Project No. 031019
RFP MSHA #J53R1011
Account No. B2532538
July 2006

D'APPOLONIA

FINAL REPORT
DEMONSTRATION PROJECT - MINE VOID DETECTION
TIME DOMAIN ELECTROMAGNETIC (TDEM)
SURFACE GEOPHYSICAL METHOD
LOTS BRANCH TAILINGS IMPOUNDMENT SITE
PRENTER, WEST VIRGINIA

Lots Branch Tailings Impoundment

Prepared for

MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON, VIRGINIA

Project No. 031019
July 2006

FINAL REPORT
DEMONSTRATION PROJECT - MINE VOID DETECTION
TIME DOMAIN ELECTROMAGNETIC (TDEM)
SURFACE GEOPHYSICAL METHOD
LOTS BRANCH TAILINGS IMPOUNDMENT SITE
PRENTER, WEST VIRGINIA

Prepared for

MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON, VIRGINIA

D'Appolonia
275 CENTER ROAD
MONROEVILLE, PA 15146-2144
PHONE: (412) 856-9440
FAX: (412) 856-9535
info@dappolonia.com

TABLE OF CONTENTS

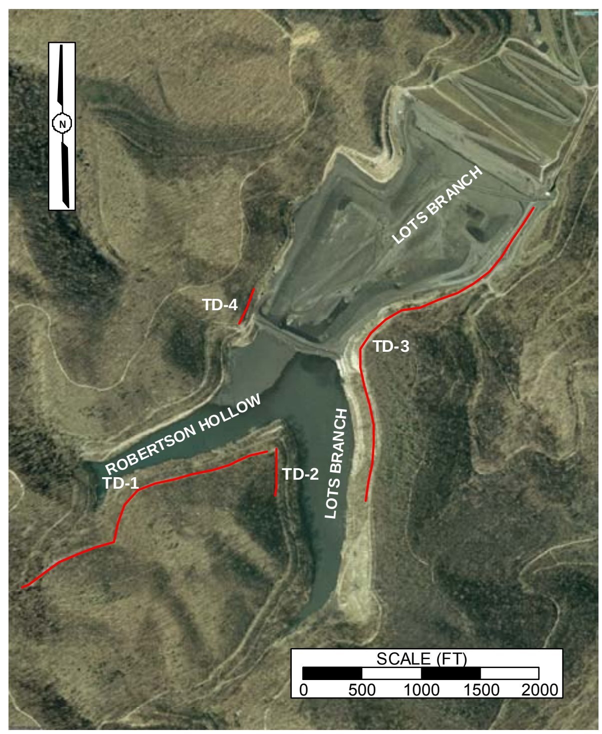
LIST OF FIGURES

DAPPOLONIA

DEMONSTRATION PROJECT - MINE VOID DETECTION
TIME DOMAIN ELECTROMAGNETIC (TDEM)
SURFACE GEOPHYSICAL METHOD
LOTS BRANCH TAILINGS IMPOUNDMENT SITE
PRENTER, WEST VIRGINIA

EXECUTIVE SUMMARY

This Report presents the results of the results of a demonstration project of the Time Domain Electromagnetic (TDEM) surface geophysical method and the subsequent verification of the geophysical interpretation based on borings and imaging of parts of mine workings within the Lewiston Coal at the Lots Branch tailings impoundment site in Prenter, West Virginia. TDEM is a technique that offers the possibility of deriving electrical cross sections of the ground. The TDEM measurements were conducted as a companion technique to a DC resistivity survey, which also results in the mapping of electrical cross sections. The overall concept exploited for both techniques is that mine workings can be identified on the basis of conductive mine water, which will stand out as being more conductive than natural ground.



Lots Branch coal refuse facility with location of TDEM survey lines

The Lewiston Coal is the seam that outcrops in the portion of the valley that will eventually be filled with fine tailings (fine coal refuse slurry). Knowledge of the mining within this seam was known on the basis of mine maps. Further refinement in terms of relating the mine maps to the ground surface was obtained using a downhole laser imaging system developed by Carnegie Mellon University and commercialized by Workhorse Technologies, Inc. of Braddock, PA.

This demonstration project focused on the ability to detect mine workings which may be in close proximity to an impoundment, where the potential for a breakthrough of tailings into the workings exist. In such a setting, the continuity and width of coal barriers are critical parameters in the subsequent engineering evaluation of the potential for a breakthrough. The TDEM geophysical method offers a surface technique which can detect underground voids using portable equipment which could readily be deployed at a mine site.

The Lots Branch impoundment is approximately 100 acres in size with a depth of impounded fine refuse of nearly 200 feet. The impoundment is situated in the central portion of Lots Branch and extends upstream and includes Robertson Hollow. Future development of the impoundment is planned to result in disposal of fine refuse slurry above the level of the Lewiston coal seam, which has been underground mined throughout the perimeter of the impoundment, a length of approximately 15,000 feet. Thus, the presence and continuity of the outcrop coal barrier is a factor in evaluating the potential for impoundment breakthrough to the abandoned mine workings. A geophysical method such as TDEM has the potential to be an effective tool to gather information on the coal barrier and mine voids. Considering that the project objectives included distinguishing between mined and un-mined areas, the smallest target of the geophysical method is an entry (void in the shape of a tunnel) of the order of 15- to 25-feet in width and about 6-feet in height, or parallel entries separated by coal pillar(s) which could represent a target of approximately 75-feet in width. Areas of more extensive mine workings represent a larger target. If the mine voids are sufficiently conductive as a result of mine water, they represent a significant contrast in conductivity relative to the intact rock.

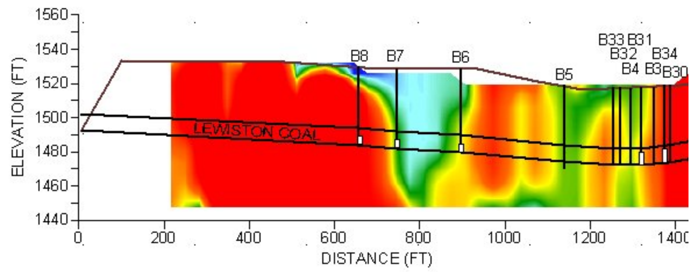
The TDEM survey was conducted with a PROTEM-47 system with a 5-meter multi-turn transmitter loop manufactured by Geonics Limited. Four profiles were obtained over mined areas in the Lewiston seam. The setup of the TDEM measurement system was designed to yield resistivity through and beneath the Lewiston Coal, typically at a depth of 40 to 60 feet.

The TDEM measurements were conducted along existing access roads located over coal barriers and workings of the Lewiston seam at the impoundment perimeter. The alignment of mine entries that extend to the outcrop of the coal seam are approximately perpendicular to these access roads, and thus underlie the TDEM line and can be represented as a two dimensional target. Other mine workings are adjacent the TDEM line, and tend to be concentrated on only one side of the line. These conditions introduce three dimensional aspects to the survey. Upon processing of the TDEM data, 2-dimensional (2D) profiles are developed showing the variation in resistivity of subsurface materials along the survey line. The stratigraphy of the overburden and coal is generally in continuous layers, interrupted by mine workings. Accordingly, the 2D profiles are interpreted by evaluating resistivity anomalies and variations. Among the causes of such anomalies and variations include conductive mine water either in flooded workings or along entry floors that can result in resistivity "lows," or non-conductive dry air which can result in resistivity "highs" relative to the coal and overburden strata. Based on theoretical considerations, it was anticipated that the TDEM measurements would be able to detect wet or flooded workings, which underlie the survey line or may be located adjacent to the line, but the detection of anomalously high resistivity that could indicate the presence of dry workings would probably not be practical.

The test profiles were located to traverse mine workings in the Lewiston Coal under varying degrees of flooding. The Lewiston Coal seam ranges in thickness from about 4 to 6 feet and dips to the northwest at about 1.5 degrees. As such, the mine workings on the north side of the impoundment dip away from the valley wall and are dry. The workings on the south side of the valley dip towards the impoundment and mine water seeps into the valley. Flooded or partially flooded workings were expected to be encountered where mine workings terminate at barrier coal on the southern edge of the impoundment. Thus the TDEM survey lines were primarily located on this side of the impoundment. The actual degree of flooding would depend on the efficiency of the natural drainage barrier along these mine workings or if a constructed drainage is present.

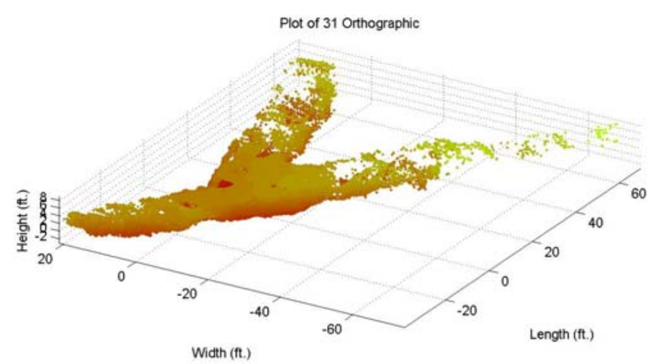
These probable differences in flooding allow for the Lots Branch site to be grouped into three basic areas, as discussed below.

Southern side of Robertson Hollow



Results of portion of profile TD-1 on the southern side of Robertson Hollow – a pronounced resistivity low centered at 800 feet corresponds to known workings, but there is poor depth resolution. The results are suggestive of workings between about 1150 and 1300 feet where the coal is at a low point and where previously unknown workings were confirmed to exist on the basis of laser imaging. The color-coding is depicted in terms of a rainbow spectrum with blue being low resistivity and red being high, shown to a maximum of 1000 ohm-meters. All illustrations in this introductory summary are color-coded the same. Borings encountering void or gob are shown with white rectangles at the level of the coal. The top and bottom of the coal are depicted in the cross sections based on the results of the exploratory borings (e.g., B7 is Boring B7, which indicated a mine void at the base of the coal).

The southern side of Robertson Hollow was surveyed with two TDEM Profiles TD-1 and TD-2. Based on the dip of the coal seam and the mine map, TD-1 was anticipated to encounter flooded or partially flooded workings while TD-2 was expected to be close to these workings. These profiles depict conditions similar to the results of the DC resistivity surveying over the same locations, except that the TDEM results do not have the same vertical resolution. The TDEM results appear to indicate the presence of a resistivity lows suggestive of at least partially flooded mine workings where such workings are mapped. In the area of the known entry, the results indicate that relatively low resistivity values are located east of the entry, rather than at the entry itself, similar to the DC resistivity results. This discrepancy is interpreted to be due to the observation that the point of water accumulation within the mine would be east of the entry, rather than the entry and

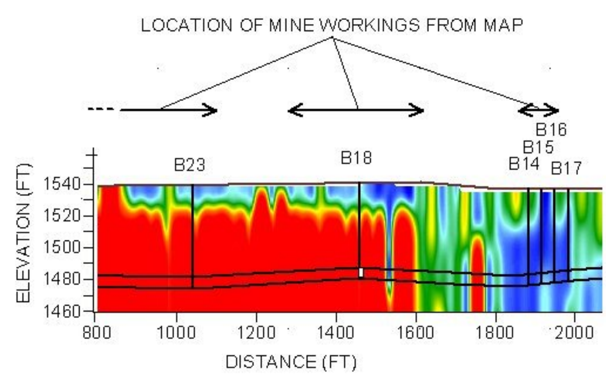


Laser image of a concealed mine entry with a previously unknown tunnel penetrated by Boring B31 and surveyed by Workhorse Technologies is suggestive of a drainage hole and/or undocumented workings in this area.

Exploration borings and the laser imaging provide confirmation of the location of the two entry tunnels indicated on the mine map, which allow for the definition of 140 feet of open tunnel associated with the northern entry and 80 feet of tunnel associated with the southern entry. In addition, the results image 80 feet of an unknown tunnel extending from the northern entry towards the east. This is the same area that the TDEM and resistivity results indicate anomalously low resistivity values at the level of the Lewiston Coal.

The southern side of Lots Branch

The southern side of Lots Branch is another area where it was anticipated that the mine workings would be at least partially flooded. The actual TDEM results are not suggestive that flooded workings are present, similar to the results from the DC resistivity surveying. This may be due to the workings being well drained. Where observed in the field, a mine entry located at the down dip area of the survey appeared to exhibit limited seepage or be dry at the time of the survey. One boring that encountered mine workings (B18) and all borings that encountered solid coal in this area were observed to be dry to the level of the Lewiston seam. The TDEM results define a resistivity low centered where borings were drilled in an attempt to hit a concealed opening, but this low is much broader than would be expected from the mapped size of the entry. The overall observation from the data sets is that under relatively dry mine conditions electrical measurements with the TDEM technique would not be suitable for defining a correlation of the mine map to the ground surface.



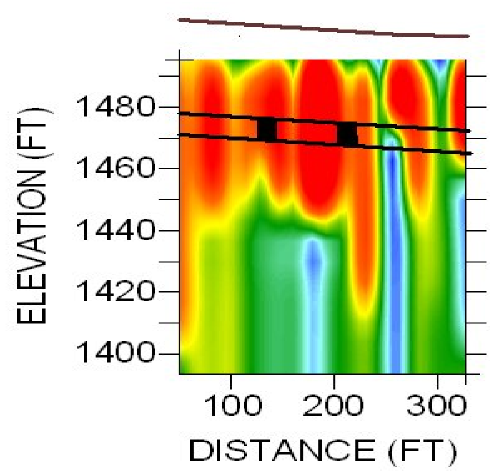
Results of portion of profile TD-3 on the southern side of Lots Branch – a pronounced resistivity low centered at 1900 feet corresponds to known workings, but the borings did not encounter the mapped workings and it is not known if water is present in the mine at this location.

The northern side of Robertson Hollow merging into the northern side of Lots Branch

TDEM surveying in this area was restricted to a single profile because it was anticipated that in this area mine water would tend to drain away from the coalcrop and the workings would be dry. Dry workings were not expected to be visible based on any types of EM measurements, which basically respond to conductive zones. Nevertheless it did prove possible to identify relatively dry workings with DC resistivity measurements and it was thought that there might be an observable contrast between an air void and the surrounding rock. The TDEM indicate that high resistivity values are present at the level of the Lewiston Coal, but it is not practical to distinguish the entries.

The basic conclusion from the results of the TDEM surveying is that the technique is of limited usefulness unless the workings are flooded. Forward modeling and experience at an alternative site (Weisner Hollow impoundment in Jefferson County, PA) illustrates the capability of TDEM to detect and map flooded workings. Low resistivity anomalies are indicated with horizontal and vertical resolution when mine workings under flooded conditions represent conductive zones.

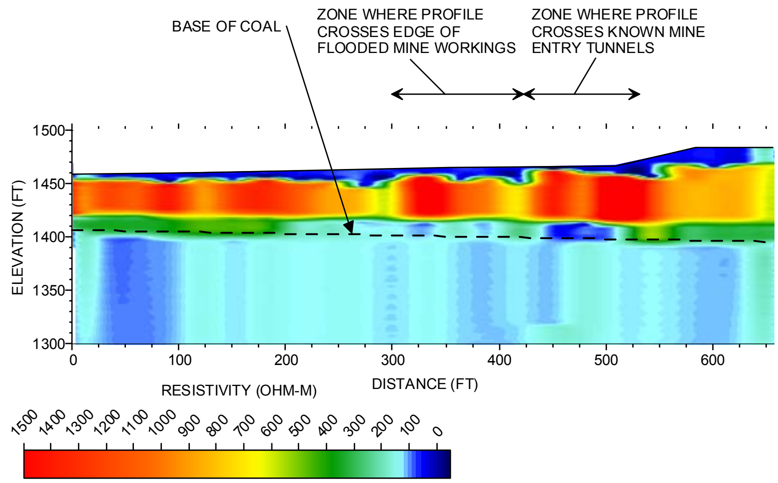
At the Lots Branch site the results do depict a general relationship with the results of the DC resistivity surveying, but the TDEM measurements do not have the same degree of depth resolution. The TDEM measurements identified a zone of relatively low resistivity east of the mapped entry on the south side of Robertson Hollow, where DC resistivity results also suggested the presence of partially flooded mine workings confirmed to exist by the laser imaging conducted by Workhorse Technologies. Where workings are dry, the TDEM results depict a general high resistivity, but the individual workings do not stand out from the overall high resistivity



Results of portion of profile TD-4 on the northern side of Lots Branch – the dry entries in the Lewiston seam shown in black are not distinguishable from the coal at this location.

associated with the Lewiston Coal and surrounding sandstone.

The best application of the TDEM technique based on the findings from Lots Branch site and the Weisner Hollow impoundment site appears to be where workings are fully flooded and where surface constraints and/or depth restrict the application of the DC resistivity technique. Based on theoretical forward modeling, TDEM appears to be capable of "seeing" deeper than the DC resistivity measurements. Field confirmation of the ability of the TDEM technique to image such deep, flooded workings still remains to be obtained.



Results of TDEM measurements taken over fully flooded mine workings at a coal refuse facility located at Weisner Hollow in Jefferson County, PA. In this case, the workings traversed by the TDEM profile are clearly delineated.

FINAL REPORT
DEMONSTRATION PROJECT - MINE VOID DETECTION
TIME DOMAIN ELECTROMAGNETIC (TDEM)
SURFACE GEOPHYSICAL METHOD
LOTS BRANCH TAILINGS IMPOUNDMENT SITE
PRENTER, WEST VIRGINIA

1 INTRODUCTION

This Report presents the results of the results of a demonstration project of the Time Domain Electromagnetic (TDEM) surface geophysical method and the subsequent verification of the geophysical interpretation based on borings and imaging of parts of mine workings within the Lewiston Coal at the Lots Branch tailings impoundment site in Prenter, West Virginia (Figures 1 and 2). The Lewiston Coal is the seam that outcrops in the portion of the valley that will eventually be filled with fine tailings (fine coal refuse slurry), as shown in a sectional view on Figure 3. In addition to the TDEM surveying, DC resistivity surveying was also conducted. The results of the DC resistivity measurements are presented in a separate report (D'Appolonia, 2006), although some of the results of the resistivity survey are also included in this report for the purpose of comparison with the TDEM results. Imaging of portions of the mine workings was obtained using a downhole laser system developed by Carnegie Mellon University and commercialized by Workhorse Technologies, Inc. of Braddock, PA.

This demonstration project focused on the ability to detect mine workings which may be in close proximity to an impoundment, where the potential for a breakthrough of tailings into the workings exist. In such a setting, the continuity and width of coal barriers are critical parameters in the subsequent engineering evaluation of the potential for a breakthrough. The TDEM geophysical method offers a surface technique which can detect underground voids using portable equipment which could readily be deployed at a mine site. The objectives of applying the geophysical method at a mine demonstration site included:

- Detection of mine workings interpreted from resistivity anomalies associated with a contrast between the mine environment and intact rock.

- Mapping of mine entries if sufficient resolution of the resistivity results can distinguish separate individual targets such as two entries separated by a coal pillar.

- Assessment of the continuity of coal barrier pillars through interpretation of intact rock resistivity.

A mine map was available to aid in the design of the geophysical program, providing a general location and depth for the investigation of voids. An exploration drilling and mine void imaging program was incorporated into the project to assist in validation of the results of the geophysical surveys.

The project consisted of the following tasks:

- A Work Plan was prepared presenting the proposed location and limits of the geophysical surveys on the Lots Branch impoundment, along with survey procedures, the exploration drilling program to verify the surveys, and special access and safety requirements. Prior to preparation of the Work Plan, short test surveys were performed to help establish procedures and view potential results from the TDEM method. This initial TDEM survey was inconclusive because of an instrument malfunction, but this malfunction allowed for improved measurement procedures to be defined to avoid similar difficulties during the main survey. The work Plan was submitted in April 2005.

- The main geophysical survey was performed in May 2005 and consisted of four profiles covering slightly more than 6,000 feet of line. Concurrent with the geophysical surveying, location and elevation surveys were performed to accurately locate the traverses, mine entries, coal outcrop, and mine discharges.

- The TDEM, together with the DC resistivity surveying conducted in parallel, were processed and interpreted to identify resistivity anomalies for comparison with the available mine map and for targeting confirmatory borings.

- A drilling program was prepared and implemented consisting of four cored holes to retrieve samples for characterization of the site stratigraphy, and 24 air rotary borings to explore coal seam and mine conditions for verification of the geophysical surveys. As part of the exploration program, the larger mine voids encountered were subjected to laser imaging to identify entry alignment and dimensions.

The TDEM survey was conducted with a PROTEM-47 system with a 5-meter multi-turn transmitter loop manufactured by Geonics Limited. As shown on Figure 2, four profiles were obtained over mined areas in the Lewiston seam. The setup of the TDEM measurement system was designed to yield resistivity through and beneath the Lewiston Coal, typically at a depth of 40 to 60 feet.

The test profiles were selected to take advantage of access accounting for terrain and alignment constraints, as well as mine equipment (haul truck) interference. The profiles were also located to traverse mine workings in the Lewiston Coal under varying degrees of flooding. The Lewiston Coal seam ranges in thickness from about 4 to 6 feet and dips to the northwest at about 1.5 degrees (Figures 3 and 4). As such, the mine workings on the north side of the impoundment dip away from the valley wall and are dry. The workings on the south side of the valley dip towards the impoundment and mine water seeps into the valley. Flooded or partially flooded workings were expected to be encountered where mine workings terminate at barrier coal on the southern edge of the impoundment. These probable differences in flooding allow for the Lots Branch site to be grouped into three basic areas:

- The southern side of Robertson Hollow – in this area mine workings were expected to be at least partially flooded.

- The southern side of Lots Branch – in this area the workings were expected to be at least partially flooded. One mine entry is exposed on this side of the valley.

- The northern side of Robertson Hollow merging into the northern side of Lots Branch – in this area the workings were expected to be dry.

Thus the TDEM survey lines were primarily located on of the southern side of the impoundment, where abandoned workings had a higher probability of being flooded. The actual degree of flooding would depend on the efficiency of the natural drainage barrier along these mine workings or if a constructed drainage is present.

Subsequent sections of this report present the theory of the TDEM method (Section 2), the basic background of the Lots Branch site (Section 3), field procedures covering the geophysical surveying, as well as the drilling and imaging of the mine voids (Section 4). Section 5 provides the results of the TDEM surveying with observations regarding the application of the TDEM technique in an environment such as the Lot's Branch Tailings Impoundment. Section 6 provides conclusions and recommendations.

2 BACKGROUND THEORY OF THE TDEM TECHNIQUE

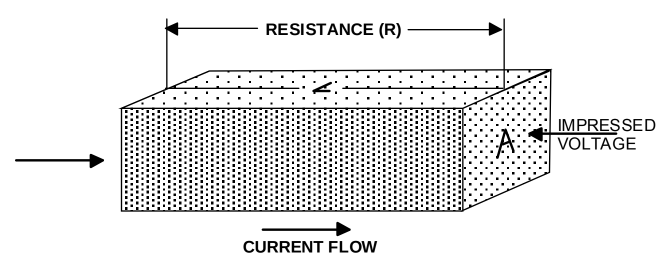
The starting point of any geophysical investigation must be basic physics. Geophysics will be effective only if a target of interest has a physical contrast with the surrounding ground. For example, a mine entry containing metal tracks could be an easy target for a magnetic survey, but if the tracks are not present, the magnetic contrast of the entry might be too subtle to measure. Another important consideration is if the geophysical contrast of the target can be distinguished from other features with similar contrasts – what geophysicists call the signal to noise (S/N) ratio. A mine entry might be relatively easy to identify with a gravity survey that can detect a void space as a zone of low density, but if the target is located in an area of rugged topography, the errors associated with the topographic corrections can easily mask the response from the mine workings. Notwithstanding the above difficulties, mine workings can be associated with measurable physical contrasts.

Conventional DC resistivity techniques have been applied for many years to a variety of geotechnical applications based on their ability to measure the distribution of subsurface materials with different electrical properties. More recently, electromagnetic (EM) techniques, with different advantages (and disadvantages) compared with conventional DC resistivity, have been used effectively to measure the resistivity of the earth.

The purpose of making electrical measurements of the subsurface is to determine the subsurface resistivity distribution of the ground, which can then be related to physical conditions of interest such as lithology, porosity, the degree of water saturation, and the presence or absence of voids in the rock. The basic electrical measurement parameter is resistivity. Resistivity is not to be confused with resistance. Resistance (R), measured in ohms, is the result of an electrical measurement, where according to Ohm's Law:

$$V = IR \text{ or } R = V/I$$

where V = voltage in volts and I = current in amps.



