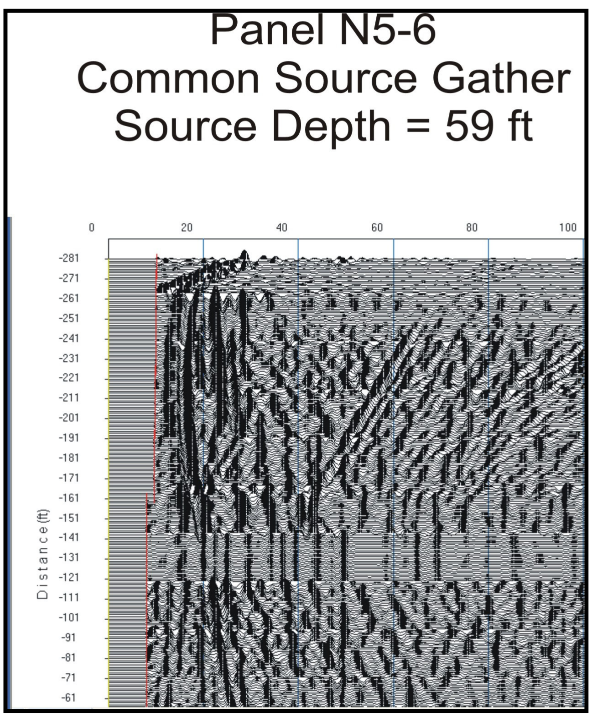


FIGURE B - 27 PANEL NS #6- #3 COMMON SOURCE GATHER SOURCE DEPTH 141 FT

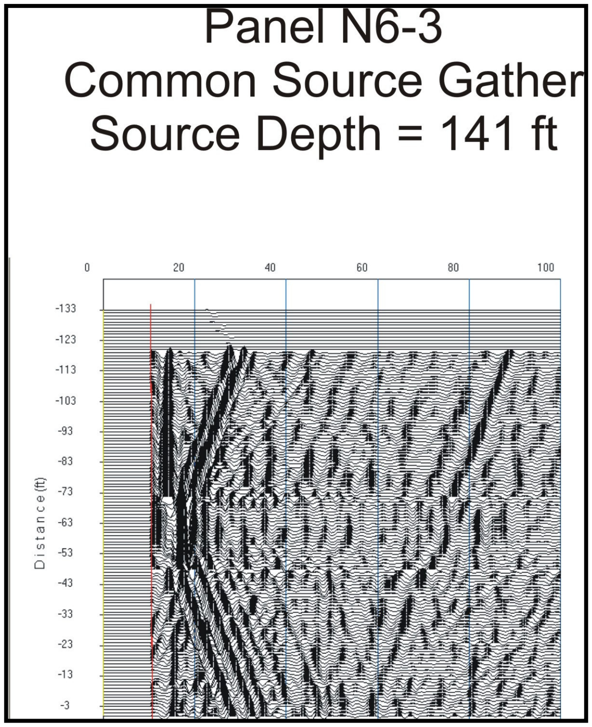


FIGURE B - 28 PANEL NS #6- #3 COMMON SOURCE GATHER SOURCE DEPTH 187 FT

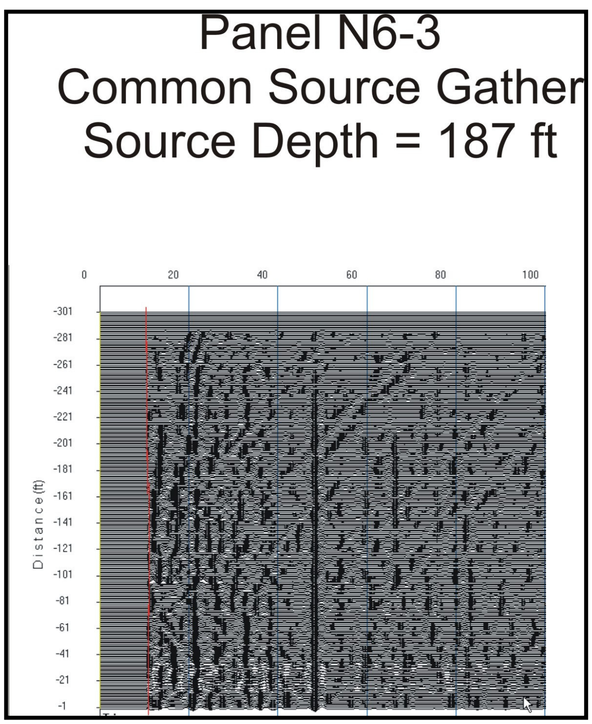


FIGURE B - 29 PANEL NS #6- #3 COMMON SOURCE GATHER SOURCE DEPTH 237 FT

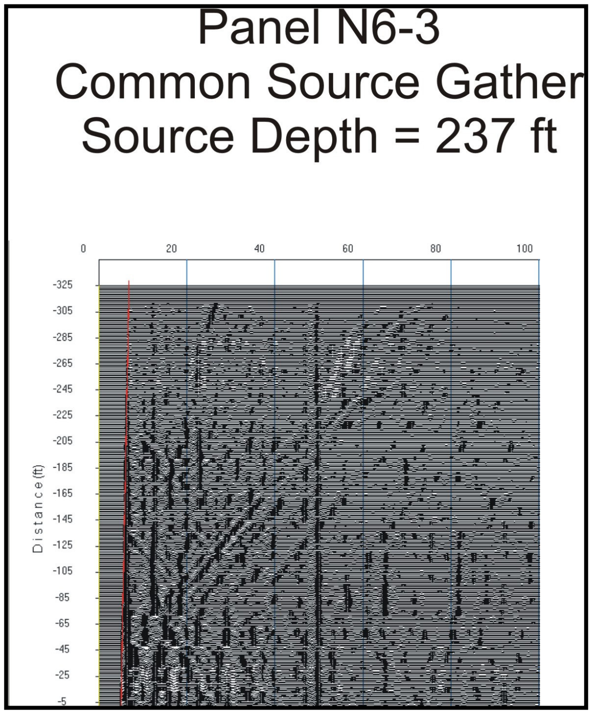


FIGURE B - 30 PANEL NS #6- #3 COMMON SOURCE GATHER SOURCE DEPTH 251 FT

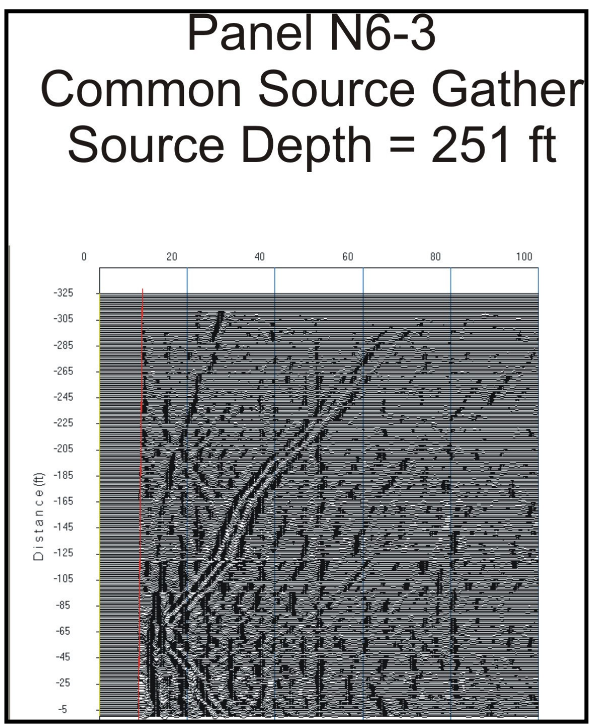


FIGURE B - 31 PANEL NS #6- #3 COMMON SOURCE GATHER SOURCE DEPTH 62 FT

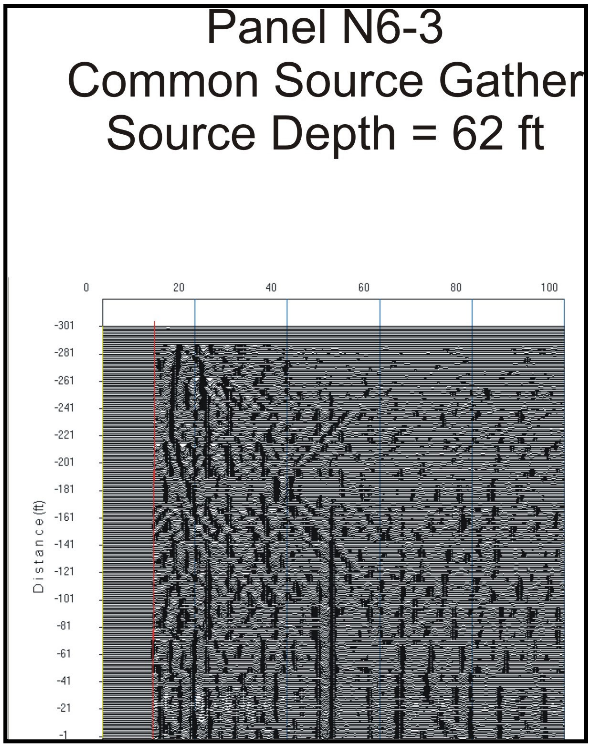


FIGURE B - 32 PANEL NS #6- #4 COMMON SOURCE GATHER SOURCE DEPTH 142 FT

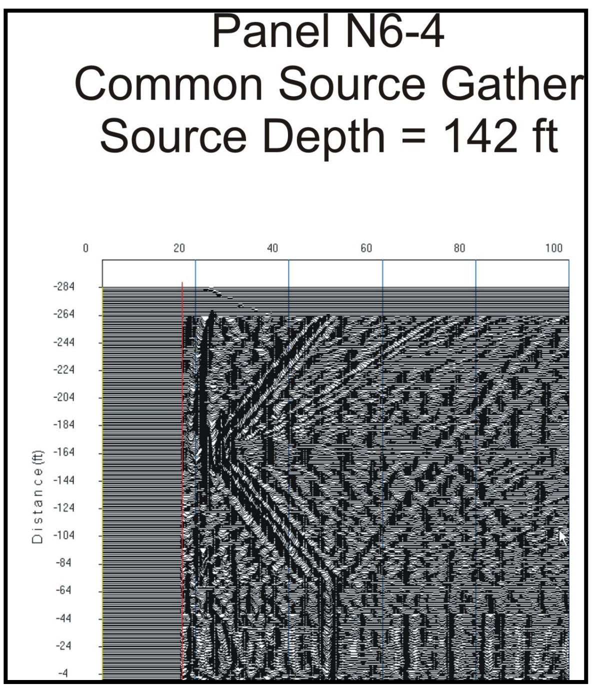


FIGURE B - 33 PANEL NS #6- #4 COMMON SOURCE GATHER SOURCE DEPTH 191 FT

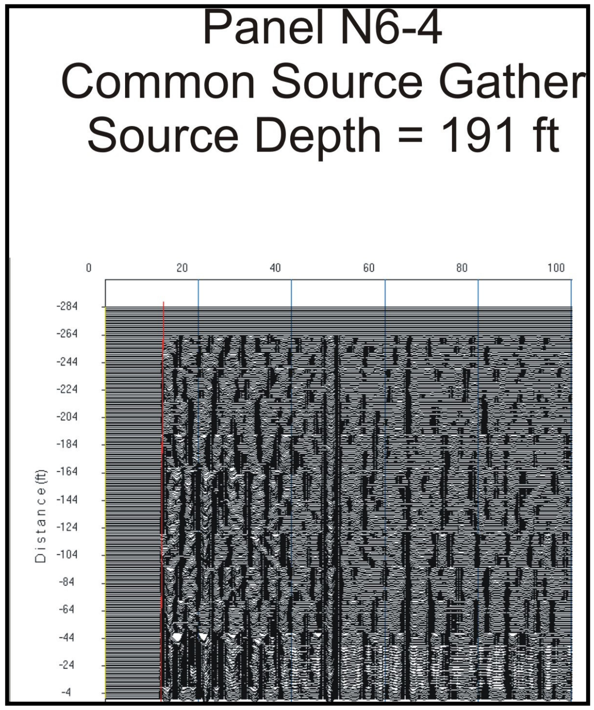


FIGURE B - 34 PANEL NS #6- #4 COMMON SOURCE GATHER SOURCE DEPTH 236 FT

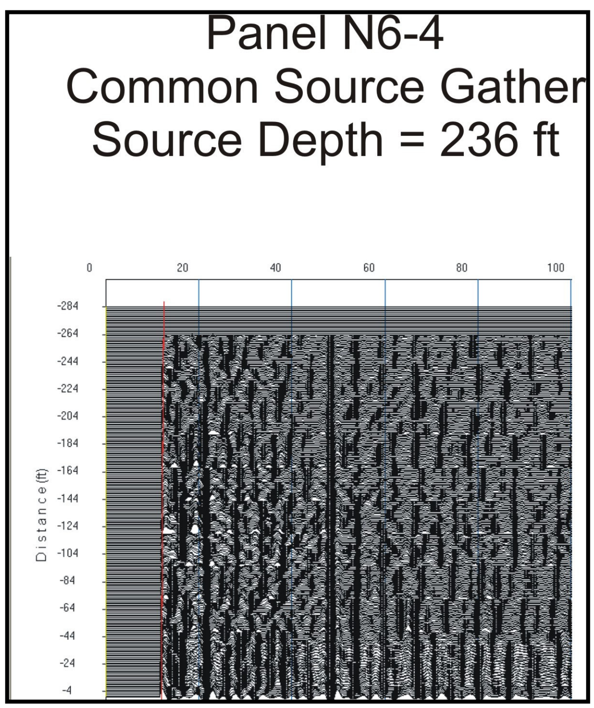


FIGURE B - 35 PANEL NS #6- #4 COMMON SOURCE GATHER SOURCE DEPTH 254 FT

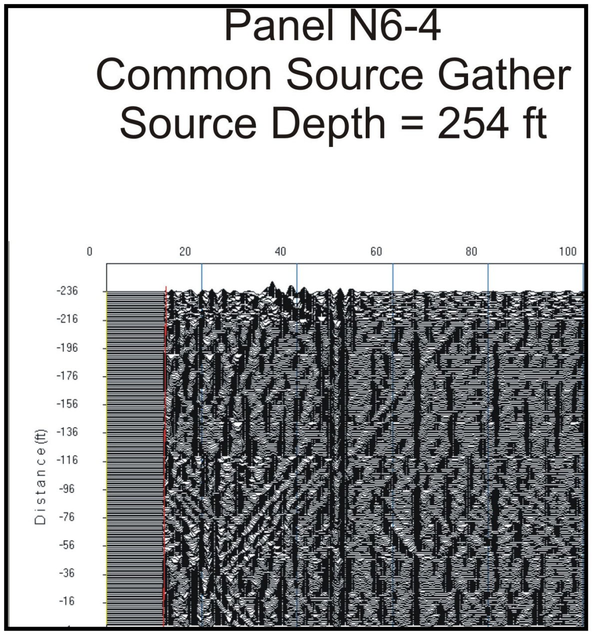


FIGURE B - 36 PANEL NS #6- #4 COMMON SOURCE GATHER SOURCE DEPTH 61 FT

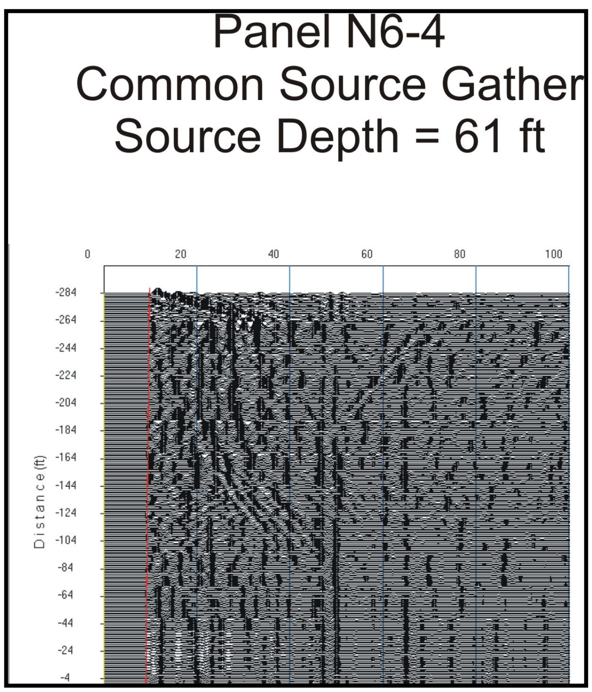
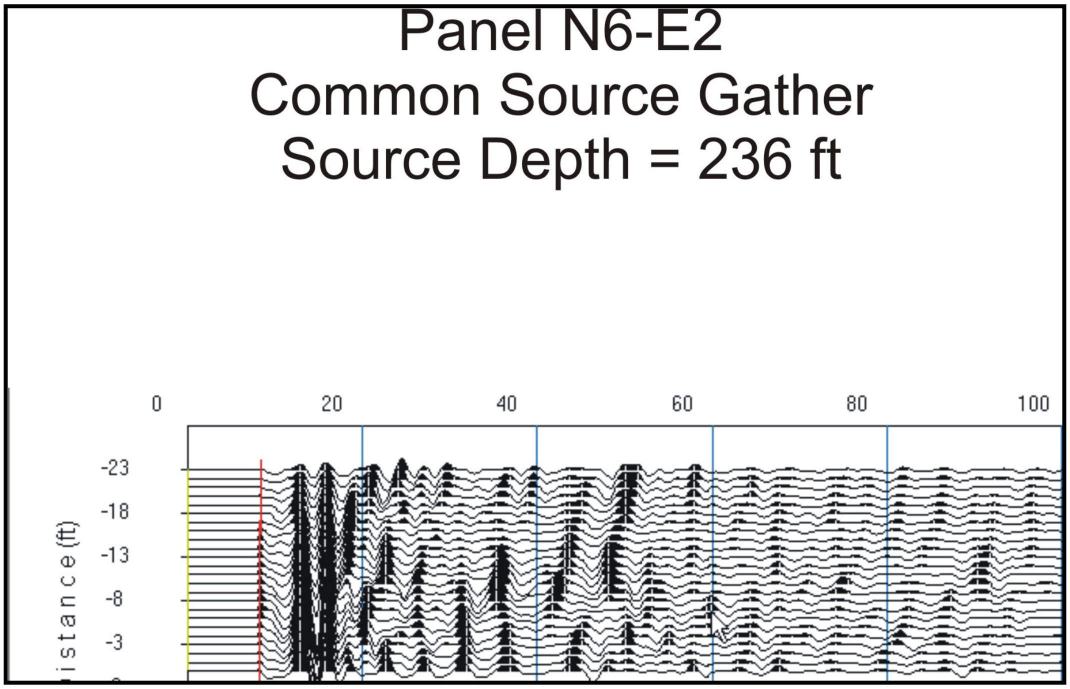


FIGURE B - 37 PANEL NS #6-EW #2 COMMON SOURCE GATHER SOURCE DEPTH 236 FT



APPENDIX C GEOPHYSICAL LOGS

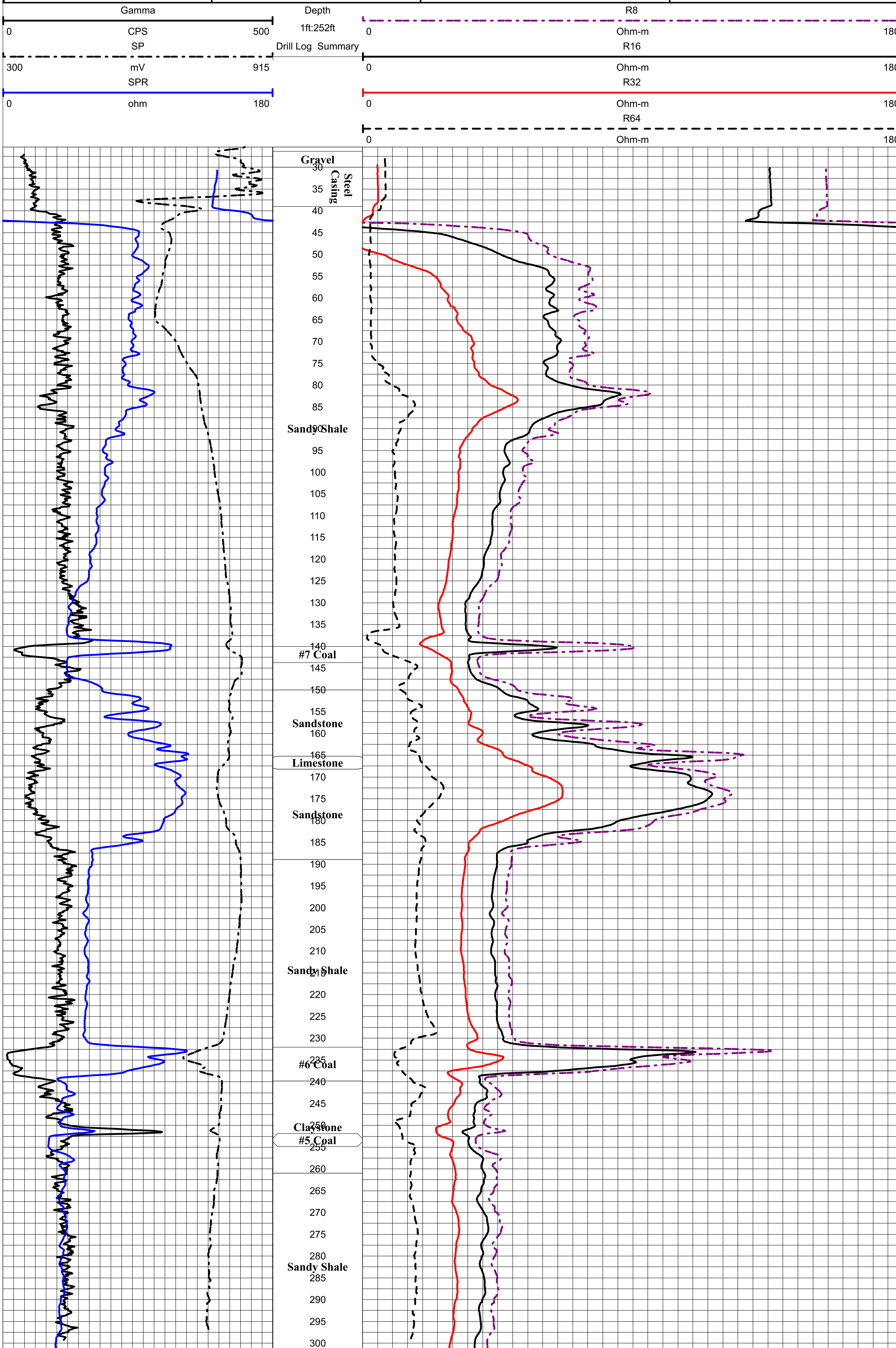
TABLE OF CONTENTS

BLACKHAWK
A DIVISION OF ZAPATAENGINEERING
301 Commercial Rd, Ste B
Golden, CO 80401 USA
(303) 278-8700 www.blackhawkgeo.com

