FINDING COAL ADITS: WHAT CLIENTS WANT

EXAMPLE: MINE TUNNEL UNDER ILLINOIS LANDFILL

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Abstract

Geotechnical issues arise when surface structures are proposed above abandoned subsurface mine structures. This is particularly true for landfills where liner integrity is of paramount importance. When an abandoned coal mine tunnel (70 feet below ground surface) was encountered along the slope of a newly developed landfill expansion cell in eastern Illinois, the extent of coal mining in the area became an issue. Typically, the owners of such situations acknowledge that using drilling alone to map the extent of subsurface mine workings is cost-prohibitive. However, using the "time is money" cliché, they then demand prompt action with "Tricorder-like" precision and low-cost subsurface investigative methods.

Following discussions with owners in which possible methods of investigation and their limitations are introduced, the next course of action commonly includes:

- A test program to prove the efficacy of the proposed methods
- A production phase investigation program to map the mine workings if the test program proves successful
- Selection of drill locations to test subsurface targets.

A test program was implemented at the aforementioned landfill location to determine the most effective geophysical method(s) for an expanded investigation. Seismic reflection, electrical resistivity/induced polarization (IP), and ground penetrating radar (GPR) methods were tested in an area thought to contain the extension of a known mine tunnel. Following the test program, an expanded survey was conducted using all three methods along the main access road and on a cut bench along the slope of the new cell. Based on the results of the expanded investigations, drilling targets were identified and ranked according to the spatial concentration of geophysical anomalies and the confidence level of their interpretation as possible mine structures. Boreholes were drilled to confirm the subsurface targets.

Introduction

Two mine headings were exposed while excavating the slope of a new cell at a landfill in eastern Illinois (Figure 1). The mine openings appear to be the northern extension of an underground mine developed in the early part of the 20th Century. Based on existing documents, the new cell should have been north of the old mine workings.

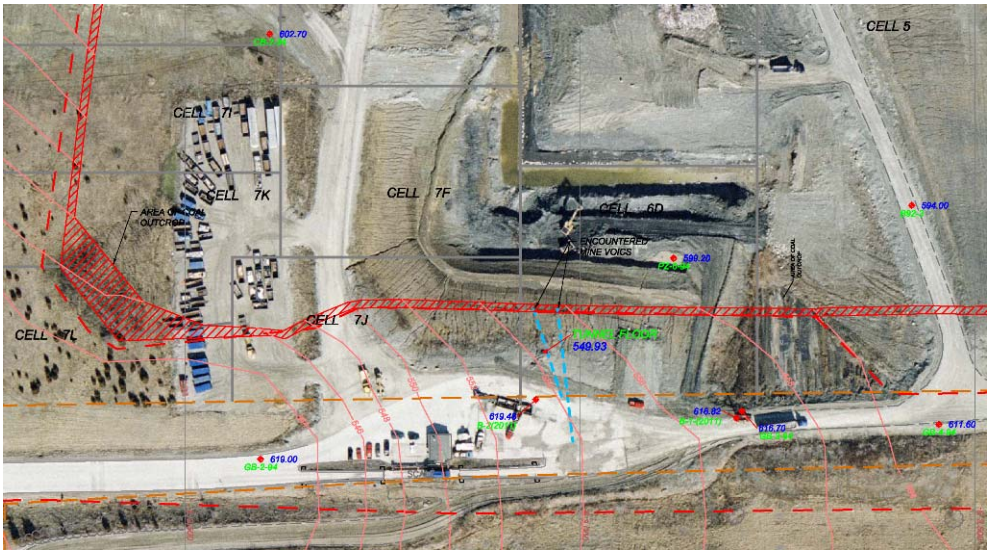

Figure 1 Mine tunnel location and projection of tunnels and coal seam outcrop

The problem posed by underground mine tunnels is the potential for destabilizing base liners and drainage containment structures. The investigation was part of a mine void stabilization project. As part of the remediation planning effort, HGI was contracted to determine the extent of the known mine tunnels and investigate the possible existence of underground mine structures in adjacent cells and haul road. The area of investigation is shown in Figure 2.