Sketch of parameters to define resistivity

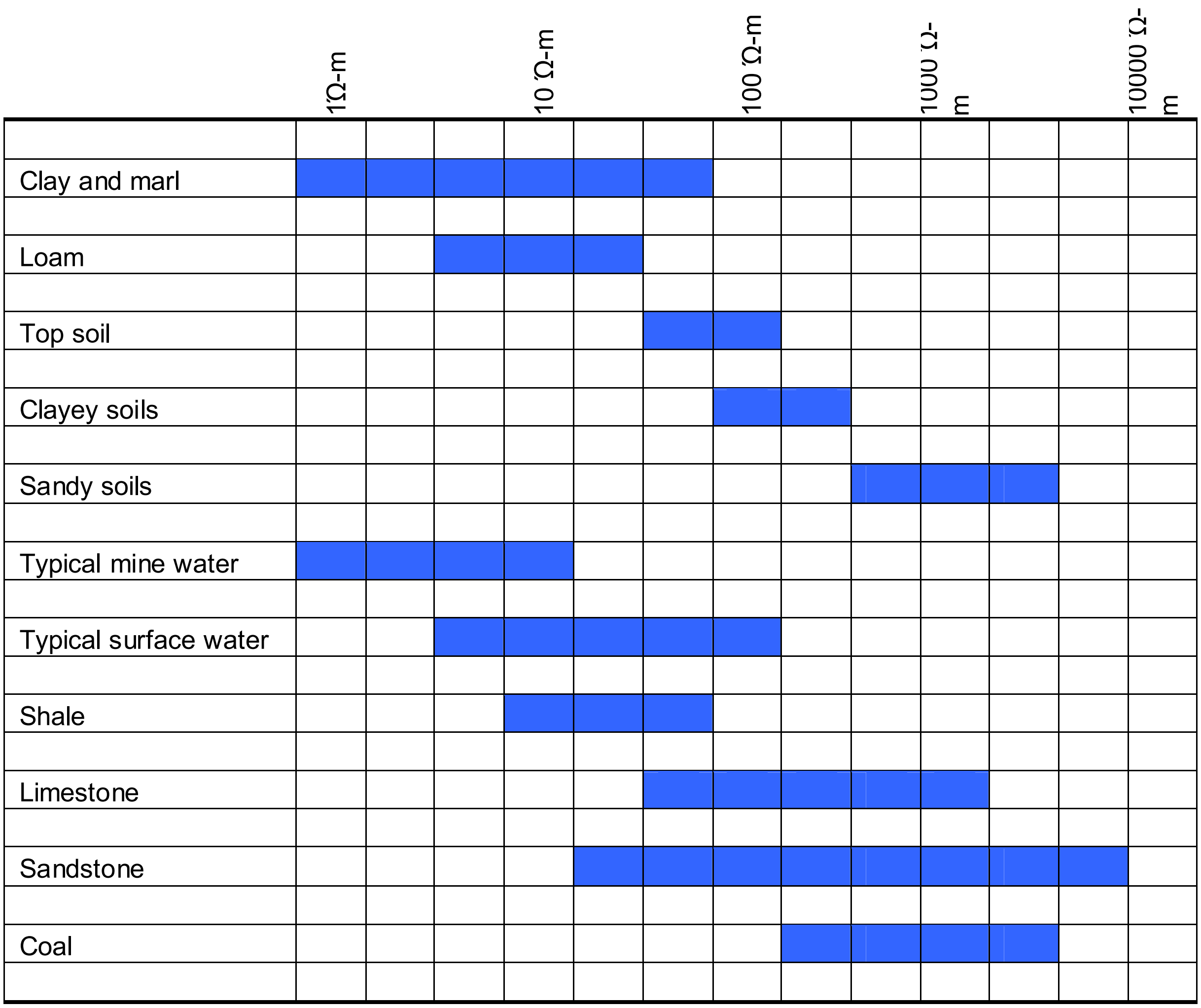
Resistivity of a material is a fundamental physical property related to the ability of a material to conduct electricity. If R is the resistance of a block of conductive material having length L and cross-sectional area A (see sketch), then resistivity is given as:

$$\rho = RA/L$$

The time domain electromagnetic (TDEM) technique, along with most electromagnetic (EM) methods, was developed to locate areas of high conductivity and its measurements are normally given in units of conductivity. Resistivity and conductivity are different ways to describe the same physical property and are simply the inverse of one another, and resistivity is used in this report. The unit used to measure ground resistivity for this demonstration project is the ohm-meter (ohm-m). The corresponding unit of conductivity would then be the inverse of an ohm, referred to as a mho, or Siemen, per meter or S/m. The term "mho," which is a term that reflects its inverse relationship to the ohm, was discontinued in favor of the term "Siemen" in the late 70s. The most common unit of conductivity is the µS/cm, which is 0.0001 S/m. With this conversion, 10,000 µS/cm = 1 S/m = 1 ohm-m. 500 µS/cm corresponds to 20 ohm-m. For the purpose of this demonstration and to be able to compare the TDEM and DC resistivity results in an "apples to apples" sense, results are presented in ohm-m.

Coal itself usually has a high resistivity compared to other sedimentary rock types (Table 1). This property has formed the basis for detecting coal from borehole logs and the measurement of the electrical variations in the ground have been used as a tool for exploring for coal as early as 1934 (Ewing et al., 1936). Several studies have demonstrated that the electrical variations associated with mine voids can be used as the basis for mapping underground workings (Johnson, 2003a,b; Johnson and Snow, 2002; and Johnson, Snow and Clark, 2002). Mine water with conductivity in the range of typical surface water could be about 500 µS/cm (20 ohm-m). If the mine water is more acidic, the conductivity could approach 5,000 µS/cm (2 ohm-m). In either case, the contrast between a flooded or even a partially flooded mine compared to a typical coal resistivity of 500 to 1,500 ohm-m will approach two orders of magnitude. Mine water within fractures such as from roof collapse may affect the resistivity of rock surrounding the workings. This may make the volume of the workings appear somewhat larger and could make them more detectable. It is unlikely that it will decrease the resistivity of the rock to a point where is could be misinterpreted as open workings. In the case of the Lot's Branch site, the average conductivity of ground water from the Lewiston Coal based on the results of the boring program is about 800 µS/cm, which corresponds to an average resistivity of about 12 ohm-m, although the overall variability is large, with the range in conductivity measured to range from as low as 100 µS/cm (100 ohm-m) to greater than 2,000 µS/cm (5 ohm-m).

TABLE 1 – TYPICAL RANGE OF EARTH MATERIALS IN OHM-METERS

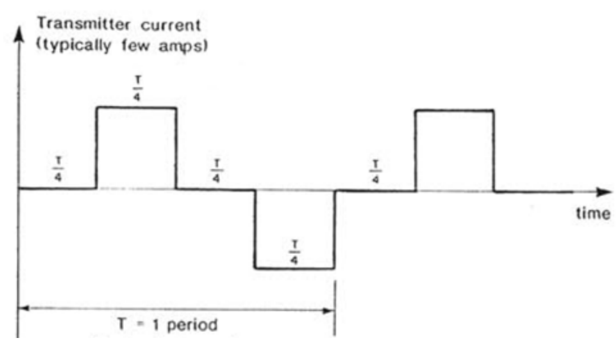


modified after Benson (1988)

The detection of voids depends on whether or not the void has a physical contrast with the surrounding rock. If the void is dry, the void will be difficult to detect with electrical measurements. Air does not transmit an electrical current, but unless the coal is of an unusually low resistivity, it could be difficult to distinguish high-resistivity coal from a void.

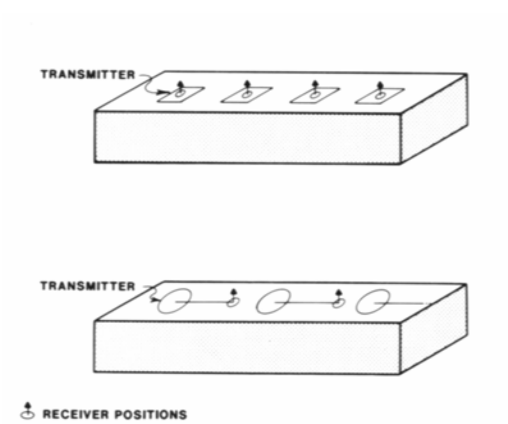
Background of TDEM Measurements

Electromagnetic techniques can be broadly divided into two groups, frequency domain (FDEM) and time domain (TDEM). In frequency-domain instrumentation the transmitter current varies sinusoidally with time at a fixed frequency which is selected on the basis of the desired depth of exploration of the measurement (high frequencies result in shallower depths). In most TDEM instrumentation the transmitter current, while still periodic, is a modified symmetrical square wave, as shown here. It is seen that after every second quarter-period the transmitter current is abruptly reduced to zero for one quarter period, whereupon it flows in the opposite direction.



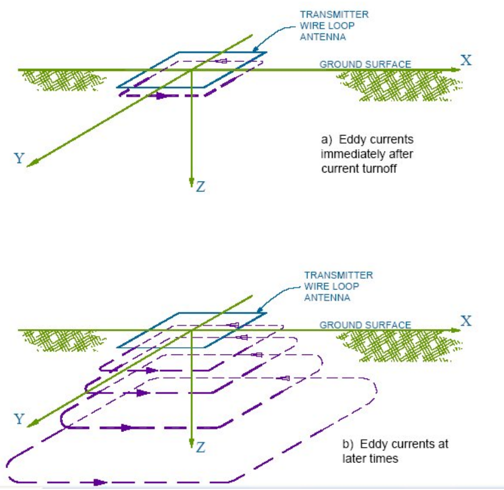
TDEM transmitter current waveform

TDEM offers advantages over FDEM because of greater exploration depth, better depth resolution, and less noise. Recent work by the DOE (Hammack, 2003) for mapping of abandoned mine workings also made this observation. The TDEM may also offer advantages over DC Resistivity by penetrating to deeper depths, as determined by forward modeling performed for this study and discussed subsequently.



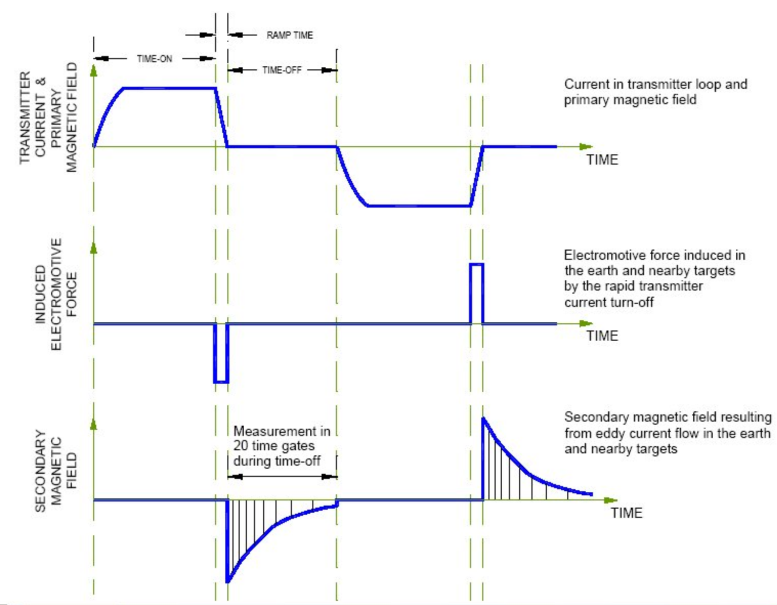
Typical TDEM survey configurations

Two different TDEM resistivity sounding survey configurations that can be used are shown here. In one case the receiver is located in the center of the transmitter loop and in the other the receiver is at a fixed distance outside the transmitter loop. When using a multi-turn transmitter loop, the manufacturer recommends that the receiver is outside the transmitter.



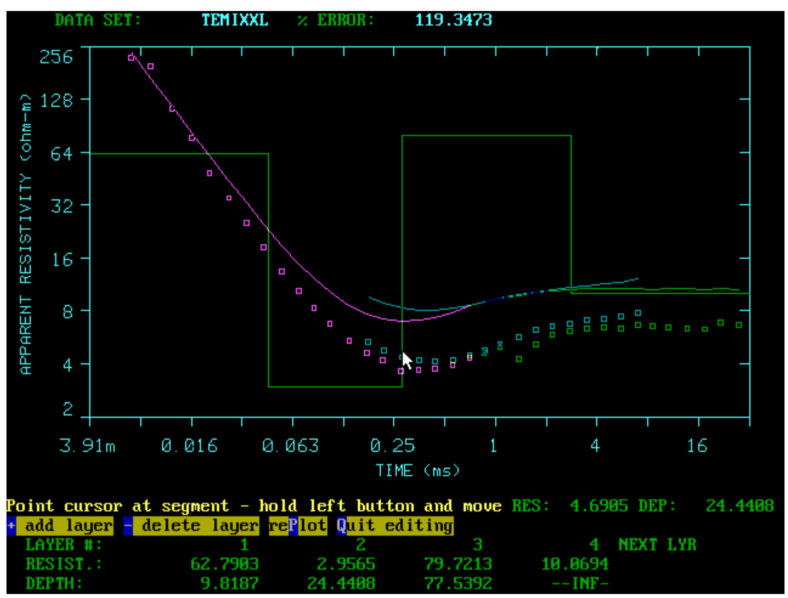
Progression of current flow (from McNeill, 1990)

The principles of TDEM resistivity soundings can be easily understood. The process of abruptly reducing the transmitter current to zero induces, in accord with Faraday's law, a short duration voltage pulse in the ground, which causes a loop of current to flow in the immediate vicinity of the transmitter wire. Immediately after the transmitter current is turned off, the current loop can be thought of as an image in the ground of the transmitter loop. The amplitude of the current starts to decay immediately because of finite ground resistivity. This decaying current similarly induces a voltage pulse which causes more current to flow, but now at a larger distance from the transmitter loop, and also at greater depth. This deeper current flow also decays due to finite resistivity of the ground, inducing even deeper current flow and so on. The amplitude of the current flow as a function of time is determined by measuring its decaying magnetic field using a small multi-turn receiver coil. By making measurement of the voltage out of the receiver coil at successively later times, measurement is made of the current flow and thus also of the electrical resistivity of the earth at successively greater depths, which process forms the basis of resistivity sounding in the time domain (Hoekstra and Blohm, 1990; McNeill, 1994).



Transmitter and corresponding receiver voltage (from McNeill, 1990)

The output voltage of the receiver coil is shown schematically along with the transmitter current. To accurately measure the decay characteristics of this voltage the receiver contains 20 narrow time gates, each sequentially recording the amplitude of the decaying voltage at 20 successive times. Note that, to minimize distortion in measurement of the transient voltage, the early time gates, which are located where the transient voltage is changing rapidly with time, are very narrow, whereas the later gates, situated where the transient is varying more slowly, are much broader. This technique is desirable as wider gates enhance the signal-to-noise ratio, which becomes smaller as the amplitude of the transient decays at later times. It will be noted above that there are four receiver voltage transients generated during each complete period (one positive pulse plus one negative pulse) of transmitter current flow. Nevertheless, measurement is made only of those two transients that occur when the transmitter current has just been shut off, as in this case accuracy of the measurement is not affected by small errors in location of the receiver coil. This feature offers a very significant advantage over frequency domain measurements, which are generally very sensitive to variations in the transmitter coil/receiver coil spacing given that the frequency domain receiver measures while the transmitter current is flowing. Finally, particularly for shallower soundings, where it is not necessary to measure the transient characteristics out to very late times, the period is typically of the order of one millisecond or less, which means that in a total measurement time of a few seconds, measurement can be made and stacked on several thousand transient responses, which is important because the transient response from one pulse is exceedingly small and it is necessary to improve the signal-to-noise ratio by adding the responses from a large number of pulses (McNeill, 1994).



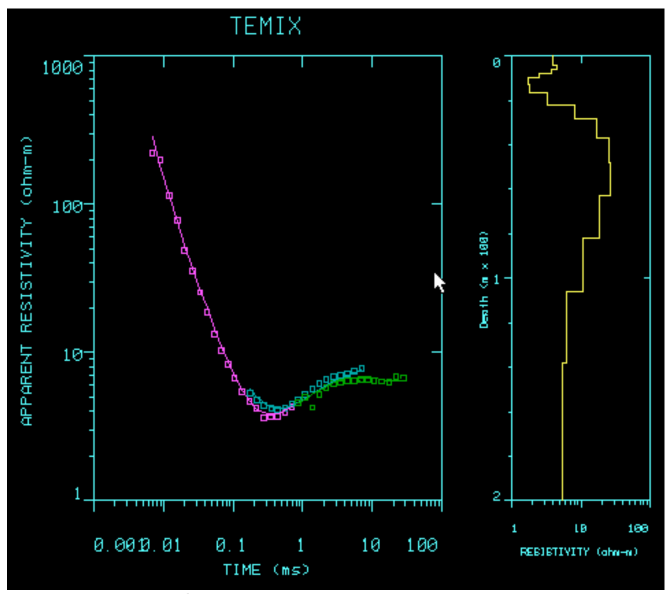
First step in TDEM interpretation with TEMIX – developing theoretical models to obtain a best fit to the field data

The data from a resistivity

sounding consists of a series of values of receiver output voltage at each of a succession of gate times. These gates are located in time typically from a few microseconds up to tens or even hundreds of milliseconds after the transmitter current has been turned off, depending on the desired depth of exploration. The receiver coil measures the time rate of change of the magnetic field e(t)=dB/dt, as a function of time during the transient. Properly calibrated, the units of e(t) are volts per m^2 of receiver coil area, but because the measured signals are extremely small it is common to use nanovolts per m^2, and measured decays typically range from many thousands of nV/m^2 at early times to less than 0.1 nV/m^2 at late times. Modem receivers are calibrated in $nV/\ m^2$ or V/m^2 and to check the calibration a “Q-coil”, which is a small short-circuited multi-turn, coil laid on the ground at an accurate distance from the receiver coil, can be used to provide a transient signal of known amplitude. (McNeill, 1994) This procedure was followed at Lots Branch to calibrate the readings made during the main survey.

TDEM Interpretation

In the early days of TDEM sounding, particularly in Russia where the technique was developed, extensive use was made of numerically calculated apparent resistivity curves for a variety of layered earth geometrics. The field data would be compared with a selection of curves, from which the actual geoelectric section would be determined.



Interpretation of a single TDEM sounding with TEMIX – the interpretation of multiple soundings forms the basis for generating a geo-electrical cross section

More recently, the advent of relatively fast computer inversion programs such as TEMIX by INTERPEX Limited of Golden, Colorado (or their newer Windows version IX1D) allow the field transient data to be automatically inverted to a layered-earth geometry in a matter of seconds. Inverse modeling allows the interpreter to obtain a model that best fits the data in a least squares sense. This is done using ridge regression to iteratively adjust the parameters of a starting model supplied by the user. The INTERPEX software generates a layered earth model at each of the sounding locations. A series of soundings along a line are used to create a series of layered-earth soundings that are used to generate a 2-dimensional geo-electric cross section. The data from the cross-section are used by Surfer to create the color image plots presented in this report.

Forward modeling of coal mine workings offers the possibility of determining the TDEM measurements that would theoretically be made in the field, considering the two dimensional target of an entry. The MOTEM program developed by Geonics offers the possibility of calculating theoretical measurements for a limited number of different subsurface conditions that can then be used as a basis for evaluating the probability of success for detecting mine voids. The results depict what electrical cross sections should look like for different subsurface conditions. These theoretical electrical profiles can then be compared to real-world profiles and facilitate the interpretation of real subsurface conditions. A discussion of forward modeling with a comparison to actual case histories is presented in Appendix B.

Project experience with TDEM measurements presented in Appendix B demonstrates that commercially available technology has been successful at a site with flooded workings. While site specific geologic conditions will influence the effectiveness of the method, the modeling suggests that the TDEM technique could be effective for mapping flooded workings deeper than about 100 feet in settings similar to the eastern coal fields. The technique could have significant advantages over the DC resistivity method where the required length of the resistivity profile to acquire deep images is often limited by surface interference.

3 SITE BACKGROUND

The Lots Branch tailings impoundment is currently being developed by the Pine Ridge Coal Company (a Division of Peabody Energy). The proposed elevation of fine coal refuse is at Elevation 1495 feet, which will cover exposed workings of the Lewiston Coal seam (Figures 2 and 3). The Lewiston seam was underground mined from the 1930s through the 1950s and is found at an elevation of about 1540 feet near the upstream limits of the impoundment to about Elevation 1460 near the northwest abutment of the embankment. Approximately two-thirds of the overall area of the tailings impoundment will eventually cover the Lewiston Coal. The general dip of this seam is about 1.5 degrees towards the northwest (Figure 4) and the seam ranges in thickness from about 4 to 6 feet.

Geologically, the Lewiston Coal (also called the Stockton – Lewiston Coal) is part of the Pennsylvanian age Kanawha Series and is overlain by the Homewood Sandstone and underlain by the Coalburg Sandstone, also of the Kanawha Series. Shale is often encountered immediately above and below the Lewiston Coal. The Homewood Sandstone is consistently present as a massive, competent unit in all of the borings. In most cases shale and coal are interbedded immediately above the main portion of the Lewiston seam and this upper coal may or may not have been removed during the mining process, depending on its thickness. Appendix C provides the boring logs from the coreholes and air rotary borings.

Chemical testing consisting of pH, conductivity and temperature measurements was conducted if water was encountered during drilling, as well as from seeps and surface water. Table 2 presents these results. The pH varies from 4 to 7 and the conductivity ranges from 100 µS/cm to >1,990 µS/cm.

The mine map of Lewiston Coal workings was provided by Pine Ridge Coal Company as presented in a permit application prepared by Alliance Consulting, Inc. One of the goals of this investigation was to verify the fit of the mine map to the ground surface and this was achieved by surveying exposed entries and also from the results of mine imaging conducted by Workhorse Technologies.

TABLE 2 – RESULTS OF CHEMICAL TESTING FROM BORINGS, SEEPS AND SURFACE WATER

Boring or other identified location	*Specific conductance (µmho/cm)*	*pH*	*Temp-erature (ºF)*	*Depth of GW from surface (ft)*	*Depth of GW (ft)*	*Comments*
B1						Corehole, caved at 7.1 ft
B2	790	7	68	46.15	2.95	Opaque with coal fines
B3	1020	6	68	42.2	4.9	Opaque with coal fines
B4	1250	6	62	42.2	4.9	Opaque with coal fines
B5				32.1		Corehole, caved at 5.7
B6	1420	5	68	42.1	3.4	Opaque with coal fines
B7				40.9	0.3	Caved at 41.2
B8	> 1990	5	68	40.85	2.26	Opaque with coal fines
B9	310	6	71	45.35	3.0	Gray color
B11						Dry
B12						Dry
B13				40.6	0.1	Caved at 40.7 ft
B14						Dry
B15						Dry
B16				33.3		Corehole- Water level not representative of water in Lewiston Coal
B17						Dry
B18						Dry
B20	140	6	61	46.95	2.55	Clear
B22	100	6	63	45.06	0.75	Black
B23	410	6	59	65.33	1.87	Opaque with coal fines
B25				38.7	0.1	
B28						Dry
B29						Corehole, caved at 7.1 ft
B30	320	6	68	42.55	2.55	Opaque with coal fines
B31						Dry
B32	1020	6	59	39.7	1.05	Opaque with coal fines
B33	1060	6	59	39.25	2.08	Opaque with coal fines
B34				42.5	0.2	Caved at 42.7

TABLE 2 – Continued

Boring or other identified location	*Specific conductance (μmho/cm)*	*pH*	*Temp-erature (ºF)*	*Depth of GW from surface (ft)*	*Depth of GW (ft)*	*Comments*
Impoundment water	600	6		n/a	n/a	Measured at two location in impoundment
Entry "D"	530	6		n/a	n/a	Estimated flow 1-2 gpm in 5/05
Seep 19m west of Line CC-1	130	5		n/a	n/a	Measurement made from point ~ 12 ft below Lewiston Coal
Seep along Line CC-1, 450 ft from west end	960	5		n/a	n/a	From Lewiston Coal, flow estimated at 40-50 gpm in 5/05
Seep along Line CC-1, 525 ft from west end	1380	4.5		n/a	n/a	From Lewiston Coal, flow estimated at 100-120 gpm in 5/05 and combines seepage from 450 and 558 ft
Seep along Line CC-1, 558 ft from west end	1370	4		n/a	n/a	From Lewiston Coal, flow estimated at 20-30 gpm in 5/05
Seep along Line CC-1, 1280 ft from west end	590	5		n/a	n/a	From Lewiston Coal, flow estimated at 10-20 gpm in 5/05

Within the area of the proposed impoundment, four main entries corresponding to the mine map within the survey area and designated as Entries A, B, C and D (Figure 2) are still open, although they are observed to be partially collapsed. These were surveyed and the results of the imaging from Boreholes B13, B25, B31 and B34 were also incorporated to define a "fit" of the mine map to the ground surface shown on Figure 2. Based on registering the mine map, surveys, and the surface topographic map, the mine map should be shifted 50±5 feet east and 25±5 feet north of the position shown on previous maps, which assume that the coordinate system for the mine map is the same as the modern topographic map. This fit required correcting some distortions in the mine map that were possibly introduced when the mine map was scanned. By slightly rotating the mine map (0.2 degrees clockwise), matching the grid lines to the modern grid lines to make sure that the scale was correct, and then shifting the map to match mine entries and the results of the drilling and imaging program, the final fit was established by shifting the mine map 50±5 feet east and 25±5 feet north of the modern map coordinates. This correlation can be seen on Figure 2 by comparing the surface topographic map grid (shown in black) with the mine map grid (shown in green). It is possible that some further adjustment in the registration of the maps could result from surveying the other entries, but it is expected that the fit of the mine map shown on Figure 2 is essentially correct.

The dip of the coal seam (Figure 4) controls the drainage of mine water. Entries along the eastern side of Lots Branch and the southern side of Robertson Hollow are locations where mine drainage occurs. Unless the coal fracturing allows for good natural drainage or drain holes were installed during mining, it was expected that the mine workings away from these entries could be fully or partially flooded. The borings penetrating mine workings along the eastern side of Lot's Branch or the southern side of Robertson Hollow drilled in September 2005 encountered only limited evidence of water, and the amount of water that may have been present at the time of the geophysical surveying in May 2005 is not known. Nevertheless, at least some water was present in these portions of the mine (generally at lower elevations) at the time of the survey. At the time of the geophysical surveying four seepage points were mapped along the southern side of Robertson Hollow. They are shown in Figure 8 along with resistivity results obtained from experimental DC resistivity Line CC-1, further discussed in the DC resistivity report (D'Appolonia, 2006). The main seep had a flow of more than 100 gal/minute, assumed to originate from a concealed entry. The other seeps were less than about one tenth of the flow of this main seep in May 2005. At the time of the laser imaging in September 2005, the highest flow was less than 10 gal/minute and it may be that there was not enough water in the mine to pond at that time, although water was observed to flow into the bottom of Boring B30, expected to be only a few inches from a dry entry tunnel. For this reason, a drainage system to keep the floor of the mine dry may have been employed on the northern side of the northern entry tunnel based on the observed locations of the mine discharge, the geophysical results, and the laser imaging.

The coal on the northern and western side of Lots Branch dips towards the northwest, away from the valley. The mine workings on this side of the valley are therefore expected to be dry, which is what is generally observed at the exposed entries and also from the borings that penetrated mine voids.

The shape of the Lots Branch Valley is also controlled by the mining of another coal seam located above the Lewiston seam, the Five Block Coal. The Five Block seam is located stratigraphically approximately 30 - 50 feet above the Lewiston. This coal was also underground mined and the workings can be observed where a strip mine bench has been developed along the southeastern side of the tailings impoundment. This strip bench is currently being used as a road for hauling coarse coal refuse to the back of the impoundment. Room and pillar workings and augering of this coal are also observable in the area of Robertson Hollow.

The Five Block Coal has been reported in the past to be on fire. Smoke can be observed to emanate from the ground about 150 feet west of the south end of line TD4 (Figure 2). This situation may influence conditions in the Lewisburg mine workings. Air temperatures in mine voids were noted during drilling as shown in Table 3 and the temperature of groundwater from within the Lewiston Coal is indicated in Table 2.