Lithological E-Logs

FIGURE:	C-1	BOREHOLE	XHT-EW #1
LOGGING DATE:	April 21, 2005	DRILL DATE:	April 15, 2005
PROJECT:	Geophysical Void Detection Demonstration	LOCATION:	Riola Mine Complex - BBCC Vermilion County, IL

CAPTION:
Gamma: Natural Gamma (counts per sec.)
SP: Spontaneous Potential (milli-Volt)
SPR: Single Point Resistance (Ohm)
R8: Normal Resistivity-8" Spacing (Ohm-m)

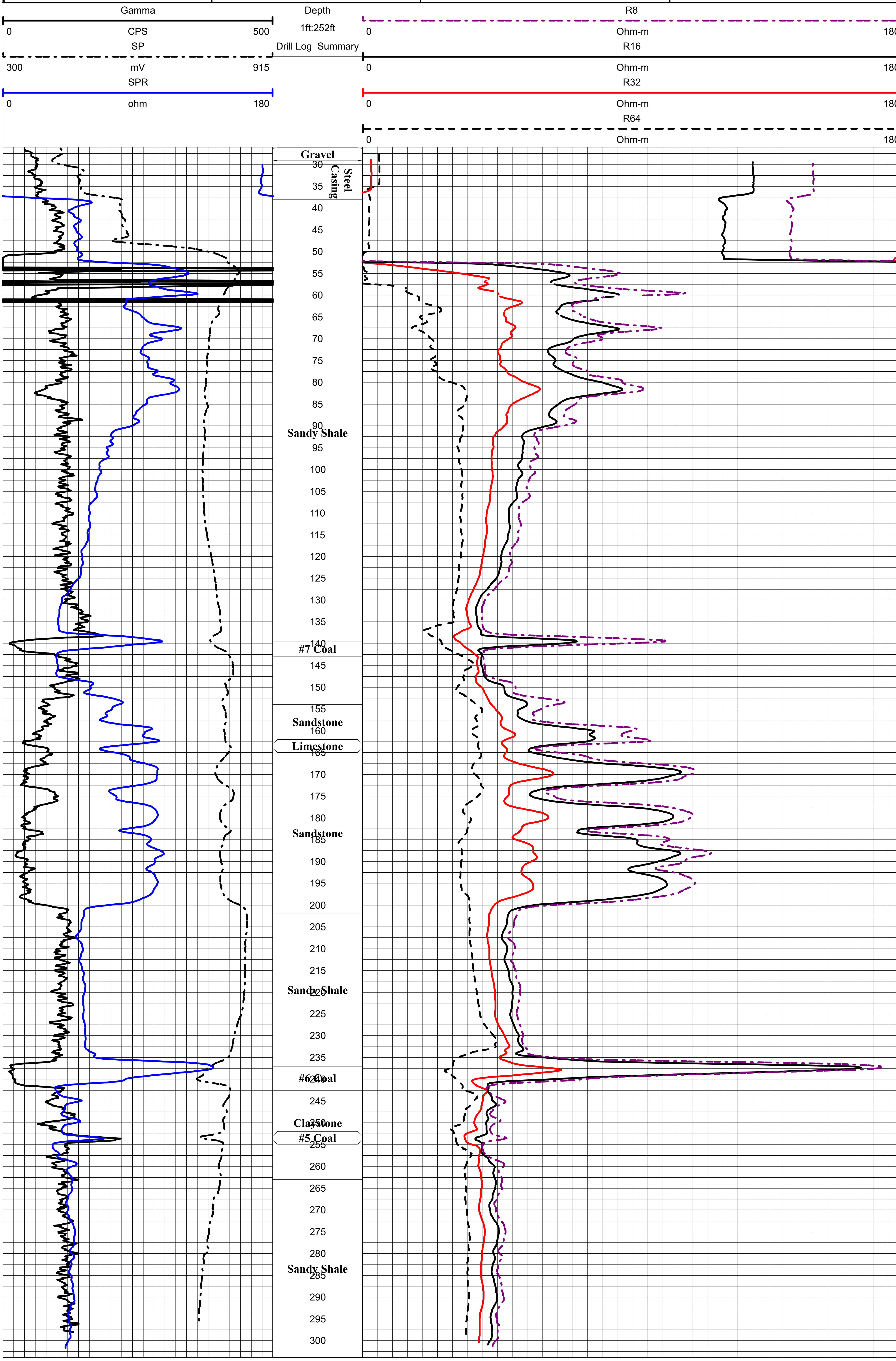


BLACKHAWK
A DIVISION OF ZAPATAENGINEERING
301 Commercial Rd, Ste B
Golden, CO 80401 USA
(303) 278-8700 www.blackhawkgeo.com

Lithological E-Logs

FIGURE:	C-2	BOREHOLE	XHT-EW #2
LOGGING DATE:	April 21, 2005	DRILL DATE:	April 20, 2005
PROJECT:	Geophysical Void Detection Demonstration	LOCATION:	Riola Mine Complex - BBCC Vermilion County, IL

CAPTION:
Gamma: Natural Gamma (counts per sec.)
SP: Spontaneous Potential (milli-Volt)
SPR: Single Point Resistance (Ohm)
R8: Normal Resistivity-8" Spacing (Ohm-m)



BLACKHAWK
A DIVISION OF ZAPATAENGINEERING

301 Commercial Rd, Ste B
Golden, CO 80401 USA
(303) 278-8700 www.blackhawkgeo.com

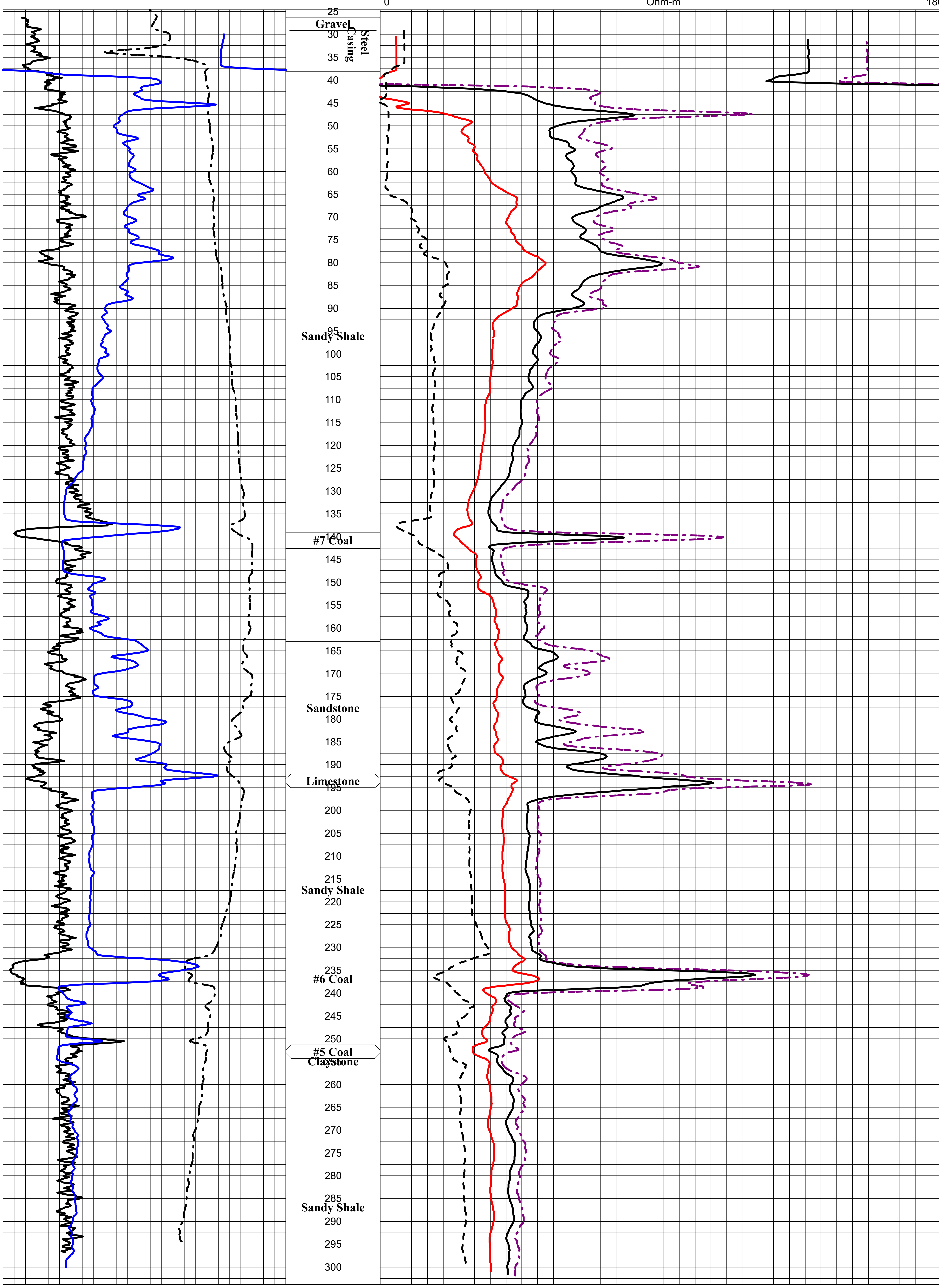
Lithological E-Logs

FIGURE:	C-3	BOREHOLE	XHT-NS #3
LOGGING DATE:	April 20, 2005	DRILL DATE:	April 19, 2005
PROJECT:	Geophysical Void Detection Demonstration	LOCATION:	Riola Mine Complex - BBCC Vermilion County, IL

CAPTION:
Gamma: Natural Gamma (counts per sec.)
SP: Spontaneous Potential (milli-Volt)
SPR: Single Point Resistance (Ohm)
R8: Normal Resistivity-8" Spacing (Ohm-m)

Log	Min	Units	Max
Gamma	0	CPS	500
SP	300	mV	915
SPR	0	ohm	180
R8	0	Ohm-m	180
R16	0	Ohm-m	180
R32	0	Ohm-m	180
R64	0	Ohm-m	180

Depth 1ft:252ft
Drill Log Summary



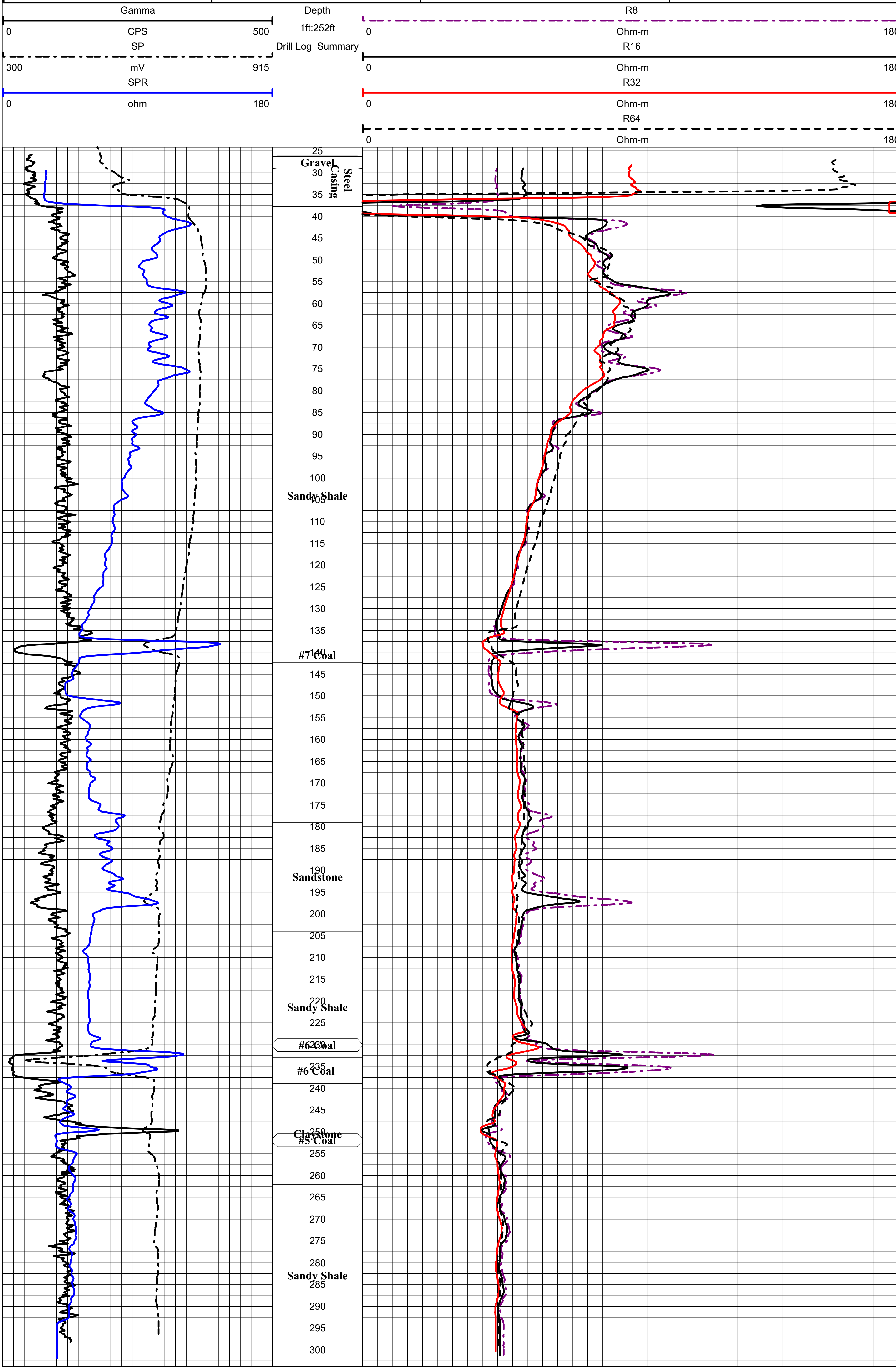
BLACKHAWK
A DIVISION OF ZAPATAENGINEERING

301 Commercial Rd, Ste B
Golden, CO 80401 USA
(303) 278-8700 www.blackhawkgeo.com

Lithological E-Logs

FIGURE:	C-4	BOREHOLE	XHT-NS #4
LOGGING DATE:	April 22, 2005	DRILL DATE:	April 20-21, 2005
PROJECT:	Geophysical Void Detection Demonstration	LOCATION:	Riola Mine Complex - BBCC Vermilion County, IL

CAPTION:
Gamma: Natural Gamma (counts per sec.)
SP: Spontaneous Potential (milli-Volt)
SPR: Single Point Resistance (Ohm)
R8: Normal Resistivity-8" Spacing (Ohm-m)



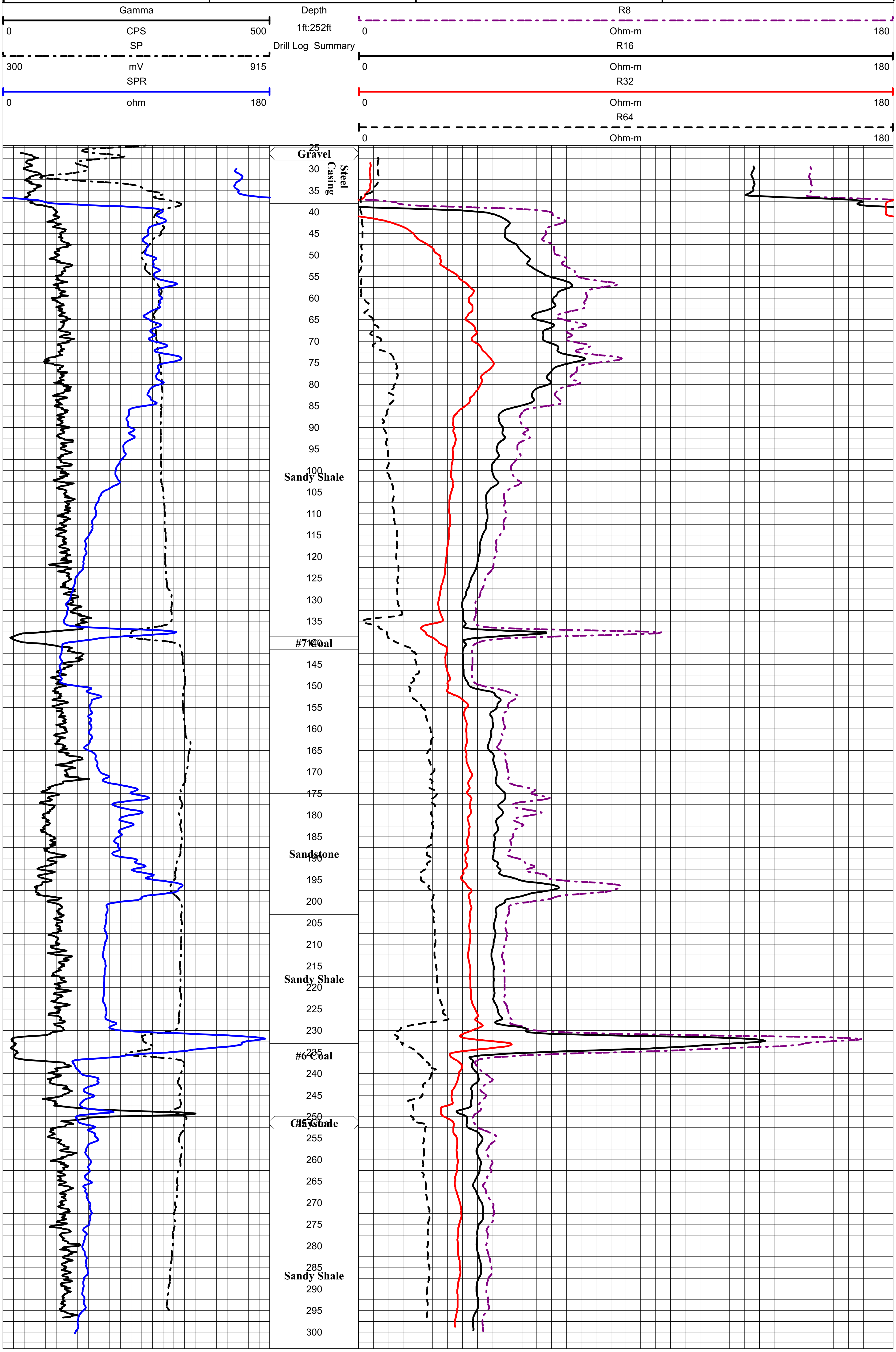
BLACKHAWK
A DIVISION OF ZAPATA ENGINEERING

301 Commercial Rd, Ste B
Golden, CO 80401 USA
(303) 278-8700 www.blackhawkgeo.com

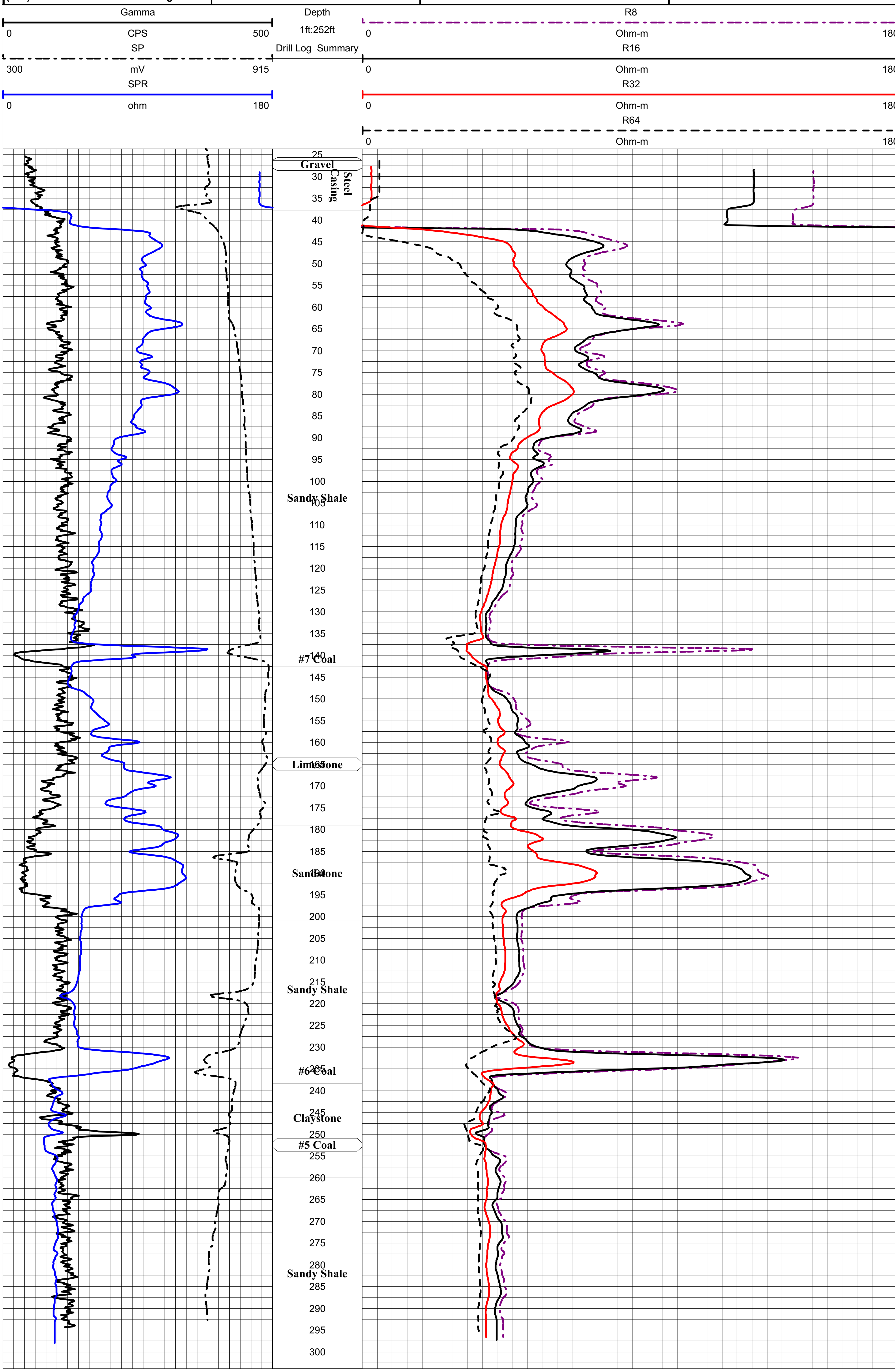
Lithological E-Logs

FIGURE:	C-5	BOREHOLE	XHT-NS #5
LOGGING DATE:	April 20, 2005	DRILL DATE:	April 18-19, 2005
PROJECT:	Geophysical Void Detection Demonstration	LOCATION:	Riola Mine Complex - BBCC Vermilion County, IL

CAPTION:
Gamma: Natural Gamma (counts per sec.)
SP: Spontaneous Potential (milli-Volt)
SPR: Single Point Resistance (Ohm)
R8: Normal Resistivity-8" Spacing (Ohm-m)