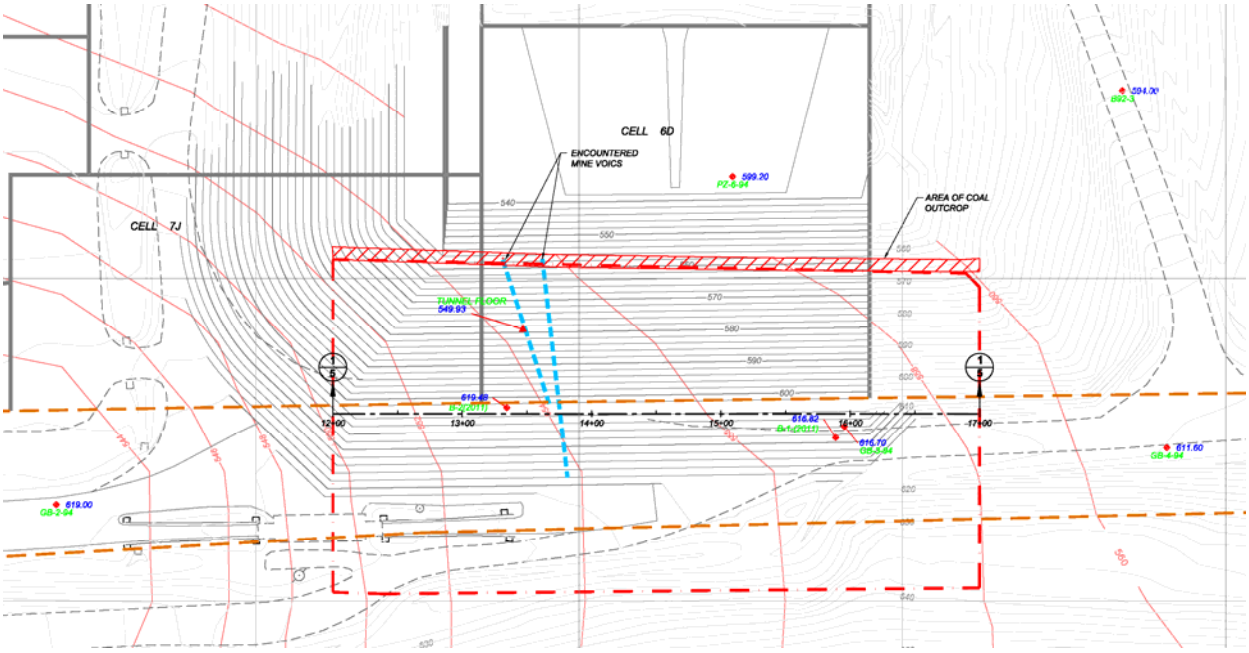

Figure 2 Proposed survey area showing projection of tunnels and coal seam outcrop

The objective of the geophysical surveys was to identify mine works within the limit of influence of the south boundary of newly constructed cells in order to stabilize the mine works to avoid potentially damaging impacts to the baseliner and containment systems within these areas. The reported limit of previous strip mining of the Herrin #6 coal seam was determined from historical documents to be farther south.

HGI was consulted to assess the feasibility of not only delineating the extent of underground mine structures, but also distinguishing between mine rooms and pillars with precision criteria based on guaranteed drilling results. The following excerpt is from the RFP:

"The goal of the geophysical study is to define any existing coal mine workings to the level where they can be mapped with enough accuracy to allow drilling into voids or coal pillars. It will be required that voids no smaller than 5 foot in width to be indicated. It is understood that the delineation of edges of mined segments of the coal will be difficult to pin down and the ability to identify the center and edge of a mined feature will be dependent on both the depth and intensity of data gathering (cost). As such, it is desired that probable void containing areas be delineated at using screening level of data gathering and followed up with more intensive study to reach delineation accuracy sufficient to drill holes and hit void or support coal with a probability of more than 50% with a minor void dimension of 10 foot and 100% for voids with minor dimensions in excess of 15 feet."

The above performance criteria suggest that the preparer is an engineer with a desire to quantify the uncertainties of geophysical methods… in this case, dictating the desired target resolution regardless of the limitations in efficacy and resolution of geophysical methods in variable geologic terrain. If not achievable at specified unrealistic criteria, would lesser results in resolution be useless? Would the delineation of mining limits and mapping of spatial room and pillar patterns be better than alternative investigative methods, i.e., drilling? And what are the consequences of not achieving the exact RFP specifications? Should penalties be applied? One can only hope for a reasonable client/contractor relationship within which reasonable goals can be set and achieved.

Geologic Setting

The bedrock surface is situated beneath 35 to 40 feet of unconsolidated river sediments consisting of clay and silt. Bedrock is heavily weathered and consists of Middle Pennsylvanian age siltstone and shale formations frequently displaying fluvial sand channels (ISGS, 2005). The degree of weathering is spatially highly variable.

Elevation at the crest of the cells placed the mine tunnels approximately 70 to 80 feet below the ground surface. At the openings, the tunnels are approximately 10 feet in diameter within a coal seam thickness of approximately 5 feet. Overburden stratigraphy is variable in terms of composition and weathering characteristics of loosely indurated siltstone and shale. Unconsolidated clay and soft weathered shale can account for one half to two thirds of the overburden thickness. Siltstone, a discontinuous limestone layer, and shale may directly overly the coal at any given location. Typically, clay always underlies the coal seam.

Test Survey

A test program was implemented at the aforementioned landfill location to determine the most effective geophysical method(s) for an expanded investigation. Seismic reflection, electrical resistivity/induced polarization (IP), and ground penetrating radar (GPR) methods were tested in an area thought to contain the extension of a known mine tunnel. The strategy of the test survey included a reconnaissance survey that would indicate the presence or absence of extensive room and pillar mining to be followed by a spatially expansive exploration program if room and pillar structures were found to be present.

The test survey traverse was located adjacent to an access road (Figure 3) where surface coupling was readily available for seismic, resistivity/IP, and GPR surveys.