TABLE 3 – AIR TEMPERATURE RECORDED IN MINE VOIDS

Boring No.	Air Void Thickness (ft)	Elev. Base of Lewiston Coal (ft)	Temperature (ºF)
B6	1.0	1480.16	68
B7	2.2	1491.97	70.2
B8	0.3	1484.17	68
B11	6.7	1463.76	82.1
B13	5.7	1465.21	72.6
B18	4.1	1481.2	66.5
B25	8.0	1462.73	75.4
B31	6.0	1473.8	Not recorded*
B34	5.8	1475.54	Not recorded*

* Temperature of water from B30, immediately next to mine workings penetrated by B31 and B34, was 68 ºF.

Air and groundwater temperatures from the Lewiston Coal are not natural. The boring with the highest recorded air temperature is B11, which is near an observed area of smoke along the Five Block seam. This boring emitted warm, moist air throughout the survey. Warm moist air was also observed to emit from mine openings A, B and C along the western side of Lots Branch.

The Coalburg Coal seam underlies the Coalburg Sandstone beneath the Lewiston seam at approximately El. 1350 – 1370 in this area. This is the coal seam currently being mined. Although this coal outcrops in the Lots Branch valley that has already been filled with tailings, the coal barrier is several hundred feet in width. The closest point of the existing room-and-pillar workings to the tailings impoundment when it is completely full is located in the portion of the impoundment designated as Roberson Hollow (Figure 2) and the workings are greater than 200 feet horizontal distance away. Because of its depth below the ground surface and the fact that the mine is dry, this seam has not been considered a viable target for the geophysical surveying.

The Hernshaw (El. ~924) and Dorothy (El. ~1270) coal seams also exist in the Lots Branch area, but no underground mining is reported for either seam in this area.

The coal refuse disposal plan for the Lots Branch impoundment includes constructing the embankment with a maximum crest level of El. 1530 with a maximum tailings level (fine coal refuse) at El. 1495. Accordingly, the continuity and integrity of the Lewiston seam coal barrier is of interest along a substantial portion of the impoundment perimeter, along with a limited section of the Coalburg seam in the upstream, southern end of the impoundment.

4 FIELD PROCEDURES

The TDEM survey was conducted in two phases using a Geonics PROTEM-47, which uses a TEM-47 transmitter with a PROTEM receiver. An initial survey consisting of three lines was conducted between December 1 -5, 2004. This initial TDEM survey was inconclusive because of an instrument malfunction. Although the measurements appeared in the field to have been properly collected, subsequent processing efforts indicated that good quality data were not obtained and the problem was eventually identified by the manufacturer Geonics as an instrument malfunction.

The main TDEM survey presented in this report took place from May 4 – 20, 2005 and consisted of four survey lines as shown on Figure 2, which were made along portions of the same lines used for the DC resistivity technique. The intent of this procedure was to derive subsurface resistivity profiles. The system was expected to map the extent of the flooded workings on the southeastern side of the Lots Branch site. Based on the results of the geophysical surveying, primarily the results of the DC resistivity surveying presented in a separate report (D'Appolonia 2006), four coreholes and 24 air rotary borings were drilled between September 15 – 21, 2005. Six boreholes encountering mine voids were selected for imaging by Workhorse Technologies. Of these, it was practical to image mine workings from four of these borings between September 19 – 21, 2005. These field efforts are discussed separately.

4.1 TDEM Survey

The TDEM survey presented in this report took place from May 4 – 20, 2005 along four survey lines shown on Figure 2. The equipment used for the TDEM measurements was the Geonics PROTEM-47, which uses a TEM-47 transmitter with a PROTEM receiver. With this system, a multi-turn transmitter loop 5m on a side was moved in tandem with the receiver unit at 5 meter increments along the profile lines. The TEM-47 transmitter coil, which consisted of eight-loops of wire, was laid out on the ground as a five-meter square. The receiver coil, a high-frequency multi-turn receiver coil with an effective area of 100 square meters, was placed on the ground and leveled with a bubble level at a distance of 15 meters in front of the transmitter loop. The separation distance was chosen based on recommendations by the manufacturer, although the measurements are not particularly sensitive to this distance. The transmitter and receiver coils were then connected with a reference cable. The transmitter was set to transmit 2 amps and the receiver was set to make 20 readings at relatively short time increments (12.4 to 162.4 μs) to enhance resolution within approximately the top 30 meters.

At the beginning of each day, a system check was run with a calibration loop (Q-coil) provided by Geonics to verify the accuracy of the field measurements. The Q-coil simulated a precise EM field that can be measured by the receiver such that its operation can be checked. Once the system was verified to be within calibration, the production measurements were made along the profile. After the measurements were obtained along a profile over the course of a day, the data that were recorded in the data logger were transferred to a computer for archiving and additional processing. The first processing step was to convert the data from the default format to a format that could be read by the processing software TEMIX, contained as a component of the software package IX1D written and distributed by INTERPEX Limited of Golden, Colorado. The data from different days were then grouped by line and merged. Data at each station consisted of measurements at each of 20 time channels. These were plotted and measurements that were visibly inaccurate (that is, did not plot along a smooth curve) were deleted from the data set. The deleted data were primarily from the later parts of the decay curve where measured values were very small and in the noise level. The deleted data did not appear to adversely affect the inversion results. A layered earth model was entered and the inversion process was run using the layered earth model as a starting point. The same starting model was used whenever possible, thus providing a more consistent result. The final model data was output in a format that could be used by Surfer to generate colored cross sections depicting the subsurface resistivity distribution.

The data before processing by IX1D is apparent resistivity, which is a direct conversion from the voltage measurements and assumes a uniform half-space. IX1D inverts the apparent resistivity into a layered earth model of calculated layer resistivity that would cause the observed apparent resistivities. The layer resistivity values resulting from the inversion are called simply *resistivity* throughout this report. All the figures were prepared using *resistivity* values and not *apparent resistivity* values.

The overall goal of the geophysical demonstration was to identify the continuity of barrier coal at the outcrop and if there are areas where the data indicate the possibility of encountering unmapped workings within the barrier coal. This was best accomplished by conducting the survey along profiles over the top of and more or less parallel to the line of the barrier coal and the four profile lines were obtained in this manner. This procedure was able to take advantage of the situation that trails and haul roads for impoundment access usually follow along surface contour lines, thus minimizing the need for corrections to be applied to the geophysical data for surface topography. The test profiles were selected to take advantage of access accounting for terrain and alignment constraints, as well as mine equipment (haul truck) interference.

The bulk of the TDEM surveying was conducted at locations where the possibility existed for encountering flooded workings. Based on this assumption, the southern side of Robertson Hollow was surveyed with two TDEM Profiles TD-1 and TD-2 and the southern side of Lots Branch was surveyed with TD-3. TD-4 was conducted as a short profile to evaluate the TDEM response over dry workings in the Lewiston Coal.

Surface control in terms of site coordinates and elevation was provided with the location of benchmarks by Cornerstone Consulting and Design, Inc. of Danville, WV. D'Appolonia extended this surveying to specific geophysical lines and borehole locations.

4.2 Drilling

Based on the results of the geophysical surveying (both TDEM and resistivity surveys), 4 coreholes and 24 air rotary borings were drilled between September 15 – 21, 2005. Both the coreholes and air rotary borings were drilled by L. G. Hetager Drilling, Inc. of Punxsutawney, PA. The location of these coreholes and air rotary borings is provided on Figure 2. Boring Logs are provided in Appendix C. These borings and coreholes were located considering both TDEM and DC resistivity surveys, but with emphasis on the results of the DC resistivity surveying, as discussed in greater detail in the report for that method (D'Appolonia 2006).

NX size core (2 1/8 inch core from a 3 inch hole) was obtained from the four coreholes. The air rotary borings were drilled such that 6 inch diameter holes were obtained. A few of these holes were reamed out to 8 ¾ diameter holes and cased with 6 inch PVC casing in anticipation that the downhole equipment from Workhorse Technologies would require casing. In actuality, the cuttings from the reaming process proved to be an interference to the work conducted by Workhorse Technologies and a field decision was made by Workhorse Technologies personnel to conduct their surveying from uncased 6 inch holes.

Upon completion of the boreholes, they were sounded with an M-scope water level indicator to detect and measure the depth to ground water. The results of the water level monitoring are summarized in Table 2 and on the boring logs in Appendix C. In mine voids, the bottom of the void was encountered without detecting a measurable water surface and therefore was characterized as “dry.” However, based on M-scope response and visual observation of sediments, the bottom of the mine voids was moist to wet.

Boreholes were grouted on September 27th and 28th (except for Borings B16 and B17 which were grouted during the week of September 19th). Borings were grouted with Type II Portland cement grout by personnel of Hetager Drilling under the direction of D'Appolonia field personnel. Borings that did not encounter mine voids were filled with grout. Wooden or PVC pipe spacers were used to accomplish the grouting of borings that encountered mine voids. PVC pipe was used to span mine voids in borings that were partially or entirely reamed to 8 ¼ inches or more in diameter (Borings B11, B13, and B31). These borings were first sounded, and then a length of nominal 6 inch diameter PVC pipe, cut so that the top of the pipe would extend at least 1.5 feet above the top of the void, was lowered to the bottom of the boring. The PVC pipe was then filled with grout. A machined wooden plug was then placed in the top of the pipe, and plastic and paper were added to hold bentonite chips in place above the wooden plug. Approximately 1 to 2 feet of bentonite chips was then placed in the boring. Grout was pumped into the remainder of the boring above the bentonite chips. Due to concern that the bell-joints in the 6 inch diameter PVC pipe would become stuck in the upper portions of 6 ¼ inch diameter borings with mine voids (Borings B6, B7, B8, B18, B25, and B34), solid wood tree trunks of 4 to 5 inches in diameter were used to span the distance from the bottom of these borings to a distance at least 1.5 feet above the top of the mine void. Machined wooden plugs, retention material, and bentonite were then placed on top of the spacer prior to pumping grout into the remainder of the boring. Grout was allowed to settle for at least 3 hours and was then topped off. A schematic showing the grouting procedures is provided with the boring logs in Appendix C.

4.3 Imaging of Mine Voids

Imaging of portions of the mine workings was obtained using a down-the-borehole dry hole laser range based geometric scanner called a Ferret, developed by Carnegie Mellon University and commercialized by Workhorse Technologies, Inc. of Braddock, PA. If flooded workings had been encountered, an imaging tool called the Submersible Ferret that utilizes a sonar scanning system would have been used. As only dry workings were encountered, the laser-based Ferret scanner was deployed.

The Ferret is operated by being lowered on a cable down a borehole into a mine void. Once deployed into a void space the operator initializes a pan and tilt sequence to produce a scan of the void. Ferret is capable of collecting angular data to 0.1 degree increments and range data to 65 meters while maintaining accuracies to within 10mm. In the field, the collected data set is converted into a 3 dimensional point cloud model of the void. The point cloud is then converted into a mesh model allowing the client and operator to view a user-friendly 3-D model of the underground space. Video data are also collected during the scan using a low light camera. These data are post-processed to produce plan views, sectional views, and volume estimations.

Close-up of Ferret tool showing the laser and laser tilt axis with borehole camera below.

Six boreholes encountering mine voids were selected for imaging. Of these, it was practical to image mine workings from four of these borings between September 19 – 21, 2005. Boreholes B13, B25, B31 and B34 were surveyed. Borehole 11 could not be surveyed because drill cuttings in the mine prevented the Ferret from having sufficient space to rotate within the mine void and Borehole B18 could not be entered because the imaging sonde could not fit past an obstruction in the borehole.

The Ferret fits down a 6 inch diameter hole and for the shallow depths encountered at the Lots Branch site mechanical linkage was maintained between the instrument and the surface to provide a surface referenced orientation. The mine voids were first viewed with the video camera and the operator made decisions as to what angular range would effectively image each void.

Close-up of Ferret tool and deployment at the Lots Branch site hanging from a tripod entering into an uncased hole – B18

Preliminary scans were obtained to quickly obtain rough images of each void and then the operator would select the final scanning parameters to obtain a satisfactory resolution of the mine void. By examining the data in the field informed decisions could be made as to what supplemental scans were needed to map a void. Three-dimensional images of a single scan were viewed in the field using software developed at Carnegie Mellon University specifically for the Ferret tool.

Surveyed locations and elevations of the boreholes were not available to Workhorse Technologies in the field, so each hole was locally referenced. Elevations were referenced as negative depth in feet from the surface. The zero azimuth for the scans at each hole was referenced to a predominant physical surface feature such as the centerline of the road or another borehole and defined as an azimuth with respect to magnetic north. In the laboratory a single composite model was generated for each hole with all the points from all scans. The zero azimuth of the model was referenced to magnetic north and a file containing all of the points was then prepared to display in X, Y, Z coordinates. By summing the point file with surveyed hole coordinates the models were georeferenced by D'Appolonia as shown on Figures 7, 12 and 13.

5 RESULTS

The TDEM profiles were located to traverse mine workings in the Lewiston Coal primarily under varying degrees of flooding, but also where dry mine conditions were known to exist. As discussed in Section 3, the mine workings on the north side of the impoundment dip away from the valley wall and are dry. The workings on the south side of the valley dip towards the impoundment and mine water seeps into the valley. Flooded or partially flooded workings were expected to be encountered where mine workings terminate at barrier coal on the southern edge of the impoundment. The actual degree of flooding would depend on the efficiency of the natural drainage barrier along these mine workings or if a constructed drainage is present. These probable differences in flooding allow for the Lots Branch site to be grouped into three basic areas:

- The southern side of Robertson Hollow – in this area mine workings were expected to be flooded. There is a drainage seep that appears to correspond to a concealed entry, such that there is some control for the location of the mine map with respect to ground surface. The approximate coalcrop of the Lewiston Coal has been benched to create an access road for loggers.
- The southern side of Lots Branch – in this area the workings were expected to be at least partially flooded. Control for the location of the mine map is available from only one location (Entry D on Figure 2).
- The northern side of Robertson Hollow merging into the northern side of Lots Branch – in this area the workings were expected to be dry. The approximate coalcrop of the Lewiston Coal has been benched along the length of Robertson Hollow. Along Lots Branch, the Lewiston has been exposed in places where coal refuse has been excavated and the three entries labeled A, B and C have been identified (Figure 2).

These three areas are reviewed separately.

5.1 Southern side of Robertson Hollow

The southern side of Robertson Hollow was surveyed with two TDEM Profiles TD-1 and TD-2 (Figure 2). Thirteen control borings were drilled in this area. Three borings (B6, B7 and B8) encountered relatively small voids and soft material interpreted to be mine gob; two borings (B31 and B34) encountered relatively dry mine workings interpreted to correspond to the known concealed mine entry (Figure 2). The size of the voids and the presence of mine gob were not conducive to the imaging of the mine from Borings B6, B7 and B8, but Boreholes B31 and B34 did offer suitable conditions and were imaged by Workhorse Technologies.

The two TDEM survey profiles obtained on the southern side of Robertson Hollow, TD-2 and TD-1 are shown on Figures 5 and 6, respectively. The resistivity values shown in the depth sections here and elsewhere in the report are the result of the 1D inversion (by IX1D software) and as such are called "resistivity" as opposed to "apparent resistivity" which refers to unprocessed data. The resistivity values (from the 1D inversion) are formatted for use by SURFER software to create the colored and scaled sections. Profile TD-2 does not suggest the presence of flooded mine workings at the level of the Lewiston Coal, consistent with the mine map. When compared to the results of the DC resistivity survey over the same profile (Figure 5) there are similarities and differences. The TDEM indicates values of ground resistivity in the range of 500 – 1000 ohm-meters, similar to the results from the DC resistivity surveying for the sandstone above the Lewiston Coal. There is also a decrease in resistivity at the level of the Lewiston Coal at the southern end of the profile with both the TDEM and resistivity techniques. The main difference between the two techniques is that the TDEM results indicate a layer of low resistivity from the ground surface to a depth of about 10 to 20 feet. Given that the ground surface along TD-2 was a cut bench with competent rock essentially at the ground surface, there is no reason to expect that a low resistivity layer is present at the surface and the DC resistivity results, which should precisely define such a layer, do not indicate its presence. Another difference between the two techniques is that the TDEM results do not indicate horizontal layering, as indicated by the DC resistivity measurements.

TDEM profile TD-1 on Figure 6 does traverse mine workings. The overall distribution of resistivity from the TDEM results is partially similar to the DC resistivity results using the pole-dipole configuration. There is a resistivity low at the level of the Lewiston Coal centered at 800 feet along the profile that corresponds to the resistivity low encountered with the pole-dipole results. This low does correspond to the mapped mine workings, which extend approximately from Boring B6 to B8, which is where mine gob was encountered in borings B6, B7 and B8. The zone from B6 to B7 is marked as the resistivity low on profile TD-1 and is the zone of lowest resistivity the pole-dipole DC resistivity configuration. A difference from the DC resistivity results is that the pole-dipole results also depict a localized resistivity low at Boring B8 that is not observed on the TDEM profile.

The second area of known mine workings is the entry encountered by Borings 31 and 34 shown on Figure 2 and imaged by Workhorse Technologies (Figures 7 and 8). The laser imaging provides confirmation of the precise location of the two entry tunnels indicated on the mine map and allows for the definition of 140 feet of open tunnel associated with the northern entry and 80 feet of tunnel associated with the southern entry. In addition, the results image 80 feet of an unknown tunnel extending from the northern entry towards the east.

The results of the TDEM survey along profile TD-1 (Figure 6) do not suggest the presence of the entry tunnels, but an area of relatively low resistivity is encountered between about 1140 and 1320 feet along the profile. This is also the zone where anomalously low resistivity values are observed from the DC resistivity results, especially with the pole-dipole configuration, as also shown on Figure 6.

At the time of the geophysical surveying four seepage points were mapped along the coalcrop line, one with a flow of more than 100 gal/minute located about 50 feet east of the centerline of the easternmost entry tunnel. Based on the results of the borings, this zone of highest seepage corresponds to the point of lowest elevation of the Lewiston Coal and is where the lowest resistivity values were measured with DC resistivity measurements from an experimental profile (CC-1) following the outcrop of the Lewiston Coal (Figure 8), as discussed in greater detail in the DC resistivity report (D'Appolonia 2006). At the time of the laser imaging in September 2005, the highest flow was less than 10 gal/minute and the mine voids did not encounter water in them, although water flowed into the bottom of Boring B30, only inches away from a dry entry tunnel. For this reason, it is assumed that an engineered drainage was used to keep the floor of the mine dry, probably with a drain on the northern side of the eastern entry tunnel. As the lowest point in the coal is about 50 feet east of the entry tunnels and previously unknown workings have been identified, it is assumed that drainage was established such that the main drainage outfall at the surface was set to be at this lowest point in the coal, which is the location of the largest seep.

The remainder of TD-1 does not suggest the presence of mine workings. The zone where mine workings are mapped (the area where Borings B1 and B2 were drilled, but where mine voids were not encountered) is marked on TD-1 by a zone of surficial low resistivity, similar to the zone of surficial low resistivity along all of profile TD-2. The origin of this anomaly is not known as the resistivity results do not indicate that a surficial low resistivity zone is present. In any case the anomaly does not appear to relate to the presence of mine workings as nothing appears at the level of the Lewiston Coal. There is a break in the TDEM results at 1490 feet along TD-1 that does not appear to represent actual ground conditions because of the abruptness of the change. It is not certain what caused this change, but may be due to an unintentional change in processing procedures such as using a different starting model. It did not occur at the start of a new work day. A relative low at 2250 feet along the profile appears to correlate with a low on the Wenner configuration results, and to a lesser degree on the pole-dipole results, but mining is not known to have taken place in this area and the change is not so pronounced that the presence of workings would be strongly suspected. Because the TDEM results do not have the same vertical resolution as the resistivity, direct comparisons are difficult.

5.2 The Southern Side of Lots Branch

The southern side of Lots Branch is another area where it was anticipated that the mine workings would be at least partially flooded. Where mine workings are present from the beginning of TD-3 to about 1020 feet along the profile and also from between about 1260 to 1620 feet (Figure 9), there is no indication that the mine is flooded. In actuality, the TDEM results from the beginning of the line to about 1620 feet, with the exception of a very localized low at about 1540 feet, do not indicate any distinction between coal workings and intact coal. Boring B18 confirms the presence of a mine void at a distance of 1450 feet along the profile, but the TDEM results do not indicate that a mine void is likely in this area (only the DC resistivity results with the Wenner-Schlumberger configuration for Line NL-7 suggest a possible resistivity low in this location). At the level of the Lewiston Coal high resistivity zones are present in these areas where partially flooded workings are thought to be present.

The TDEM results define a resistivity low from about 1820 to 1980 feet along profile TD-3 centered where Borings B14, B15, B16 and B17 were drilled in an attempt to hit a concealed opening. This resistivity low appears to be a stronger indication than the DC resistivity results that flooded workings could be present, but unfortunately the borings did not encounter the known entry to confirm the presence of water. The resistivity low extends farther to the north than the expected location of the entry, similar to the DC resistivity results with the Wenner configuration. The elevation of the Lewiston Coal appears to be locally low immediately north of the entry, so this may be a point where mine water has accumulated, but it should be noted that none of the borings in the area of the entry encountered water in the solid coal.

The TDEM results south of the entry intended to be penetrated by Borings B14, B15, B16 and B17 depict variable resistivity values at the level of the Lewiston Coal that are not reflected in the DC resistivity results. A resistivity low is present in the general area of the southernmost entry crossed by TD-3 at 2780 to 2880 feet along the profile that was not crossed by the DC resistivity profiles. This resistivity may be reflective of water in a concealed entry, but the strongest low is present slightly north of the assumed entry location, so the significance of this observation is uncertain.

The overall observation from the data sets is that electrical measurements from the TDEM technique would not be suitable for defining a correlation of the mine map to the ground surface. Based on the results of the borings, where none encountered water in the intact coal and the only boring in this area to have penetrated mine workings, B18, encountered relatively dry conditions in the mine, as well as the observation of limited seepage or dry conditions at Entry D, the mine workings in this area appear to be well drained. An attempt was made to image the mine from this boring with the laser imaging system, but an obstruction in the borehole made it impractical to insert the imaging tool. The possibility that the TDEM results could be responding to the presence of water at the two concealed entries from about 1820 to 1980 feet and 2780 to 2880 feet along profile TD-3 is uncertain.

5.3 The Northern Side of Robertson Hollow and Northern Side of Lots Branch

TDEM surveying in this area was restricted to profile TD-4 (Figures 2 and 10) because it was anticipated that in this area mine water would tend to drain away from the coalcrop and the workings would be dry. Dry workings were not expected to be visible based on any types of EM measurement, which basically respond to conductive zones. Nevertheless it did prove possible to identify relatively dry workings with DC resistivity measurements and it was thought that there might be an observable contrast between an air void and the surrounding rock. Profile TD-4 crossed Entries A and B, but the results are not indicative that the entries are present. The TDEM data are presented with two contour scales, the first with the same contouring as the resistivity profiles. With this presentation it is not practical to discern if the entries stand out as resistivity highs, because the entire section has a high resistivity. When the contouring is expanded such that the zones of highest resistivity can be distinguished, these zones do not correlate well with the dry entries.

Two borings (B25 and B13) from the northern side of the valley that encountered dry workings were imaged by Workhorse Technologies (Figures 11 and 12). One of the images from Boring B25 was able to map more than 200 feet of concealed entry tunnel. Figures 11 and 12 are presented to provide the available information on the mine workings on the northern side of Lots Branch and for consistency with the DC resistivity report.

6 CONCLUSIONS AND RECOMMENDATIONS

The demonstration project illustrated the application of the TDEM surface geophysical method along the south perimeter of the Lewiston seam coal barrier at the Lots Branch impoundment that may be subject to slurry deposition. Approximately 6,000 total feet of survey line were obtained along the impoundment perimeter in about two weeks. The equipment used for this project was manufactured by Geonics, Ltd. Their equipment is the most widely used and most available of TDEM equipment. The equipment used (the EM-47 transmitter and Protem receiver) were specifically designed for shallow investigations such as this one. Following processing and interpretation in conjunction with the results of the DC resistivity surveys, 28 borings were targeted to explore resistivity anomalies, obtain data on the stratigraphy, and allow laser imaging of selected mine workings.

The forward modeling and experience at an alternative site (Weisner Hollow impoundment in Jefferson County, PA) presented in Appendix B illustrates the capability of TDEM to detect and map flooded workings. Low resistivity anomalies are indicated with horizontal and vertical resolution when mine workings under flooded conditions represent conductive zones. Based on experience with other electrical methods (DC Resistivity), it was anticipated that partially flooded or wet mine conditions may be sufficiently conductive for the TDEM method to detect and potentially map mine voids.

Considering the objectives of the demonstration project at Lots Branch, the TDEM method achieved the following:

- Detection of mine workings in limited areas, at locations where workings were more extensive and contained water. At locations of one or two entries and where there was little evidence of water within the workings, the method yielded little results that could be interpreted as workings.
- Mapping of mine workings, that is distinguishing between entries and pillars, was not achieved for the conditions present (attributed to the limited or no evidence of water in the workings).

- Assessment of the continuity of barrier coal pillars was possible in limited areas, although it was of restricted value due to the resolution and inability to map individual entries.

The limited resolution achieved at the Lots Branch site is believed to be associated with the limited presence of water within the mine workings. The equipment selected for the study was specifically designed for shallow applications such as this one, and is the most widely used and available TDEM equipment.

The survey conducted for Weisner Hollow where the mine workings were flooded indicated the ability to detect the mine entries, with a resolution that could be effective at mapping the set of entries. Given its ability to detect flooded entries at Weisner Hollow, it would be useful in assessing the continuity of barrier coal pillars.

Some of the TDEM results from Lots Branch demonstrate a general relationship with the results of the DC resistivity surveying, but without the same degree of depth resolution. The TDEM measurements identified a zone of relatively low resistivity east of the mapped entry on the south side of Robertson Hollow, where DC resistivity results also suggested the presence of partially flooded mine workings confirmed to exist by the laser imaging conducted by Workhorse Technologies. Where workings are dry, the TDEM results depict a general high resistivity, but the individual workings do not stand out from the overall high resistivity associated with the Lewiston Coal and surrounding sandstone.