BLACKHAWK A DIVISION OF ZAPATAENGINEERING 301 Commercial Rd, Ste B Golden, CO 80401 USA (303) 278-8700 www.blackhawkgeo.com	Lithological E-Logs		CAPTION: Gamma: Natural Gamma (counts per sec.) SP: Spontaneous Potential (milli-Volt) SPR: Single Point Resistance (Ohm) R8: Normal Resistivity-8" Spacing (Ohm-m)
	FIGURE: C-6	BOREHOLE XHT-NS #6	
	LOGGING DATE: April 25, 2005	DRILL DATE: April 21-22, 2005	
	PROJECT: Geophysical Void Detection Demonstration	LOCATION: Riola Mine Complex - BBCC Vermilion County, IL	



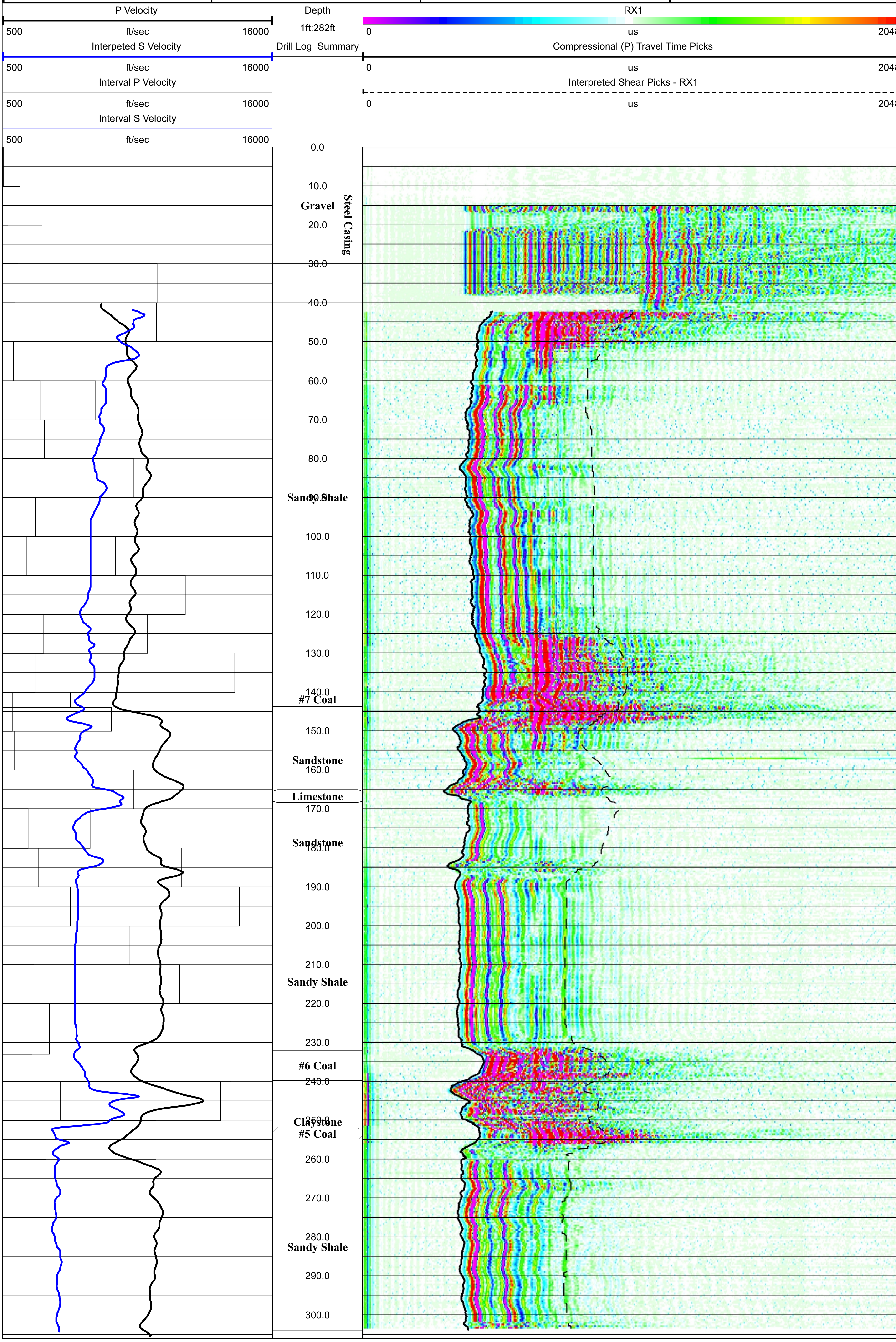
BLACKHAWK
A DIVISION OF ZAPATAENGINEERING

301 Commercial Rd, Ste B
Golden, CO 80401 USA
(303) 278-8700 www.blackhawkgeo.com

Full Waveform Sonic Log

FIGURE:	C-7	BOREHOLE	XHT-EW #1 RX1
LOGGING DATE:	April 21, 2005	DRILL DATE:	April 15, 2005
PROJECT:	Geophysical Void Detection Demonstration	LOCATION:	Riola Mine Complex-BBCC Vermilion County, IL

CAPTION:
RX1: Near Receiver Waveform Plots
RX2: Far Receiver Waveform Plots
PK1: Near Receiver First Arrival (P) Picks
PK2: Far Receiver First Arrival (P) Picks



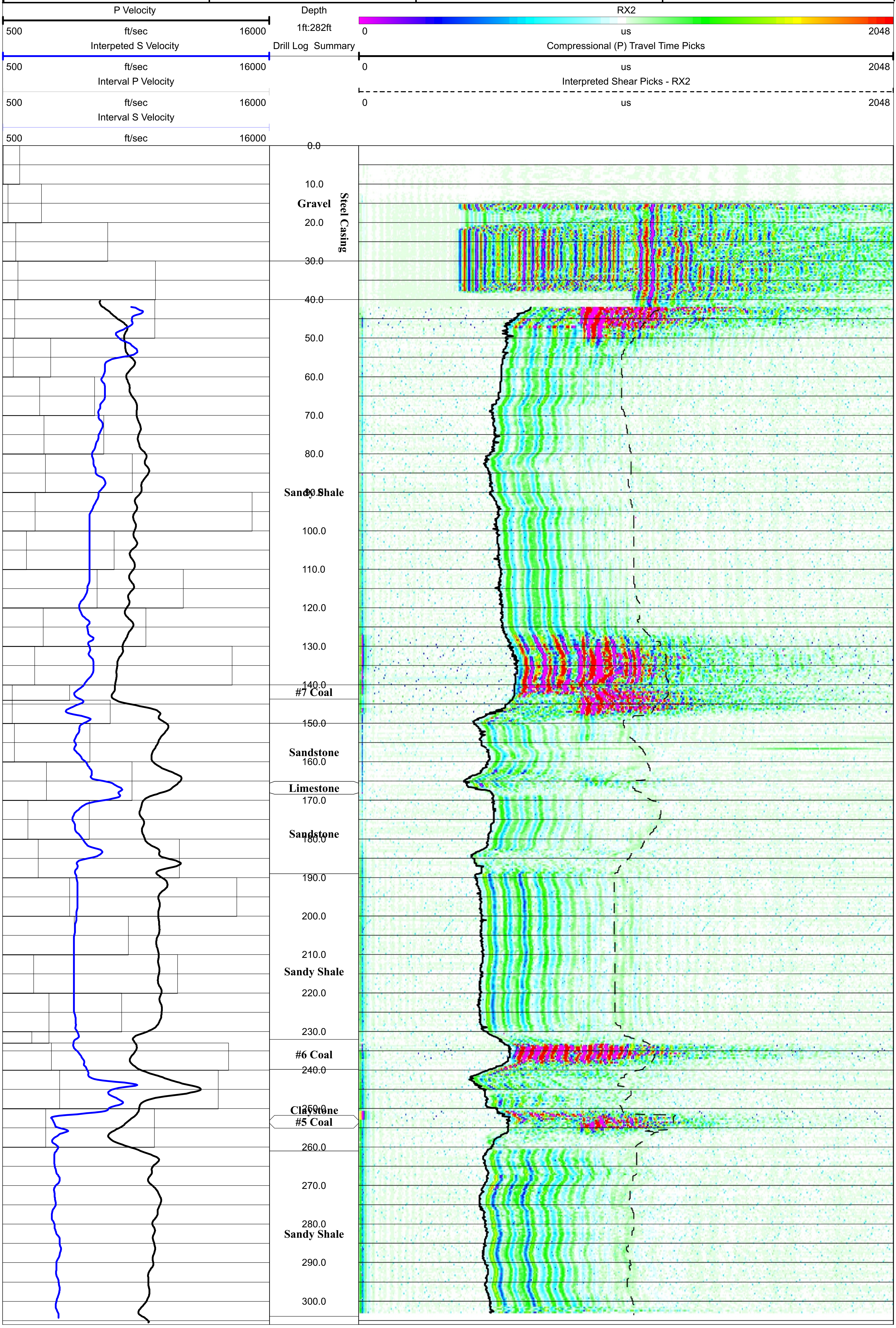
BLACKHAWK
A DIVISION OF ZAPATAENGINEERING

301 Commercial Rd, Ste B
Golden, CO 80401 USA
(303) 278-8700 www.blackhawkgeo.com

Full Waveform Sonic Log

FIGURE:	C-8	BOREHOLE	XHT-EW #1 RX2
LOGGING DATE:	April 21, 2005	DRILL DATE:	April 15, 2005
PROJECT:	Geophysical Void Detection Demonstration	LOCATION:	Riola Mine Complex-BBCC Vermilion County, IL

CAPTION:
RX1: Near Receiver Waveform Plots
RX2: Far Receiver Waveform Plots
PK1: Near Receiver First Arrival (P) Picks
PK2: Far Receiver First Arrival (P) Picks



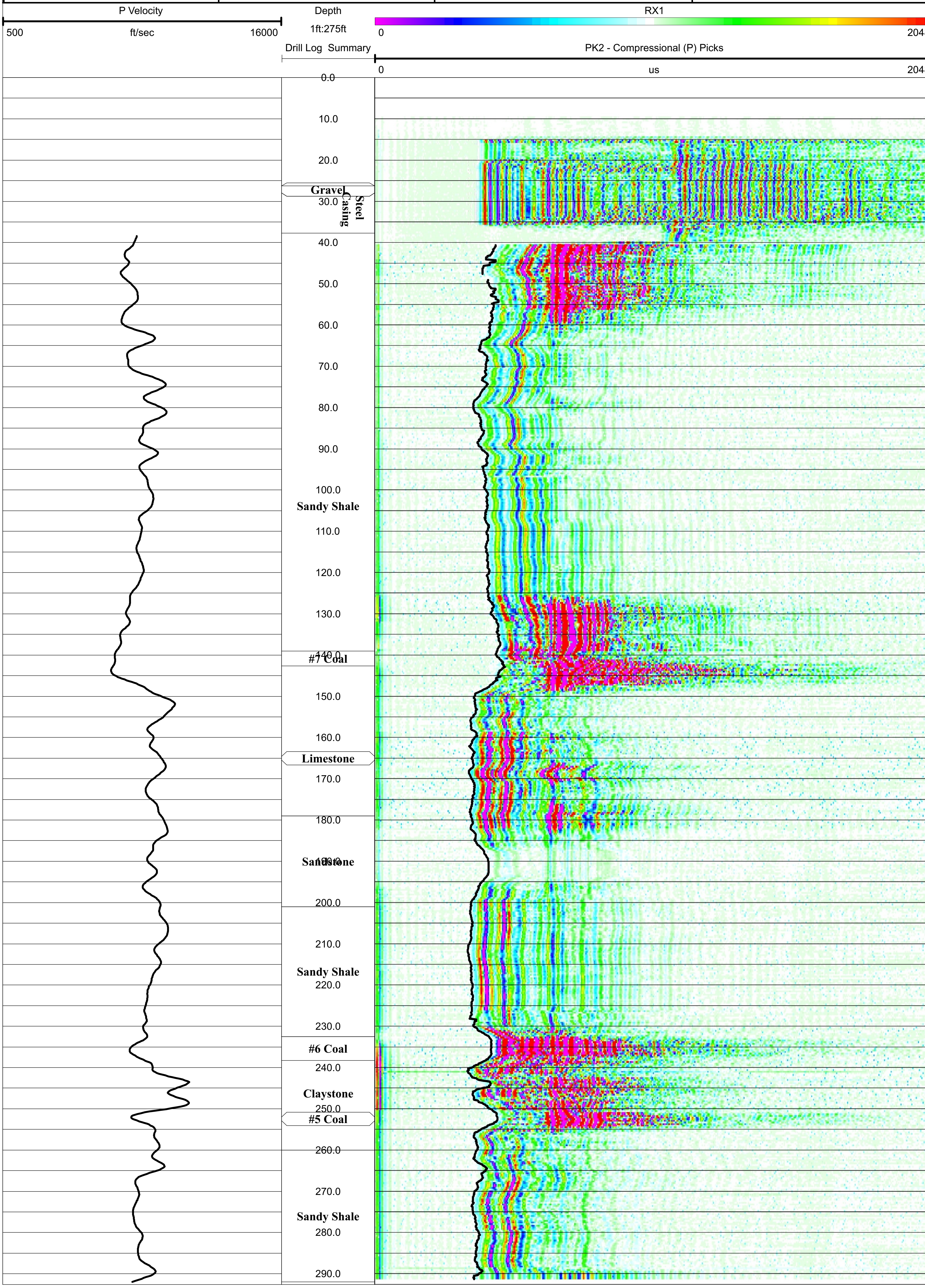
BLACKHAWK
A DIVISION OF ZAPATAENGINEERING

301 Commercial Rd, Ste B
Golden, CO 80401 USA
(303) 278-8700 www.blackhawkgeo.com

Full Waveform Sonic Log

FIGURE:	C-9	BOREHOLE	XHT-NS #6 RX1
LOGGING DATE:	April 25, 2005	DRILL DATE:	April 21-22, 2005
PROJECT:	Geophysical Void Detection Demonstration	LOCATION:	Riola Mine Complex-BBCC Vermilion County, IL

CAPTION:
RX1: Near Receiver Waveform Plots
RX2: Far Receiver Waveform Plots
PK1: Near Receiver First Arrival (P) Picks
PK2: Far Receiver First Arrival (P) Picks



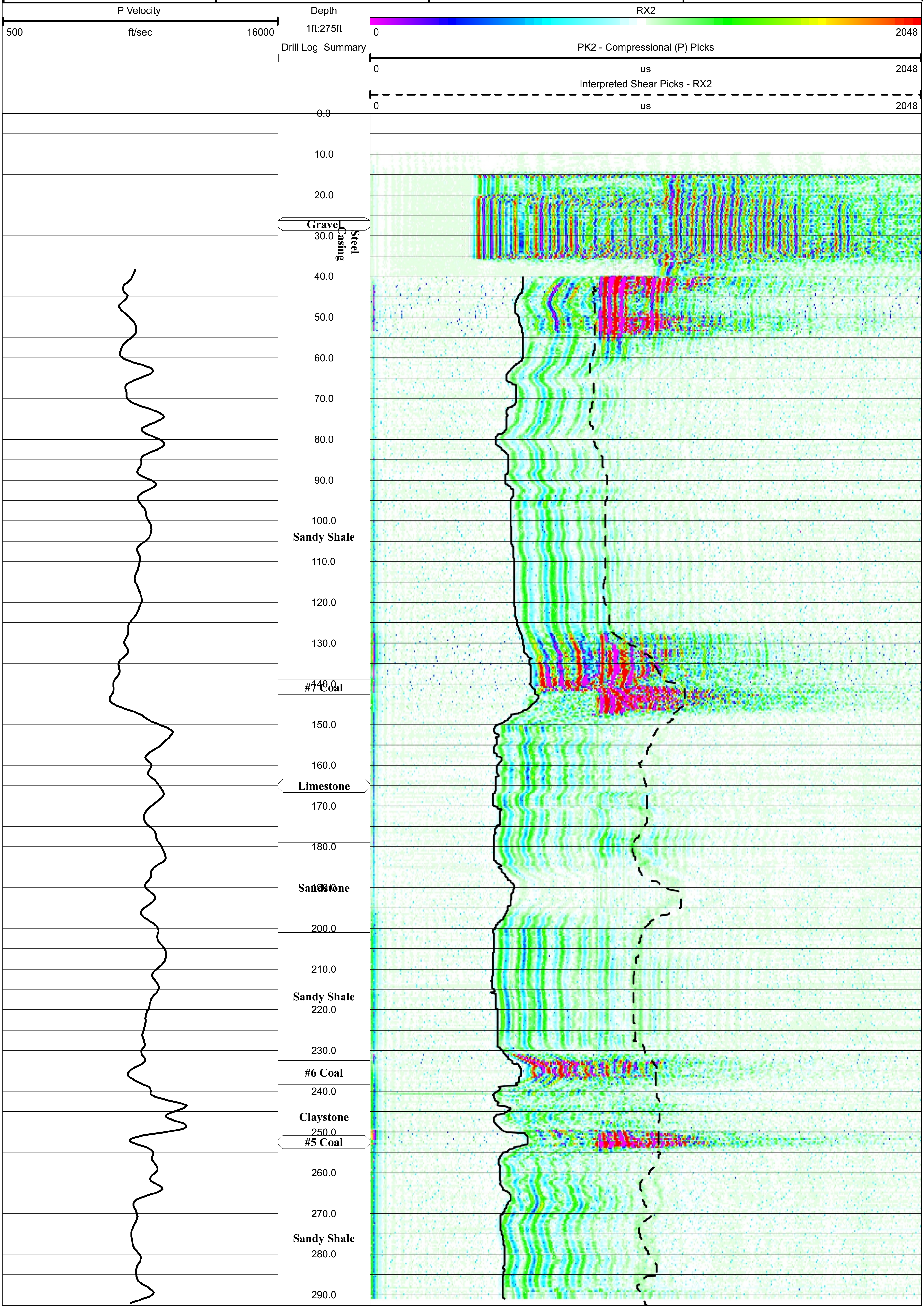
BLACKHAWK
A DIVISION OF ZAPATAENGINEERING

301 Commercial Rd, Ste B
Golden, CO 80401 USA
(303) 278-8700 www.blackhawkgeo.com

Full Waveform Sonic Log

FIGURE:	C-10	BOREHOLE	XHT-NS #6 RX2
LOGGING DATE:	April 25, 2005	DRILL DATE:	April 21-22, 2005
PROJECT:	Geophysical Void Detection Demonstration	LOCATION:	Riola Mine Complex-BBCC Vermilion County, IL

CAPTION:
RX1: Near Receiver Waveform Plots
RX2: Far Receiver Waveform Plots
PK1: Near Receiver First Arrival (P) Picks
PK2: Far Receiver First Arrival (P) Picks