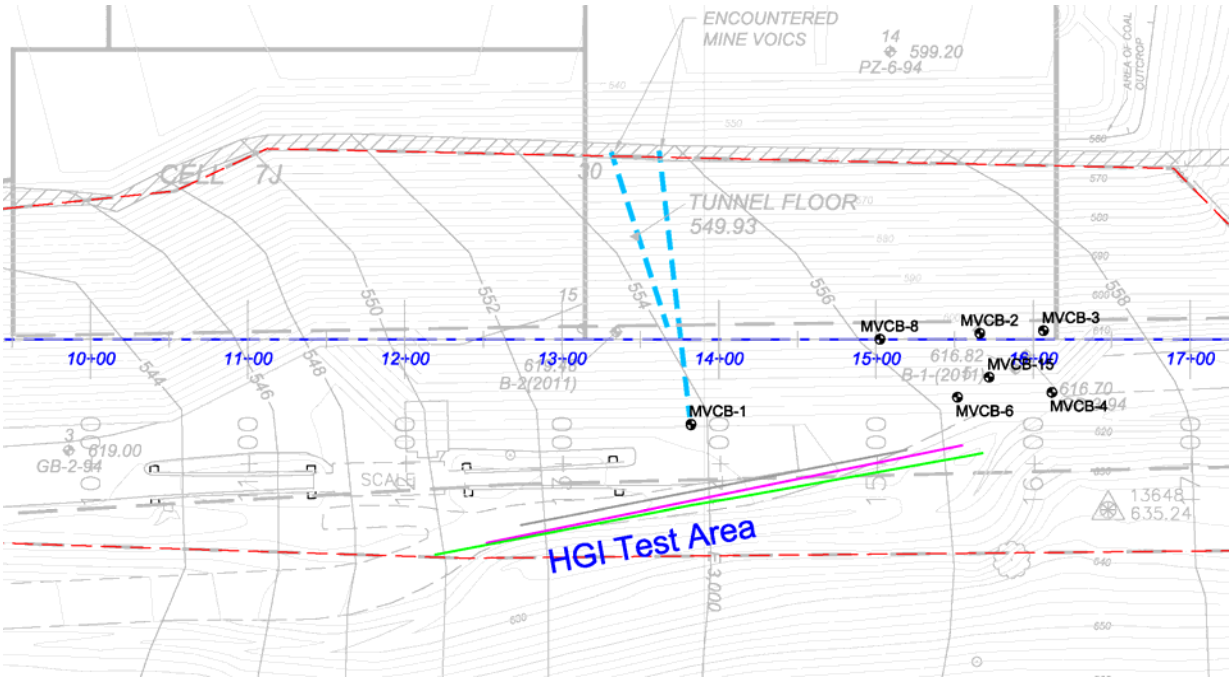

Figure 3 Test survey location

Despite the size of the area of investigation, severe constraints to survey geometry were created by unfavorable topography and access roads constructed with asphalt and a base of highly compacted clay-rich soil impregnated with large gravel… an effective barrier for intrusive electrical contacts and GPR signals. The main access road was heavily traveled by large trash haulers for the entire period of operation of the landfill, and the geophysical exploration program could not interfere with the landfill operation. Also adversely affecting geophysical investigations using all three methods were poor ground conditions resulting from the inhospitable weather conditions in eastern Illinois during the January/February survey period.

GPR For reasons including vertical and spatial resolution capability, cost, and minimal obstructiveness, a preferred geophysical method for investigating subsurface geology and relatively deeply buried targets with finite dimensions is low-frequency GPR. Based on HGI's experience with GSSI's Multiple Low Frequency (MLF) antenna system over the past 15 years in a variety of geologic settings (excluding glaciers), the effective depth of investigation using this antenna system ranges from approximately 20 to 150+ feet. Despite the abundance of natural clayey sediments, imaging to a depth of 100 feet was deemed feasible. The most debilitating factor was considered to be the compacted clay sub-base along the access road. Figure 4 shows the tunnel features observed using a multiple low frequency (MLF) antenna configured for 35-MHz.

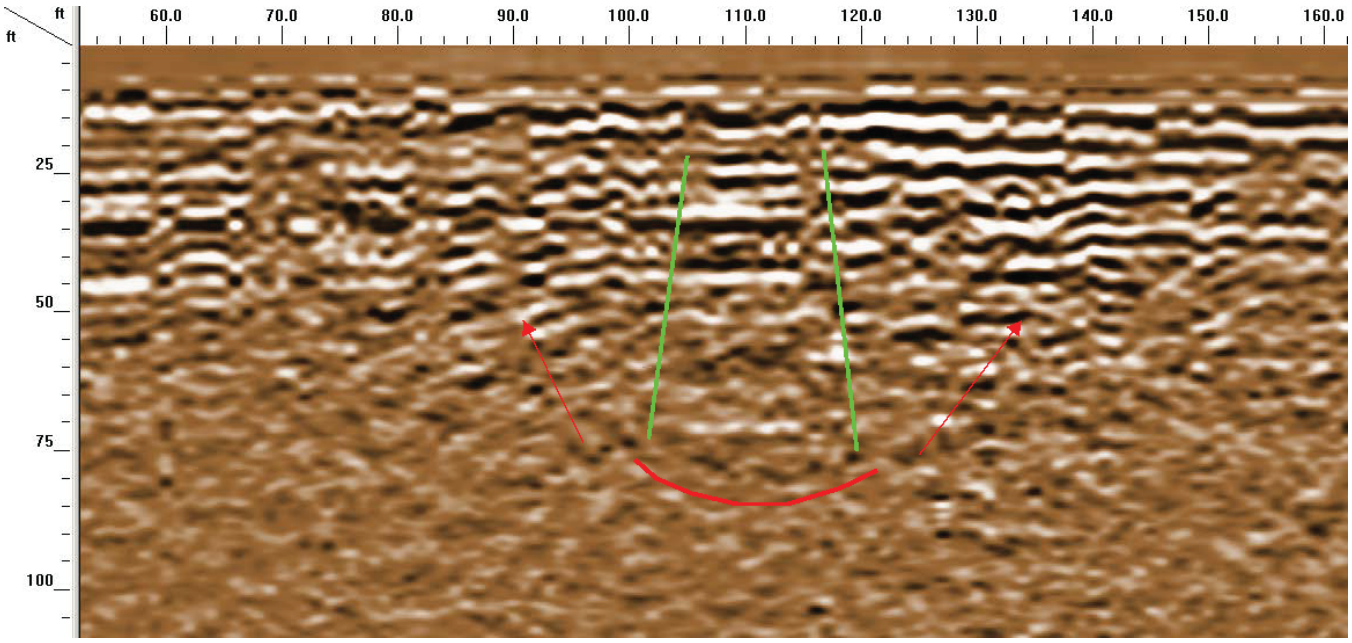

Figure 4 Radargram from test survey showing mine tunnel feature

Resistivity/IP As complementary methods to GPR, the resistivity/IP and seismic methods were selected to provide independent constraints to GPR interpretation. These methods were not, however, without site-related adverse conditions. Normal hammer emplacement methods could not be used to couple electrodes to the soil beneath the access road. Since the budget did not include more elaborate methods of coupling, the electrical method was restricted to roadside locations that were in short supply. In these areas, constraints to survey geometry would limit the linear distance along which target depths could be reached using the resistivity/IP method.