The best application of the TDEM technique based on the findings from Lots Branch site and the Weisner Hollow impoundment site appears to be where workings are fully flooded and where surface constraints and/or depth restrict the application of the DC resistivity technique. Where the DC resistivity method can be applied, the results appear to have better resolution than TDEM, but the DC resistivity technique requires sufficient space to lay out long survey lines, which is not a restriction of the TDEM method. Based on theoretical forward modeling, TDEM appears to be capable of "seeing" deeper than the DC resistivity measurements. Field confirmation of the ability of the TDEM technique to image such deep, flooded workings still remains to be obtained.

Topography and thick woods at Lots Branch restricted data collection to specific locations and hydrologic conditions limited areas where workings were flooded. In spite of these conditions, the demonstration of the TDEM surveys is promising. In general, the results (including consideration of the Weisner Hollow results) indicate a higher probability of mapping mine workings with greater flooding. This, in turn, suggests additional testing is necessary at other mines where site conditions include differing degrees of flooding. Should the demonstration project be extended to a site with flooded workings and better access, one of the targets for TDEM should be flooded mine workings at depths greater than can be effectively imaged with the DC resistivity technique.

Another conclusion from the Lots Branch demonstration survey is the quality and usefulness of the laser imaging of the mine workings conducted by Workhorse Technologies, Inc. This technology allows the measurement of void dimensions and entry orientation, along with qualitative understanding of the mine conditions, which contributes to registering the mine map with surface features and interpreting the geophysical surveys.

Respectfully submitted,

William J. Johnson, PG

Donald W. Johnson

Robert E. Snow, PE

REFERENCES

Benson, R, R.A. Glaccum, and M.R. Noel, 1988, *Geophysical Techniques for Sensing Buried Wastes and Waste Migration,* National Water Well Association, Dublin, Ohio, 236 p.

D'Appolonia, 2006, Report, *Demonstration Project – Mine Void detection, DC Resistivity Surface Geophysical Method, Lots Branch Tailings Impoundment Site, Prenter, West Virginia*, prepared for Mine Safety and Health Administration, Arlington, Virginia.

Ewing, M. A., A. P. Crary, J. W. Peoples and J. A. Peoples, 1936, *Prospecting for anthracite by the earth resistivity method*, Transactions of the American of Mining and Metallurgical Engineers, Coal Division, Vol. 119, pp 43-483.

Hammack, R.W., 2003, *Using Helicopter Electromagnetic Surveys to Identify Flooded Workings in Underground Coal Mines*, Geophysical Technologies for Detecting Underground Coal Mine Voids, Lexington, KY, July 28-30.

Hoekstra, P., and M. W. Blohm, 1990, *Case Histories of Time-Domain Electromagnetic Soundings in Environmental Geophysics*, in Geotechnical and Environmental Geophysics, ed: S. H. Ward, SEG, IG#5, Vol. 2: pp.1-15.

Johnson, W. J., 2003a, *Applications of the electrical resistivity method for detection of underground mine workings*, Geophysical Technologies for Detecting Underground Coal Mine Voids, Lexington, KY, July 28-30.

Johnson, W. J., 2003b, *Case histories of DC resistivity measurements to map shallow coal mine workings*, The Leading Edge, Vol. 22, No. 6, pp 571-573, published by the Society of Exploration Geophysicists.

Johnson, W. J. and R.E. Snow, 2002, *Geophysical methods for the detection of underground mine workings*, Association of State Dam Officials (ASDSO), Tailings Dams 2002, Las Vegas, Nevada, April 29 – May 1.

Johnson, W. J., R. E. Snow, and J. C. Clark, 2002, *Surface geophysical methods for the detection of underground mine workings*, Symposium on Geotechnical Methods for Mine Mapping Verifications, Charleston, WV, October 29.

McNeill, J.D., 1990, *Use of electromagnetic methods for groundwater studies,* in Geotechnical and Environmental Geophysics, ed: S. H. Ward, SEG, IG#5, Vol. 1: pp.191-218.

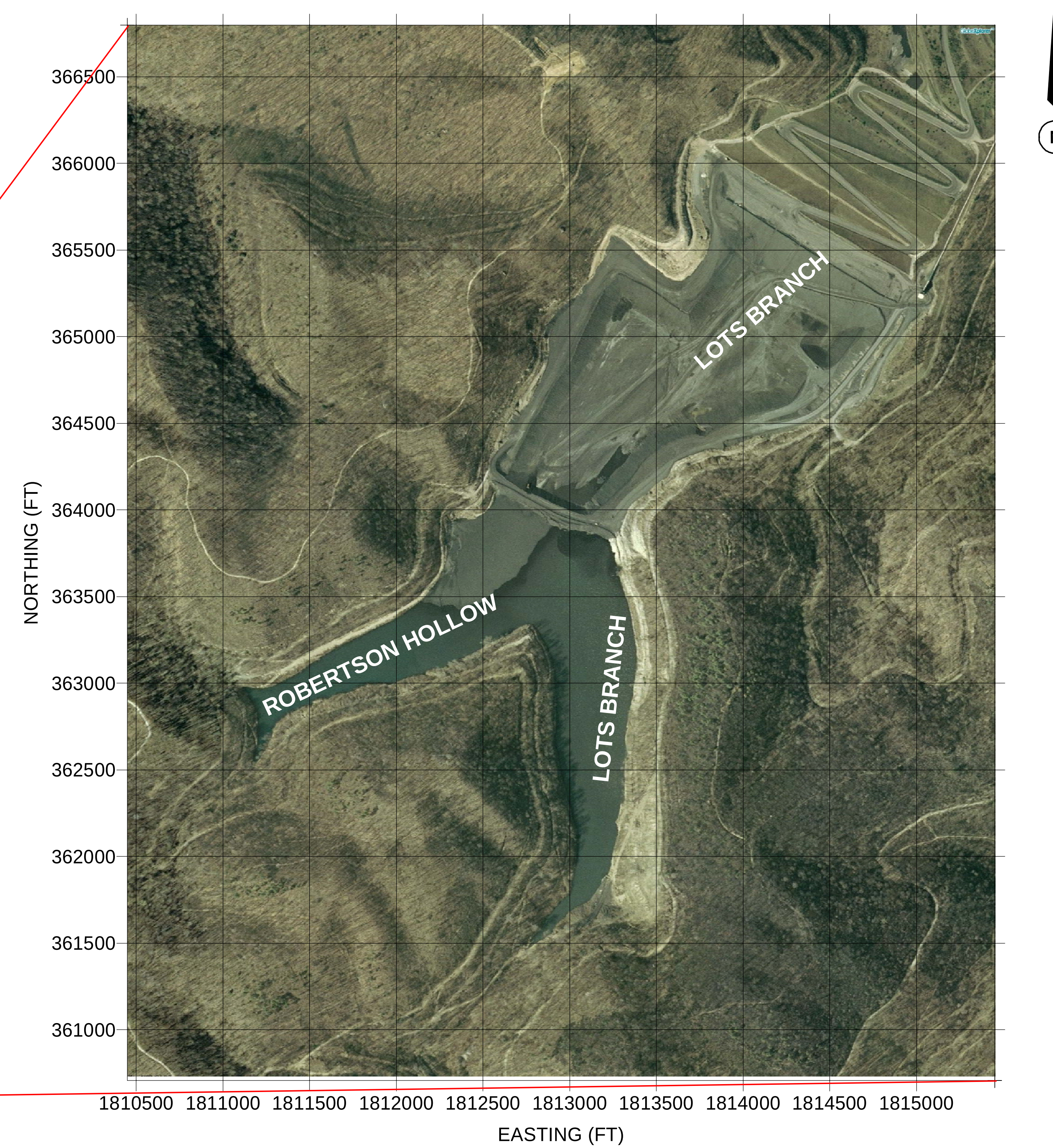
McNeill, J. D., 1994, *Principles and applications of time domain electromagnetic techniques for resistivity sounding*, Geonics Ltd. Technical Note TN-27, 15 p.

FIGURES

NOTES:

Aerial photograph taken March 15, 2003 at a best resolution of two feet and obtained from Terraserver imagery. The topographic map is from the USGS dated Jan 1, 1972.

Aerial photograph in West Virginia State Plane Coordinates in feet.



SCALE (FT)

0 500 1000 1500 2000

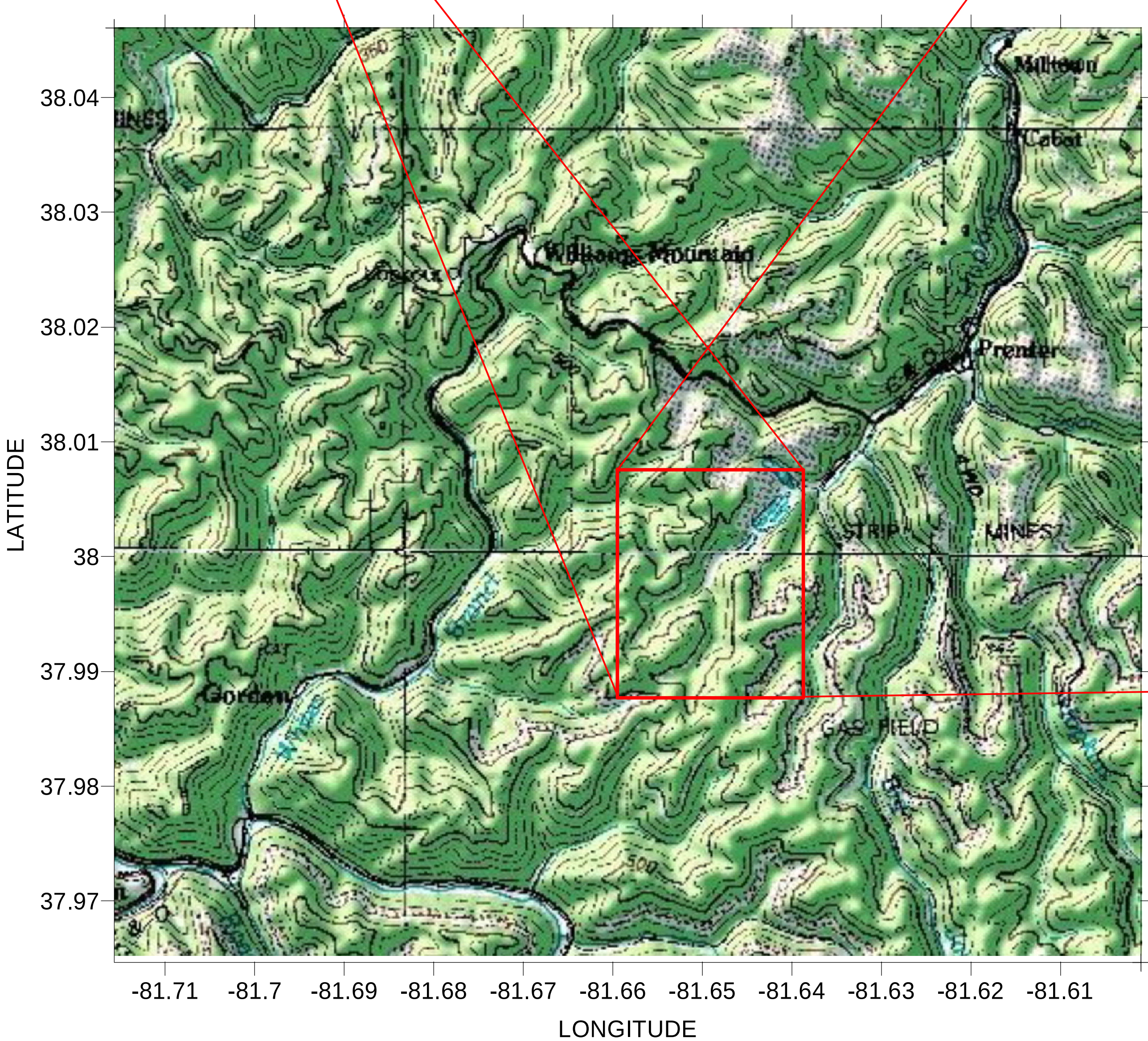


FIGURE 1

LOCATION AND AERIAL PHOTOGRAPH OF LOTS BRANCH TAILINGS IMPOUNDMENT SITE

PREPARED FOR

MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON, VIRGINIA

D'APPOLONIA

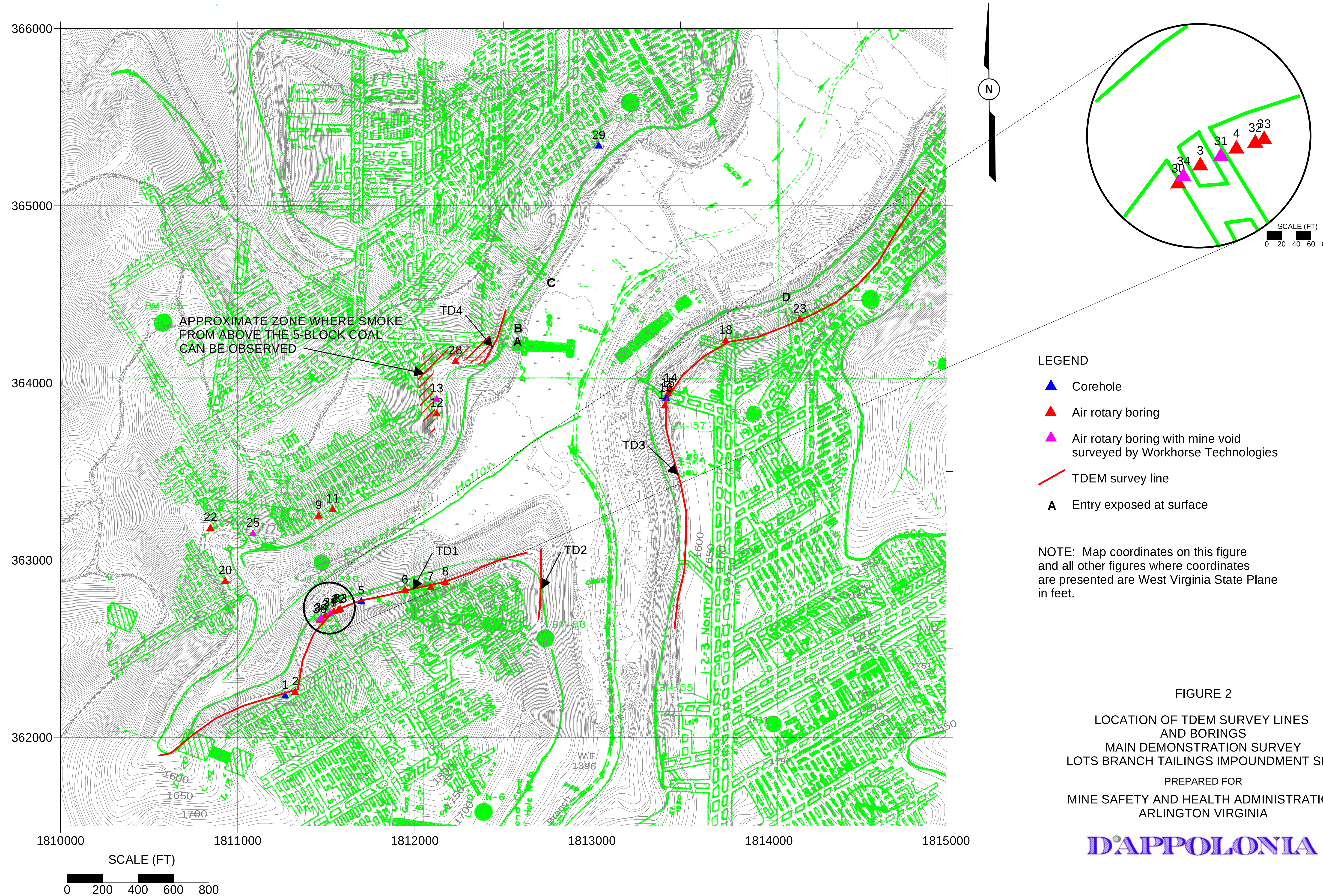


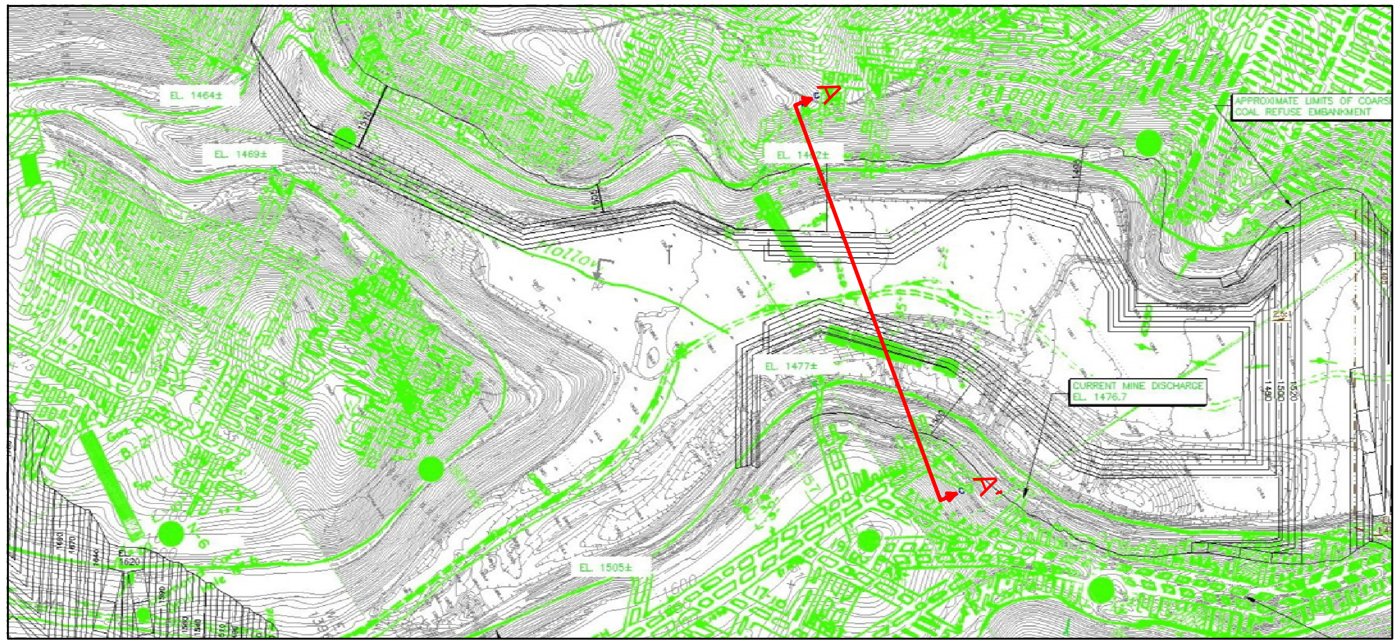
FIGURE 2

LOCATION OF TDEM SURVEY LINES
AND BORINGS
MAIN DEMONSTRATION SURVEY
LOTS BRANCH TAILINGS IMPOUNDMENT SITE

PREPARED FOR

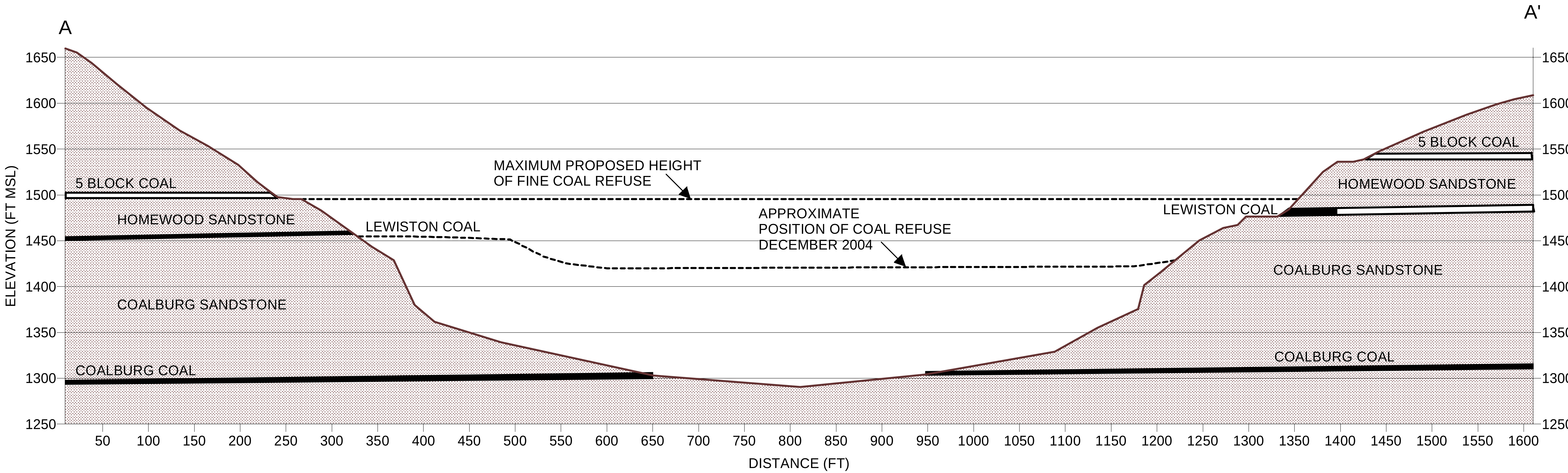
MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON VIRGINIA

D'APPOLONIA



MAP OF LOTS BRANCH TAILINGS IMPOUNDMENT
WITH OVERLAY OF LEWISTON COAL SEAM

SCALE (FT)
0 500 1000 1500 2000



NOTES: Topography taken from aerial photograph
taken April 7, 1986

Mine map provided by Pine Ridge Coal Company
and georeferenced by Alliance Consulting

Section presented with no vertical exaggeration

FIGURE 3

SECTION THROUGH LOTS BRANCH TAILINGS IMPOUNDMENT
MAIN DEMONSTRATION SURVEY
LOTS BRANCH TAILINGS IMPOUNDMENT SITE
PREPARED FOR

MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON VIRGINIA

D'APPOLONIA

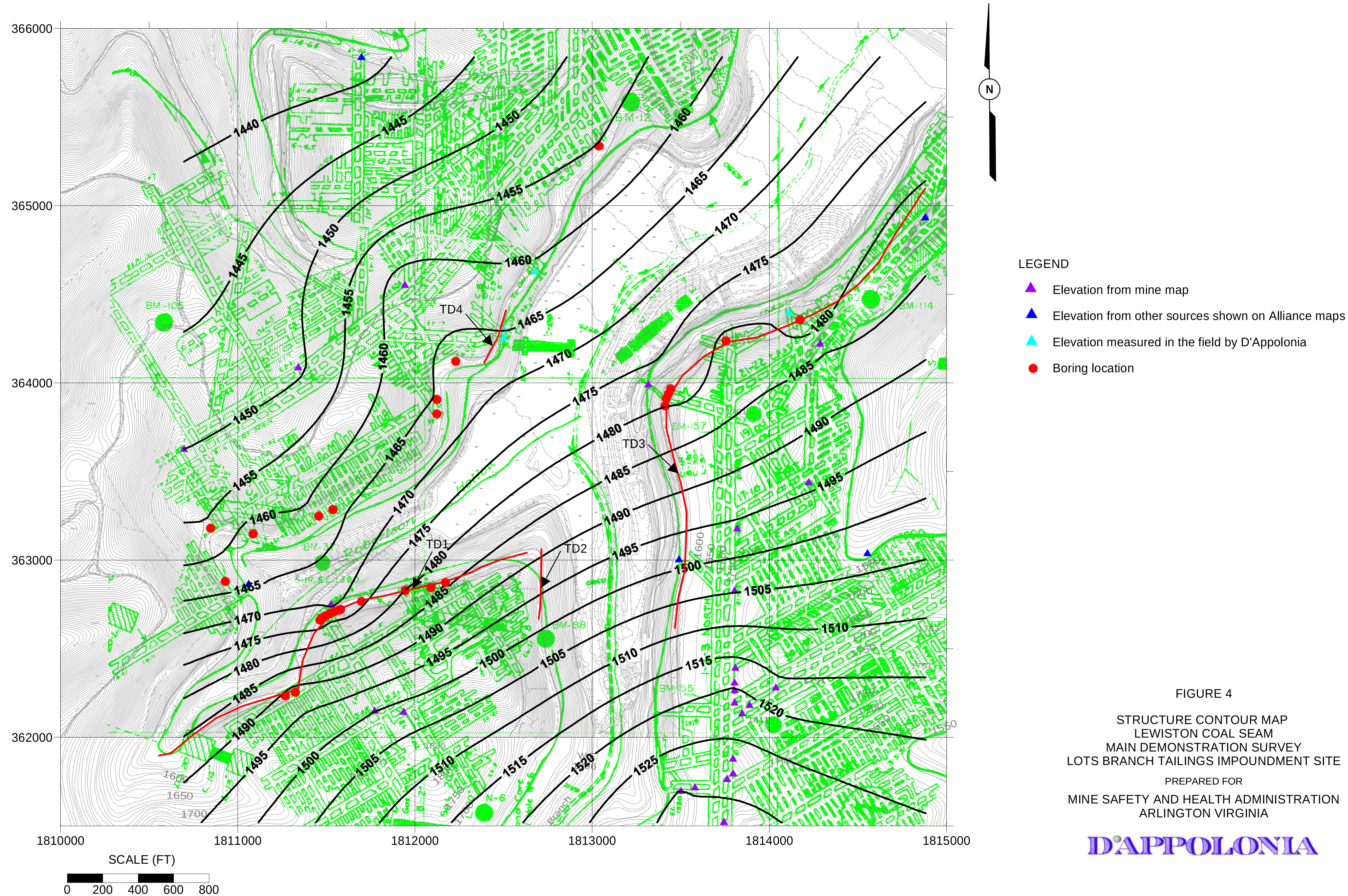


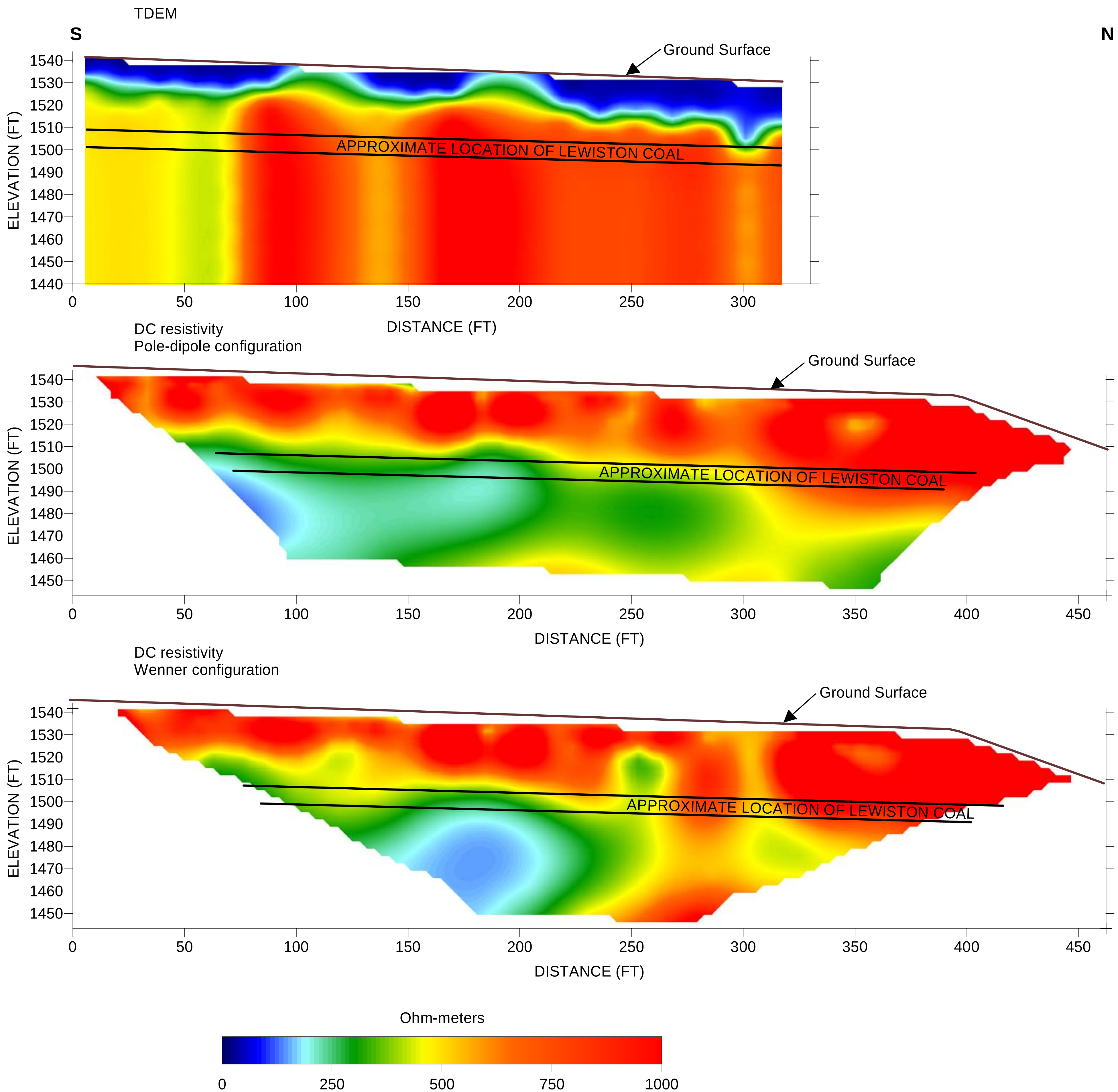
FIGURE 4

STRUCTURE CONTOUR MAP
LEWISTON COAL SEAM
MAIN DEMONSTRATION SURVEY
LOTS BRANCH TAILINGS IMPOUNDMENT SITE

PREPARED FOR

MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON VIRGINIA

D'APPOLONIA



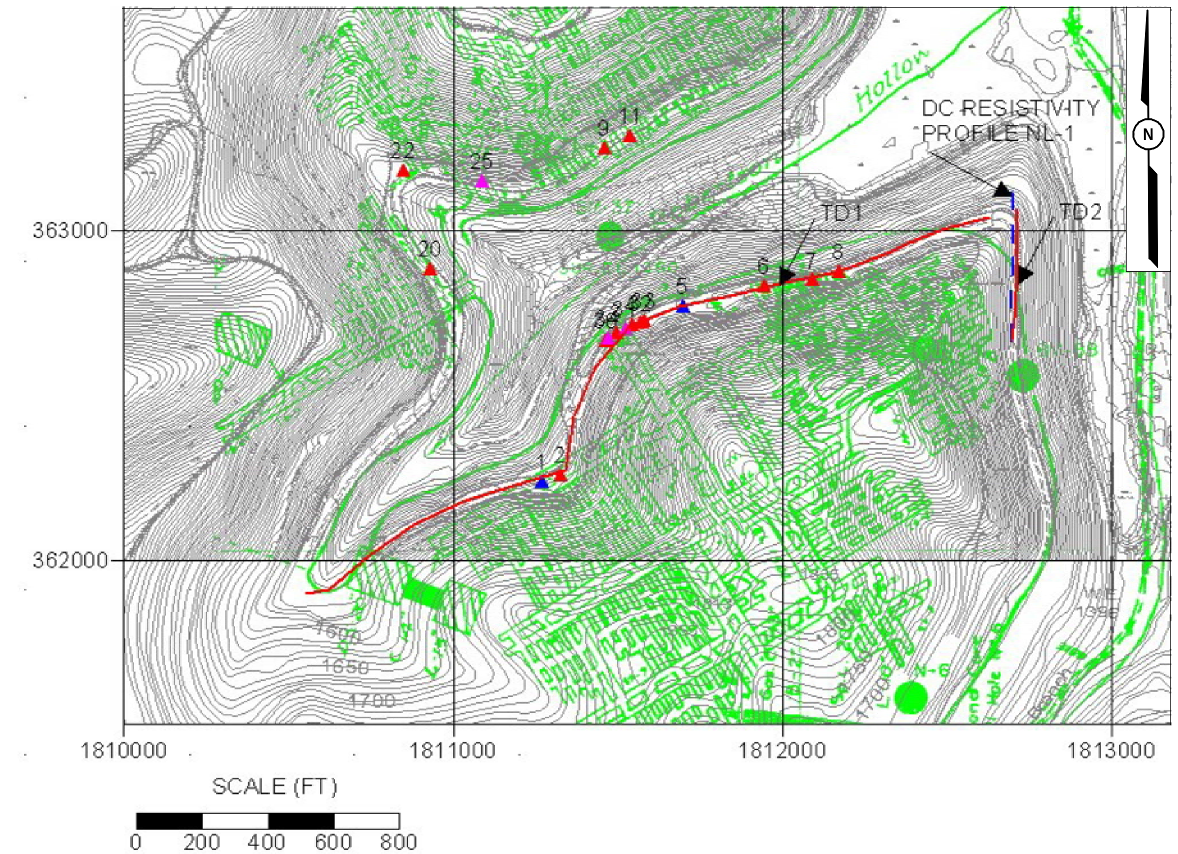


FIGURE 5

TDEM PROFILE TD-2 WITH COMPARISON
TO DC RESISTIVITY RESULTS
MAIN DEMONSTRATION SURVEY
LOTS BRANCH TAILINGS IMPOUNDMENT SITE

PREPARED FOR

MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON VIRGINIA

D'APPOLONIA

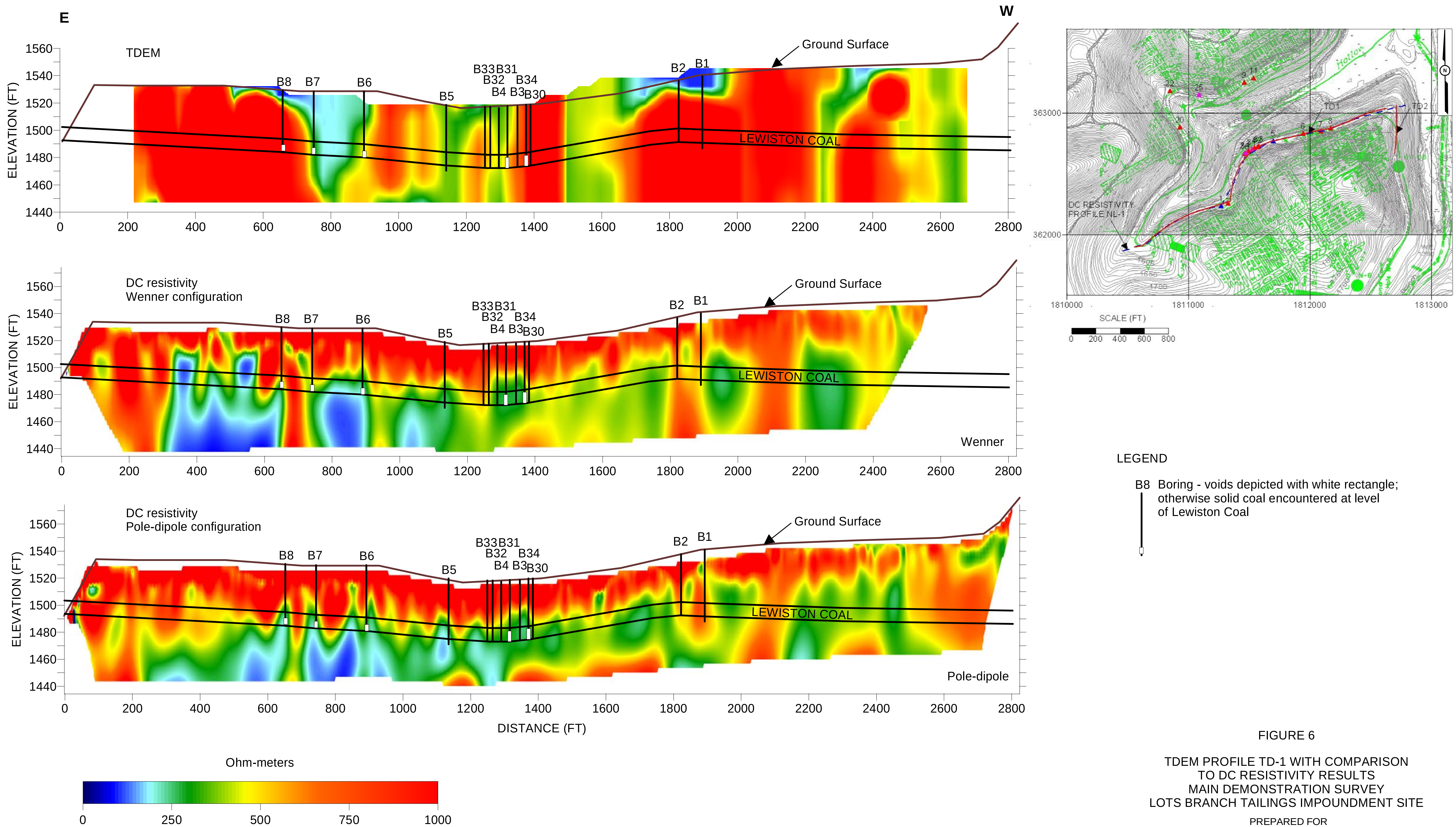


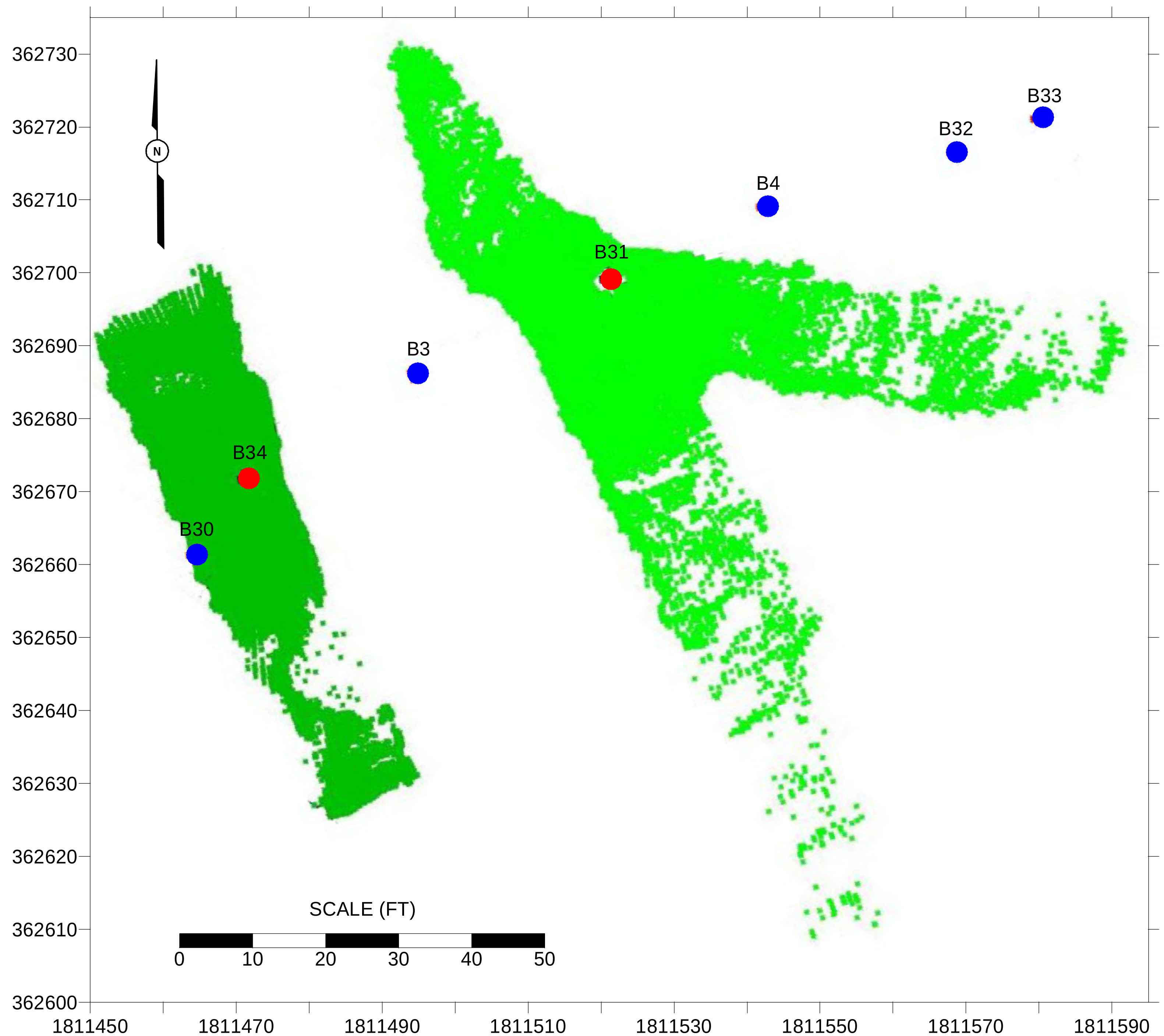
FIGURE 6

TDEM PROFILE TD-1 WITH COMPARISON
TO DC RESISTIVITY RESULTS
MAIN DEMONSTRATION SURVEY
LOTS BRANCH TAILINGS IMPOUNDMENT SITE

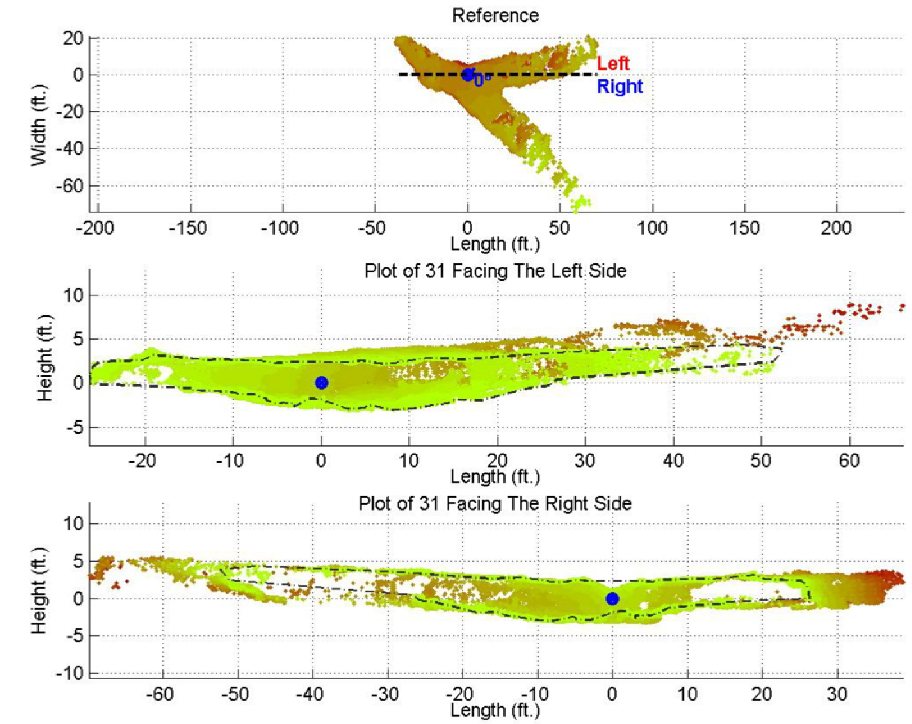
PREPARED FOR

MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON VIRGINIA

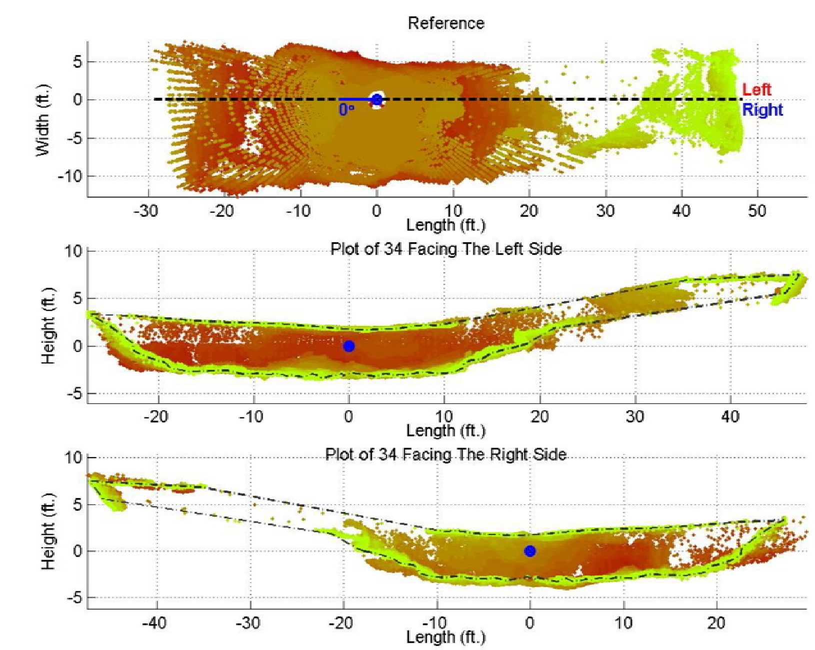
D'APPOLONIA



TOP-DOWN VIEW OF COMBINED
LASER IMAGING FROM BORINGS
B31 AND B34



TOP-DOWN AND
LONGITUDINAL
SECTIONS FROM
BORING B31



TOP-DOWN AND
LONGITUDINAL
SECTIONS FROM
BORING B34

LEGEND

- (blue) Air rotary boring encountering intact coal
- (red) Air rotary boring encountering mine void and imaged by Workhorse Technologies

NOTE:

Color coding of laser imaging relates to the depth of a point beyond an arbitrary cut line and is intended for visualization purposes only, to show the relationship of a section to the rest of the points. The range for each plot varies.

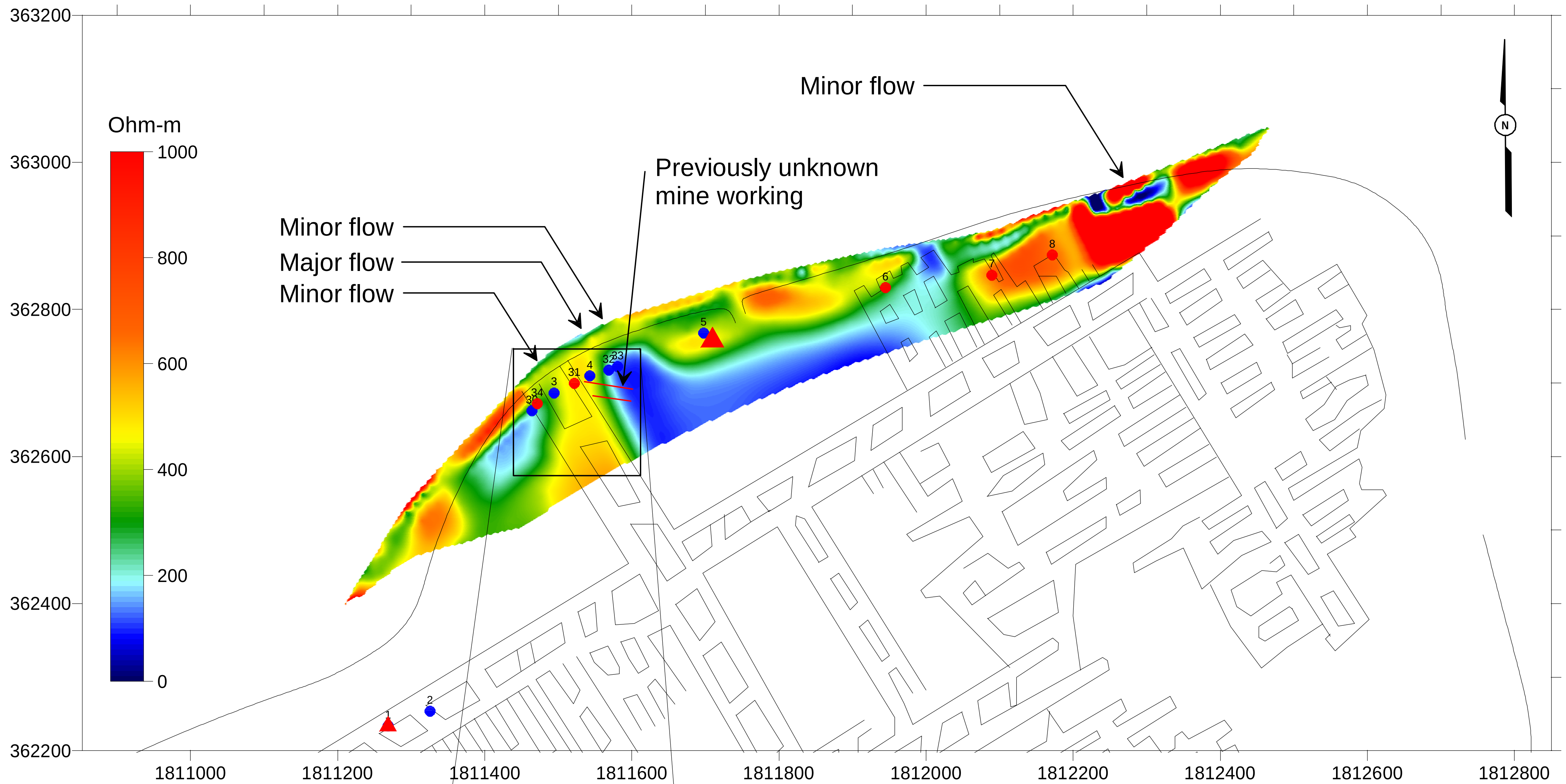
FIGURE 7

RESULTS OF LASER IMAGING INTO ENTRY TUNNELS
ON THE SOUTH SIDE OF ROBERTSON HOLLOW
MAIN DEMONSTRATION SURVEY
LOTS BRANCH TAILINGS IMPOUNDMENT SITE

PREPARED FOR

MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON VIRGINIA

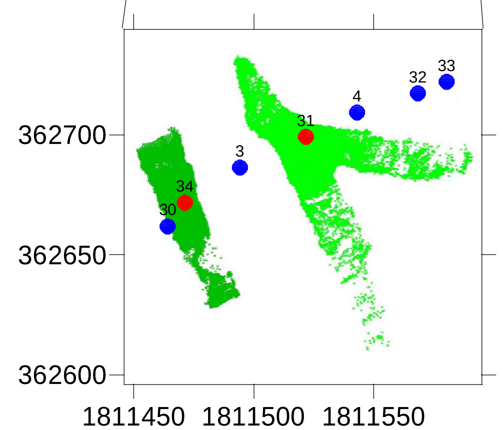
D'APPOLONIA



SCALE (FT)

0 100 200 300 400

RESISTIVITY DISTRIBUTION OBTAINED FROM USING THE WENNER CONFIGURATION ALONG EXPERIMENTAL DC RESISTIVITY PROFILE CC-1 FOLLOWING THE OUTCROP OF THE LEWISTON COAL (for additional information see D'Appolonia, 2006)



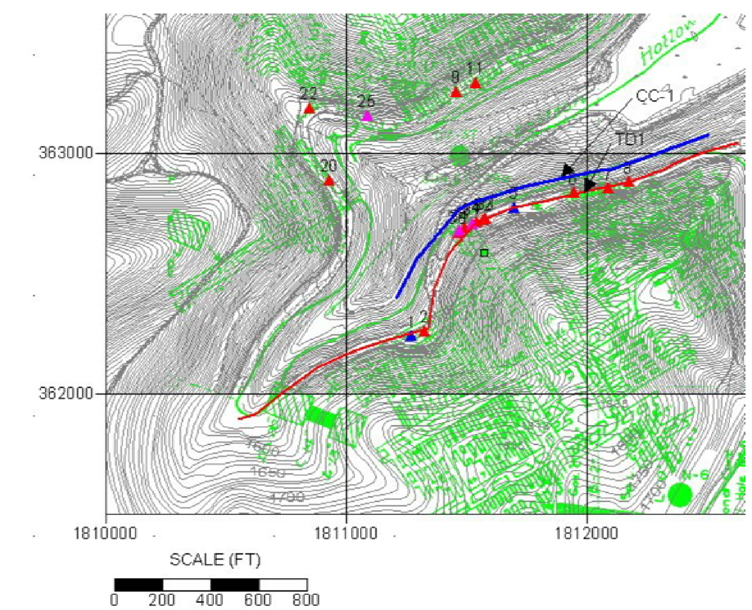
Layout of mine entry from laser imaging system surveyed by Workhorse Technologies - note that results identify a previously unknown tunnel extending into area of resistivity anomaly.

SCALE (FT)

0 20 40 60 80

LEGEND

- ▲ Corehole
- ● Air rotary boring
- ● Air rotary boring with mine void



KEY MAP WITH LOCATION OF RESISTIVITY PROFILE CC-1 AND TDEM PROFILE TD-1

NOTE: For additional information on the generation of the resistivity image, refer to the D'Appolonia report for the demonstration of the DC resistivity technique at the Lots Branch site (D'Appolonia, 2005).