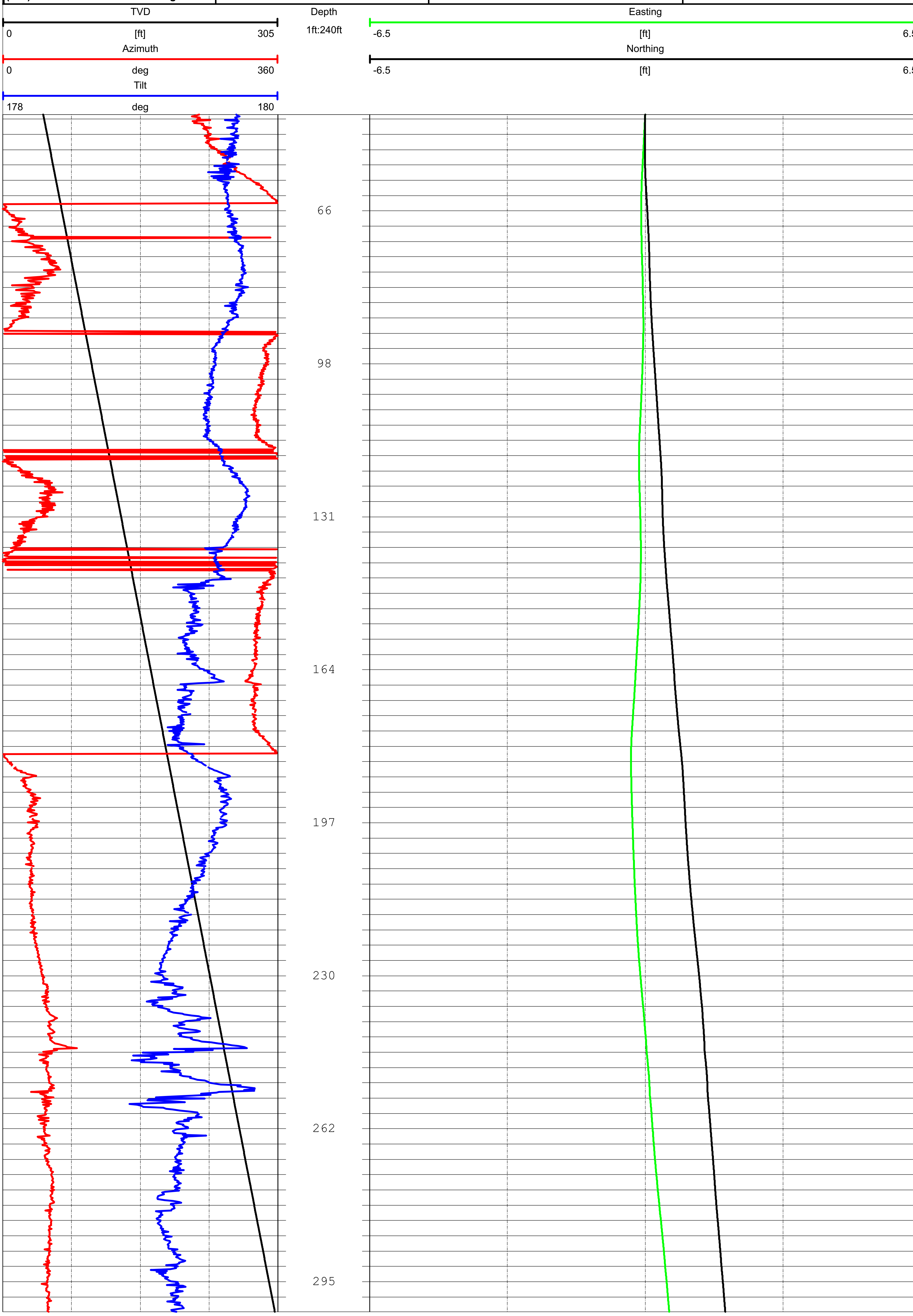
BLACKHAWK
A DIVISION OF ZAPATAENGINEERING

301 Commercial Rd, Ste B
Golden, CO 80401 USA
(303) 278-8700 www.blackhawkgeo.com

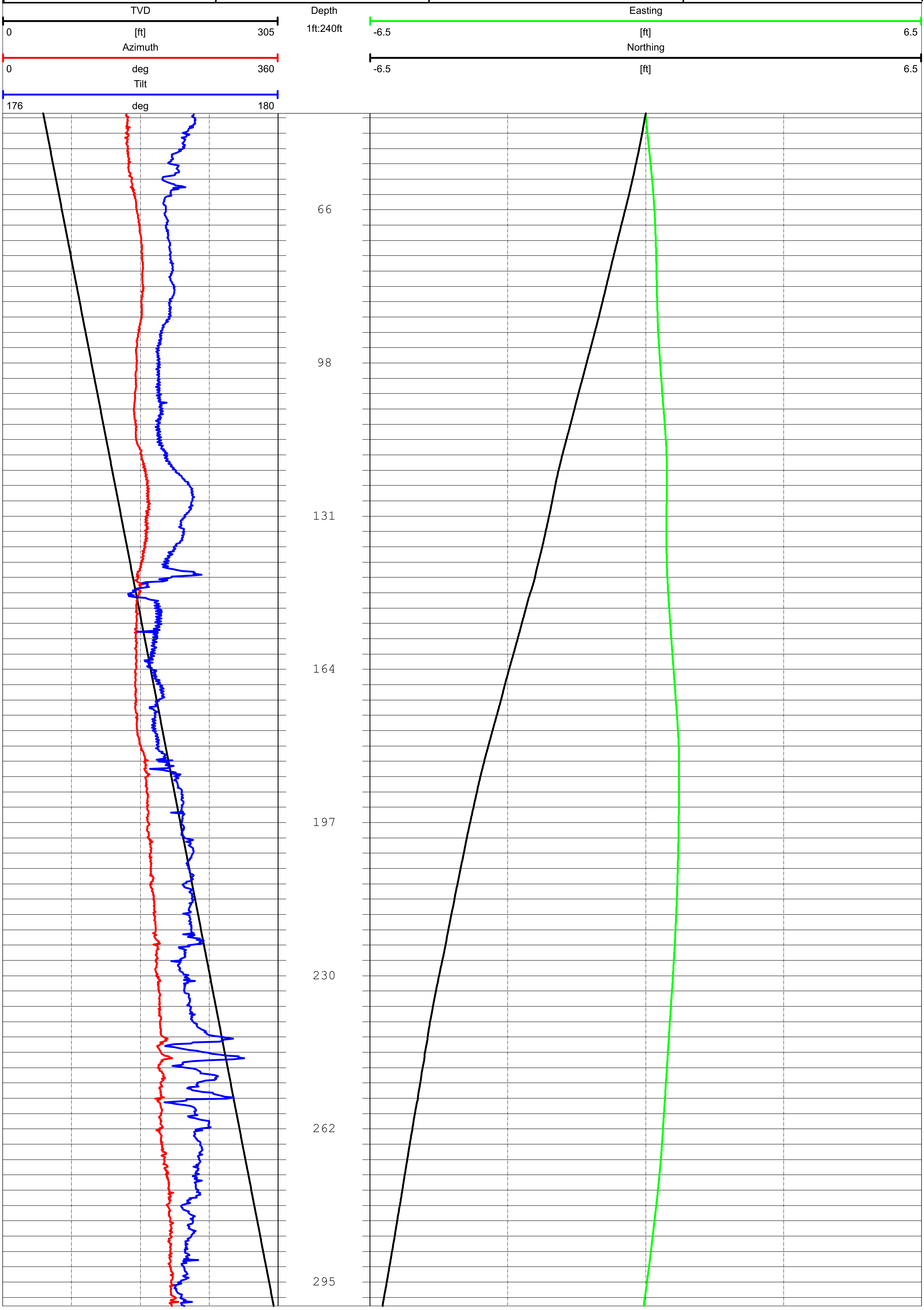
Deviation Log

FIGURE:	C-11	BOREHOLE	XHT-EW #1
LOGGING DATE:	April 21, 2005	DRILL DATE:	April 15, 2005
PROJECT:	Geophysical Void Detection Demonstration	LOCATION:	Riola Mine Complex - BBCC Vermilion County, IL

CAPTION:
Tilt: Borehole Inclination
TVD: True Vertical Depth
Azimuth: Borehole Bearing
Northing: Borehole Northing
Easting: Borehole Easting



BLACKHAWK A DIVISION OF ZAPATA ENGINEERING	Deviation Log		CAPTION:
301 Commercial Rd, Ste B Golden, CO 80401 USA (303) 278-8700 www.blackhawkgeo.com	FIGURE: C-12	BOREHOLE XHT-EW #2	Tilt: Borehole Inclination TVD: True Vertical Depth Azimuth: Borehole Bearing Northing: Borehole Northing Easting: Borehole Easting
	LOGGING DATE: April 21, 2005	DRILL DATE: April 20, 2005	
	PROJECT: Geophysical Void Detection Demonstration	LOCATION: Riola Mine Complex - BBCC Vermilion County, IL	

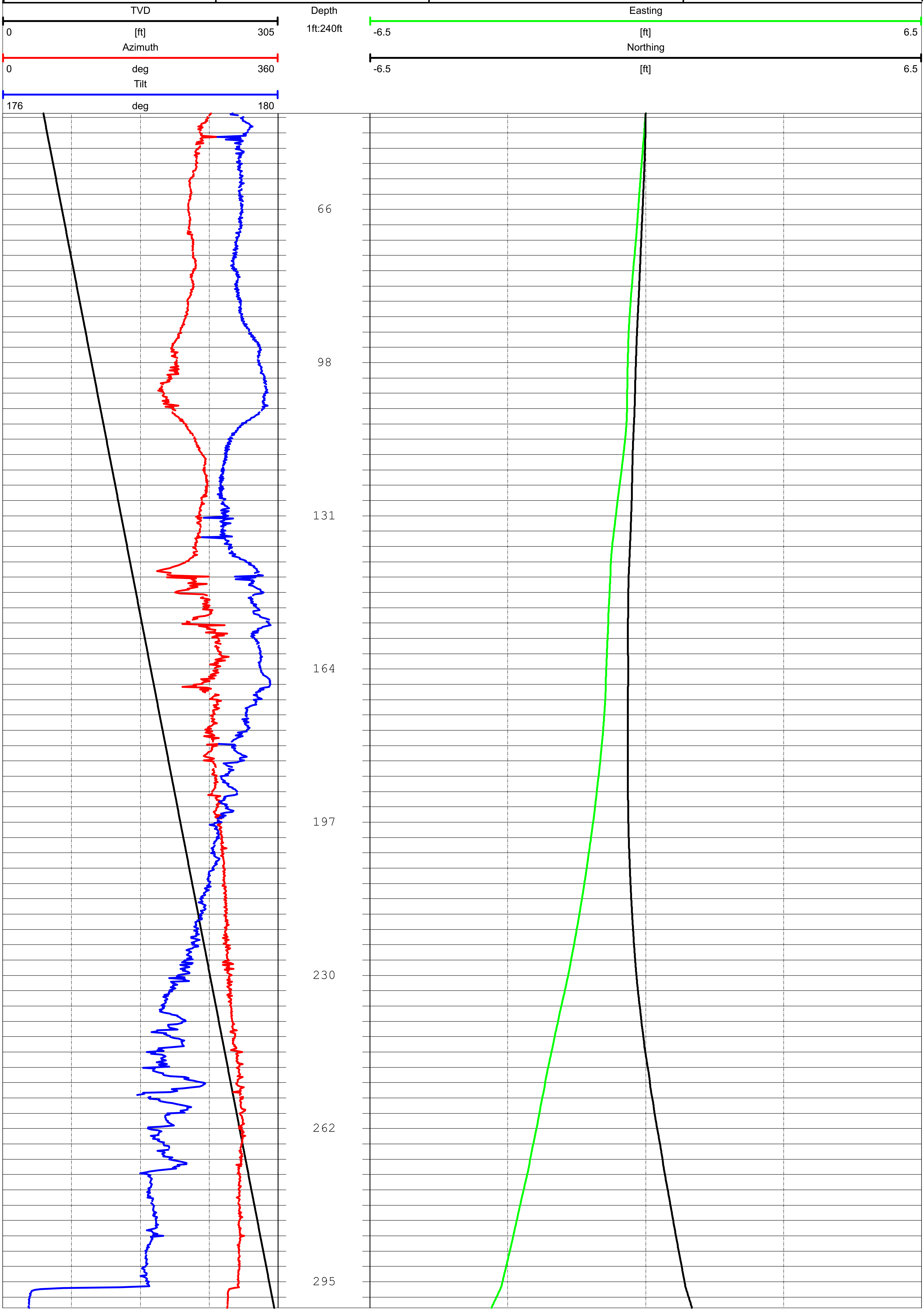


Deviation Log

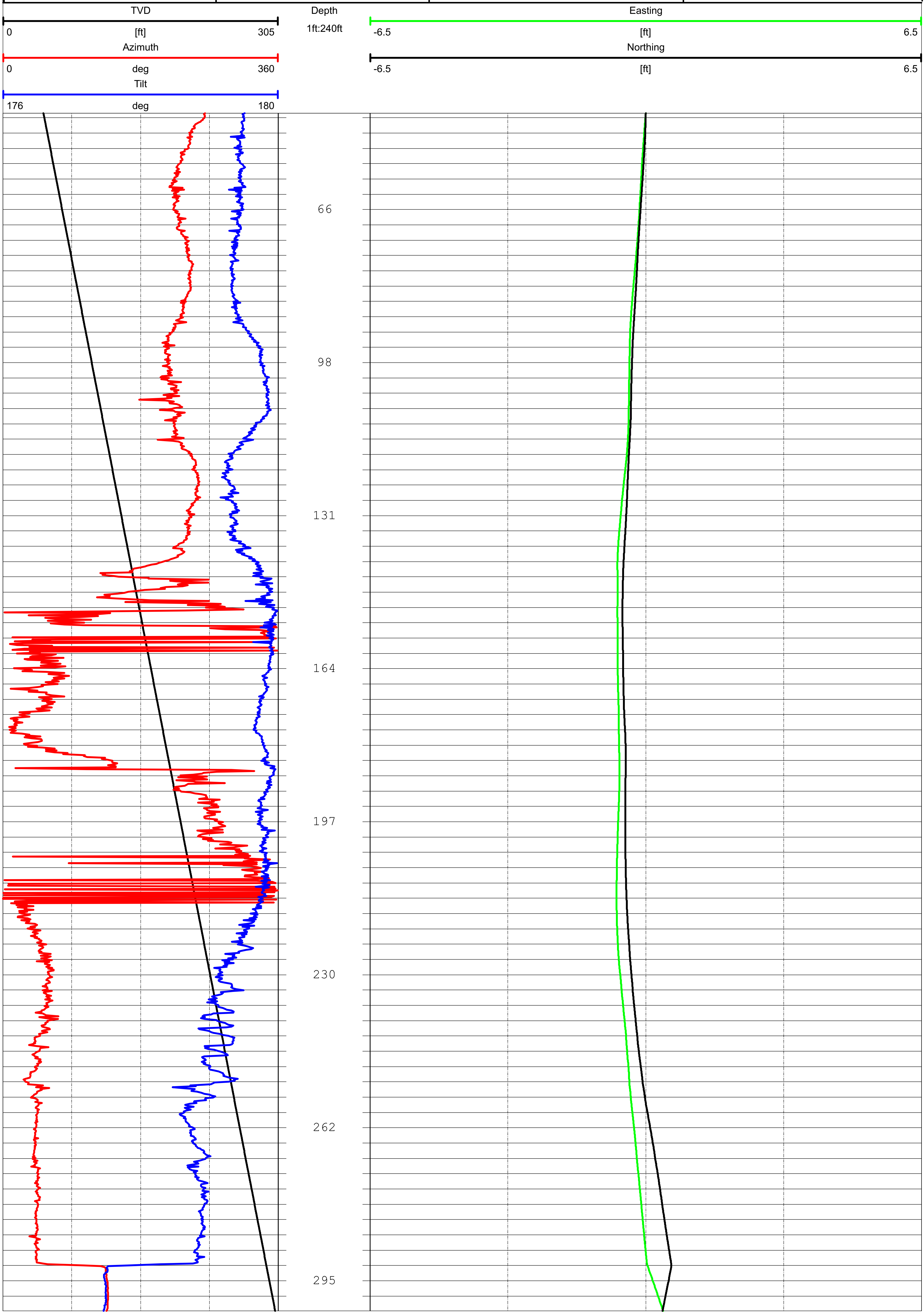
BLACKHAWK
A DIVISION OF ZAPATAENGINEERING
301 Commercial Rd, Ste B
Golden, CO 80401 USA
(303) 278-8700 www.blackhawkgeo.com

FIGURE:	C-13	BOREHOLE	XHT-NS #3
LOGGING DATE:	April 20, 2005	DRILL DATE:	April 19, 2005
PROJECT:	Geophysical Void Detection Demonstration	LOCATION:	Riola Mine Complex - BBCC Vermilion County, IL

CAPTION:
Tilt: Borehole Inclination
TVD: True Vertical Depth
Azimuth: Borehole Bearing
Northing: Borehole Northing
Easting: Borehole Easting



BLACKHAWK A DIVISION OF ZAPATA ENGINEERING 301 Commercial Rd, Ste B Golden, CO 80401 USA (303) 278-8700 www.blackhawkgeo.com	**Deviation Log** FIGURE: C-14 — BOREHOLE XHT-NS #4 LOGGING DATE: April 22, 2005 — DRILL DATE: April 20-21, 2005 PROJECT: Geophysical Void Detection Demonstration — LOCATION: Riola Mine Complex - BBCC Vermilion County, IL	CAPTION: Tilt: Borehole Inclination TVD: True Vertical Depth Azimuth: Borehole Bearing Northing: Borehole Northing Easting: Borehole Easting



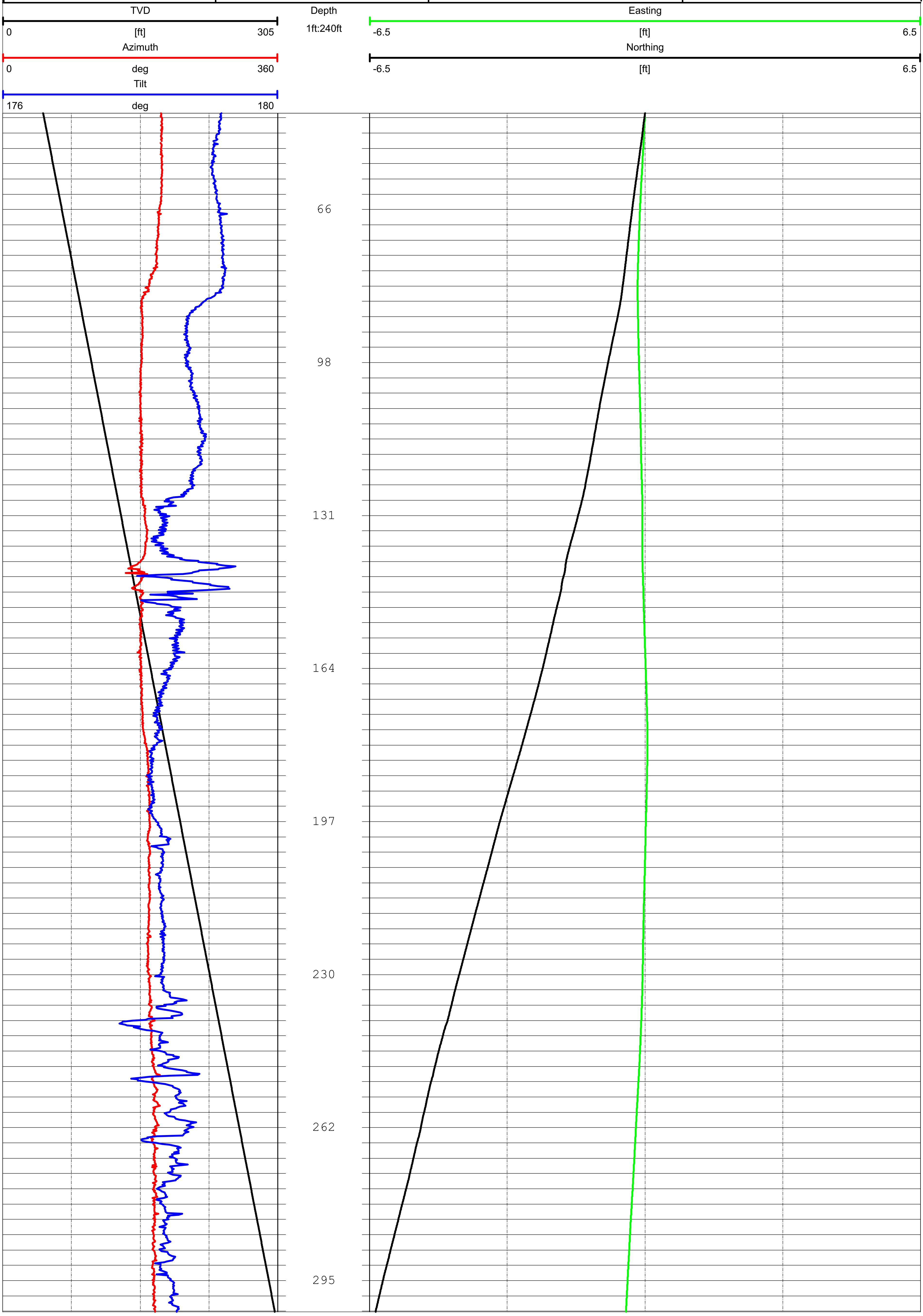
BLACKHAWK
A DIVISION OF
ZAPATAENGINEERING

301 Commercial Rd, Ste B
Golden, CO 80401 USA
(303) 278-8700 www.blackhawkgeo.com

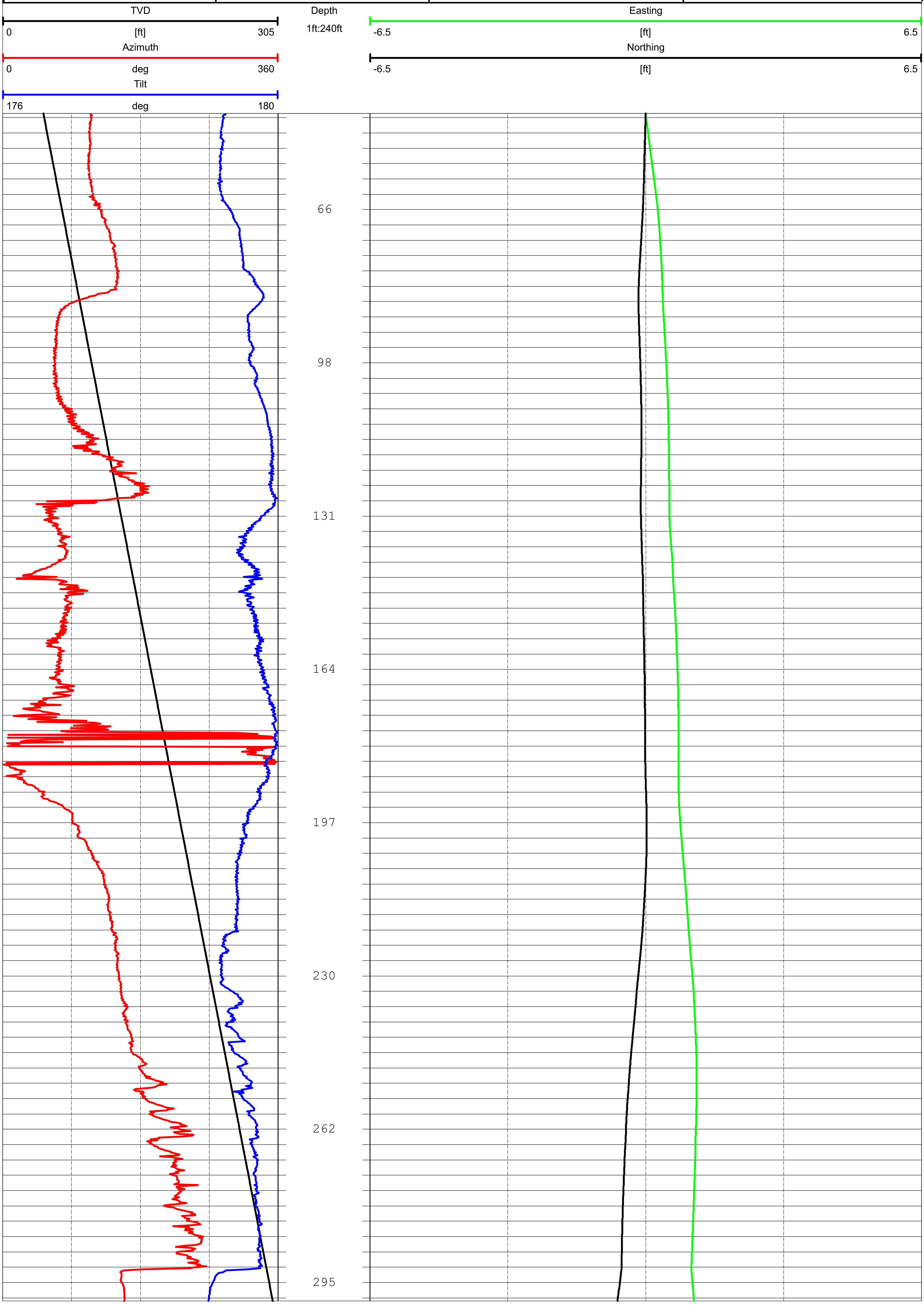
Deviation Log

FIGURE:	C-15	BOREHOLE	XHT-NS #5
LOGGING DATE:	April 20, 2005	DRILL DATE:	April 18-19, 2005
PROJECT:	Geophysical Void Detection Demonstration	LOCATION:	Riola Mine Complex - BBCC Vermilion County, IL

CAPTION:
Tilt: Borehole Inclination
TVD: True Vertical Depth
Azimuth: Borehole Bearing
Northing: Borehole Northing
Easting: Borehole Easting



BLACKHAWK A DIVISION OF ZAPATAENGINEERING	Deviation Log		CAPTION:
301 Commercial Rd, Ste B Golden, CO 80401 USA (303) 278-8700 www.blackhawkgeo.com	FIGURE: C-16	BOREHOLE XHT-NS #6	Tilt: Borehole Inclination TVD: True Vertical Depth Azimuth: Borehole Bearing Northing: Borehole Northing Easting: Borehole Easting
	LOGGING DATE: April 25, 2005	DRILL DATE: April 21-22, 2005	
	PROJECT: Geophysical Void Detection Demonstration	LOCATION: Riola Mine Complex - BBCC Vermilion County, IL	