Despite the good contrast in conductivity of clayey sediments and air/water-filled voids, locating a 10-foot diameter resistive target buried under approximately 80 feet of conductive soil is akin to locating one dead light bulb in a panel of a million lighted bulbs. However, forward modeling using site parameters indicated that maybe only 100,000 light bulbs would be present, i.e., the method would be feasible. The resistivity results delineated changes in bedrock composition, but did not reveal tunnel features. However, IP results detected an anomaly at the projected tunnel location (Figure 5).

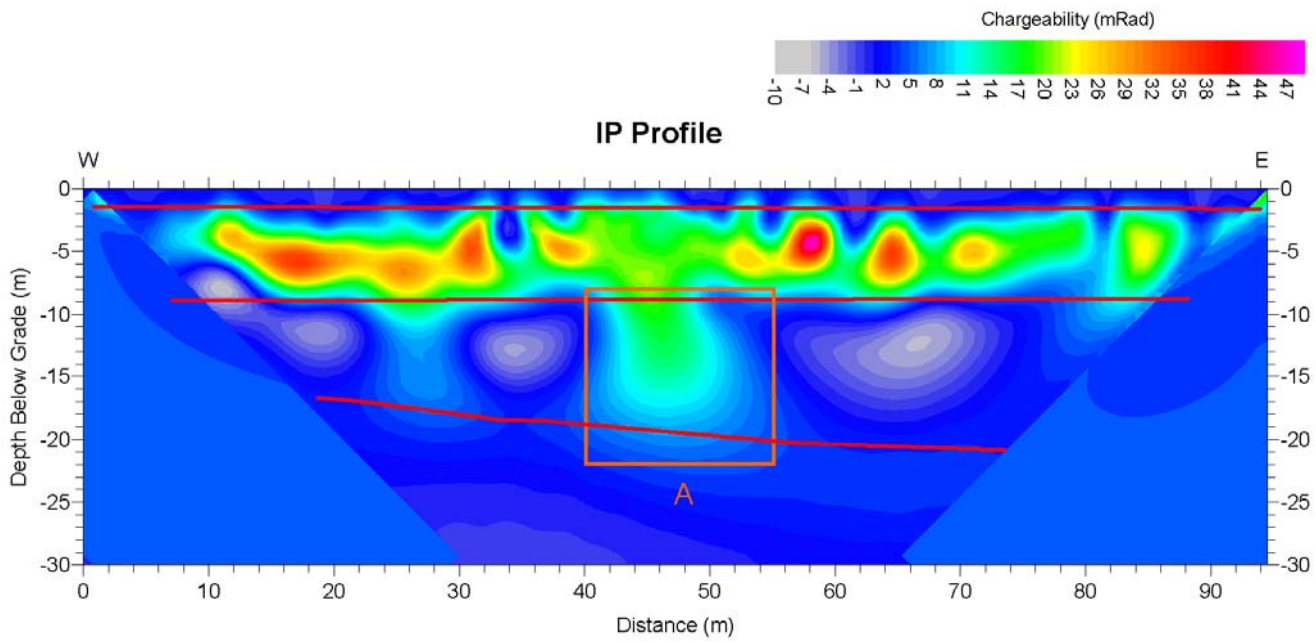

Figure 5 Test IP profile

Seismic The benefit of using seismic methods for subsurface investigation of stratigraphic or mine-related structures is the many forms of signal analysis that can be performed on one multi-channel data set. For example, if the proper survey geometry is used, refraction, reflection, MASW, and IE (impact echo) analyses can be performed from one data set. In the subject mine tunnel investigation, end-on seismic reflection data collection was used to assess the feasibility of detecting anomalies using CDP stacking, common shot offset (CSO), common receiver offset (CRO), and other time- and frequency-domain sorting methods. Figure 6 is a CDP stacked section from the test line survey showing an anomaly at the projected tunnel location.

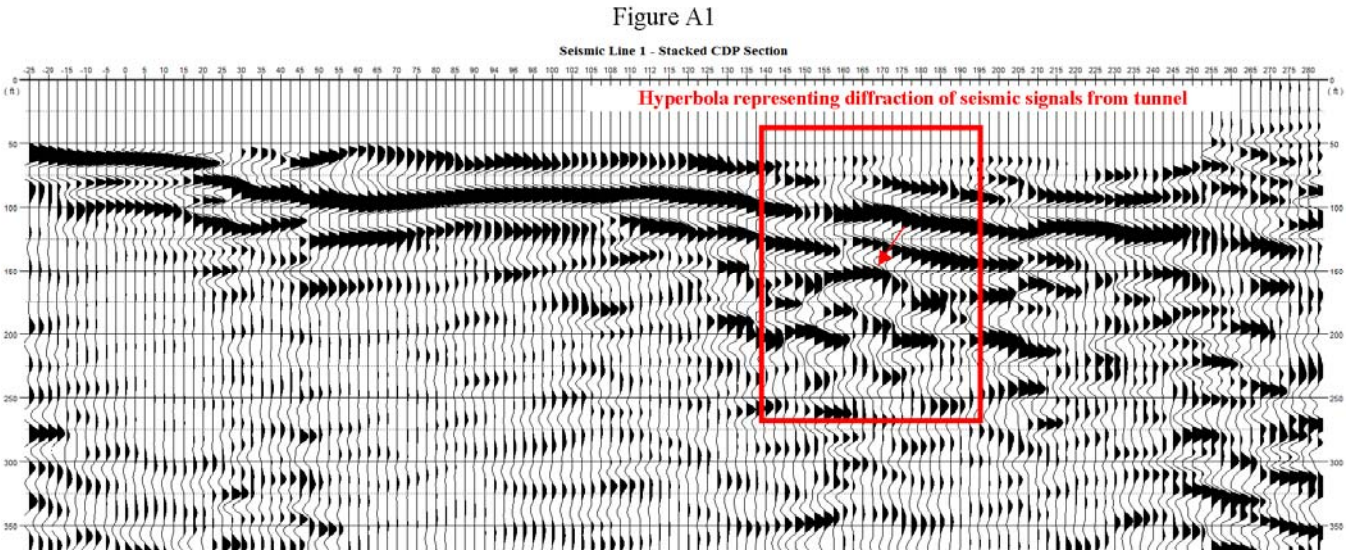

Figure 6 Test seismic profile

Expanded Survey

The expanded survey alignment was approximately 1,175 feet in length and extended across the eastern part of new cell development. A combined total of approximately 3,180 linear feet of geophysical data were collected (Figure 7). The seismic and GPR surveys were conducted along the haul road. However, due to the road conditions, the resistivity/IP survey took place on a bench cut into the south slope of one of the cells. The expanded survey included:

- Seismic reflection line of approximately 1,330 feet
- Resistivity/IP line (3 linear arrays) totaling approximately 690 feet
- 35-MHz GPR line of approximately 1,160 feet

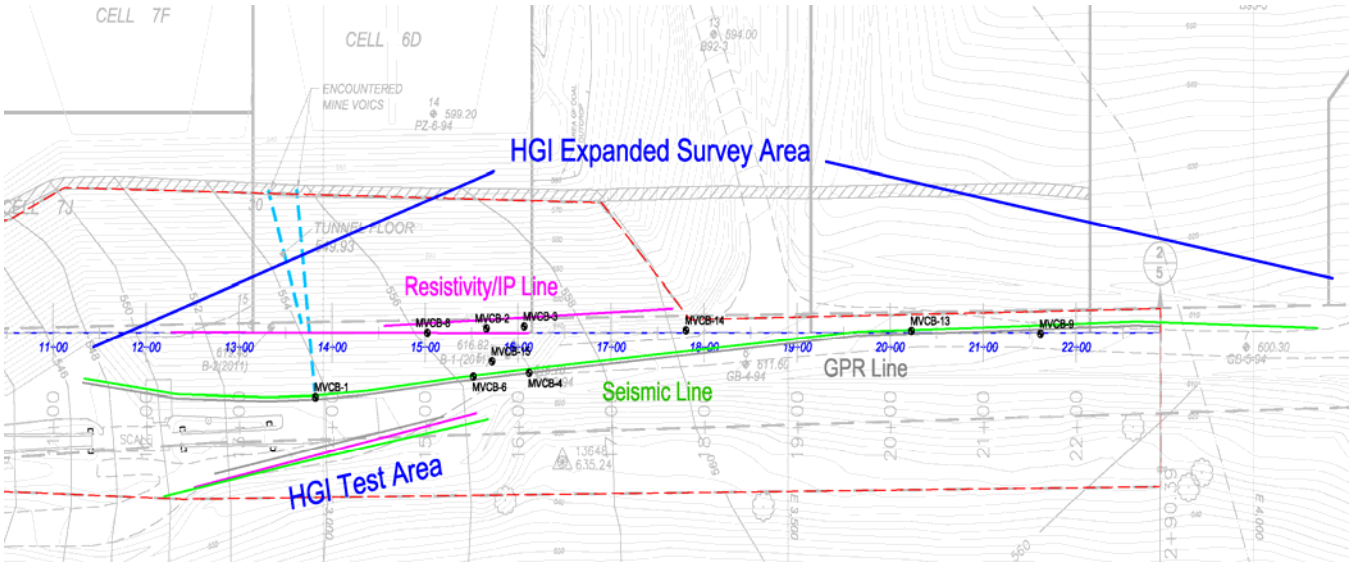

Figure 7 Expanded survey location

Poor weather conditions persisted during the expanded survey efforts (Figure 8), affecting data collected by all methods, but mostly detrimental for the GPR and resistivity surveys. Survey parameters for the three geophysical methods remained the same as those for the test survey.

Figure 8 Ground conditions for resistivity survey

Seismic reflection data were collected using a Geometrics Geode® 48-channel exploration seismograph and 40-Hertz geophones deployed at 5-foot station spacing along a linear array. Seismic energy was provided by a 90-pound propelled energy generator (PEG). A 24-channel roll-along data acquisition technique with a constant shot offset of 50 feet was used. Figure 9 illustrates the seismic survey geometry and Table 1 lists the seismic survey data collection parameters.