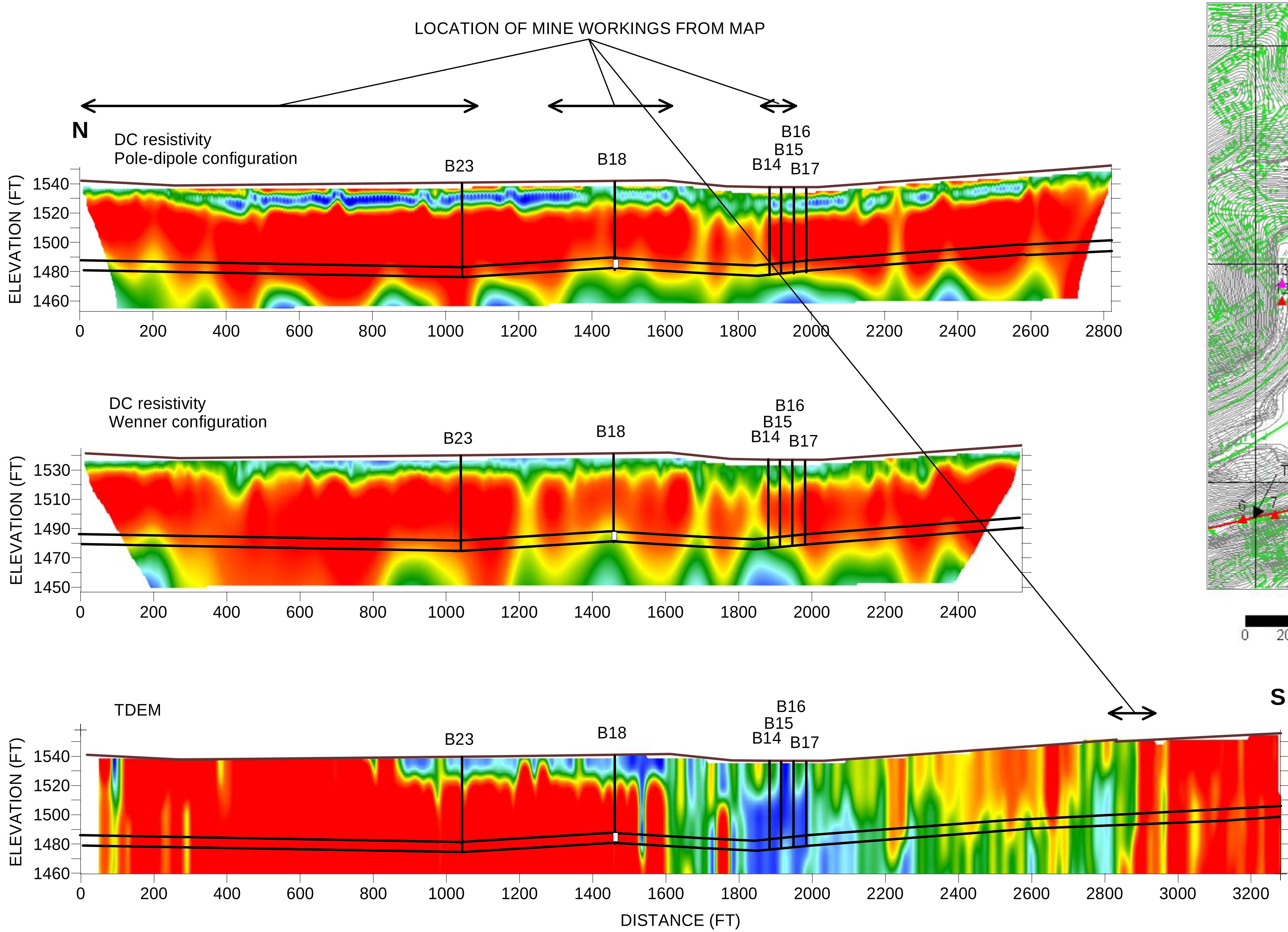
FIGURE 8

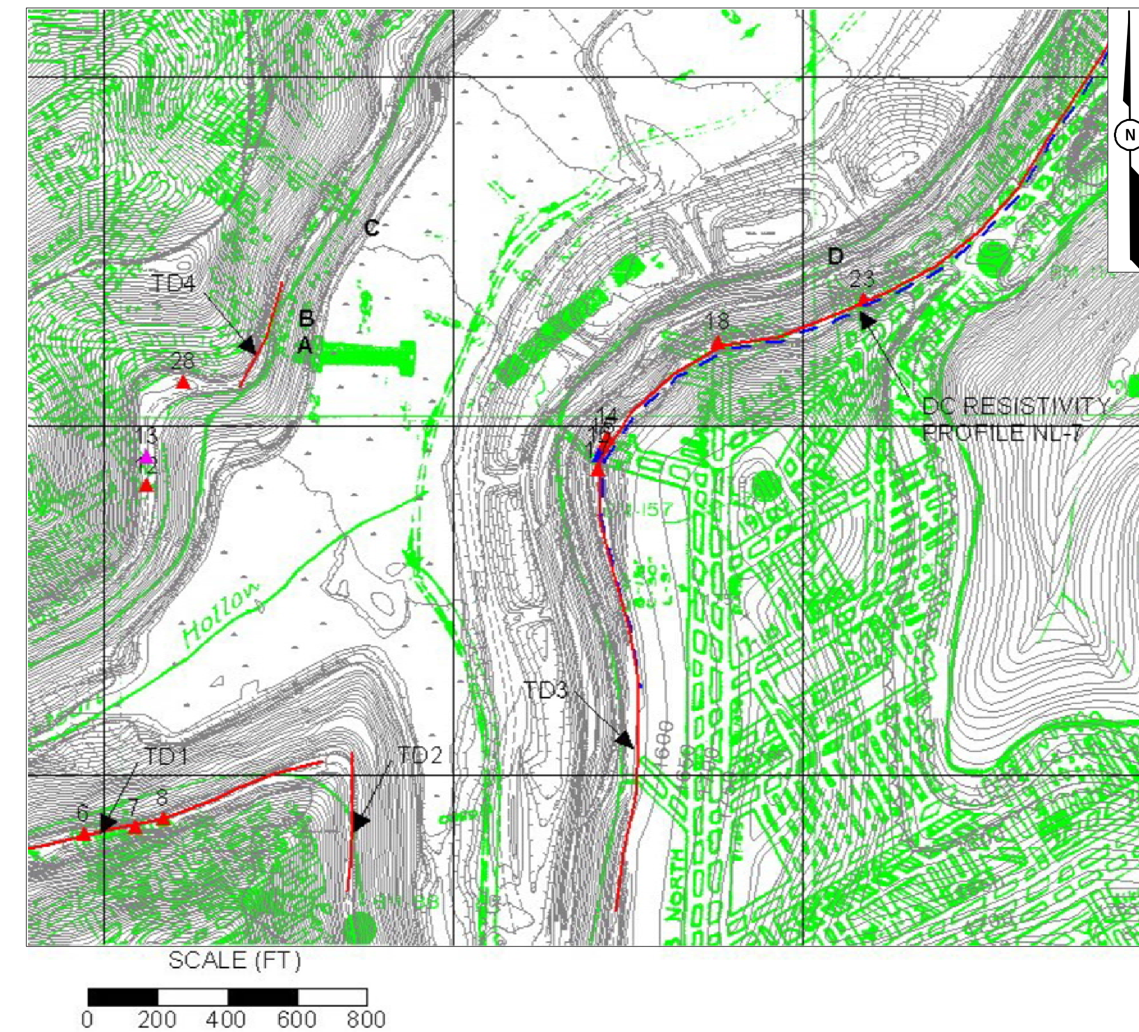
PLAN VIEW OF RESISTIVITY FROM DC RESISTIVITY MEASUREMENTS WITH LOCATION OF MINE DRAINAGE
MAIN DEMONSTRATION SURVEY
LOTS BRANCH TAILINGS IMPOUNDMENT SITE

PREPARED FOR

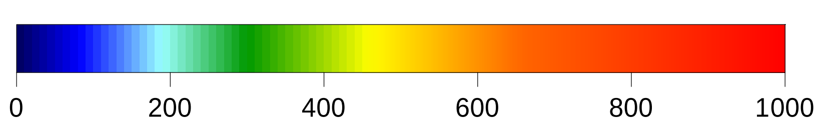
MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON, VIRGINIA

D'APPOLONIA





Ohm-meters



LEGEND

B18 Boring - voids depicted with white rectangle; otherwise solid coal encountered at level of Lewiston Coal

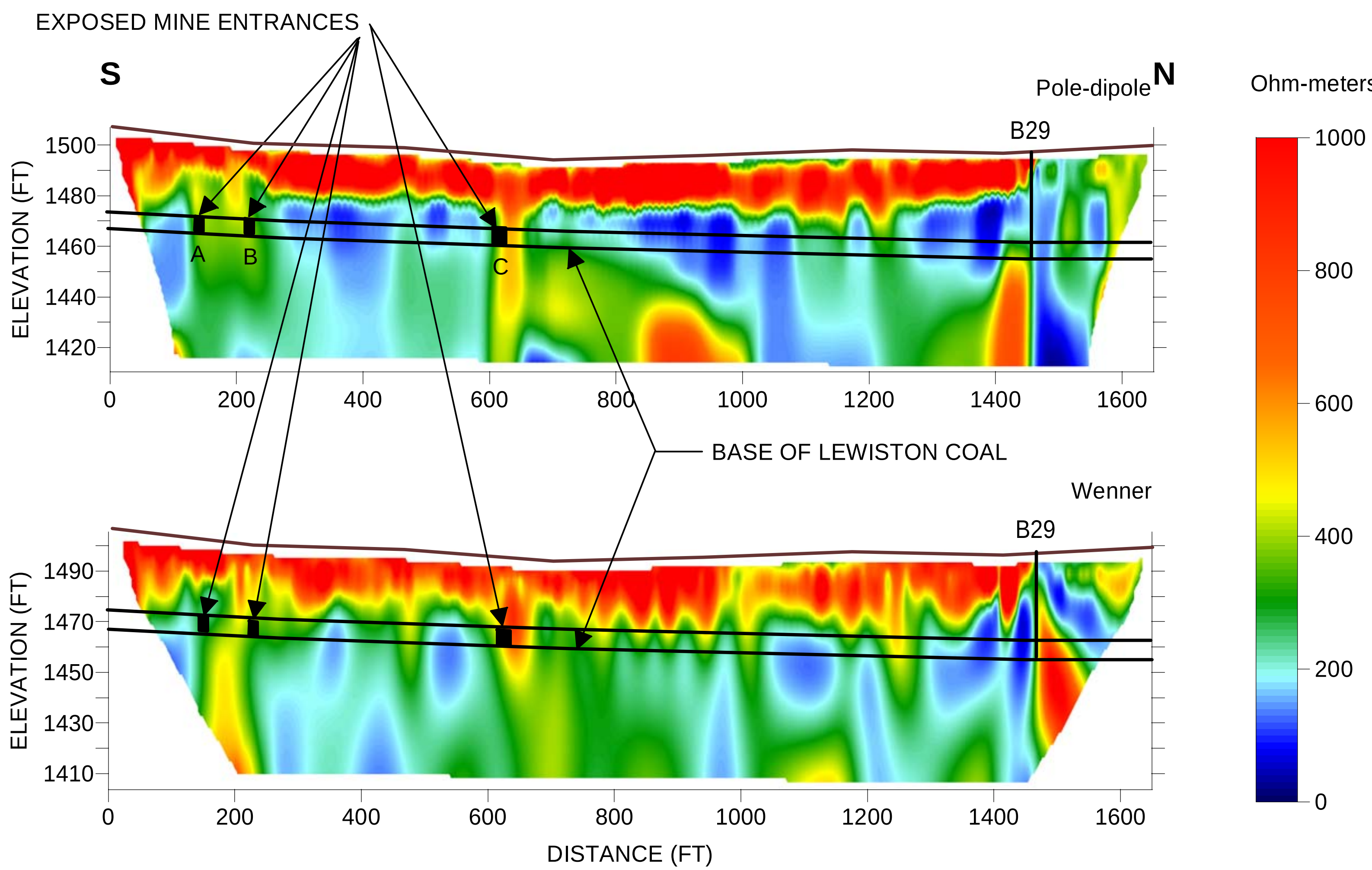
FIGURE 9

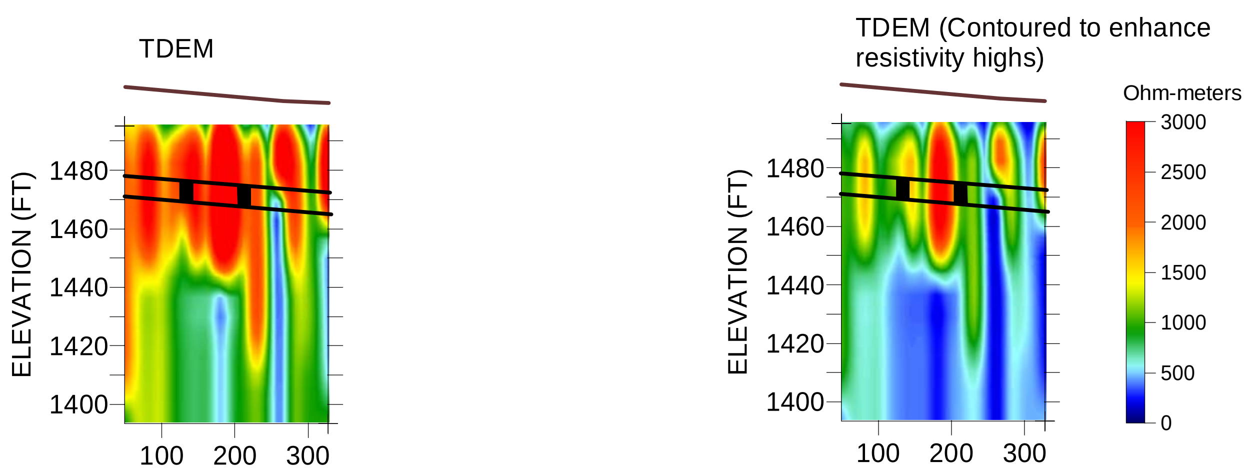
TDEM PROFILE TD-3 WITH COMPARISON
TO DC RESISTIVITY RESULTS
MAIN DEMONSTRATION SURVEY
LOTS BRANCH TAILINGS IMPOUNDMENT SITE

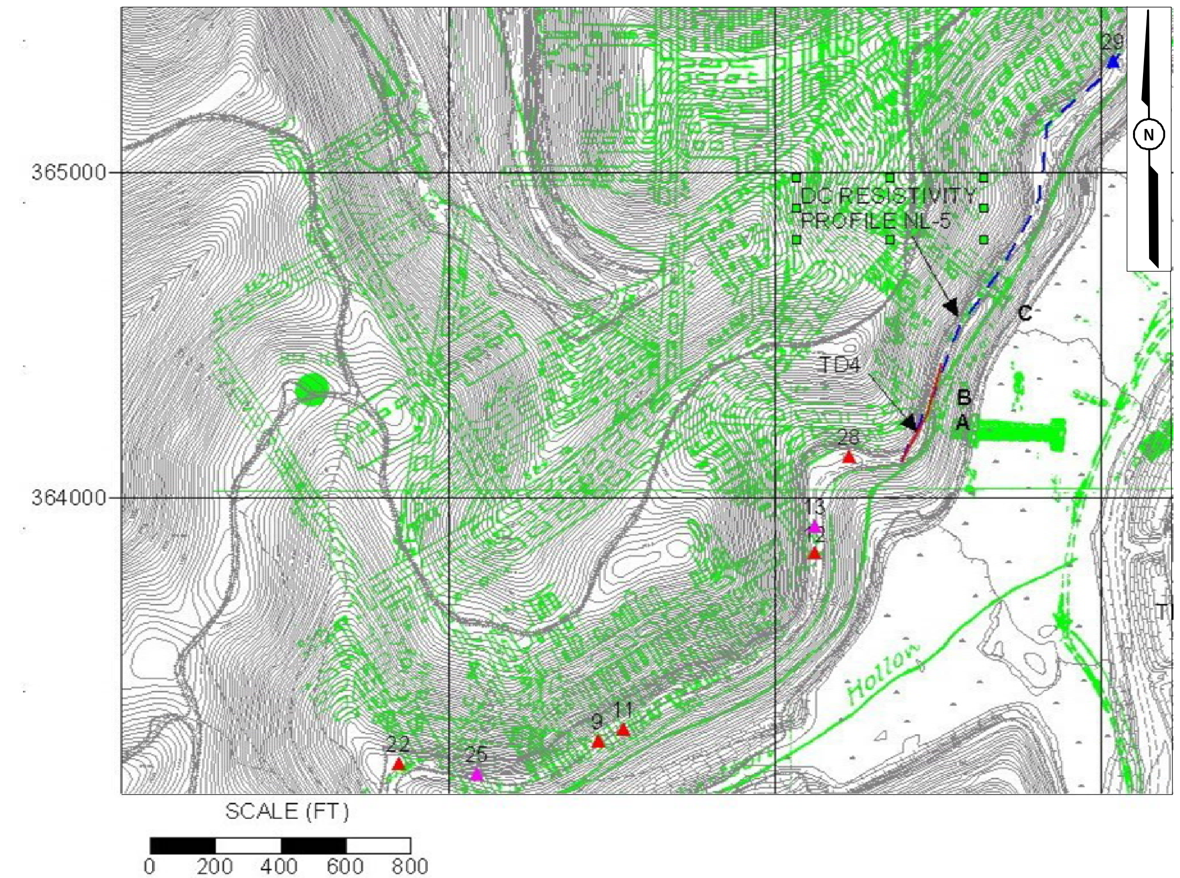
PREPARED FOR

MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON, VIRGINIA

D'APPOLONIA







NOTE: Boring B29 encountered solid coal.

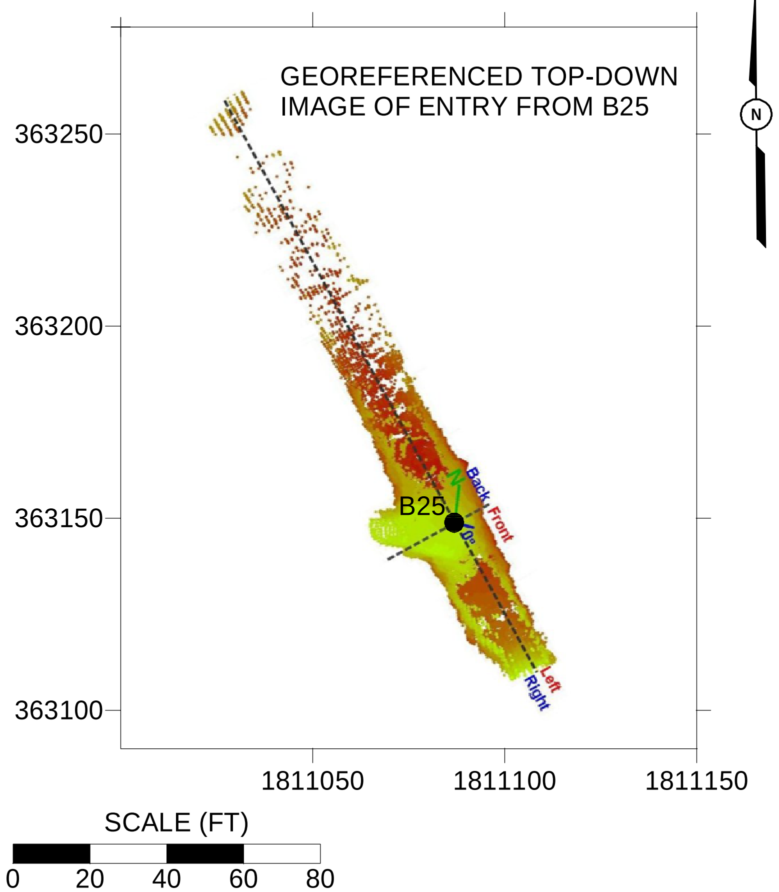
FIGURE 10

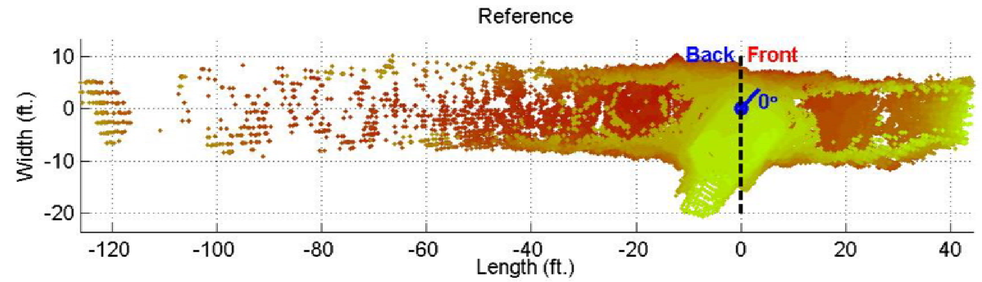
TDEM PROFILE TD-4 WITH COMPARISON
TO DC RESISTIVITY RESULTS
MAIN DEMONSTRATION SURVEY
LOTS BRANCH TAILINGS IMPOUNDMENT SITE

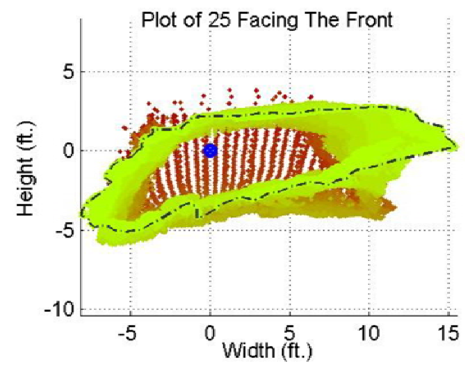
PREPARED FOR

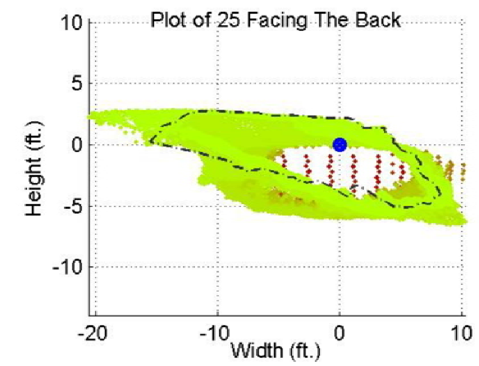
MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON, VIRGINIA