APPENDIX D DRILL LOGS

TABLE OF CONTENTS

FIGURE D - 1 Magnum Drilling Services, Inc. Drill Log XHT-EW #1

MAGNUM DRILLING SERVICES INC
DRILL LOG

XHTEW1
20050502BG1
BLACKHAWK/RIOLA MINE

CORE			DRILLING			LITH. CODE NO.	BED	DESCRIPTION OF ROCK / NOTE	RIG # TH-55	
Run No.	Cut	Rec.	FEET FROM	TO	Thick				CORE GRAPH	CORE DESC.
				15.00	15.00	056.5		UNCONS clay w/gravel tan or buff		
			15.00	22.00	7.00	057.6		UNCONS silt w/gravel red or brown		
			22.00	24.00	2.00	057.3		UNCONS silt w/gravel med gray		
			24.00	27.00	3.00	058		UNCONS sand w/gravel - LARGE		
			27.00	30.00	3.00	057.3		UNCONS silt w/gravel med gray		
			30.00	37.00	7.00	530		SANDSTONE med gray		
			37.00	134.00	97.00	334		SANDY SHALE med gray		
			134.00	140.00	6.00	124		SHALE dark gray		
			140.00	143.70	3.70	020		**COAL**		
			143.70	150.00	6.30	331		SANDY CLAYSTONE med gray		
			150.00	165.50	15.50	530		SANDSTONE med gray		
			165.50	168.00	2.50	900		LIMESTONE		
			168.00	187.00	19.00	530		SANDSTONE med gray		
			187.00	189.00	2.00	638		SANDSTONE, LIMEY med gray w/nodules		
			189.00	231.00	42.00	334		SANDY SHALE med gray		
			231.00	233.00	2.00	136		SHALE med gray w/**COAL** strks		
			233.00	239.80	6.80	020		**COAL**		
			239.80	247.00	7.20	401		LIMEY SANDY CLAYSTONE		
			247.00	249.00	2.00	331		SANDY CLAYSTONE med gray		
			249.00	252.50	3.50	231		LIMEY CLAYSTONE med gray - NODULES		
			252.50	253.00	0.50	116		BLACK SHALE w/**COAL** strks		
			253.00	253.80	0.80	020		**COAL**		
			253.80	261.00	7.20	231		LIMEY CLAYSTONE med gray - NODULES		
			261.00	303.00	42.00	334		SANDY SHALE med gray		
			303.00	307.00	4.00	124		SHALE dark gray		
			307.00	311.00	4.00	214		BLACK LIMEY SHALE		
			311.00	320.00	9.00	334		SANDY SHALE med gray		
				320.00		TD		TOTAL DEPTH		

HYDROLOGICAL DATA : Depth of Water : 30.00'

DRILL HOLE DATA

DATE DRILLED		04-18-2005	
DATE COMPLETED		04-18-2005	
DRILLER	DANNY S	HELPER	JOEY
SURFACE ELEVATION			
TOTAL DEPTH		320.00'	
CORE SIZE			
CASING DEPTH		39.50'	
NUMBER OF CEMENT BAGS		32	

LOCATION

SECTION : TWNSHP : RANGE : QUAD :
COUNTY : VERMILION
STATE : IL
LANDOWNER :
MAP NUMBER :
PROJECT AREA : RIOLA MINE
DRILL HOLE : **XHTEW1**
SECTION HOLE# LEASE

NOTE:

Page 1 of 1

FIGURE D - 2 MAGNUM DRILLING SERVICES, INC. DRILL LOG XHT-EW #2

MAGNUM DRILLING SERVICES INC
DRILL LOG

XHTEW2
20050502BG1
BLACKHAWK/RIOLA MINE

RIG # TH-55

Run No.	CORE Cut	CORE Rec.	DRILLING FEET FROM	DRILLING FEET TO	DRILLING FEET Thick	LITH. CODE NO.	BED	DESCRIPTION OF ROCK / NOTE	CORE GRAPH	CORE DESC.
				12.00	12.00	052.5		UNCONS silty or sandy clay tan or buff		
			12.00	15.00	3.00	056.3		UNCONS clay w/gravel med gray		
			15.00	25.00	10.00	057.3		UNCONS silt w/gravel med gray		
			25.00	29.00	4.00	056.3		UNCONS clay w/gravel med gray - LARGE		
			29.00	40.00	11.00	530		SANDSTONE med gray - WEATHERED		
			40.00	128.00	88.00	334		SANDY SHALE med gray		
			128.00	133.00	5.00	124		SHALE dark gray		
			133.00	139.40	6.40	114		BLACK SHALE		
			139.40	143.00	3.60	020		**COAL**		
			143.00	144.00	1.00	137		UNDERCLAY med gray		
			144.00	154.00	10.00	331		SANDY CLAYSTONE med gray		
			154.00	163.00	9.00	530		SANDSTONE med gray		
			163.00	164.00	1.00	900		LIMESTONE		
			164.00	202.00	38.00	530		SANDSTONE med gray		
			202.00	237.00	35.00	333		SANDY SHALE med gray w/sandstone strks		
			237.00	242.50	5.50	020		**COAL**		
			242.50	244.00	1.50	137		UNDERCLAY med gray		
			244.00	253.00	9.00	231		LIMEY CLAYSTONE med gray - NODULES		
			253.00	253.90	0.90	020		**COAL**		
			253.90	263.00	9.10	331		SANDY CLAYSTONE med gray		
			263.00	310.00	47.00	334		SANDY SHALE med gray		
			310.00	312.00	2.00	214		BLACK LIMEY SHALE		
			312.00	320.00	8.00	334		SANDY SHALE med gray		
				320.00		TD		TOTAL DEPTH		

HYDROLOGICAL DATA : Depth of Water :

DRILL HOLE DATA

DATE DRILLED		04-20-2005	
DATE COMPLETED		04-20-2005	
DRILLER	DANNY S	HELPER	JOEY
SURFACE ELEVATION			
TOTAL DEPTH		320.00'	
CORE SIZE			
CASING DEPTH		38.00'	
NUMBER OF CEMENT BAGS		32	

LOCATION

SECTION : TWNSHP : RANGE : QUAD :
COUNTY : VERMILION
STATE : IL
LANDOWNER :
MAP NUMBER :
PROJECT AREA : RIOLA MINE
DRILL HOLE : XHTEW2
SECTION HOLE# LEASE

NOTE:

Page 1 of 1

FIGURE D - 3 MAGNUM DRILLING SERVICES, INC. DRILL LOG XHT-NS #3

MAGNUM DRILLING SERVICES INC
DRILL LOG

XHTNS3
20050502BG1
BLACKHAWK/RIOLA MINE

RIG # TH-55

Run No.	CORE Cut	CORE Rec.	DRILLING FEET FROM	DRILLING FEET TO	DRILLING FEET Thick	LITH. CODE NO.	BED	DESCRIPTION OF ROCK / NOTE	CORE GRAPH	CORE DESC.
				12.00	12.00	052.5		UNCONS silty or sandy clay tan or buff		
			12.00	16.00	4.00	056.3		UNCONS clay w/gravel med gray		
			16.00	26.00	10.00	057.3		UNCONS silt w/gravel med gray		
			26.00	29.00	3.00	056.3		UNCONS clay w/gravel med gray		
			29.00	47.00	18.00	530		SANDSTONE med gray - WEATHERED		
			47.00	48.00	1.00	900		LIMESTONE		
			48.00	133.00	85.00	334		SANDY SHALE med gray		
			133.00	135.00	2.00	124		SHALE dark gray		
			135.00	139.00	4.00	116		BLACK SHALE w/**COAL** strks		
			139.00	142.60	3.60	020		**COAL**		
			142.60	144.00	1.40	137		UNDERCLAY med gray		
			144.00	163.00	19.00	331		SANDY CLAYSTONE med gray		
			163.00	173.00	10.00	530		SANDSTONE med gray		
			173.00	181.00	8.00	331		SANDY CLAYSTONE med gray		
			181.00	193.00	12.00	530		SANDSTONE med gray		
			193.00	194.00	1.00	900		LIMESTONE		
			194.00	228.00	34.00	333		SANDY SHALE med gray w/sandstone strks		
			228.00	234.00	6.00	334		SANDY SHALE med gray		
			234.00	239.70	5.70	020		**COAL**		
			239.70	242.00	2.30	137		UNDERCLAY med gray		
			242.00	252.50	10.50	231		LIMEY CLAYSTONE med gray - NODULES		
			252.50	253.10	0.60	020		**COAL**		
			253.10	254.00	0.90	137		UNDERCLAY med gray		
			254.00	270.00	16.00	131		CLAYSTONE med gray		
			270.00	304.00	34.00	334		SANDY SHALE med gray		
			304.00	308.00	4.00	134		SHALE med gray		
			308.00	311.00	3.00	114		BLACK SHALE		
			311.00	320.00	9.00	334		SANDY SHALE med gray		
				320.00		TD		TOTAL DEPTH		

HYDROLOGICAL DATA : Depth of Water : 181.00'

DRILL HOLE DATA

DATE DRILLED		04-19-2005	
DATE COMPLETED		04-19-2005	
DRILLER	DANNY S	HELPER	JOEY
SURFACE ELEVATION			
TOTAL DEPTH		320.00'	
CORE SIZE			
CASING DEPTH		39.00'	
NUMBER OF CEMENT BAGS		32	

LOCATION

SECTION : TWNSHP : RANGE : QUAD :
COUNTY : VERMILION
STATE : IL
LANDOWNER :
MAP NUMBER :
PROJECT AREA : RIOLA MINE
DRILL HOLE : XHTNS3
SECTION HOLE# LEASE

NOTE:

Page 1 of 1

FIGURE D - 4 MAGNUM DRILLING SERVICES, INC. DRILL LOG XHT-NS #4

MAGNUM DRILLING SERVICES INC
DRILL LOG

XHTNS4
20050502BG1
BLACKHAWK/RIOLA MINE

RIG # TH-55

Run No.	CORE Cut	CORE Rec.	DRILLING FEET FROM	DRILLING FEET TO	DRILLING Thick	LITH. CODE NO.	BED	DESCRIPTION OF ROCK / NOTE	CORE GRAPH	CORE DESC.
				12.00	12.00	056.5		UNCONS clay w/gravel tan or buff		
			12.00	16.00	4.00	056.3		UNCONS clay w/gravel med gray		
			16.00	25.00	9.00	057.3		UNCONS silt w/gravel med gray		
			25.00	29.00	4.00	057.6		UNCONS silt w/gravel red or brown		
			29.00	43.00	14.00	530		SANDSTONE med gray - WEATHERED		
			43.00	134.00	91.00	334		SANDY SHALE med gray		
			134.00	138.00	4.00	124		SHALE dark gray		
			138.00	139.00	1.00	114		BLACK SHALE		
			139.00	142.40	3.40	020		**COAL**		
			142.40	143.00	0.60	137		UNDERCLAY med gray		
			143.00	160.00	17.00	331		SANDY CLAYSTONE med gray		
			160.00	179.00	19.00	334		SANDY SHALE med gray		
			179.00	204.00	25.00	533		SANDSTONE med gray w/shale strks		
			204.00	220.00	16.00	334		SANDY SHALE med gray		
			220.00	228.00	8.00	333		SANDY SHALE med gray w/sandstone strks		
			228.00	229.90	1.90	334		SANDY SHALE med gray		
			229.90	230.00	0.10	020		**COAL**		
			230.00	233.00	3.00	334		SANDY SHALE med gray		
			233.00	238.90	5.90	020		**COAL**		
			238.90	251.50	12.60	131		CLAYSTONE med gray		
			251.50	252.40	0.90	020		**COAL**		
			252.40	262.00	9.60	331		SANDY CLAYSTONE med gray		
			262.00	306.00	44.00	334		SANDY SHALE med gray		
			306.00	308.50	2.50	214		BLACK LIMEY SHALE		
			308.50	320.00	11.50	334		SANDY SHALE med gray		
				320.00		TD		TOTAL DEPTH		

HYDROLOGICAL DATA : Depth of Water :

DRILL HOLE DATA

DATE DRILLED		04-20-2005	
DATE COMPLETED		04-21-2005	
DRILLER	DANNY S	HELPER	JOEY
SURFACE ELEVATION			
TOTAL DEPTH		320.00'	
CORE SIZE			
CASING DEPTH		38.00'	
NUMBER OF CEMENT BAGS		32	

LOCATION

SECTION : TWNSHP : RANGE : QUAD :
COUNTY : VERMILION
STATE : IL
LANDOWNER :
MAP NUMBER :
PROJECT AREA : RIOLA MINE
DRILL HOLE : XHTNS4 (SECTION / HOLE# / LEASE)

NOTE:

Page 1 of 1

FIGURE D - 5 MAGNUM DRILLING SERVICES, INC. DRILL LOG XHT-NS #5

MAGNUM DRILLING SERVICES INC
DRILL LOG

XHTNS5
20050502BG1
BLACKHAWK/RIOLA MINE

Run No.	CORE Cut	CORE Rec.	DRILLING FEET FROM	DRILLING FEET TO	DRILLING FEET Thick	LITH. CODE NO.	BED	DESCRIPTION OF ROCK / NOTE	RIG # TH-55 CORE GRAPH	CORE DESC.
				13.00	13.00	056.5		UNCONS clay w/gravel tan or buff		
			13.00	16.00	3.00	056.3		UNCONS clay w/gravel med gray		
			16.00	24.00	8.00	057.3		UNCONS silt w/gravel med gray		
			24.00	28.00	4.00	057.6		UNCONS silt w/gravel red or brown		
			28.00	39.00	11.00	530		SANDSTONE med gray - WEATHERED		
			39.00	133.00	94.00	334		SANDY SHALE med gray		
			133.00	138.50	5.50	124		SHALE dark gray		
			138.50	141.60	3.10	020		**COAL**		
			141.60	142.00	0.40	137		UNDERCLAY med gray		
			142.00	155.00	13.00	131		CLAYSTONE med gray		
			155.00	175.00	20.00	331		SANDY CLAYSTONE med gray		
			175.00	203.00	28.00	530		SANDSTONE med gray		
			203.00	233.00	30.00	333		SANDY SHALE med gray w/sandstone strks		
			233.00	238.70	5.70	020		**COAL**		
			238.70	243.00	4.30	137		UNDERCLAY med gray		
			243.00	251.00	8.00	231		LIMEY CLAYSTONE med gray - NODULES		
			251.00	251.80	0.80	116		BLACK SHALE w/**COAL** strks		
			251.80	253.00	1.20	137		UNDERCLAY med gray		
			253.00	270.00	17.00	331		SANDY CLAYSTONE med gray		
			270.00	208.00	28.00	334		SANDY SHALE med gray		
			298.00	305.00	7.00	333		SANDY SHALE med gray w/sandstone strks		
			305.00	307.00	2.00	224		LIMEY SHALE dark gray		
			307.00	320.00	13.00	334		SANDY SHALE med gray		
				320.00		TD		TOTAL DEPTH		

HYDROLOGICAL DATA : Depth of Water :

DRILL HOLE DATA

DATE DRILLED		04-19-2005	
DATE COMPLETED		04-19-2005	
DRILLER	DANNY S	HELPER	JOEY
SURFACE ELEVATION			
TOTAL DEPTH		320.00'	
CORE SIZE			
CASING DEPTH		39.00'	
NUMBER OF CEMENT BAGS		32	
NOTE:			

LOCATION

SECTION : TWNSHP : RANGE : QUAD :
COUNTY : VERMILION
STATE : IL
LANDOWNER :
MAP NUMBER :
PROJECT AREA : RIOLA MINE
DRILL HOLE : XHTNS5
SECTION HOLE# LEASE

Page 1 of 1

FIGURE D - 6 MAGNUM DRILLING SERVICES, INC. DRILL LOG XHT-NS #6

MAGNUM DRILLING SERVICES INC
DRILL LOG

XHTNS6
20050502BG1
BLACKHAWK/RIOLA MINE

RIG # TH-55

CORE			DRILLING			LITH.				
Run No.	Cut	Rec.	FEET FROM	TO	Thick	CODE NO.	BED	DESCRIPTION OF ROCK / NOTE	CORE GRAPH	CORE DESC.
				12.00	12.00	056.5		UNCONS clay w/gravel tan or buff		
			12.00	15.00	3.00	056.3		UNCONS clay w/gravel med gray		
			15.00	24.00	9.00	057.3		UNCONS silt w/gravel med gray		
			24.00	28.00	4.00	056.3		UNCONS clay w/gravel med gray		
			28.00	50.00	22.00	530		SANDSTONE med gray - WEATHERED		
			50.00	132.00	82.00	334		SANDY SHALE med gray		
			132.00	139.00	7.00	124		SHALE dark gray		
			139.00	142.60	3.60	020		**COAL**		
			142.60	144.00	1.40	137		UNDERCLAY med gray		
			144.00	152.00	8.00	131		CLAYSTONE med gray		
			152.00	153.00	1.00	900		LIMESTONE		
			153.00	158.00	5.00	231		LIMEY CLAYSTONE med gray - NODULES		
			158.00	175.00	17.00	334		SANDY SHALE med gray		
			175.00	201.00	26.00	530		SANDSTONE med gray		
			201.00	232.50	31.50	333		SANDY SHALE med gray w/sandstone strks		
			232.50	238.30	5.80	020		**COAL**		
			238.30	252.00	13.70	131		CLAYSTONE med gray		
			252.00	252.90	0.90	020		**COAL**		
			252.90	260.00	7.10	331		SANDY CLAYSTONE med gray		
			260.00	306.00	46.00	334		SANDY SHALE med gray		
			306.00	308.00	2.00	210		BLACK LIMEY SHALE		
			308.00	320.00	12.00	334		SANDY SHALE med gray		
				320.00		TD		TOTAL DEPTH		

HYDROLOGICAL DATA : Depth of Water : 60.00'

DRILL HOLE DATA

DATE DRILLED		04-21-2005	
DATE COMPLETED		04-22-2005	
DRILLER	DANNY S	HELPER	JOEY
SURFACE ELEVATION			
TOTAL DEPTH		320.00'	
CORE SIZE			
CASING DEPTH		38.00'	
NUMBER OF CEMENT BAGS		32	

NOTE:

LOCATION

SECTION : TWNSHP : RANGE : QUAD :
COUNTY : VERMILION
STATE : IL
LANDOWNER :
MAP NUMBER :
PROJECT AREA : RIOLA MINE
DRILL HOLE : XHTNS6
SECTION HOLE# LEASE

Page 1 of 1

FIGURE D - 7 MAGNUM DRILLING SERVICES, INC. DRILL LOG CONF NS #1

MAGNUM DRILLING SERVICES INC
DRILL LOG

CONF.NS1
20050502BG1
BLACKHAWK/RIOLA MINE

RIG # TH-55

CORE Run No.	CORE Cut	CORE Rec.	DRILLING FEET FROM	DRILLING FEET TO	DRILLING FEET Thick	LITH. CODE NO.	BED	DESCRIPTION OF ROCK / NOTE	CORE GRAPH	CORE DESC.
				12.00	12.00	052.5		UNCONS silty or sandy clay tan or buff		
			12.00	15.00	3.00	056.3		UNCONS clay w/gravel med gray		
			15.00	24.00	9.00	057.3		UNCONS silt w/gravel med gray		
			24.00	28.00	4.00	056.3		UNCONS clay w/gravel med gray - LARGE		
			28.00	50.00	22.00	530		SANDSTONE med gray - WEATHERED		
			50.00	132.00	82.00	334		SANDY SHALE med gray		
			132.00	139.00	7.00	124		SHALE dark gray		
			139.00	142.60	3.60	020		**COAL**		
			142.60	144.00	1.40	137		UNDERCLAY med gray		
			144.00	152.00	8.00	131		CLAYSTONE med gray		
			152.00	153.00	1.00	900		LIMESTONE		
			153.00	158.00	5.00	231		LIMEY CLAYSTONE med gray - NODULES		
			158.00	175.00	17.00	334		SANDY SHALE med gray		
			175.00	201.00	26.00	530		SANDSTONE med gray		
			201.00	227.00	26.00	333		SANDY SHALE med gray w/sandstone strks		
			227.00	233.00	6.00	005		OLD WORKS-voids		
				233.00		TD		TOTAL DEPTH		

HYDROLOGICAL DATA : Depth of Water :

DRILL HOLE DATA

DATE DRILLED		04-21-2005	
DATE COMPLETED		04-21-2005	
DRILLER	DANNY S	HELPER	JOEY
SURFACE ELEVATION			
TOTAL DEPTH		233.00'	
CORE SIZE			
CASING DEPTH		38.00'	
NUMBER OF CEMENT BAGS		1 1/4 YARDS & PLUG	
NOTE:	MINE VOID PLUG		

LOCATION

SECTION : TWNSHP : RANGE : QUAD :
COUNTY : VERMILION
STATE : IL
LANDOWNER :
MAP NUMBER :
PROJECT AREA : RIOLA MINE
DRILL HOLE : CONF.NS1
SECTION HOLE# LEASE

Page 1 of 1

FIGURE D - 8 MAGNUM DRILLING SERVICES, INC. DRILL LOG CONF NS #2

MAGNUM DRILLING SERVICES INC
DRILL LOG

NS#2
20051010BG1
BLACKHAWK/RIOLA MINE

CORE			DRILLING			LITH. CODE NO.	BED	DESCRIPTION OF ROCK / NOTE	RIG # TH-55	
			FEET							
Run No.	Cut	Rec.	FROM	TO	Thick				CORE GRAPH	CORE DESC.
				7.00	7.00	052.5		UNCONS silty or sandy clay tan or buff		
			7.00	19.00	12.00	053.6		UNCONS silt red or brown		
			19.00	22.00	3.00	058		UNCONS sand w/gravel		
			22.00	33.00	11.00	057.6		UNCONS silt w/gravel red or brown		
			33.00	42.00	9.00	530		SANDSTONE med gray		
			42.00	77.00	35.00	334		SANDY SHALE med gray		
			77.00	81.00	4.00	530		SANDSTONE med gray		
			81.00	130.00	49.00	334		SANDY SHALE med gray		
			130.00	136.00	6.00	124		SHALE dark gray		
			136.00	139.00	3.00	134		SHALE med gray		
			139.00	140.00	1.00	020		**COAL**		
			140.00	140.90	0.90	116		BLACK SHALE w/**COAL** strks		
			140.90	141.40	0.50	020		**COAL**		
			141.40	152.00	10.60	131		CLAYSTONE med gray		
			152.00	154.00	2.00	331		SANDY CLAYSTONE med gray		
			154.00	160.00	6.00	530		SANDSTONE med gray		
			160.00	172.00	12.00	334		SANDY SHALE med gray		
			172.00	203.00	31.00	530		SANDSTONE med gray		
			203.00	213.00	10.00	333		SANDY SHALE med gray w/sandstone strks		
			213.00	230.00	17.00	323		SANDY SHALE dark gray w/sandstone strks		
			230.00	237.80	7.80	005		OLD WORKS-voids		
			237.80	238.00	0.20	131		CLAYSTONE med gray		
				238.00		TD		TOTAL DEPTH		

HYDROLOGICAL DATA : Depth of Water : 98.00'