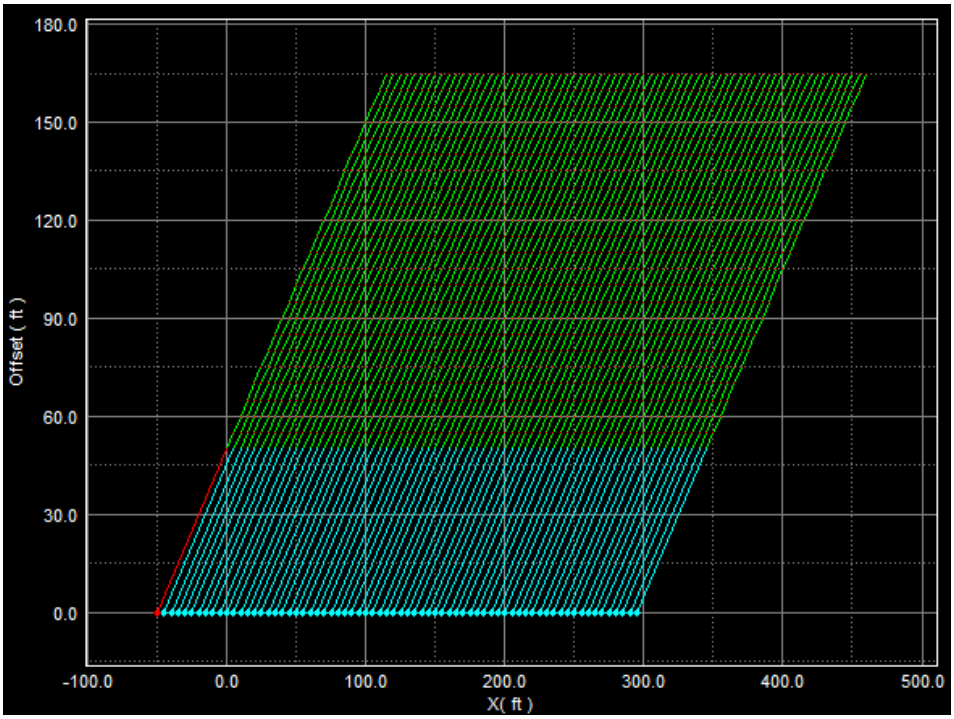

Figure 9 Seismic reflection geometry (* shot, -- shot offset, * geophone, -- geophone array)

Table 1 – Seismic Acquisition Parameters

Recording Time (ms)	Sample Rate (µs)	Acquisition Filter	Vert. Stacks (per record)	Shot Records
250	31.25	NONE	5	243

Seismic data were processed using Geogiga Technology Corporation's (GTC) Geogiga Reflector 7.1 software. Using a common offset sorts, the shot gathers were processed to reduce the effects of cultural interference and non-reflected seismic energy. The processing regimen varied by location, but included frequency, F-K and Tau-P filters, trace editing, gain adjustments, static corrections, and deconvolution. In addition to CDP stacking, common offset sections were used to identify anomalies. Seismic attributes such as frequency and signal amplitude were also mapped to identify possible buried structures.

Resistivity/IP data were collected along three overlapping lines using a Multi-Phase Technologies, LLC (MPT) DAS-1 unit and 64 electrodes. Both resistivity and induced polarization (IP) data were collected along the three lines using a dipole-dipole array. The survey geometry for each linear array included 1.5-meter electrode spacing for a total array length of 94.5 meters. Due to the limited amount of space available along the cut bench where the survey alignment was located, overlaps of 70.5 and 46.5 meters were used between array 1 and array 2, respectively. The three combined lines allowed for a total resistivity/IP line of 165 meters, or approximately 541 feet. The overlap was necessary to optimize imaging depths along the restricted bench length.

Resistivity and IP data were processed using Multi-Phase Technologies, LLC's (MPT) ERTLab™ *Solver* 3D electrical resistivity tomography inversion software. Prior to modeling, the data set for each survey was screened for duplicates, reciprocity, and tolerance limits.

GPR data were collected using a GSSI SIR-2000 digital acquisition system. One high-powered low-frequency 35-MHz bi-static GPR traverse was completed along the access haul road (Figure 7). The data were collected in discrete point mode, in which GPR pulses were manually triggered at 1-foot intervals along the line. Each scan was stacked 256 times at the measurement point to increase the signal-to-noise (S-N) ratio and recorded over a 1200 nanosecond (ns) window (Table 2).

Table 2 – GPR Acquisition Parameters

Recording Time/Trace (ns)	Samples/Trace	Acquisition Filter (MHz) (LP/HP)	Vert. Stacks (/Trace)	Traces per Foot
1200	1024	60/5	256	1

Processing was performed using Geophysical Survey System's (GSSI) RADAN for Windows XP™. Distance normalization, band-pass and spatial filters, horizontal smoothing, gain adjustments, migration,

and deconvolution were performed as essential processing steps. The degree of signal attenuation due to the high concentration of clay in the overburden and shale bedrock ranged from moderate to severe.

Results

Figures 10-13 illustrate the types of geophysical anomalies identified by the three methods.