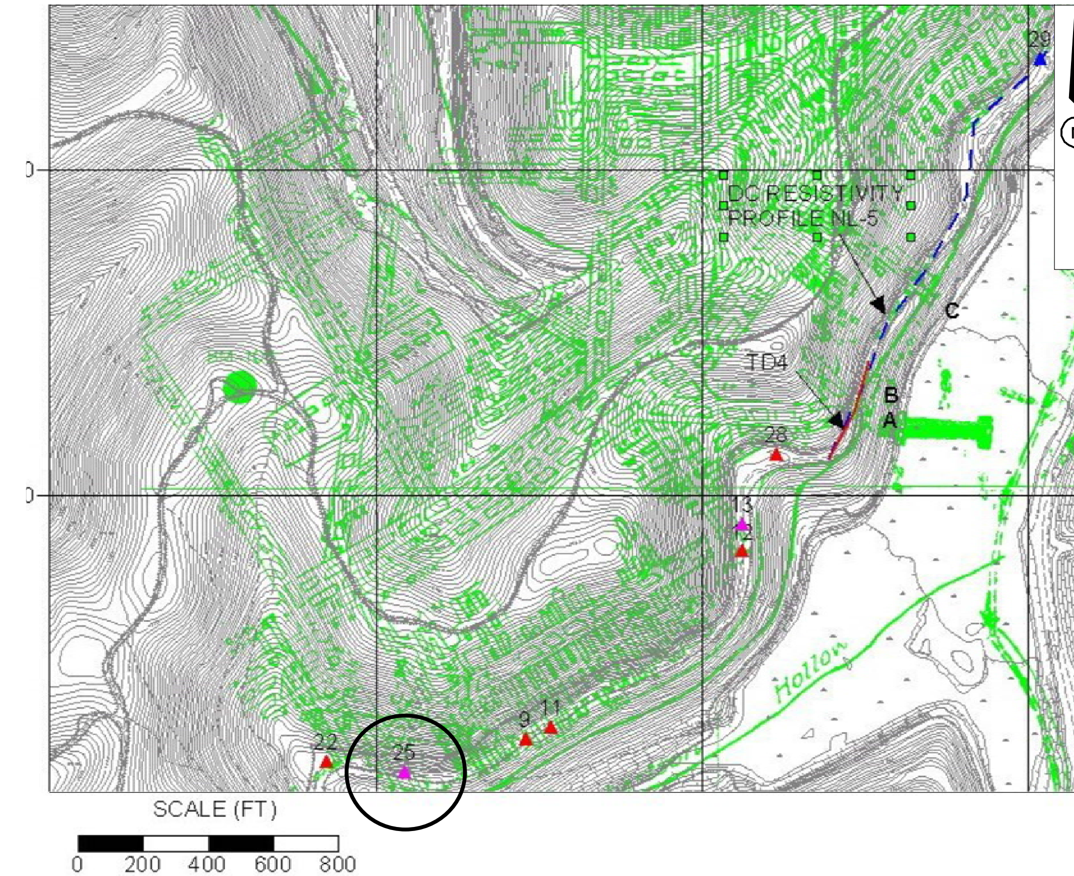
D'APPOLONIA

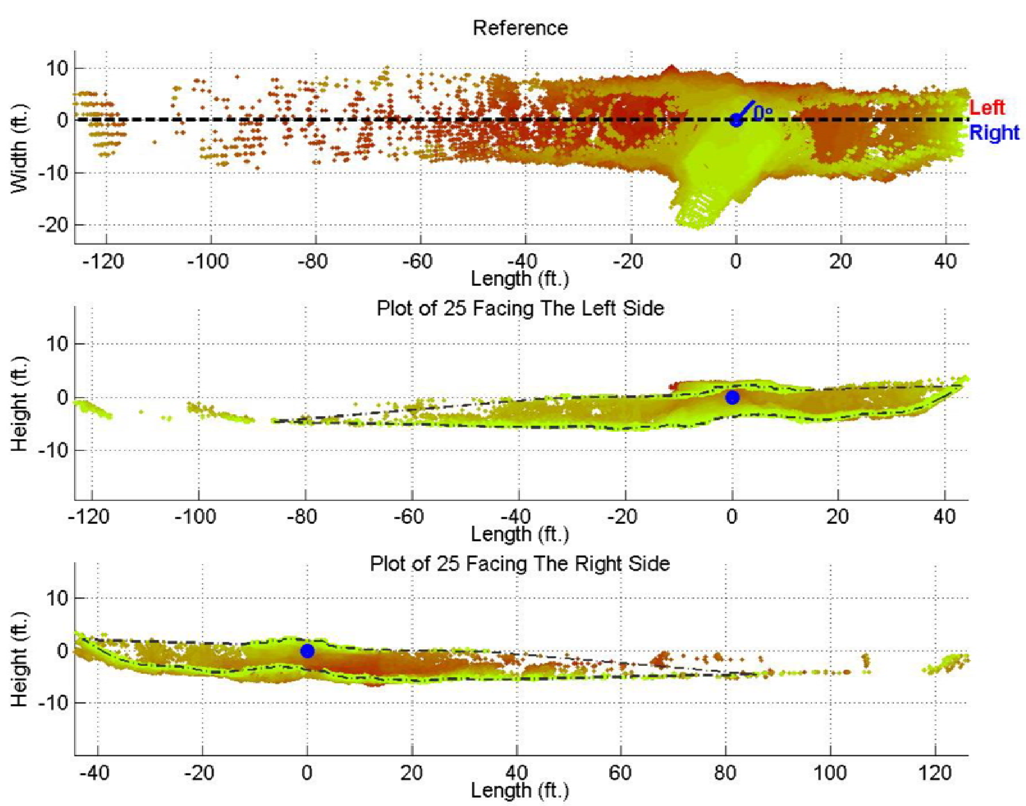


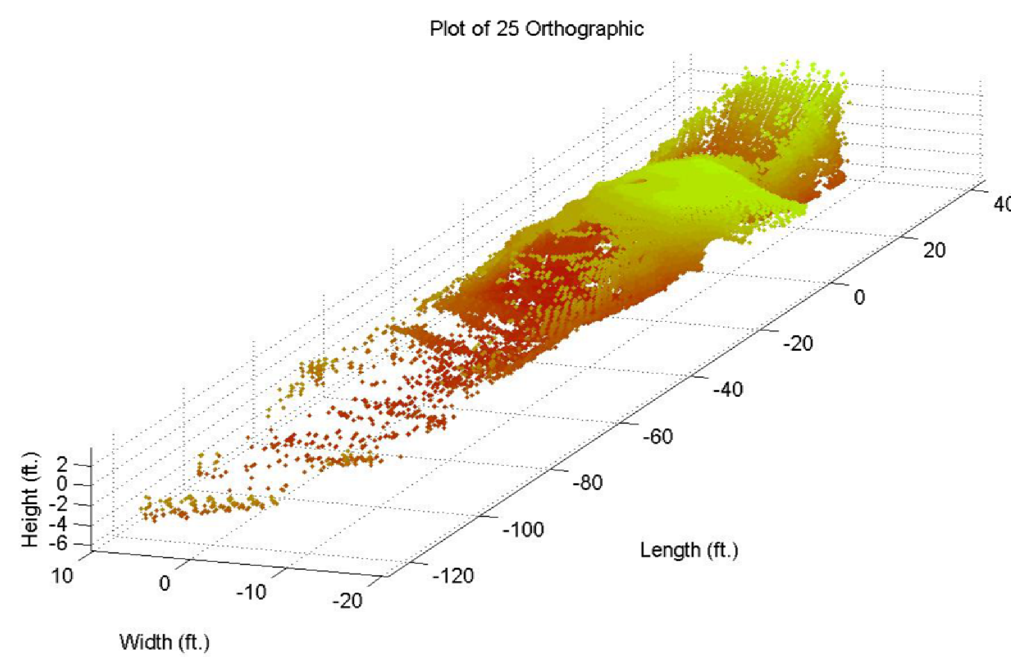












NOTE:

Color coding of laser imaging relates to the depth of a point beyond an arbitrary cut line and is intended for visualization purposes only, to show the relationship of a section to the rest of the points. The range for each plot varies.

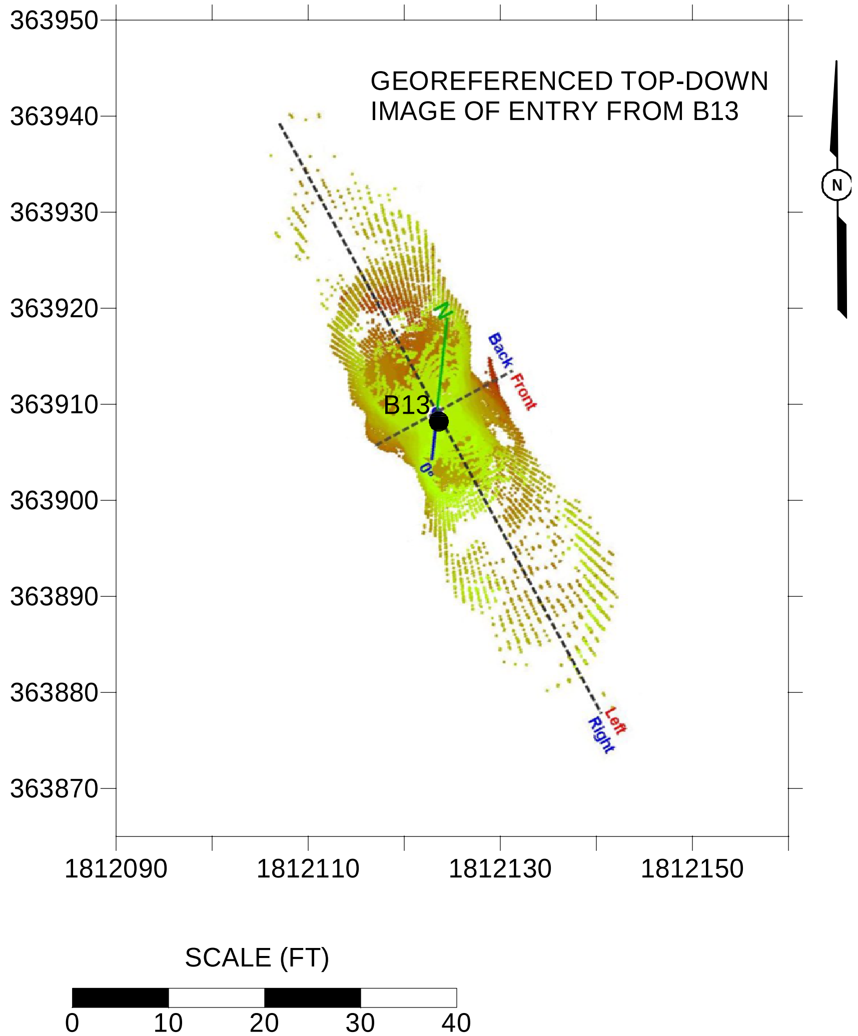
FIGURE 11

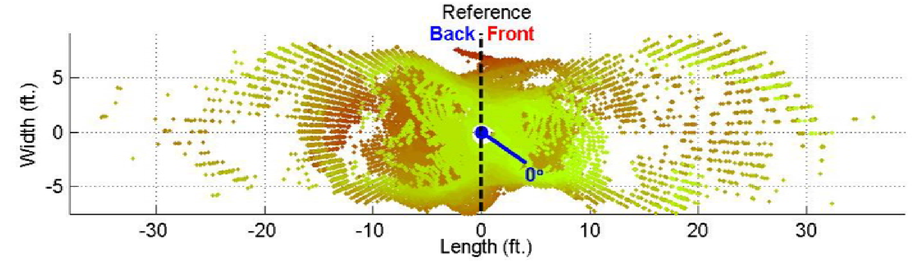
RESULTS OF LASER IMAGING INTO ENTRY TUNNELS
ON NORTH SIDE OF ROBERTSON HOLLOW FROM B-25
MAIN DEMONSTRATION SURVEY
LOTS BRANCH TAILINGS IMPOUNDMENT SITE

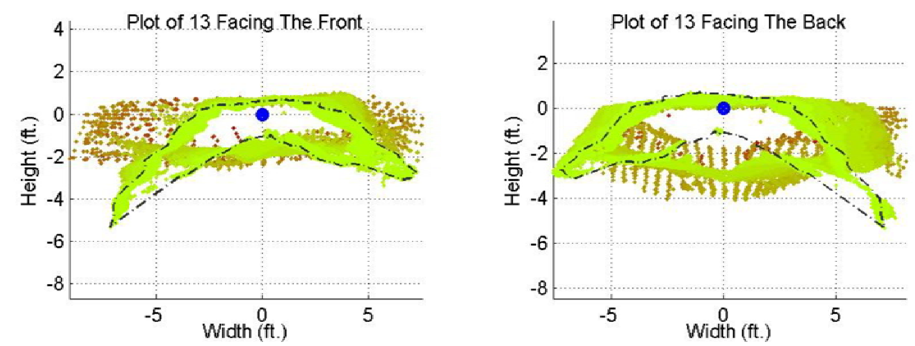
PREPARED FOR

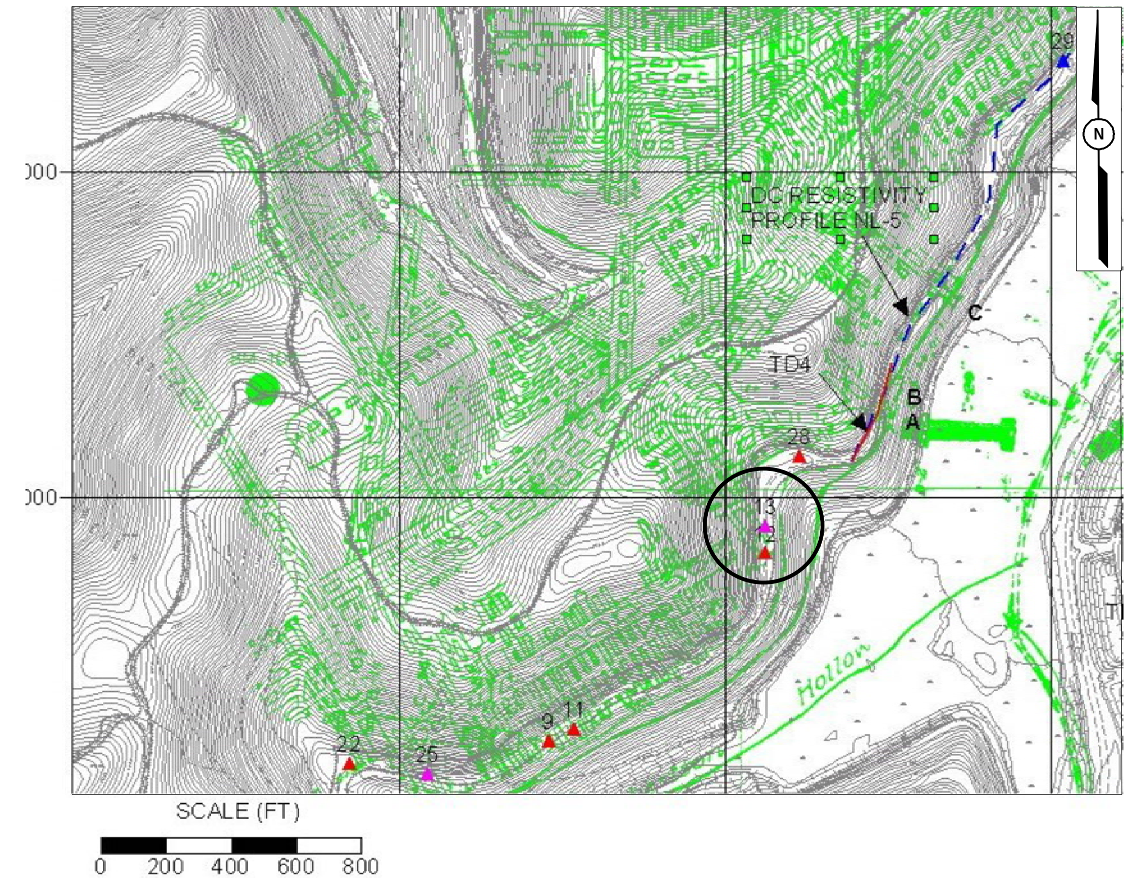
MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON, VIRGINIA

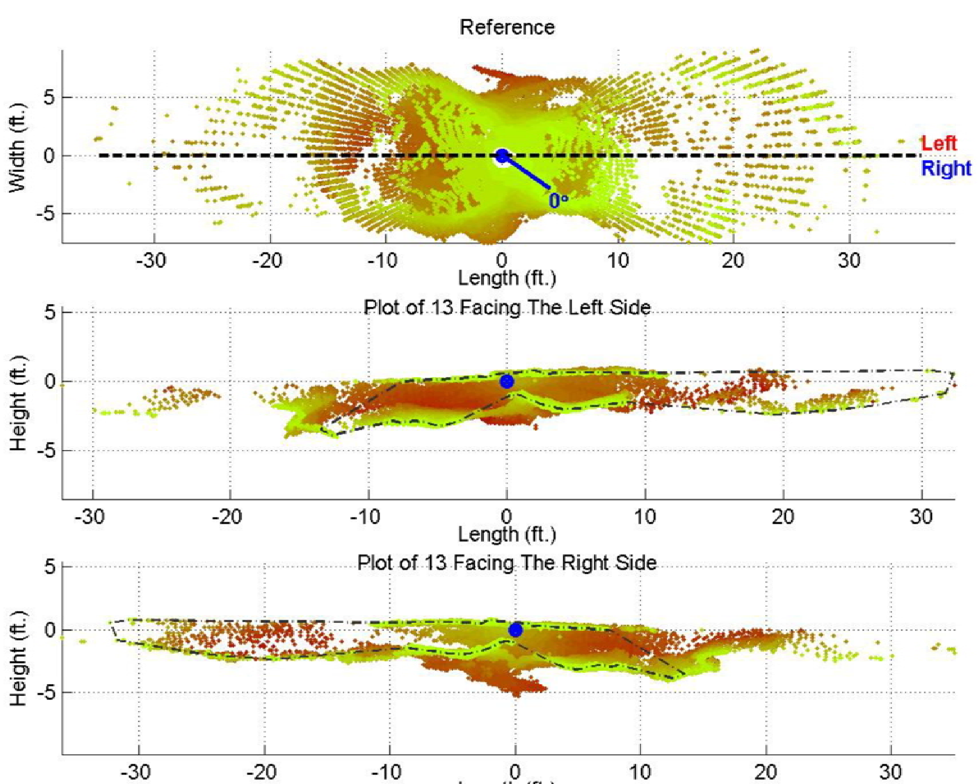
D'APPOLONIA

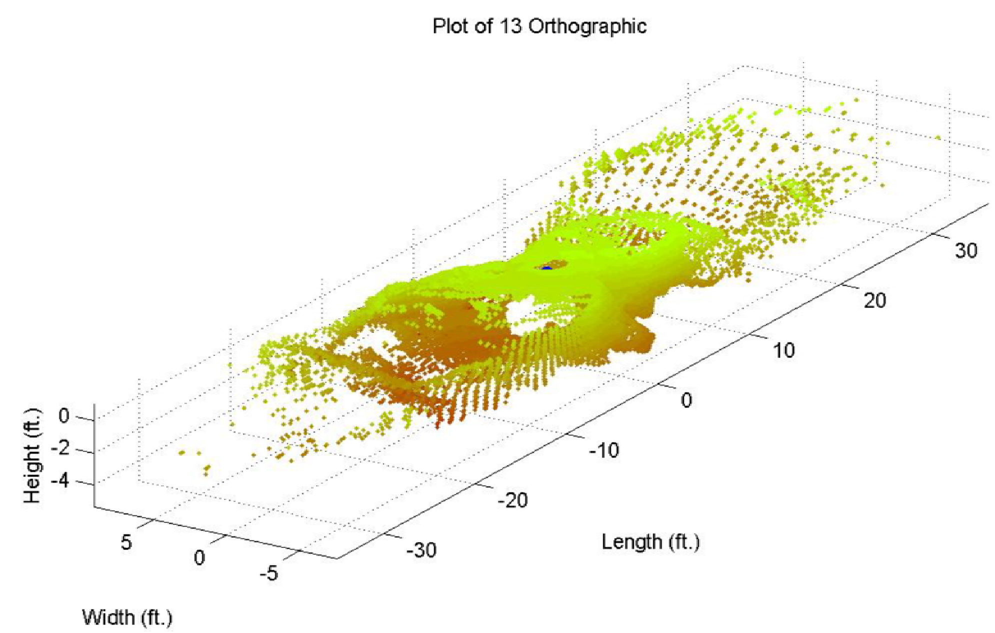












NOTE:

Color coding of laser imaging relates to the depth of a point beyond an arbitrary cut line and is intended for visualization purposes only, to show the relationship of a section to the rest of the points. The range for each plot varies.

FIGURE 12

RESULTS OF LASER IMAGING INTO ENTRY TUNNELS
ON NORTH SIDE OF ROBERTSON HOLLOW FROM B-13
MAIN DEMONSTRATION SURVEY
LOTS BRANCH TAILINGS IMPOUNDMENT SITE

PREPARED FOR

MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON, VIRGINIA

D'APPOLONIA

APPENDIX A – WORKHORSE TECHNOLOGIES REPORT

Lots Branch Impoundment, West Virginia Mine Mapping Investigation

Prepared for:

D'Appolonia
275 Center Road
Monroeville, PA 15146-1451

Release Date: **October 14, 2005**

Project No: **031019**

Prepared by:

Workhorse Technologies, Inc.
484 West 7th Avenue
Homestead, PA 15120

Warren (Chuck) Whittaker
Operations Manager

William (Red) Whittaker
Chief Scientist

Introduction

Workhorse Technologies, LLC, conducted laser mapping of the dry voids associated with old coal mine workings at the Lots Branch Impoundment of Pine Ridge Coal Company located near the town of Prenter in Boone County, West Virginia. The investigation is in support of the D'Appolonia demonstration project "Mine Void Detection with DC Resistivity and TDEM Surface Geophysical Methods" for the U.S. Department of Labor, Mine Safety and Health Administration.

4 voids associated with old coal mines were mapped and modeled. Figure 1 shows the orthographic representations of the modeled voids associated with coal mines accessed through holes 13, 25, 31, and 34.

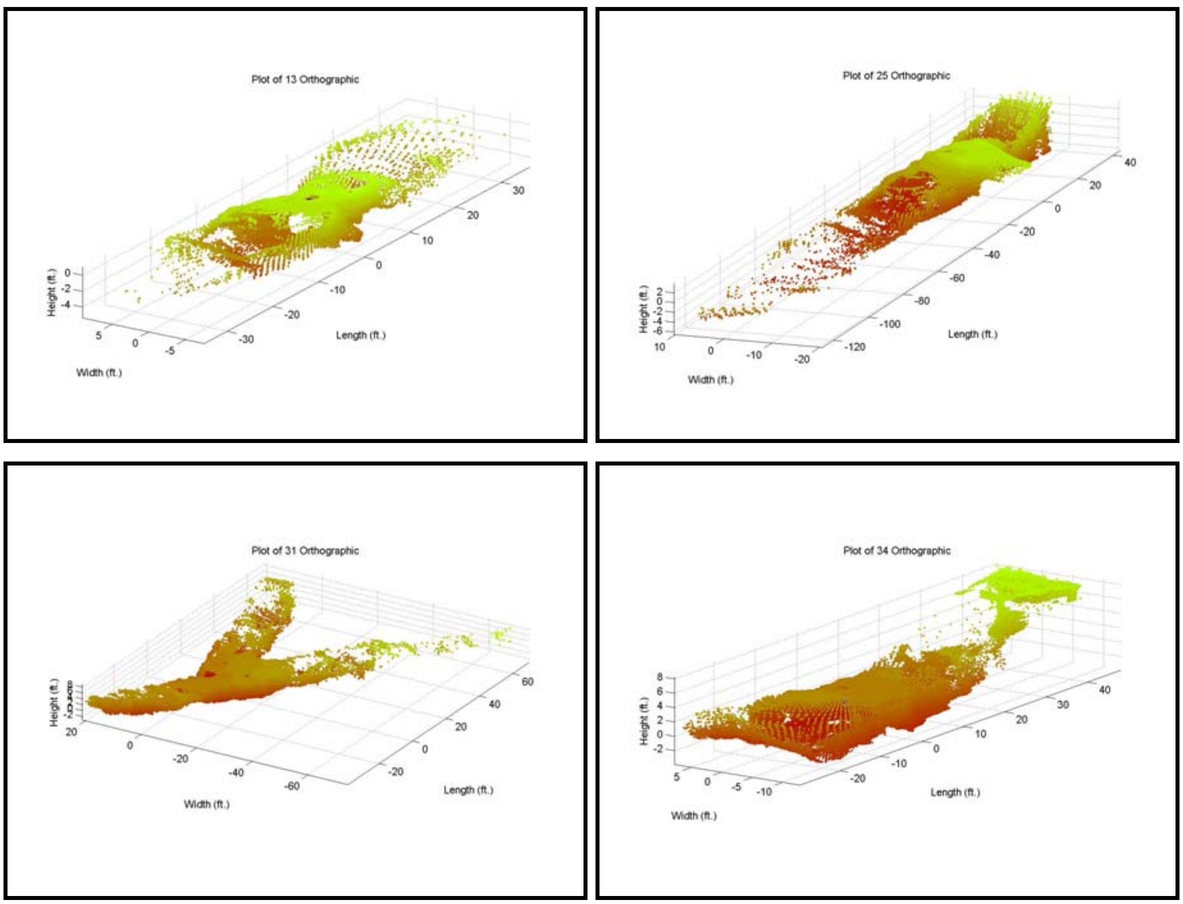


Figure 1: Orthographic views of mine void models for holes 13, 25, 31, and 34

The field work was conducted on September 19, 20, and 21, 2005 with D'Appolonia and MSHA personnel present. Many holes were drilled for verification of D'Appolonia's investigations. Of these, 6 holes were selected to be modeled of which 2 could not be modeled due to conditions encountered in the holes.

Ferret Laser Scans

The data was obtained using the Ferret, a tool developed for subterranean mapping. The Ferret uses a survey quality point laser range finder on a pan and tilt unit to take measurements. Figure 2 shows Ferret with rigid deployment at a typical site hanging from a tripod entering into the casing of a hole. Ferret fits down a 6 inch diameter hole and for the shallow depths encountered at this site mechanical linkage was maintained between the instrument and the surface to provide a surface referenced orientation. Using Ferret point distant measurements and pan and tilt angles are recorded in data sets called scans. Ferret is capable of collecting angular data to 0.1 degree increments and range data to 65 meters while maintaining accuracies to within 10mm. Figure 3 shows a screen capture of a raw scan for review in the field. By examining the data in the field informed decisions are made on what supplemental scans are needed to completely map a void or plan a next hole.