DRILL HOLE DATA				LOCATION
DATE DRILLED	10-03-2005			SECTION : TWNSHP : RANGE : QUAD :
DATE COMPLETED	10-04-2005			COUNTY : VERMILION
DRILLER	WAYNE	HELPER	JOEY	STATE : IL
SURFACE ELEVATION				LANDOWNER : HOLLINGSWORTH
TOTAL DEPTH	238.00'			MAP NUMBER :
CORE SIZE				PROJECT AREA : RIOLA MINE
CASING DEPTH	40.00'			DRILL HOLE : NS#2 (SECTION / HOLE# / LEASE)
NUMBER OF CEMENT BAGS	20			
NOTE:				

Page 1 of 1

FIGURE D - 9 MAGNUM DRILLING SERVICES, INC. DRILL LOG CONF NS #3

MAGNUM DRILLING SERVICES INC
DRILL LOG

NS#3
20051010BG1
BLACKHAWK/RIOLA MINE

CORE			DRILLING			LITH. CODE NO.	BED		RIG # TH-55	
Run No.	Cut	Rec.	FEET FROM	TO	Thick			DESCRIPTION OF ROCK / NOTE	CORE GRAPH	CORE DESC.
				10.00	10.00	052.5		UNCONS silty or sandy clay tan or buff		
			10.00	20.00	10.00	056.5		UNCONS clay w/gravel tan or buff - SANDY		
			20.00	23.00	3.00	057.6		UNCONS silt w/gravel red or brown		
			23.00	32.00	9.00	057.3		UNCONS silt w/gravel med gray		
			32.00	47.00	15.00	530		SANDSTONE med gray		
			47.00	75.00	28.00	334		SANDY SHALE med gray		
			75.00	82.00	7.00	530		SANDSTONE med gray		
			82.00	130.00	48.00	334		SANDY SHALE med gray		
			130.00	136.00	6.00	124		SHALE dark gray		
			136.00	138.50	2.50	134		SHALE med gray		
			138.50	141.90	3.40	020		**COAL**		
			141.90	151.00	9.10	131		CLAYSTONE med gray		
			151.00	156.00	5.00	331		SANDY CLAYSTONE med gray		
			156.00	168.00	12.00	334		SANDY SHALE med gray		
			168.00	200.00	32.00	530		SANDSTONE med gray		
			200.00	218.00	18.00	333		SANDY SHALE med gray w/sandstone strks		
			218.00	220.00	2.00	323		SANDY SHALE dark gray w/sandstone strks		
			220.00	231.00	11.00	333		SANDY SHALE med gray w/sandstone strks		
			231.00	234.00	3.00	005		OLD WORKS-voids		
			234.00	238.00	4.00	005		OLD WORKS-voids - RESISTANCE		
			238.00	239.00	1.00	131		CLAYSTONE med gray		
				239.00		TD		TOTAL DEPTH		

HYDROLOGICAL DATA : Depth of Water : 98.00'

DRILL HOLE DATA			
DATE DRILLED		10-04-2005	
DATE COMPLETED		10-04-2005	
DRILLER	WAYNE	HELPER	JOEY
SURFACE ELEVATION			
TOTAL DEPTH		239.00'	
CORE SIZE			
CASING DEPTH		41.00'	
NUMBER OF CEMENT BAGS		20	

LOCATION

SECTION : TWNSHP : RANGE : QUAD :
COUNTY : VERMILION
STATE : IL
LANDOWNER : HOLLINGSWORTH
MAP NUMBER :
PROJECT AREA : RIOLA MINE
DRILL HOLE : SECTION NS#3 HOLE# LEASE

NOTE:

Page 1 of 1

FIGURE D - 10 MAGNUM DRILLING SERVICES, INC. DRILL LOG CONF NS #4

MAGNUM DRILLING SERVICES INC
DRILL LOG

NS#4
20051010BG1
BLACKHAWK/RIOLA MINE

RIG # TH-55

CORE			DRILLING			LITH. CODE NO.	BED	DESCRIPTION OF ROCK / NOTE	CORE GRAPH	CORE DESC.
Run No.	Cut	Rec.	FEET FROM	TO	Thick					
				12.00	12.00	052.5		UNCONS silty or sandy clay tan or buff		
			12.00	14.00	2.00	058		UNCONS sand w/gravel		
			14.00	20.00	6.00	057.6		UNCONS silt w/gravel red or brown		
			20.00	32.00	12.00	057.3		UNCONS silt w/gravel med gray		
			32.00	51.00	19.00	530		SANDSTONE med gray		
			51.00	73.00	22.00	334		SANDY SHALE med gray		
			73.00	78.00	5.00	530		SANDSTONE med gray		
			78.00	118.00	40.00	334		SANDY SHALE med gray		
			118.00	137.00	19.00	124		SHALE dark gray		
			137.00	140.50	3.50	020		**COAL**		
			140.50	150.00	9.50	131		CLAYSTONE med gray		
			150.00	150.50	0.50	331		SANDY CLAYSTONE med gray		
			150.50	152.00	1.50	900		LIMESTONE		
			152.00	176.00	24.00	231		LIMEY CLAYSTONE med gray		
			176.00	200.00	24.00	530		SANDSTONE med gray		
			200.00	228.50	28.50	333		SANDY SHALE med gray w/sandstone strks		
			228.50	235.80	7.30	005		OLD WORKS-voids		
			235.80	236.00	0.20	131		CLAYSTONE med gray		
				236.00		TD		TOTAL DEPTH		

HYDROLOGICAL DATA : Depth of Water :

DRILL HOLE DATA			
DATE DRILLED		10-04-2005	
DATE COMPLETED		10-05-2005	
DRILLER	WAYNE	HELPER	JOEY
SURFACE ELEVATION			
TOTAL DEPTH		236.00'	
CORE SIZE			
CASING DEPTH		41.00'	
NUMBER OF CEMENT BAGS		20	

LOCATION	
SECTION :	TWNSHP : RANGE : QUAD :
COUNTY :	VERMILION
STATE :	IL
LANDOWNER :	HOLLINGSWORTH
MAP NUMBER :	
PROJECT AREA :	RIOLA MINE
DRILL HOLE :	SECTION: — HOLE#: NS#4 LEASE: —

NOTE:

Page 1 of 1

FIGURE D - 11 MAGNUM DRILLING SERVICES, INC. DRILL LOG CONF EW #1

MAGNUM DRILLING SERVICES INC
DRILL LOG

EW#1
20051010BG1
BLACKHAWK/RIOLA MINE

RIG # TH-55

Run No.	CORE Cut	CORE Rec.	DRILLING FEET FROM	DRILLING FEET TO	DRILLING FEET Thick	LITH. CODE NO.	BED	DESCRIPTION OF ROCK / NOTE	CORE GRAPH	CORE DESC.
				6.00	6.00	052.5		UNCONS silty or sandy clay tan or buff		
			6.00	21.00	15.00	056.5		UNCONS clay w/gravel tan or buff - SANDY		
			21.00	23.00	2.00	057.6		UNCONS silt w/gravel red or brown		
			23.00	28.00	5.00	057.3		UNCONS silt w/gravel med gray		
			28.00	31.00	3.00	530		SANDSTONE med gray - WEATHERED		
			31.00	40.00	9.00	134		SHALE med gray		
			40.00	80.00	40.00	334		SANDY SHALE med gray		
			80.00	85.00	5.00	530		SANDSTONE med gray		
			85.00	131.00	46.00	334		SANDY SHALE med gray		
			131.00	133.00	2.00	124		SHALE dark gray		
			133.00	137.70	4.70	114		BLACK SHALE		
			137.70	141.10	3.40	020		**COAL**		
			141.10	143.00	1.90	131		CLAYSTONE med gray		
			143.00	163.00	20.00	530		SANDSTONE med gray		
			163.00	163.50	0.50	900		LIMESTONE		
			163.50	165.00	1.50	331		SANDY CLAYSTONE med gray		
			165.00	170.50	5.50	530		SANDSTONE med gray		
			170.50	173.00	2.50	900		LIMESTONE		
			173.00	179.00	6.00	530		SANDSTONE med gray		
			179.00	180.00	1.00	900		LIMESTONE		
			180.00	203.00	23.00	530		SANDSTONE med gray		
			203.00	205.00	2.00	334		SANDY SHALE med gray		
			205.00	236.50	31.50	333		SANDY SHALE med gray w/sandstone strks		
			236.50	241.50	5.00	020		**COAL**		
			241.50	245.00	3.50	131		CLAYSTONE med gray		
				245.00		TD		TOTAL DEPTH		

HYDROLOGICAL DATA : Depth of Water :

DRILL HOLE DATA			
DATE DRILLED		10-05-2005	
DATE COMPLETED		10-06-2005	
DRILLER	DANNY S	HELPER	JOEY
SURFACE ELEVATION			
TOTAL DEPTH		245.00'	
CORE SIZE			
CASING DEPTH		32.00'	
NUMBER OF CEMENT BAGS		22	

LOCATION

SECTION : TWNSHP : RANGE : QUAD :
COUNTY : VERMILION
STATE : IL
LANDOWNER : HOLLINGSWORTH
MAP NUMBER :
PROJECT AREA : RIOLA MINE
DRILL HOLE : EW#1
SECTION HOLE# LEASE

NOTE:

Page 1 of 1

FIGURE D - 12 MAGNUM DRILLING SERVICES, INC. DRILL LOG CONF EW #2

MAGNUM DRILLING SERVICES INC
DRILL LOG

EW#2
20051010BG1
BLACKHAWK/RIOLA MINE

RIG # TH-55

CORE			DRILLING			LITH.				
Run No.	Cut	Rec.	FEET FROM	TO	Thick	CODE NO.	BED	DESCRIPTION OF ROCK / NOTE	CORE GRAPH	CORE DESC.
				6.00	6.00	052.5		UNCONS silty or sandy clay tan or buff		
			6.00	21.00	15.00	056.5		UNCONS clay w/gravel tan or buff - SANDY		
			21.00	23.00	2.00	057.6		UNCONS silt w/gravel red or brown		
			23.00	28.00	5.00	057.3		UNCONS silt w/gravel med gray		
			28.00	31.00	3.00	530		SANDSTONE med gray - WEATHERED		
			31.00	38.00	7.00	134		SHALE med gray		
			38.00	41.00	3.00	530		SANDSTONE med gray		
			41.00	47.00	6.00	334		SANDY SHALE med gray		
			47.00	56.00	9.00	331		SANDY CLAYSTONE med gray		
			56.00	131.00	75.00	334		SANDY SHALE med gray		
			131.00	135.00	4.00	124		SHALE dark gray		
			135.00	137.00	2.00	134		SHALE med gray		
			137.00	137.50	0.50	114		BLACK SHALE		
			137.50	141.10	3.60	020		**COAL**		
			141.10	147.00	5.90	131		CLAYSTONE med gray		
			147.00	160.50	13.50	530		SANDSTONE med gray		
			160.50	164.00	3.50	900		LIMESTONE		
			164.00	168.00	4.00	530		SANDSTONE med gray		
			168.00	172.00	4.00	630		SANDSTONE, LIMEY med gray		
			172.00	202.00	30.00	530		SANDSTONE med gray		
			202.00	230.00	28.00	333		SANDY SHALE med gray w/sandstone strks		
			230.00	236.00	6.00	005		OLD WORKS-voids		
			236.00	237.00	1.00	005		OLD WORKS-voids - RUBBLE		
				237.00		TD		TOTAL DEPTH		

HYDROLOGICAL DATA : Depth of Water :

DRILL HOLE DATA			
DATE DRILLED		10-06-2005	
DATE COMPLETED		10-06-2005	
DRILLER	DANNY S	HELPER	JOEY
SURFACE ELEVATION			
TOTAL DEPTH		237.00'	
CORE SIZE			
CASING DEPTH		32.00'	
NUMBER OF CEMENT BAGS		20	

LOCATION

SECTION : TWNSHP : RANGE : QUAD :
COUNTY : VERMILION
STATE : IL
LANDOWNER : HOLLINGSWORTH
MAP NUMBER :
PROJECT AREA : RIOLA MINE
DRILL HOLE : EW#2
SECTION HOLE# LEASE

NOTE:

Page 1 of 1

APPENDIX E SONAR LOGS

TABLE OF CONTENTS

FIGURE E - 1 ORTHOGRAPHIC PLOT OF BOREHOLES CONF NS #2, #3, AND #4

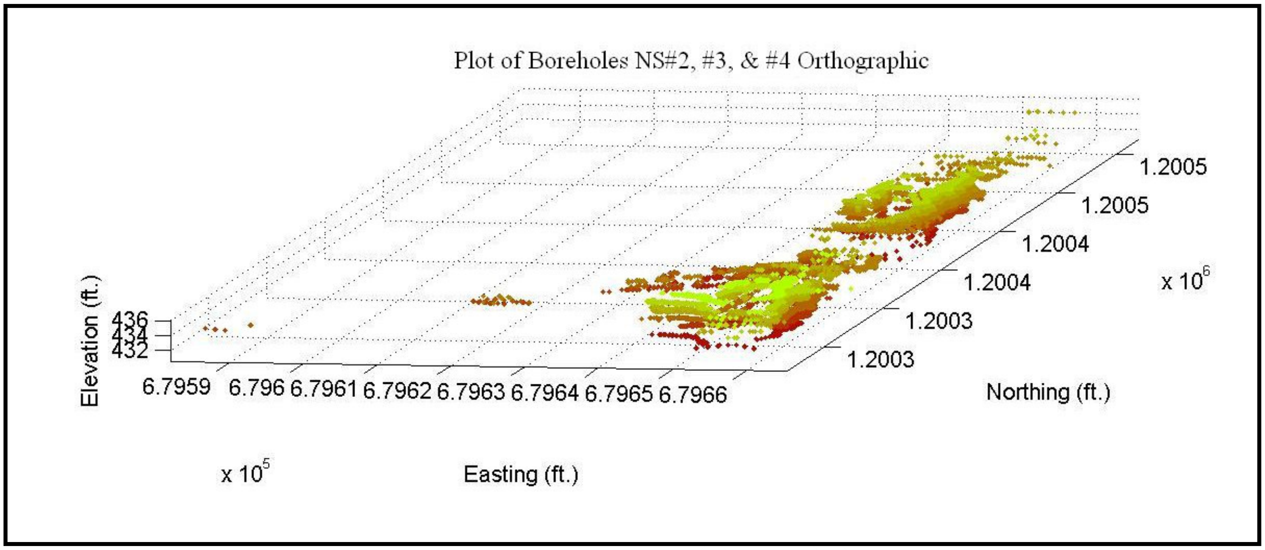


FIGURE E - 2 REFERENCE PLOT OF BOREHOLES CONF NS #2, #3, AND #4

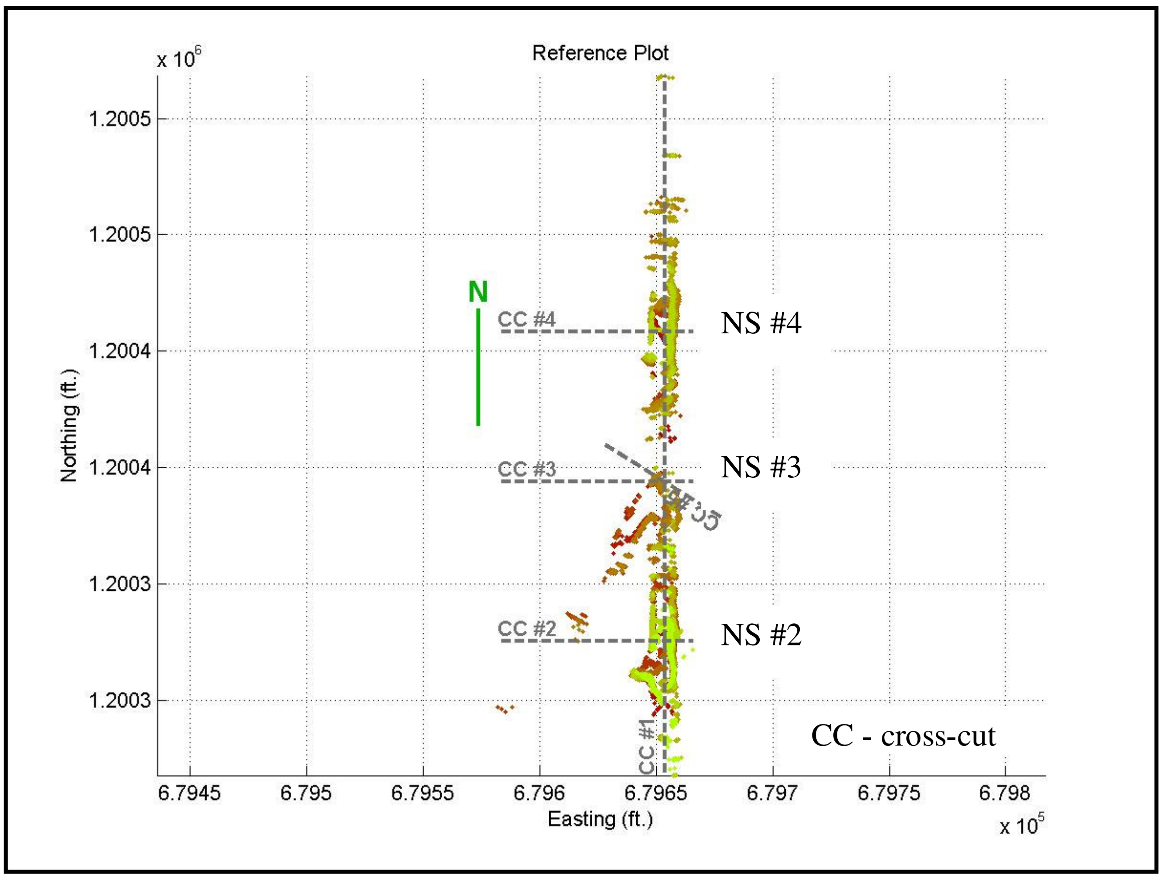


FIGURE E - 3 MODEL 1 OF BOREHOLES CONF NS #2, #3, AND #4

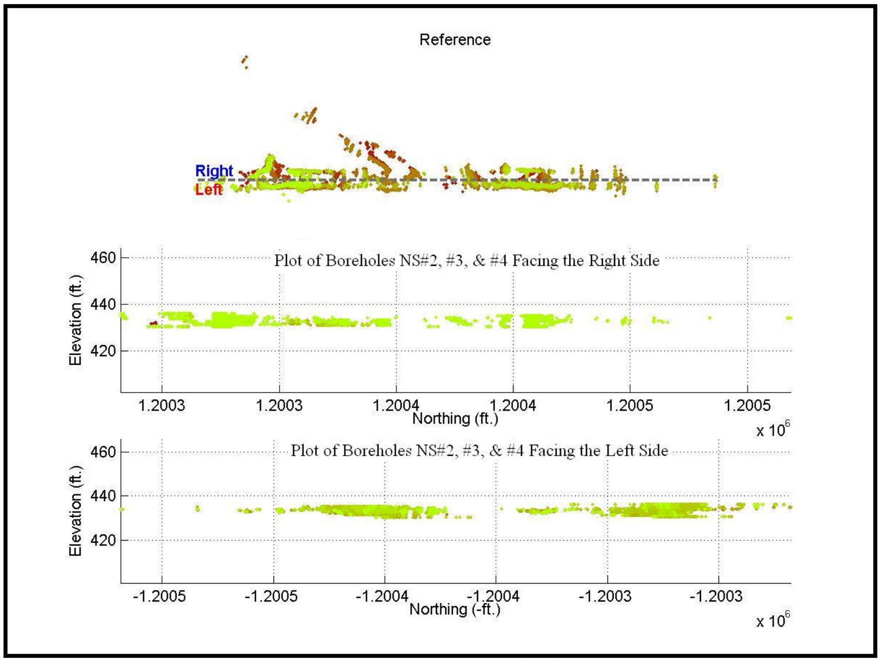


FIGURE E - 4 MODEL 2 OF BOREHOLES CONF NS #2, #3, AND #4

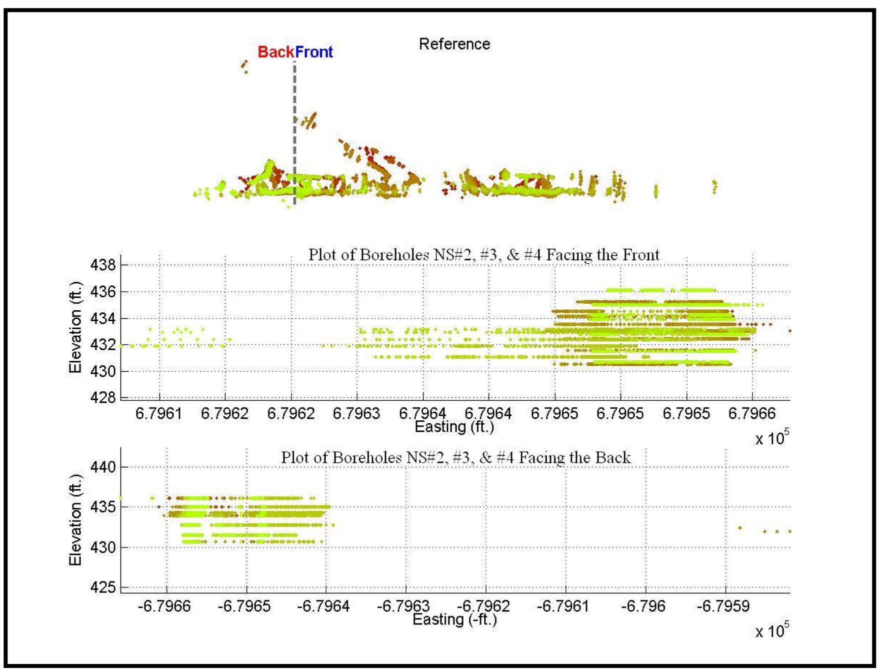


FIGURE E - 5 MODEL 3 OF BOREHOLES CONF NS #2, #3, AND #4

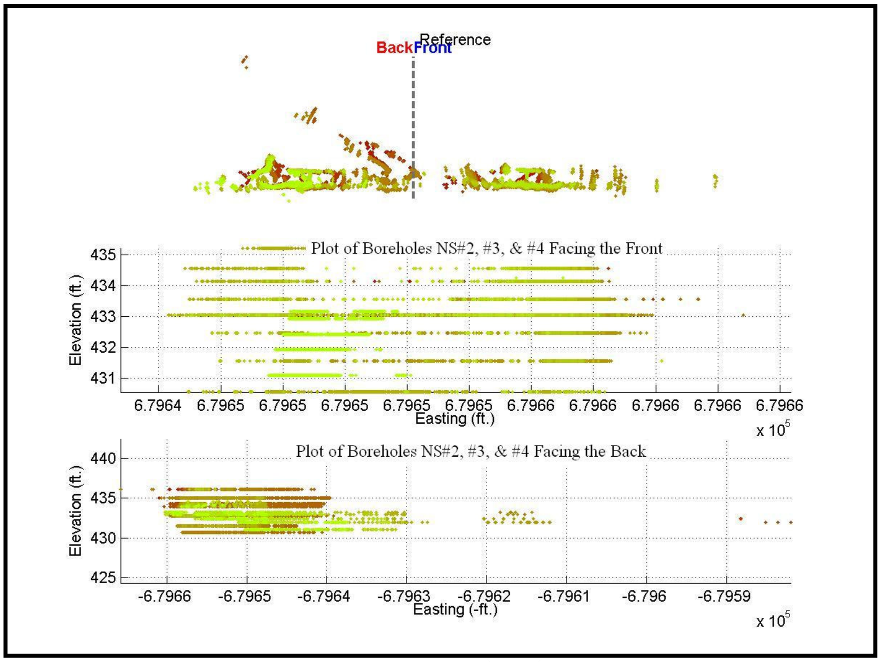


FIGURE E - 6 MODEL 4 OF BOREHOLES CONF NS #2, #3, AND #4

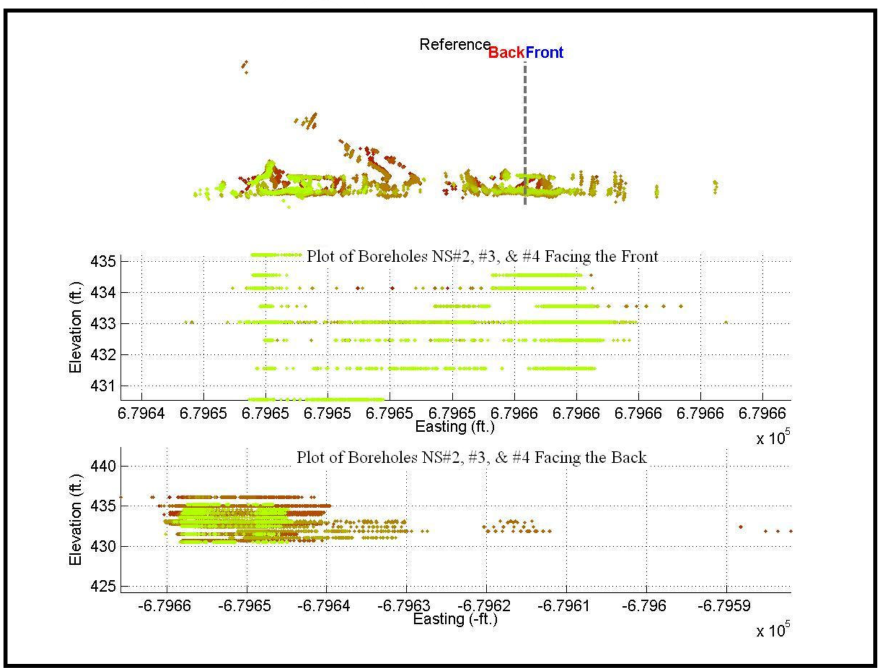


FIGURE E - 7 MODEL 5 OF BOREHOLES CONF NS #2, #3, AND #4

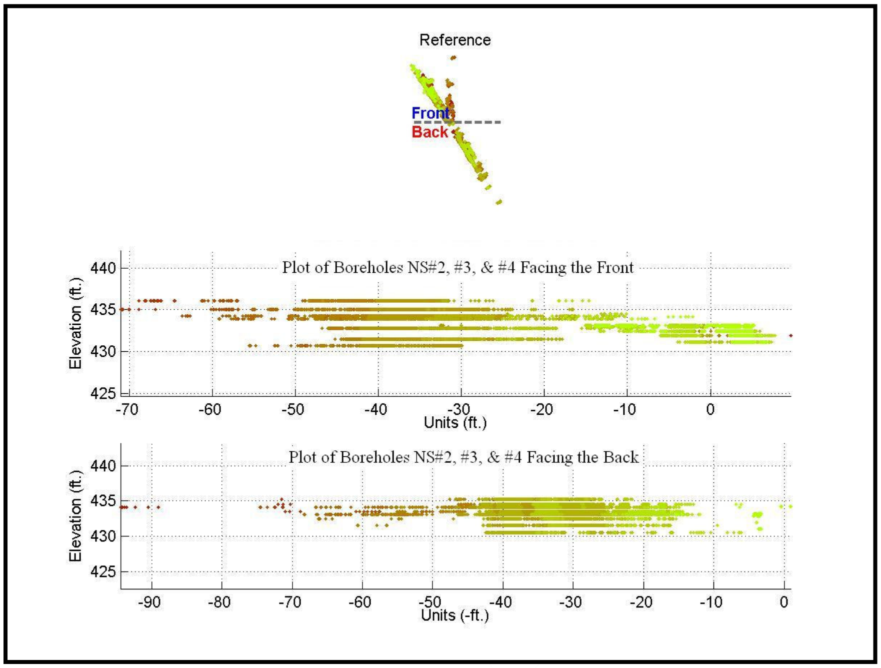


FIGURE E - 8 ORTHOGRAPHIC PLOT OF BOREHOLE CONF EW #2

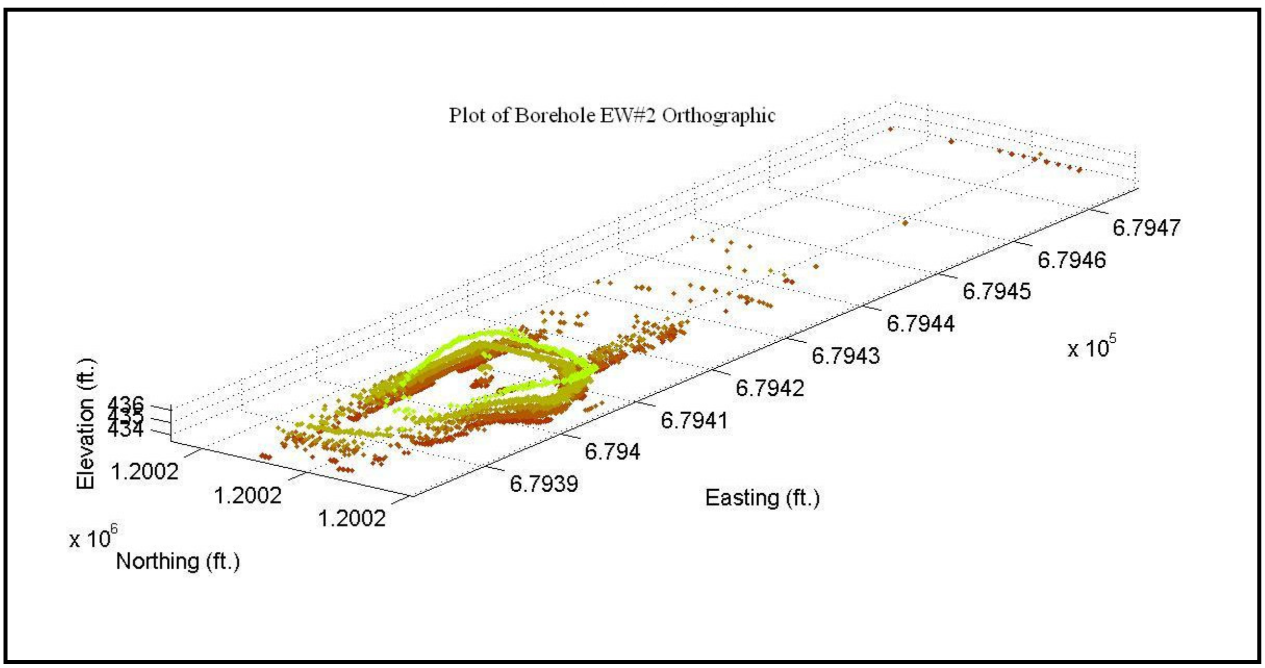


FIGURE E - 9 REFERENCE PLOT OF BOREHOLE CONF EW #2

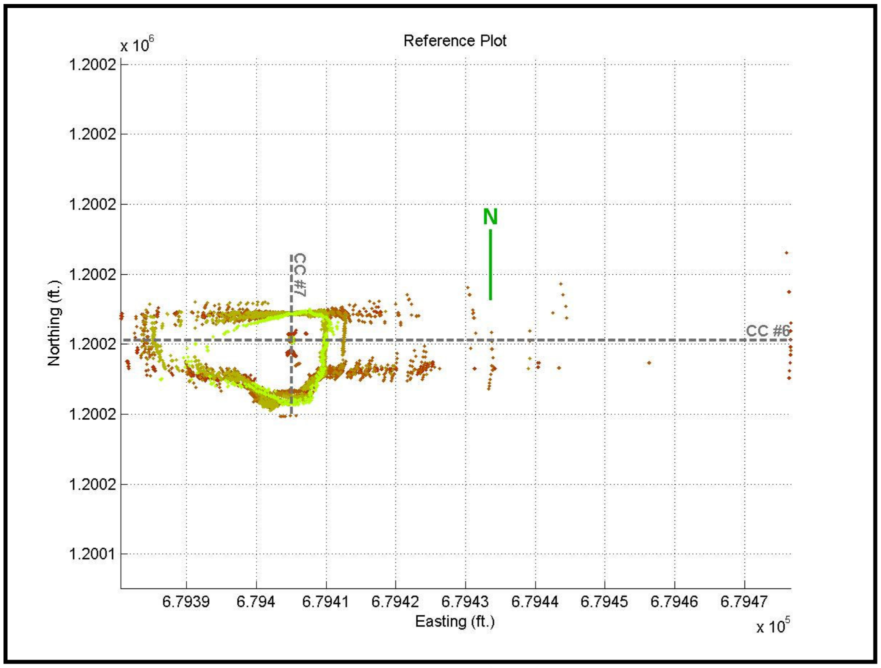


FIGURE E - 10 MODEL 1 OF BOREHOLE CONF EW #2

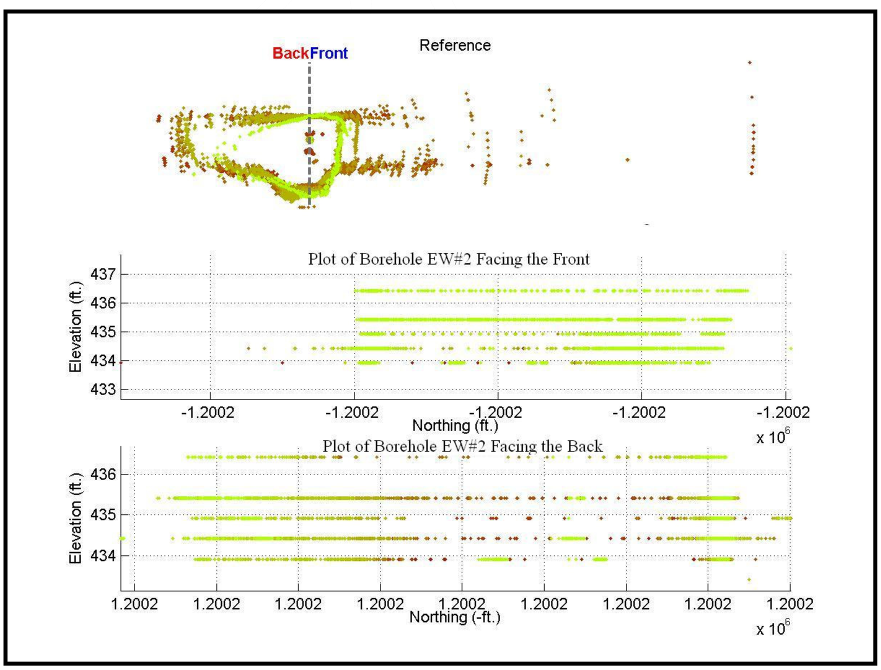
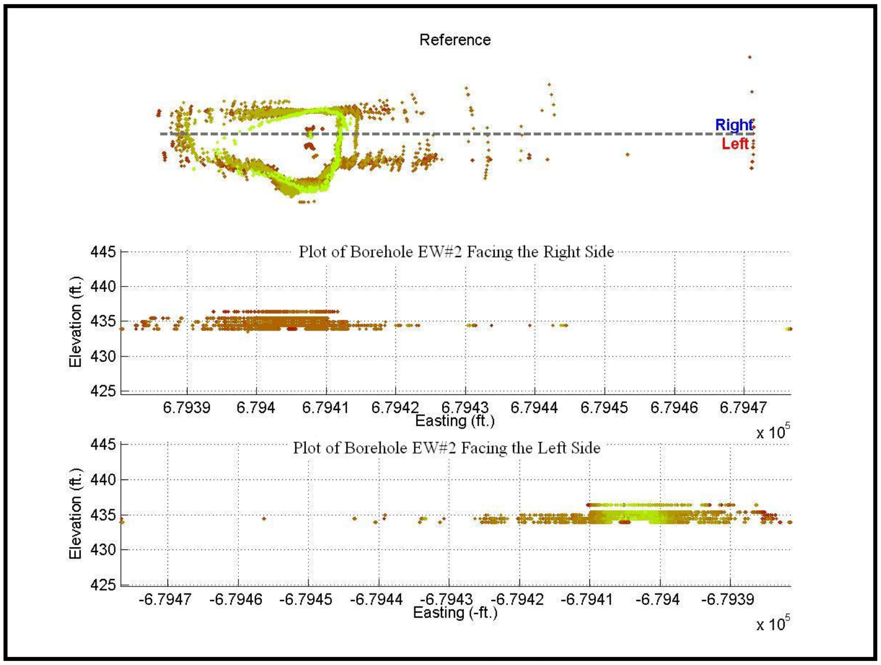


FIGURE E - 11 MODEL 2 OF BOREHOLE CONF EW #2



APPENDIX F DAILY FIELD LOGS

TABLE OF CONTENTS

FIGURE F - 1 HRS FIELD LOG FOR 11/13/04

Bay Geophysical

a division of Blackhawk GeoServices
868 Robinwood Ct. Traverse City, MI 49686
Tel: (231) 941-7660 Fax: (231) 941-7412

DATE: 11/13/04
Contract No:
SHEET______1_____ OF __1_____

FIELD ACTIVITY DAILY LOG

Project Name: MSHA Geophysical Void Detection, Georgetown, IL	Project No.: 4906BLA
Field Activity Subject: HRSW and HRPW Seismic Surveys	
Description of Daily Activities and Events: 0700 Meet in lobby with crew, discuss briefly plan of events over next two days, testing and grid setup, emergency number locator list. 0830 At site. Begin placing receiver pin flags over entire site previously established by others (surveyors), lay out two test spreads, one P-wave and one S-wave. 1300 P-wave tests completed, receiver pin flag layout completed. Begin laying Vib source point pin flags. Dick Reisinger arrives to pick up signed landowner permits. 1730 Finish S-wave test with one vib only. Will test two vibs tomorrow over same set up. Vib source points (pin flags) laid out to Line 24.	
Visitors on Site: Dick Reisinger	Changes from Plans and Specifications, and other special orders and important decisions:
Weather Conditions: Cool, sunny and breezy, 45 deg.	Important Telephone calls
Personnel on Site: John Clark (JCC), Phil Van Hollebeke (PAV), Jim Mattison (JAM), Steve Jones (SRJ), Matt Riopelle (MR), Regen Paul (RP) and Felix Harowski (FH)	
Field Engineer: PAV	

Bay Geophysical

a division of Blackhawk GeoServices
868 Robinwood Ct. Traverse City, MI 49686
Tel: (231) 941-7660 Fax: (231) 941-7412

DATE: 11/13/04
Contract No:
SHEET 1 OF 1

FIELD ACTIVITY DAILY LOG

Project Name: MSHA Geophysical Void Detection, Georgetown, IL	Project No.: 4906BLA
Field Activity Subject: HRSW and HRPW Seismic Surveys	
Description of Daily Activities and Events: 0630 Leave hotel, arrive field by 700am. Pick up P-wave phones and layout all S-wave phones to station 55 all lines. 0900 Testing both vibrators and a source array to attenuate spatial aliasing. 1100 Decision made to do A and B locations at each source location to combat aliasing. Testing line hookups for correct input locations. 1230 First production record. Check records, inputs Line 6 reversed, fixed. Restart and noticed the new cables ordered for this job are reverse polarity to the old ones. Weather too good to re-lay cables. Will mark in OBs which cables are reverse polarity, this will then be rendered during processing. Subsequence cable layouts will combine new cables only on receiver lines and old cables on rest of lines. Polarity must always be noted on the OB spreadsheet. 1530 Stan Buyno, individual who leases? Property wants to plow corn field on Thursday. PAV will contact mine landman to resolve issue. 1700 Last VP for the day. 74 Vps total. 1730 Leave site.	
Visitors on Site:	Changes from Plans and Specifications, and other special orders and important decisions:
Weather Conditions: Cool, sunny and some wind, 45 deg.	Important Telephone calls: Called Lee Kurtzweil of progress thus far.
Personnel on Site: John Clark (JCC), Phil Van Hollebeke (PAV), Jim Mattison (JAM), Steve Jones (SRJ), Matt Riopelle (MR), Regen Paul (RP) and Felix Harowski (FH)	
Field Engineer: PAV	

FIGURE F - 2 HRS FIELD LOG FOR 11/14/04

Bay Geophysical

a division of Blackhawk GeoServices
868 Robinwood Ct. Traverse City, MI 49686
Tel: (231) 941-7660 Fax: (231) 941-7412

DATE: 11/14/04
Contract No:
SHEET 1 OF 1

FIELD ACTIVITY DAILY LOG

Project Name: MSHA Geophysical Void Detection, Georgetown, IL	Project No.: 4906BLA
Field Activity Subject: HRSW and HRPW Seismic Surveys	

Description of Daily Activities and Events:

0630 Leave hotel, arrive field by 700am. Hookup jumpers, etc.
0730 First VP receiver Line 3, 102.5, VP78
0800 Slave Seisnet losing threads, keep restarting flow, no loss of data.
0830 Slave trailer loses Lambda, 12V drop, DAS reboots. Reset Lambda. 12V system OK. Seisnet still losing threads.
0910 Seisnet finally running properly, moved yesterday's files into a different folder during production. Missed two triggers from master doghouse, made up at end of VP. No more missed triggers rest of day.
1145 Called Dick Watkins regarding field plowing.
1335 Tried 2 sweeps over two positions (2x2) and compared to current production (3x2 sweeps). Data quality slightly better with current production 3x2 sweeps. Keeping 3x2 sweeps.
1700 Last VP for the day, VP375. 298 Vps total. Begin to roll tomorrow during production. Add 6 more jumpers and start swinging wire.
1700 Leave site.

Visitors on Site:	Changes from Plans and Specifications, and other special orders and important decisions:
Weather Conditions: Warmer, sunny and little wind, 55 deg.	Important Telephone calls: Called Dick Watkins (landman for Peabody) regarding landowner/land tenant of plowing intentions on 11/18/04.

Personnel on Site: Phil Van Hollebeke (PAV), Jim Mattison (JAM), Steve Jones (SRJ), Matt Riopelle (MR), Regen Paul (RP) and Felix Harowski (FH)

Field Engineer: PAV

FIGURE F - 3 HRS FIELD LOG FOR 11/16/04

Bay Geophysical

a division of Blackhawk GeoServices
868 Robinwood Ct. Traverse City, MI 49686
Tel: (231) 941-7660 Fax: (231) 941-7412

DATE: 11/16/04
Contract No:
SHEET 1 OF 1

FIELD ACTIVITY DAILY LOG

Project Name: MSHA Geophysical Void Detection, Georgetown, IL	Project No.: 4906BLA
Field Activity Subject: HRSW and HRPW Seismic Surveys	
Description of Daily Activities and Events: 0630 Leave hotel, arrive field by 700am. Hookup jumpers, etc. Light rain last night with some moisture on ground. 0833 First VP of the day, 574. 1030 Move phones. 1045 Lee Kurtzweil arrives. 1102 Wire broke on Vib #1 harness, repairing. 1130 Wire repaired. Continue data acquisition. 1528 Last VP today 735, 162 total VPs. Move wire to east side of fence. Approximately 12 Vps required on west side of fence left for S-wave survey. Moving recorders to east side of fence tomorrow.	
Visitors on Site:	Changes from Plans and Specifications, and other special orders and important decisions:
Weather Conditions: Cloudy, morning drizzle, 55 deg.	Important Telephone calls:
Personnel on Site: PAV, JAM SJ, MR, RP, FH and Lee Kurtzweil (LRK)	
Field Engineer: PAV	

FIGURE F - 4 HRS FIELD LOG FOR 11/18/04

Bay Geophysical

a division of Blackhawk GeoServices
868 Robinwood Ct. Traverse City, MI 49686
Tel: (231) 941-7660 Fax: (231) 941-7412

DATE: 11/18/04
Contract No:
SHEET 1 OF 1

FIELD ACTIVITY DAILY LOG

Project Name: MSHA Geophysical Void Detection, Georgetown, IL	Project No.: 5906BLA
Field Activity Subject: HRSW and HRPW Seismic Surveys	
Description of Daily Activities and Events: 0630 Leave hotel, arrive field by 700am. 0800 Start data acquisition, S-wave, VP 966. 0935 Move geophones to front. 1015 Resume acquisition. 1205 Move geophones and cable to front, move jumpers. 1323 Resume acquisition. 1625 End data acquisition for today. Last VP 1197. 232 total VPs today. PV and JAM stay to backup data and repair pulled wire. Crew leaves. 2130 Back at hotel.	
Visitors on Site: Dick Reisinger	Changes from Plans and Specifications, and other special orders and important decisions:
Weather Conditions: Partly cloudy warms to 65 deg. Then rain.	Important Telephone calls: Call John Clark re: P- wave parameters
Personnel on Site: PAV, JAM, SJ, MR, RP, FH, Kanaan Hanna	
Field Engineer: PAV	

From: Phil Van Hollebeke [pvanh@baygeo.com]
Sent: Thursday, November 18, 2004 8:51 PM
To: Lee Kurtzweil/Bay; Kanaan Hanna
Subject: Daily

Today's progress. Should finish tomorrow, weather dependent. It started raining around 3:30 this afternoon. Supposed to rain all night and half the day tomorrow, we'll see. JC did not send P parameters as of 945pm today. Looks like me may have time anyway.