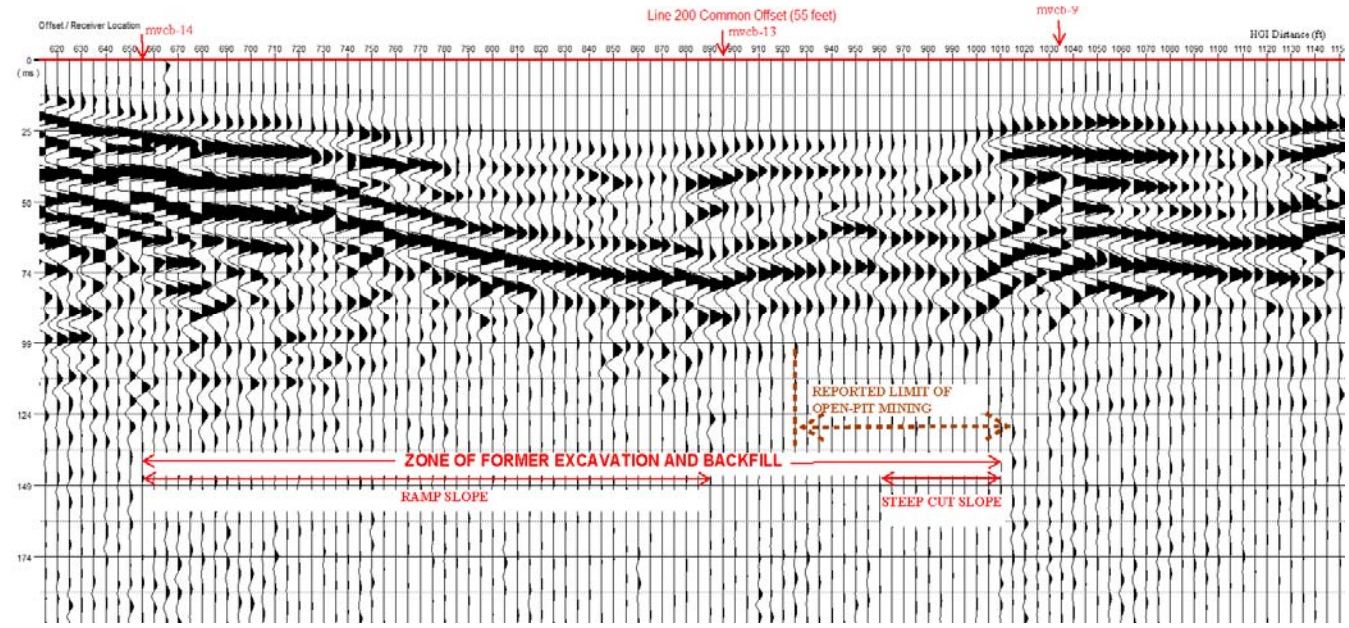

Figure 10 Common offset seismic section

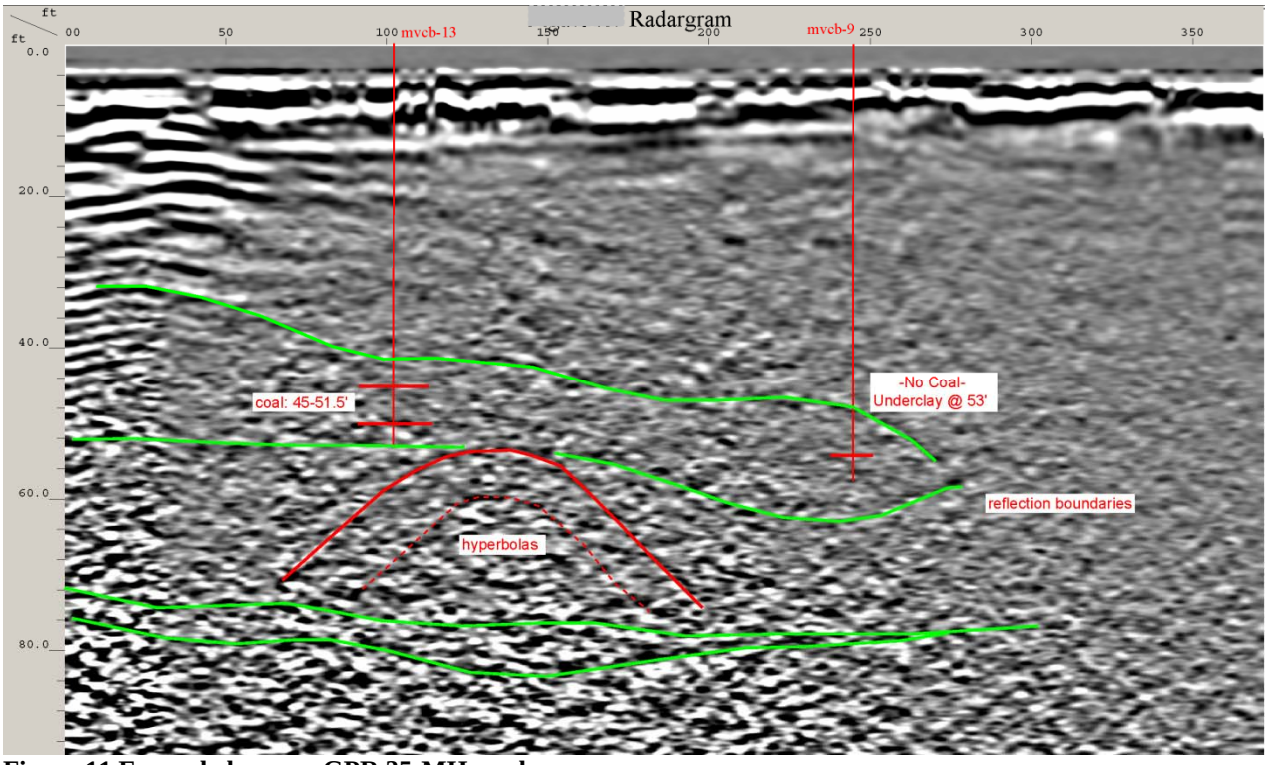

Figure 11 Expanded survey GPR 35-MHz radargram

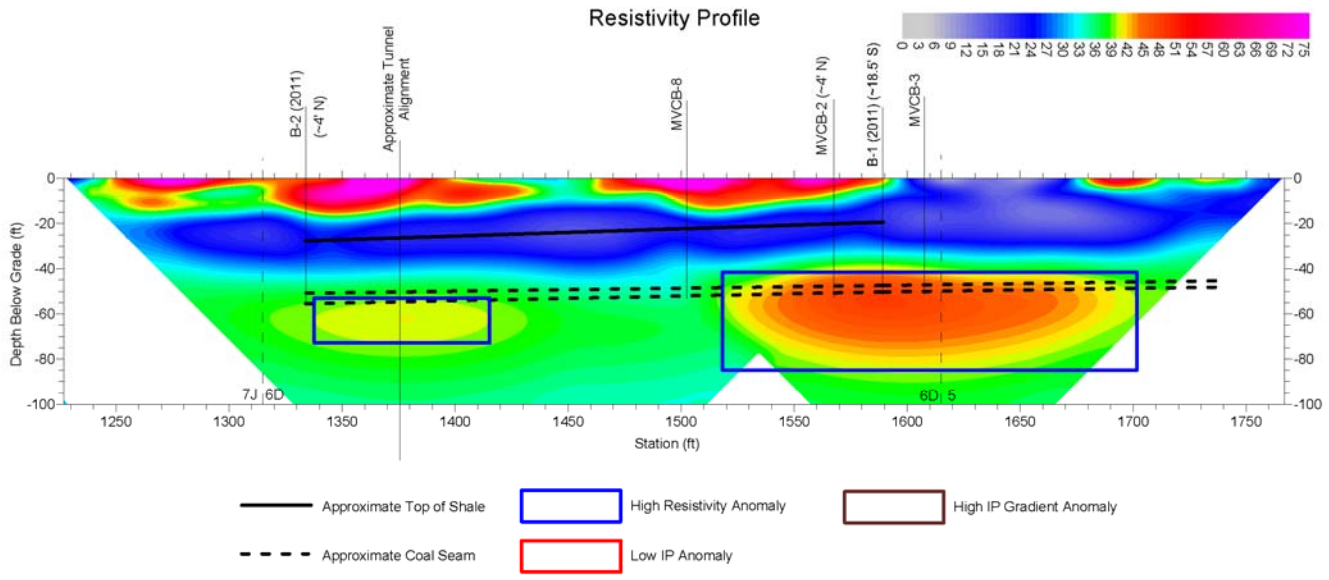

Figure 12 Expanded survey resistivity profile

Seismic, GPR, and electrical targets representing possible coal mine workings were identified and prioritized based on the confidence level of interpretation and spatial occurrences (Figure 13). Figure 13 also shows the locations of boreholes drilled to confirm the cause of geophysical anomalies. Borehole mvcb-1 was drilled to test the southward extension of the known tunnel delineated by the geophysical test surveys. Borehole mvcb-1 encountered a void at that location.

Borehole mvcb-9 was drilled in the eastern limit of an area delineated as a possible subsurface collapse feature (Station 18+50 to Station 23+00 in Figure 13) by GPR and seismic methods (Figures 10 and 11). Borehole mcvb-13 was drilled near the center of the collapse feature. Mvcb-9 encountered disturbed soil and rock debris but no coal. Mvcb-13 revealed loose soil overburden over fractured coal. Recently recovered historical data reveal that this area was previously strip mined. The geophysical anomaly is consistent with previous excavation and backfill contours shown in Figure 13.

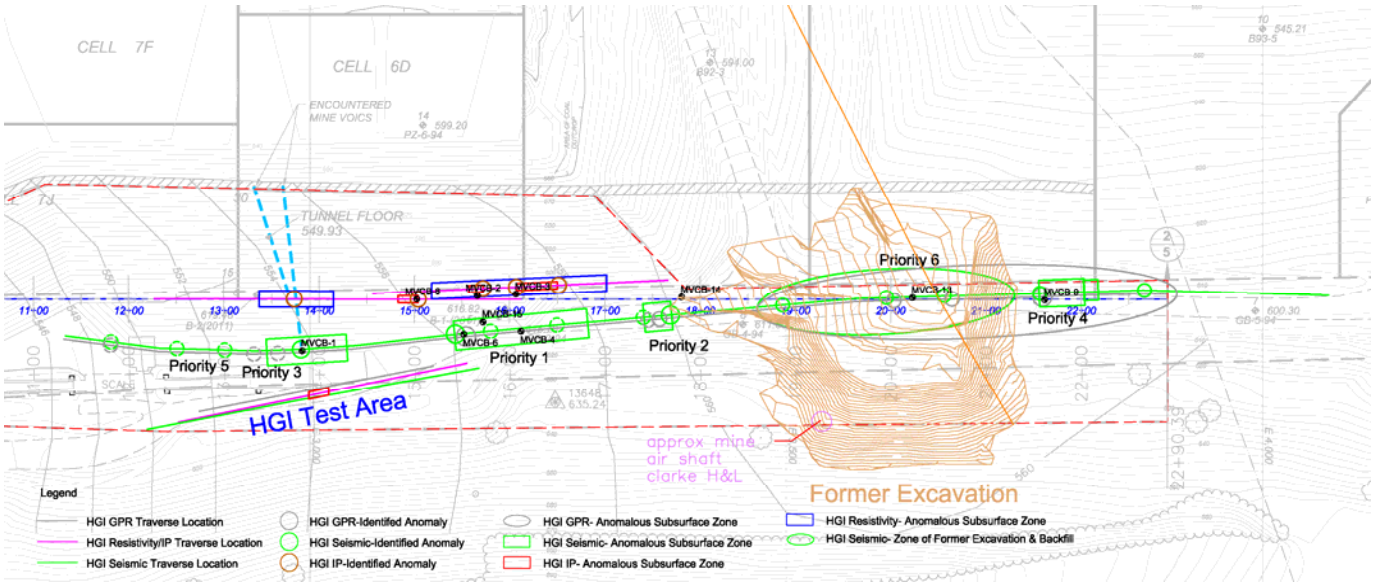

Figure 13 Prioritized geophysical drill targets

The remaining seven boreholes encountered overburden (both strip mine spoils and natural soils) underlain by coal, but no other mine tunnels.

Conclusion

For projects not qualifying for extraordinary and extenuating investigative approaches, this survey demonstrates the difficulty in resolving relatively small discrete subsurface features situated at depths defining the threshold for resolution using conventional geophysical methods.

The approach used to identify drilling targets represents a conservative approach for addressing the possible presence of these features. Drilling at the target locations would confirm the source of the geophysical anomalies and thereby confirm the presence or absence of subsurface coal mine workings.

Information from confirmatory boreholes reveals variable subsurface soil and bedrock conditions that account for many of the mapped geophysical anomalies. These include variable overburden composition and thickness, variable bedrock density (caused by differential weathering of shale bedrock), discontinuous layers of limestone overlying weathered shale (produced by sedimentary facies changes), strip mining, and a large area of excavation and backfill. These changes in overburden and bedrock properties create unique localized electromagnetic, electrical, and acoustical responses in geophysical measurements that appear as anomalies relative to background values.

Because of the natural and man-induced soil and bedrock variability, baseline or background values for seismic, electric, or electromagnetic investigations were nominally established. It could be argued that the variability in subsurface conditions is the norm. Confirmatory drilling permits the correlation of geophysical anomalies with natural and man-made subsurface features and conditions, thereby improving the confidence level of subsurface targets in future surveys.

The results of these investigations illustrate that a multi-method geophysical approach toward detecting deep anomalies is important for increasing the confidence level of data interpretation.

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