Phil Van Hollebeke
Bay Geophysical
a division of Blackhawk GeoServices

FIGURE F - 5 HRS FIELD LOG FOR 11/19/04

Bay Geophysical

a division of Blackhawk GeoServices
868 Robinwood Ct. Traverse City, MI 49686
Tel: (231) 941-7660 Fax: (231) 941-7412

DATE: 11/19/04
Contract No:
SHEET______1_____ OF ___1______

FIELD ACTIVITY DAILY LOG

Project Name: MSHA Geophysical Void Detection, Georgetown, IL	Project No.: 5906BLA
Field Activity Subject: HRSW and HRPW Seismic Surveys	
Description of Daily Activities and Events: 0630 Leave hotel, arrive field by 700am. Heavy rain, off and on. Decide to wait it out back at hotel. Will try again this afternoon. 1330 Still raining. Call for a day. Resume acquisition tomorrow. 1800 Still raining.	
Visitors on Site:	Changes from Plans and Specifications, and other special orders and important decisions:
Weather Conditions: Rain 55 deg.	Important Telephone calls: Talked with John Clark re: P- wave parameters
Personnel on Site: PAV, JAM, SJ, MR, RP, FH, RG	
Field Engineer: PAV	

FIGURE F - 6 HRS FIELD LOG FOR 11/20/04

Bay Geophysical
a division of Blackhawk GeoServices
868 Robinwood Ct. Traverse City, MI 49686
Tel: (231) 941-7660 Fax: (231) 941-7412

DATE: 11/20/04
Contract No:
SHEET 1 OF 1

FIELD ACTIVITY DAILY LOG

Project Name: MSHA Geophysical Void Detection, Georgetown, IL	Project No.: 5906BLA
Field Activity Subject: HRSW and HRPW Seismic Surveys	
Description of Daily Activities and Events: 0630 Leave hotel, arrive field by 700am. 0730 First VP 1198. Decide to shoot P- wave from low end (101) to high end. Try to get off tenant farmer's field prior to break. 1240 Data acquisition slower due to mud building up beneath vibrator, have to stop and clean cones often. 1435 Vib handle (wooden dowel) broke on vibrator. Replacing. 1630 Last VP of day, 1503. 306 total VPs today. Disconnect jumpers and roll vib control cables into back of trailer in case of rain.	
Visitors on Site:	Changes from Plans and Specifications, and other special orders and important decisions:
Weather Conditions: Cloudy, 55 deg, cools to 45 deg.	Important Telephone calls:
Personnel on Site: PAV, JAM, SJ, MR, RP, FH, RG	
Field Engineer: PAV	

FIGURE F - 7 HRS FIELD LOG FOR 11/21/04

Bay Geophysical

a division of Blackhawk GeoServices
868 Robinwood Ct. Traverse City, MI 49686
Tel: (231) 941-7660 Fax: (231) 941-7412

DATE: 11/21/04
Contract No:
SHEET 1 OF 1

FIELD ACTIVITY DAILY LOG

Project Name: MSHA Geophysical Void Detection, Georgetown, IL	Project No.: 5906BLA
Field Activity Subject: HRSW and HRPW Seismic Surveys	
Description of Daily Activities and Events: 0630 Leave hotel, arrive field by 700am. 0730 First VP 1504 Line 13. Finish S- wave today and move to P- wave at BOL 100.5. 1000 Last VP 1605, Line 15. Move cables to P- wave. 1347 First VP on P-wave after tests. 6 sweeps better than 4 sweeps. First VP 1 at 100.5, source Line 1. 1642 Last VP 135. Total VPs today: 101 S-wave and 135 P-wave. 1710 Leave field.	
Visitors on Site:	Changes from Plans and Specifications, and other special orders and important decisions:
Weather Conditions: Cloudy, cool 45 deg, warms to 55 deg.	Important Telephone calls:
Personnel on Site: PAV, JAM, SJ, MR, RP, FH, RG	
Field Engineer: PAV	

From: Phil Van Hollebeke [pvanh@baygeo.com]
Sent: Sunday, November 21, 2004 6:13 PM
To: Kanaan Hanna; Lee Kurtzweil/Bay
Subject: Today's log

Here is today's log. Moved onto P- Wave today. Shooting across receiver lines as opposed to along them. Trying to clear as much of the corn field for tenant farmer by Thanksgiving.

Phil Van Hollebeke
Bay Geophysical
a division of Blackhawk GeoServices

FIGURE F - 8 HRS FIELD LOG FOR 11/22/04

Bay Geophysical

a division of Blackhawk GeoServices
868 Robinwood Ct. Traverse City, MI 49686
Tel: (231) 941-7660 Fax: (231) 941-7412

DATE: 11/22/04
Contract No:
SHEET 1 OF 1

FIELD ACTIVITY DAILY LOG

Project Name: MSHA Geophysical Void Detection, Georgetown, IL	Project No.: 5906BLA
Field Activity Subject: HRSW and HRPW Seismic Surveys	
Description of Daily Activities and Events: 0630 Leave hotel, arrive field by 700am. 0730 First VP 136. 0752 Problems with Lambda power supply in trailer doghouse. Drops out during a sweep, generator causing this? Hooked up trailer amps to truck doghouse. 0900 everything OK. 1110 Run S-wave data to Fed-X. Sterling should have by Tuesday AM. 1200 Talk with nearby landowner to leave trailer and truck doghouse over Thanksgiving holiday. 1245 Surveyors show up from Black Beauty. Show which stations need to be surveyed for elevations, PAV will interpolate rest of survey for shots and receivers and send to Sterling. 1654 Last VP of day, 4540. 405 total VPs today.	
Visitors on Site: Eric and Bud, surveyors from Black Beauty	Changes from Plans and Specifications, and other special orders and important decisions:
Weather Conditions: Cloudy, cool 45 deg, warms to 55 deg.	Important Telephone calls:
Personnel on Site: PAV, JAM, SJ, MR, RP, FH, RG	
Field Engineer: PAV	

FIGURE F - 9 HRS FIELD LOG FOR 11/23/04

Bay Geophysical

a division of Blackhawk GeoServices
868 Robinwood Ct. Traverse City, MI 49686
Tel: (231) 941-7660 Fax: (231) 941-7412

DATE: 11/23/04
Contract No:
SHEET 1 OF 1

FIELD ACTIVITY DAILY LOG

Project Name: MSHA Geophysical Void Detection, Georgetown, IL	Project No.: 5906BLA
Field Activity Subject: HRSW and HRPW Seismic Surveys	
Description of Daily Activities and Events: 0630 Leave hotel, arrive field by 700am. 0730 First VP 4541. Rain forecasted today. Drizzle already . 1045 Starting to shoot through fence line. 1200 Move jumpers, cables, phones and recorders. 1300 Moved, ready to start. 1346 Begin VP 4736. 1545 End for the, VP 4825. 285 total VPs today. Pack up jumpers, vib. Leave trailer and truck recorders at property owners house for holiday. 0615 Leave field.	
Visitors on Site:	Changes from Plans and Specifications, and other special orders and important decisions:
Weather Conditions: Cloudy, cool 45 deg, warms to 51 deg. Some drizzle.	Important Telephone calls: Call Dick Riesinger, report progress and holiday break. Contact tenant farmer.
Personnel on Site: PAV, JAM, SJ, MR, RP, FH, RG	
Field Engineer: PAV	

FIGURE F - 10 HRS FIELD LOG FOR 11/29/04

Bay Geophysical

a division of Blackhawk GeoServices
868 Robinwood Ct. Traverse City, MI 49686
Tel: (231) 941-7660 Fax: (231) 941-7412

DATE: 11/29/04
Contract No:
SHEET 1 OF 1

FIELD ACTIVITY DAILY LOG

Project Name: MSHA Geophysical Void Detection, Georgetown, IL	Project No.: 5906BLA
Field Activity Subject: HRSW and HRPW Seismic Surveys	
Description of Daily Activities and Events: Mobilization: 0745 Crew (3- SRJ, MR and FH)) leave Traverse City, MI via ground transportation, arrive Danville at 1600 hrs. 1200 Crew (2- JAM and PAV) leave Traverse City, MI to Indianapolis, IN. Pick up supplies in Danville. Arrive hotel 7pm. PAV completes elevations for all shots and receivers and sends via email to Sterling in the requested format.	
Visitors on Site:	Changes from Plans and Specifications, and other special orders and important decisions:
Weather Conditions: Some weather along the way	Important Telephone calls:
Personnel on Site: PAV, JAM, SJ, MR, FH	
Field Engineer: PAV	

FIGURE F - 11 HRS FIELD LOG FOR 11/30/04

Bay Geophysical

a division of Blackhawk GeoServices
868 Robinwood Ct. Traverse City, MI 49686
Tel: (231) 941-7660 Fax: (231) 941-7412

DATE: 11/30/04
Contract No:
SHEET 1 OF 1

FIELD ACTIVITY DAILY LOG

Project Name: MSHA Geophysical Void Detection, Georgetown, IL	Project No.: 5906BLA
Field Activity Subject: HRSW and HRPW Seismic Surveys	
Description of Daily Activities and Events: 0630 Crew meets in lobby. Arrive field at 0700 hrs. Move vehicles into hay field. Hook up jumpers, remake cable crossings over driveway. Starting to rain 0730, light. 0830 Checking cables, some takeouts wet from rain, dry and recheck. DAS56 rebooting automatically. Sustains after warming up. Raining steadily, as predicted. 1000 Rain stopped, drizzle only. Start data acquisition, slave file 4826. 1230 Getting good production. Rain finally letting up. 1300 Rain getting heavier, quit for today, slave file 4915. Total Vps 90. Sent all up to date data to Sterling today Fed-X. Pick up more supplies.	
Visitors on Site:	Changes from Plans and Specifications, and other special orders and important decisions:
Weather Conditions: Rain, heavy at times.	Important Telephone calls:
Personnel on Site: PAV, JAM, SJ, MR, FH	
Field Engineer: PAV	

FIGURE F - 12 HRS FIELD LOG FOR 12/03/04

From: Kanaan Hanna [kanaan@blackhawkgeo.com]
Sent: Friday, December 03, 2004 9:49 AM
To: 'LeeKurtzweil'
Cc: Pieter Tackenberg; Ken Morita (kenmorita@blackhawkgeo.com); James Hild (jimh@blackhawkgeo.com)
Subject: RE: MSHA

Lee: Thank you for the update and the completion of the field work. And please thank the crew for a job well done. I will pass this information in a monthly progress report to MSHA.

Thanks,

Kanaan Hanna
Sr. Engineer
Blackhawk GeoServices
301 Commercial Road, Suite B
Golden, CO 80401
Tel: (303) 278-8700
Fax: (303) 278-0789

From: LeeKurtzweil [mailto:kurtz@baygeo.com]
Sent: Friday, December 03, 2004 5:55 AM
To: Kanaan Hanna
Subject: MSHA

Data Acquisition is complete, crew is picking up equipment.

From: LeeKurtzweil [kurtz@baygeo.com]
Sent: Friday, December 03, 2004 10:03 AM
To: Kanaan Hanna
Subject: Re: MSHA

We have contacted Phil Ames and Dick Reisinger from BBC and told them we have finished this phase and thanked them for their assistance.

----- Original Message -----
From: Kanaan Hanna
To: 'LeeKurtzweil'
Cc: Pieter Tackenberg ; Ken Morita ; James Hild
Sent: Friday, December 03, 2004 11:49 AM
Subject: RE: MSHA

Lee: Thank you for the update and the completion of the field work. And please thank the crew for a job well done. I will pass this information in a monthly progress report to MSHA.

Thanks,

Kanaan Hanna
Sr. Engineer
Blackhawk GeoServices
301 Commercial Road, Suite B
Golden, CO 80401
Tel: (303) 278-8700
Fax: (303) 278-0789

From: LeeKurtzweil [mailto:kurtz@baygeo.com]
Sent: Friday, December 03, 2004 5:55 AM
To: Kanaan Hanna
Subject: MSHA

Data Acquisition is complete, crew is picking up equipment.

FIGURE F - 13 FIELD LOG FOR XHT AND GUIDED WAVES SURVEYS 04/18/05 TO 04/30/05

Monday, April 18, 2005

Left for airport 7:30 am MDT
Arrived at airport 8:30am MDT
Flight departs 10:30 am MDT
Flight arrive Indy 1:50 pm CDT
Get rental car and drive to Danville, IL
Arrive Danville, IL 3:30 pm CDT
Contact Rick Reisinger, Mine engineer, set up meeting tomorrow morning @ 7:30am
Find generator rental, but closed at 5pm
Stop at Walmart and Lowe's to get batteries, sledgehammer, and supplies 6:30pm CDT

Tuesday, April 19, 2005

Left for site 7:30 am
Drill rig interfering with downhole seismic
Need larger source, difficult getting energy passed upper coal (#7)
Driller's need to increase hole depth
XHT-EW #1 drilled to 258ft, but filled in up to 240 ft depth
Left site 6:30 pm

Wednesday, April 20, 2005

Late start waiting for Frank and others.
Stopped at hardware store on way to site to get gloves, etc.
Arrived on site around 8:15 am
Setup and started logging borehole #3 using lithology and deviation log
Moved to borehole #5 and recorded lithology and deviation logs.
Packed up about 5:30 pm
Left site about 6:00 pm
Started thunderstorming hard about 6:15pm.

Thursday, April 21, 2005

Arrived at site 7:30am
Cam having generator problems, had to rent a replacement.
Logged hole #2, deviation and lithology
Logged hole #1, deviation, lithology, and sonic
Drilled into void on last hole (#6)
Plugged and grouted hole
Moved to new location to west and began drilling.
Packed up and left site at 6:45pm

Friday, April 22, 2005

Arrived at site 7:30 am
Deviation and Lith logged BH#4
Driller finished drilling BH#6
Setup crosshole airgun and hydrostring in BH#3 and BH#4
BH#3 and BH#5 filling in at bottom
Driller redrilled and cleaned out BH#3 and #5
Tested other boreholes for depth
Moved airgun, hydrophones and surface array to BH#4 and BH#6
Shot one run of airgun, signal amplitude very low but crosses void
Rain moving in
Packed up and left site at 4:30 pm

Saturday, April 23, 2005

Arrived at site at 7:30 am
Cold, cloudy, windy (25-35 mph winds), wind chill in low 20's
Setup crosshole testing, Rx in XHT-EW #5, Tx in XHT-EW #4
Also used surface geophones, ch 17-24 active
Snow, hail, and sleet in afternoon
Finished data collection in one borehole pair
Need to run compressor after every run of the airgun to recharge tanks
Pack up and leave site 6:40 pm

Sunday, April 24, 2005

Arrived at site at 7:45 am
Sunny, windy (25-35 mph winds), cold with windchill
Problem with airgun seal in morning
Warmed up gun in vehicle and Cameron changed seals
Collected data in Borehole Pair #3 and #6
Moved to borehole pair #3 and #5
Collected data on 4 pulls
Packed up equipment
Left site at 6:40 pm

Monday, April 25, 2005

Arrived at site at 7:30am
Setup XH equipment on BH#3 and #5, 8:30am
#5 filled in 287ft
Driller tried flushing well #4, no luck 11:30 am
Driller redrilled #4 and #5
Borehole logged BH#6, deviation, resistivity, sonic
Finish shooting XH on BH#3 to #5
Shot lower section of BH#6 to #5
Packed up and left site at 7:30 pm

Tuesday, April 26, 2005

Morning Rain
Arrive at site @ 7:45 am
Setup and acquire XH data on #5 and #6
Called generator rental and extended
Finish XH data acquisition between #5 and #6
Heavy rain in afternoon
Packed up and left site @ 3:45 pm
Field getting very muddy

Wednesday, April 27, 2005

Partly cloudy, very windy and cold
Send out Fedex to Colog
Arrived at site at 7:40 pm
Cameron exchanging trailer in morning
Finish Check Shot while Cameron getting trailer
Collect Data XHT BH#4 to BH#6
Drillers cleared out BH#1 and BH#2
Pack up and leave site 6:50 pm

Thursday, April 28, 2005

Cloudy, cool
Arrive at site 7:40 am
Compile data acquisition for Crosshole Tomography BH#1 to BH#2
Collect guided wave data for BH#3 to #2 and BH#6 to #2
Setup for data collection for BH#3 to #4
Collect 5 pulls for crosshole tomography data BH#3 to BH#4
Pack up and leave site at 6:55pm

Friday, April 29, 2005

Cloudy with scatted showers
Arrived at site 7:40 am
Setup for data collection for BH#3 to BH#4
Complete crosshole tomography data collection for BH#3 to BH#4
Clean up and leave site at 12:00 noon
Drop off rental generator
Clean out rental car (lots of mud)
Return to hotel at 1:40 pm
Help Cam pack up equipment

Saturday, April 30, 2005

Leave Danville, IL at 9:00am for Indianapolis, IN airport
Flight at 2:30 pm on Frontier direct to Denver, CO

FIGURE F - 14 FIELD LOG FOR VOID CONFIRMATION 10/03//05 TO 10/07/05

During This Period, Three Field Tasks Were Preformed:

- Conventional Borehole Drilling
- Borehole Deviation Surveys
- Borehole Sonar Surveys

Fieldwork Preformed By the Following Companies:

Prime or Subcontractor	Company Name	Task Preformed
Prime	Blackhawk A Division of ZaptataEngineering	Overall Geophysics
Subcontractor	Magnum Drilling Services	Drilling
Subcontractor	COLOG Borehole Geophysical Services	Borehole Deviation Surveys
Subcontractor	Workhorse Technologies, LLC	Borehole Sonar Surveys

Field Observations Personnel:

The following personnel were present to observe the fieldwork:

Company	Personnel
Blackhawk A Division of ZaptataEngineering	Kanaan Hanna
Mine Safety and Health Administration (MSHA)	Steven Vamossy
Mine Safety and Health Administration (MSHA)	George Gardner
The Black Beauty Coal Company (BBCC)	Philip Ames
The Black Beauty Coal Company (BBCC)	Richard Reisinger
The Black Beauty Coal Company (BBCC)	Surveying Crew and Various Personnel from BBCC

Boreholes Location Layout and field scheduling:

The location of the five confirmation boreholes with coordinates were obtained by BBCC mine surveying crew and labeled in accordance to the old mine coordinates system in the north-south and in the east-west.

Overall Site and Borehole Location and Status:

- The north-south mains consisted of four-entry system, where the west submains consisted of two-entry system. The entries are 10 ft wide separated by 20 ft pillars.
- The three boreholes in the north-south area were located in the right entry and labeled as:
    - Conf NS #2
    - Conf NS #3

  - Conf NS #4
- Conf NS #1 borehole was previously drilled in the left entry during the XHT field survey.
- The two boreholes in the west submains area were labeled Conf EW #1 and Conf EW #2.
- Boreholes Conf NS #2 through #4 were positioned in the center of the three-way intersections in-line along the right entry.
- Borehole Conf NS #3 was off by about one ft west of the centerline alignment.
- The boreholes were spaced about 64 to 68 ft apart depending on the three-way intersections and pillar geometry and spacing.

MONDAY, OCTOBER 03, 2005

- The drilling rig was mobilized and began drilling borehole Conf NS # 2

TUESDAY AND WEDNESDAY, OCTOBER 04-5, 2005

- Drilling continued in Conf NS #2, # 3 and #4.
- All three boreholes along the North-South entry confirmed the presence of voids, as follow:
  - Borehole Conf NS #2 – Void depth 230 ft, void height 7.8 ft. Drill rod showed a sudden drop all the way through the void indicating no obstructions.
  - Borehole Conf NS #3 – Void depth 231 ft, void height seven ft. Drill rod showed a southern drop during the first three ft and exhibited dragging as the drill rod as pushed during the remaining four ft. This may indicate possible collapsed area or fill materials.
  - Borehole Conf NS #4 – Void depth 229 ft, void height 7.3 ft. Drill rod showed a sudden drop all the way through the void indicating no obstructions.
- Air-field or water-field voids – The drilling crew was unable to determine the presence of water in the mine voids. A bottle partially-filled with water was used to determine the water level. All boreholes showed the water level at about 58 ft above the mine roof or at depth of about 172 ft.
- We made a decision to drill a borehole outside the boundary of the west submains to:
  - Evaluate the geophysical anomaly the entry system that extends north of the submains.
  - Determine the factors causing this anomaly
  - Determine possible old mine works area not shown on the mine map.

THURSDAY, OCTOBER 06, 2005

- Borehole Conf XHT-EW #1 was drilled to a depth of 245 ft, confirmed five ft solid coal, depth of 236 ft. The borehole was drilled to a total depth of 245 ft.

- Phil Ames, BBCC, arranged for an additional borehole Conf EW # 2 to be drilled in the left entry west submains left entry. The borehole was drilled in the center of the three-way intersection of the submains. The borehole confirmed the presence of six ft void at depth of 230 ft.

- Borehole Deviation Surveys for all boreholes were performed on Wednesday and Thursday. The field preliminary data showed minimal boreholes deviation. The deviation survey in borehole Conf NS #3 exhibited similar dragging action as the drilling.

- Borehole Sonar Surveys began on Thursday and completed on Friday morning. The survey began at borehole Conf NS #2 and continued sequentially until all boreholes (Conf NS #2, #3, and #4, and Conf EW #2) were completed The Wet Ferret (the sonar unit used) experienced no or little problems in negotiating boreholes. The unit at each borehole was lowered to the depth of the top of the void (mine roof) and began acquiring data at six to 12-in intervals until the mine floor was reached or when the unit was in mud area preventing data acquisition. The survey was then repeated from the bottom to top (mine floor to the roof) to produce 3-D sonar images. Field observations are included at the end of the field notes.

- All five boreholes were logged by the drilling crew and grouted once the boreholes deviation and sonar surveys were completed.

Borehole Sonar Field Observations:

- Borehole Conf NS #2 – The rib line was visible to a distance of about 75 ft in both north and south directions. The 90-degree crosscut was visible, confirming the three-way intersection. The south corner of the pillar was partially visible. A straight lines perpendicular to the entry were noticed near the roofline indicating the location of the timber roof support. No obstructions or rubblized materials were noticed in the vicinity of the three-way intersection area. *The sonar survey in this borehole confirmed void height 7.8 ft and the accuracy of the entry/pillar layout.*

- Borehole Conf NS #3 – The rib line was visible to a distance of about 75 ft. *only* in the south direction (toward borehole Conf NS #2). The 45-degree crosscut was visible, confirming the three-way intersection. The south corner of the pillar was partially visible. Obstructions or rubblized materials were noticed in the vicinity of the three-way intersection area north of the borehole location, which made it difficult to survey the entire height of the void. *The sonar survey in this borehole confirmed void height of about three to four ft which supports the observations made during drilling and deviation survey, where the drill rod and the deviation instrument were noticed to drag along a sloped pile of rubblized materials. The survey also confirmed the accuracy of the entry/pillar layout).*

- Borehole Conf NS #4 – The rib line was visible to a distance of about 76 ft in the north direction and about 30 ft in the south direction. This confirmed the presence of possible rubblized materials between boreholes Conf NS #3 and #4. The materials start in the vicinity of borehole Conf NS #3 and extend about 25 ft north of the borehole. The 90-degree crosscut was visible, confirming the three-way intersection. The south corner of the pillar was partially visible. A straight lines perpendicular to the entry were noticed near the roofline indicating the location of the timber roof support. No obstructions or rubblized materials were noticed in the vicinity of the three-way intersection area or north of the borehole. *The sonar survey in this borehole confirmed void height 7.8 ft and the accuracy of the entry/pillar layout.*

- In general, the sonar field results have shown that the location of all the NS boreholes were in the vicinity of the south corners of the pillars or about two to three ft west of the center line. This shift may be attributed to: 1) boreholes deviation; and 2) possible offset in the old mine map coordinate system.

- Borehole Conf EW #2 – The rib line was visible to a distance of about 65 ft in both east and west directions. The 90-degree crosscut was visible, confirming the three-way intersection and the accuracy of the entry/pillar layout. *The sonar survey in this borehole confirmed void height six ft at depth of 230 ft.*