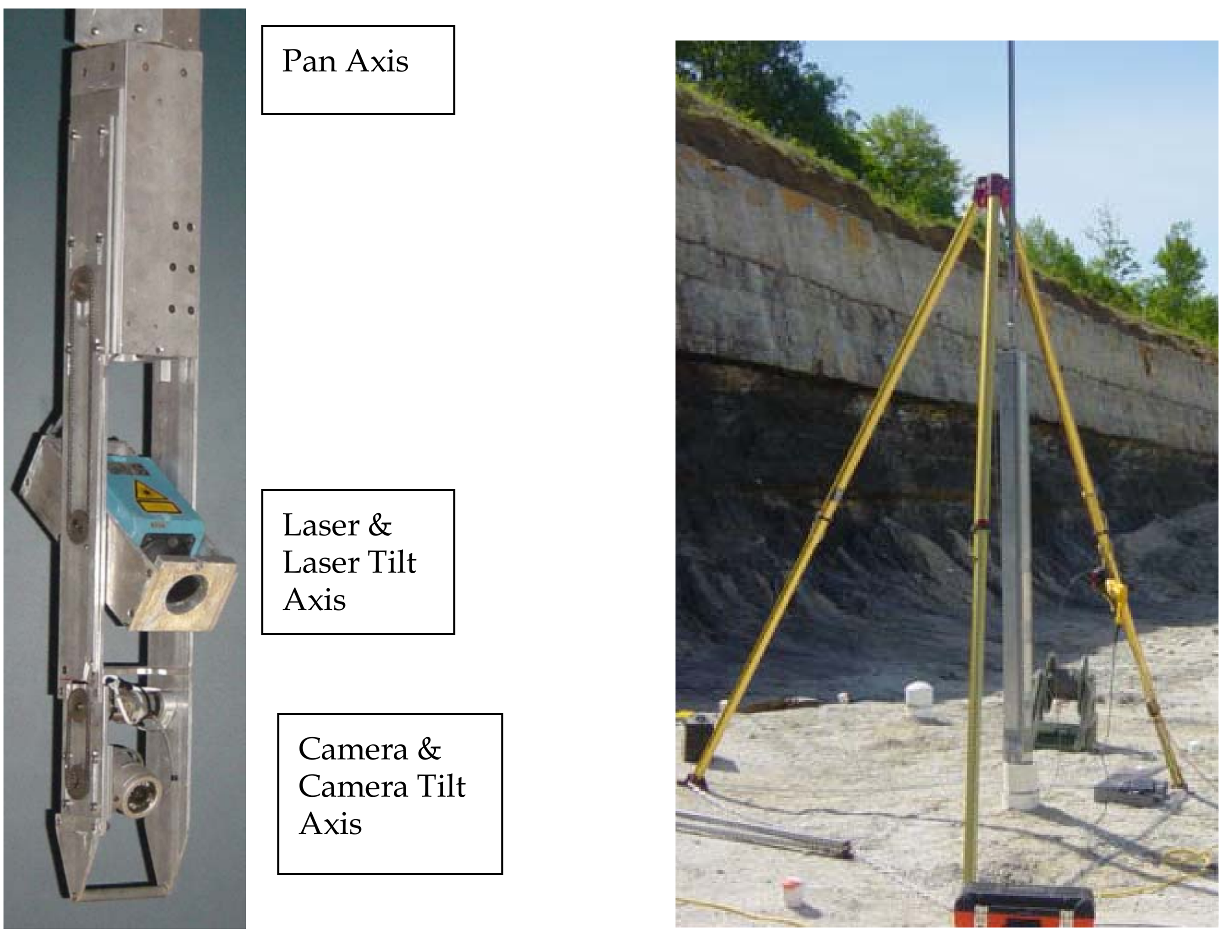


Figure 2: Ferret close-up (left) rigid deployment from tripod (right)

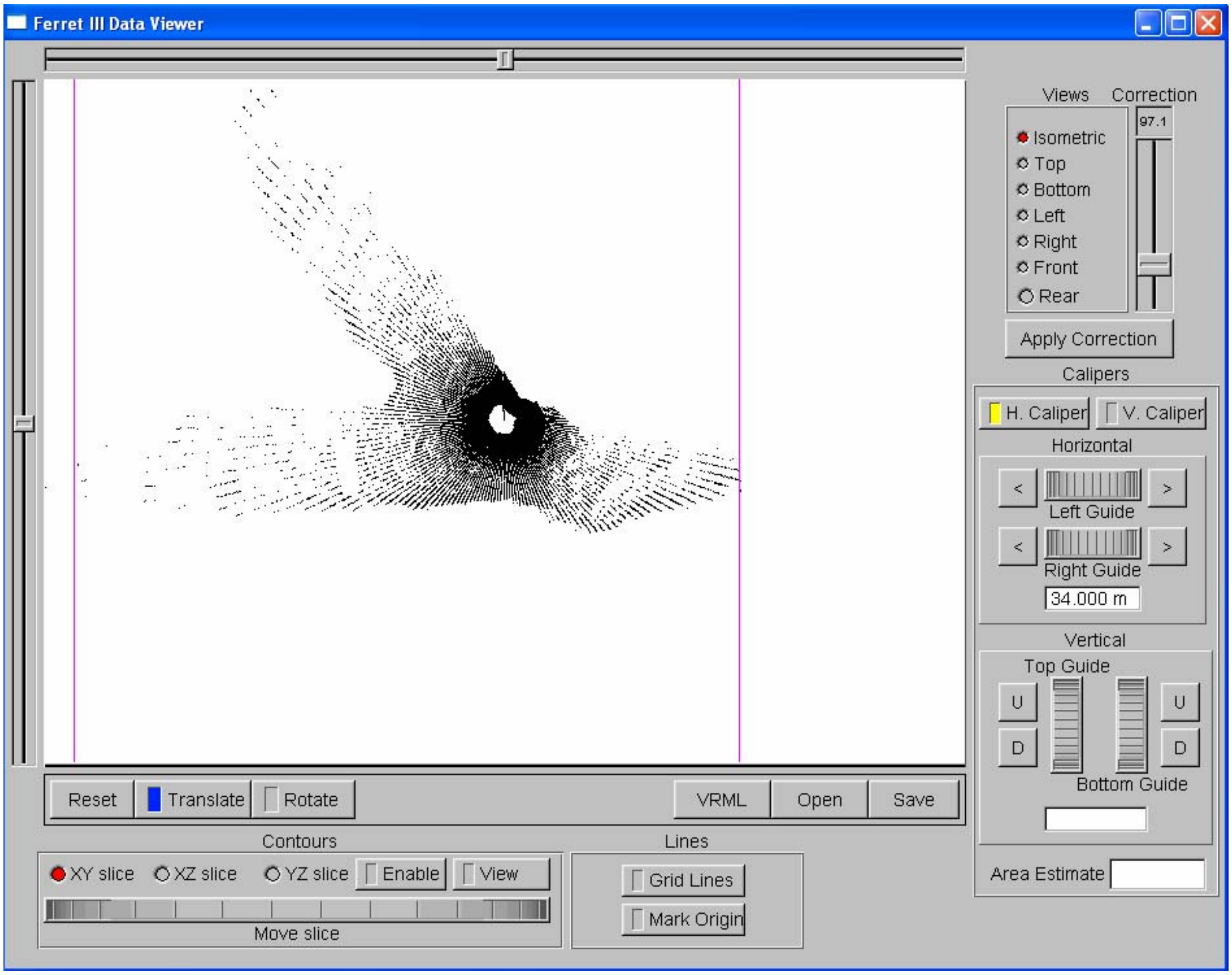


Figure 3: Field review of raw scan at hole 31

Survey of hole locations

Surveyed locations and elevations of the boreholes were not provided so each hole is locally referenced. Elevations are referenced as negative depth in feet from the surface. The zero azimuth for the scans at each hole is referenced to a predominant physical surface feature such as the centerline of the road or another borehole. For each hole a single composite model is generated which containing all the points from all scans. The zero azimuth of the model is referenced with North and a file containing all of the points is displayed in X, Y, Z coordinates. North referenced used are listed in the borehole descriptions below. These point files are found in the results section of the electronic data. By summing the point file with surveyed hole coordinates and surface elevation the models can be geo-referenced.

Boreholes

For each borehole there are statistics, volume, a north referenced horizontal plot, orthographic view of the model, and sectional views of the model. Additionally for each model there are files on the data disk with the x,y,z points, and point cloud models. The orthographic, top, side, and front plots give good representations of the model but viewing the model with a 3-D viewer offers the investigator greater insight into understanding the features from the old mines. For instance careful examination of the borehole 25 model reveals old mine posts. Individual borehole data follws:

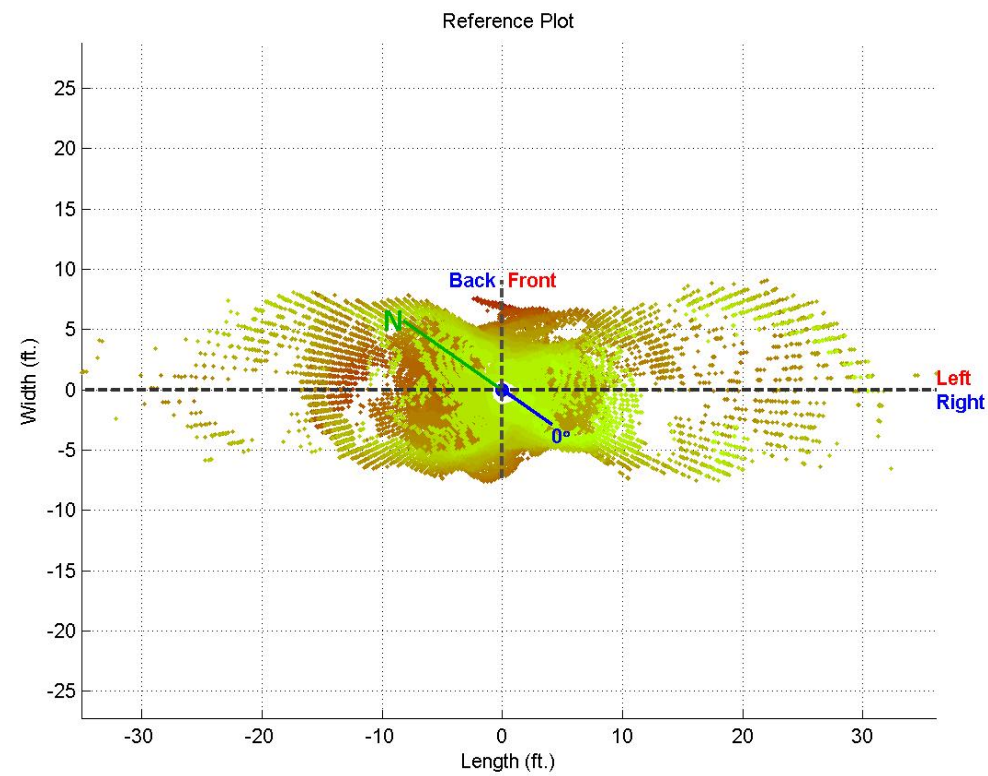
Borehole 11

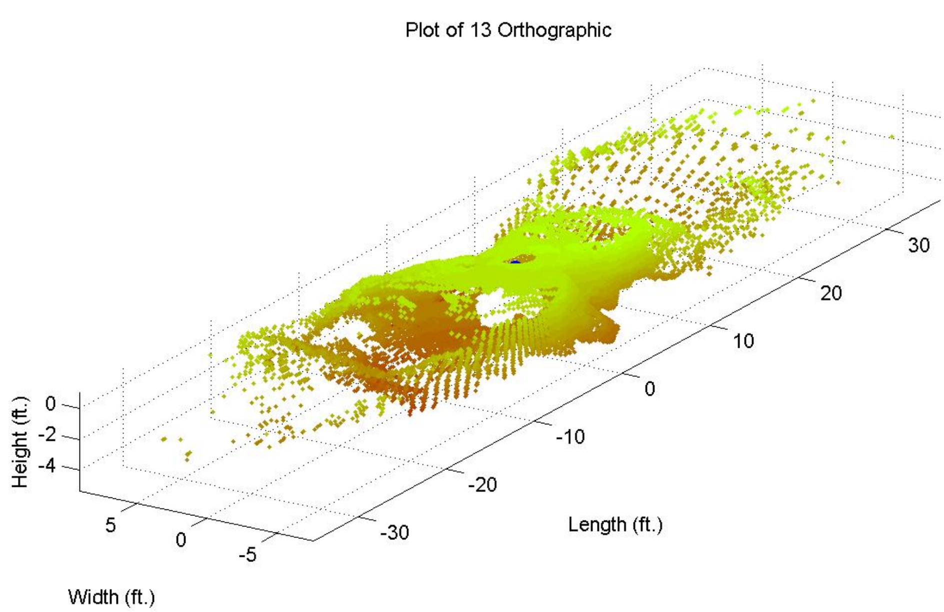
September 19, 2005	
Top of void depth	32.6 ft
Bottom of hole	38.2 ft

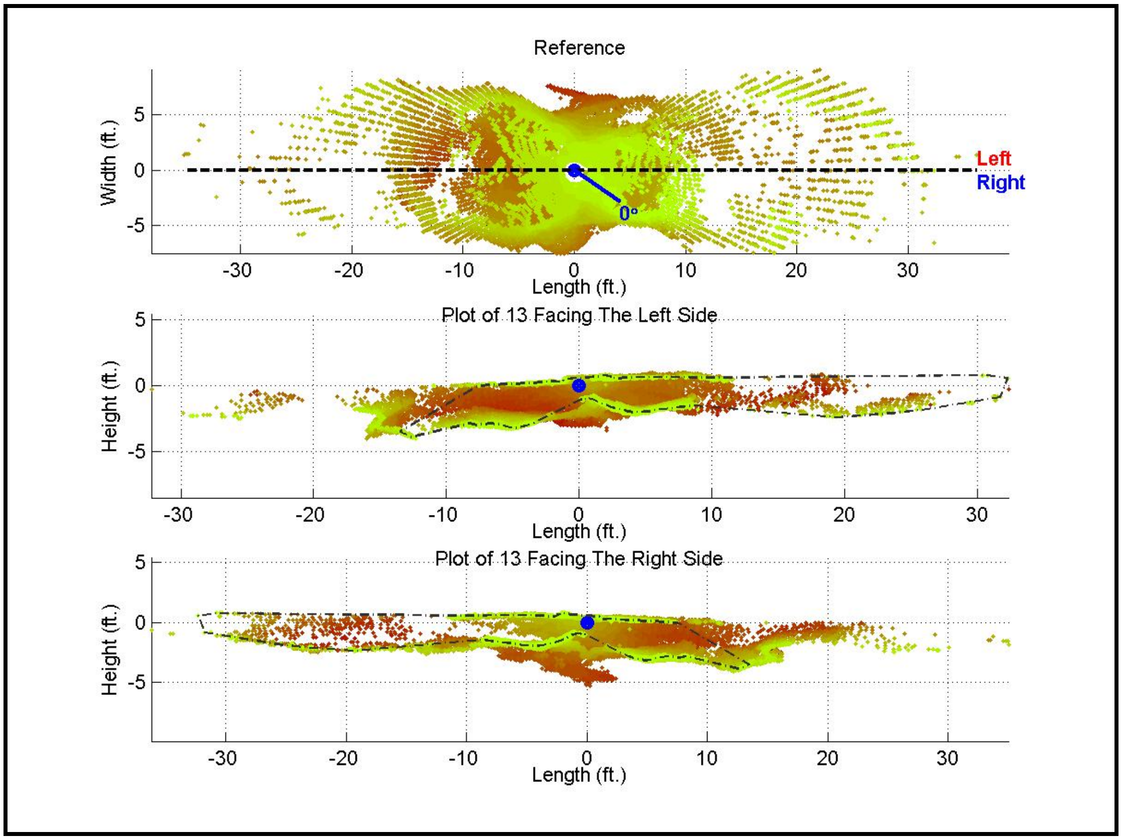
Only video data was collected at this location. There was not enough clearance for deploying the laser due to the build up of drill cuttings in the floor of the mine. No laser data was collected for this hole. The drill cuttings formed a volcano shaped cone which stands to within a foot of the bottom of the casing leaving an opening just big enough for the camera scan.

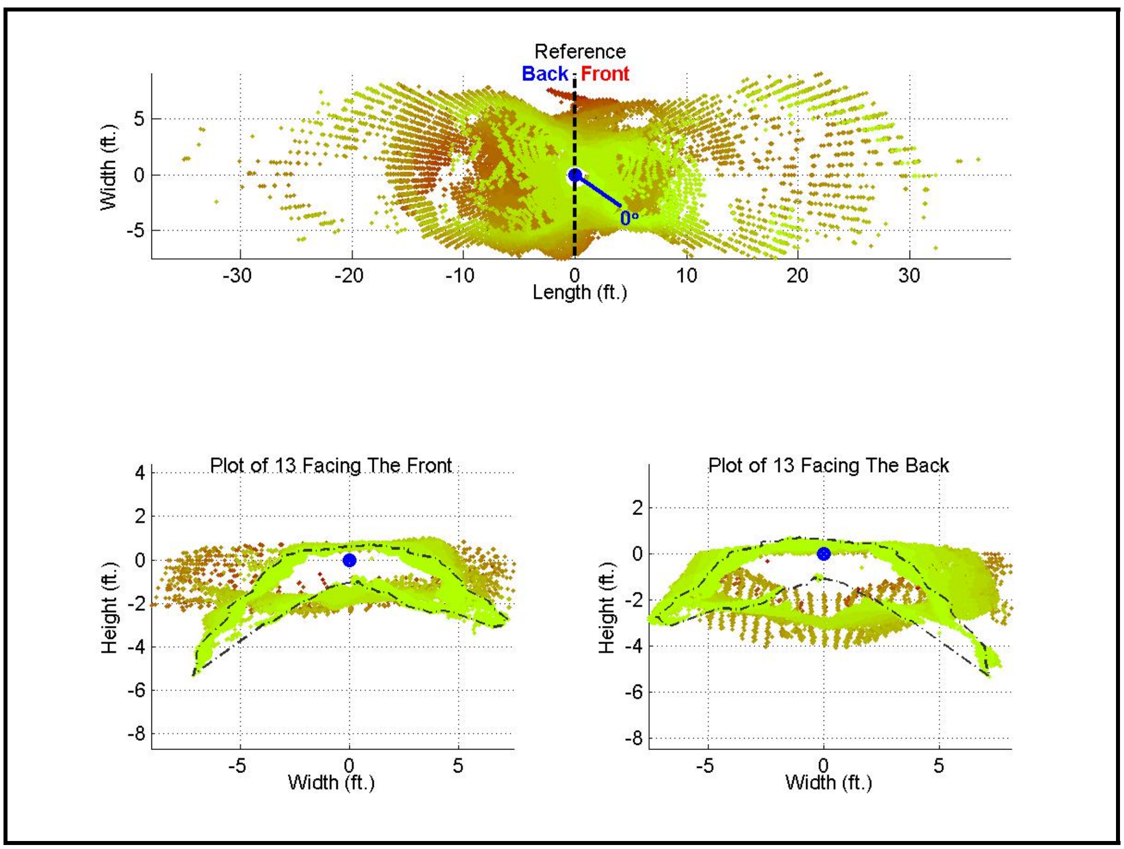
Borehole 13

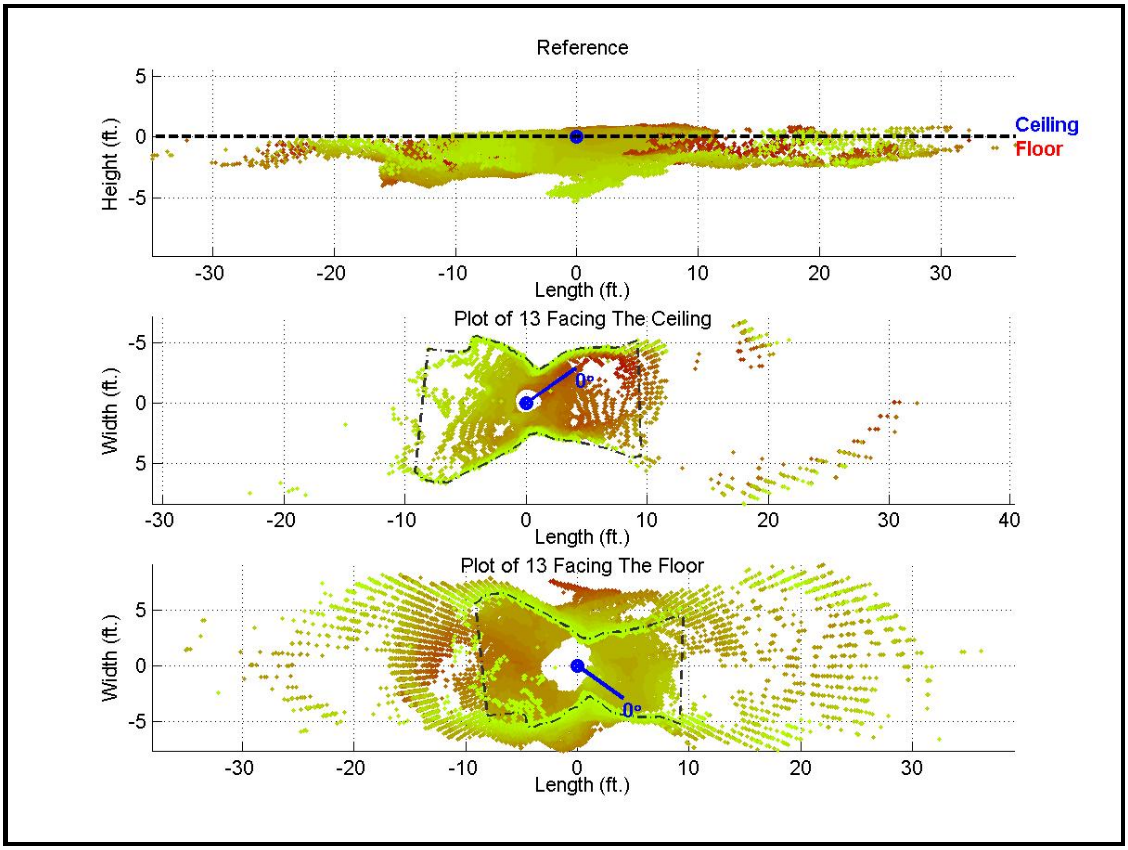
September 19, 2005	
Top of void depth	25.6 ft
Bottom of void depth	27.8 ft
Volume of void	2145 cu ft
Azimuth reference	0 was in line with the road facing South


Reference Plot
Width (ft.)
Length (ft.)
Back
Front
Left
Right
N
0°
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-20
-10
0
10
20
30


Plot of 13 Orthographic
Height (ft.)
0
-2
-4
Width (ft.)
5
0
-5
Length (ft.)
-30
-20
-10
0
10
20
30


Reference
Width (ft.)
Length (ft.)
Left
Right
0°
Plot of 13 Facing The Left Side
Height (ft.)
Length (ft.)
Plot of 13 Facing The Right Side
Height (ft.)
Length (ft.)


Reference
Back
Front
Width (ft.)
Length (ft.)
0°
Plot of 13 Facing The Front
Height (ft.)
Width (ft.)
Plot of 13 Facing The Back
Height (ft.)
Width (ft.)



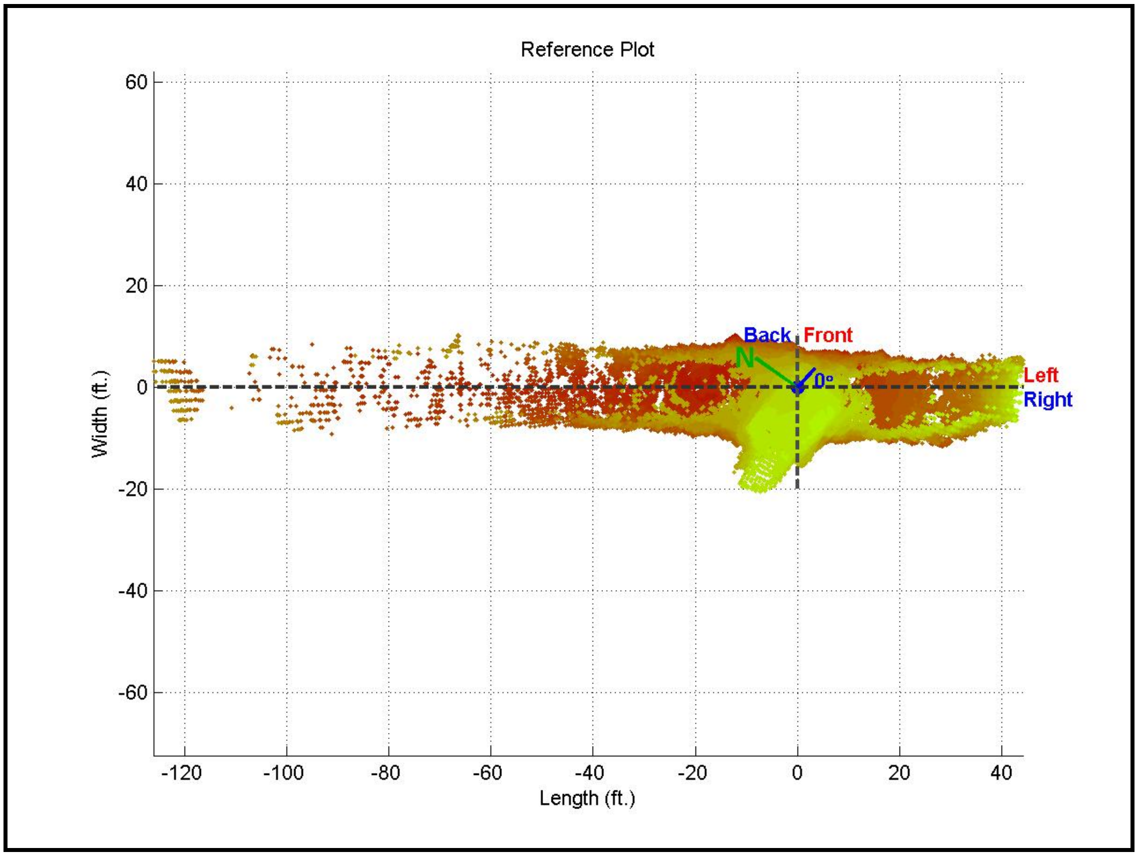
Borehole 18

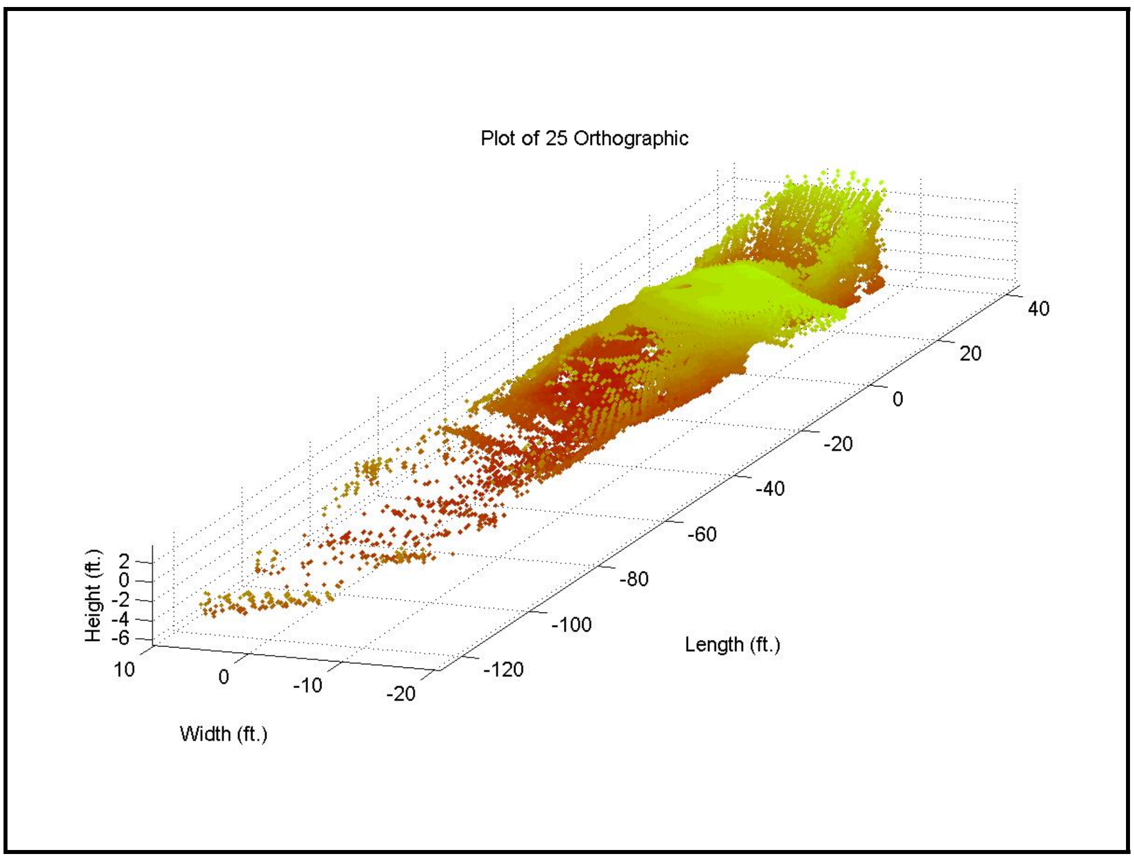
Only video data was collected at this location. There was not enough clearance in the hole to allow ferret to be lowered more than 24ft. The video shows the scrapings along the wall of the hole where the instrument was stopped. It is indeterminate whether the hole narrowed or was misaligned.

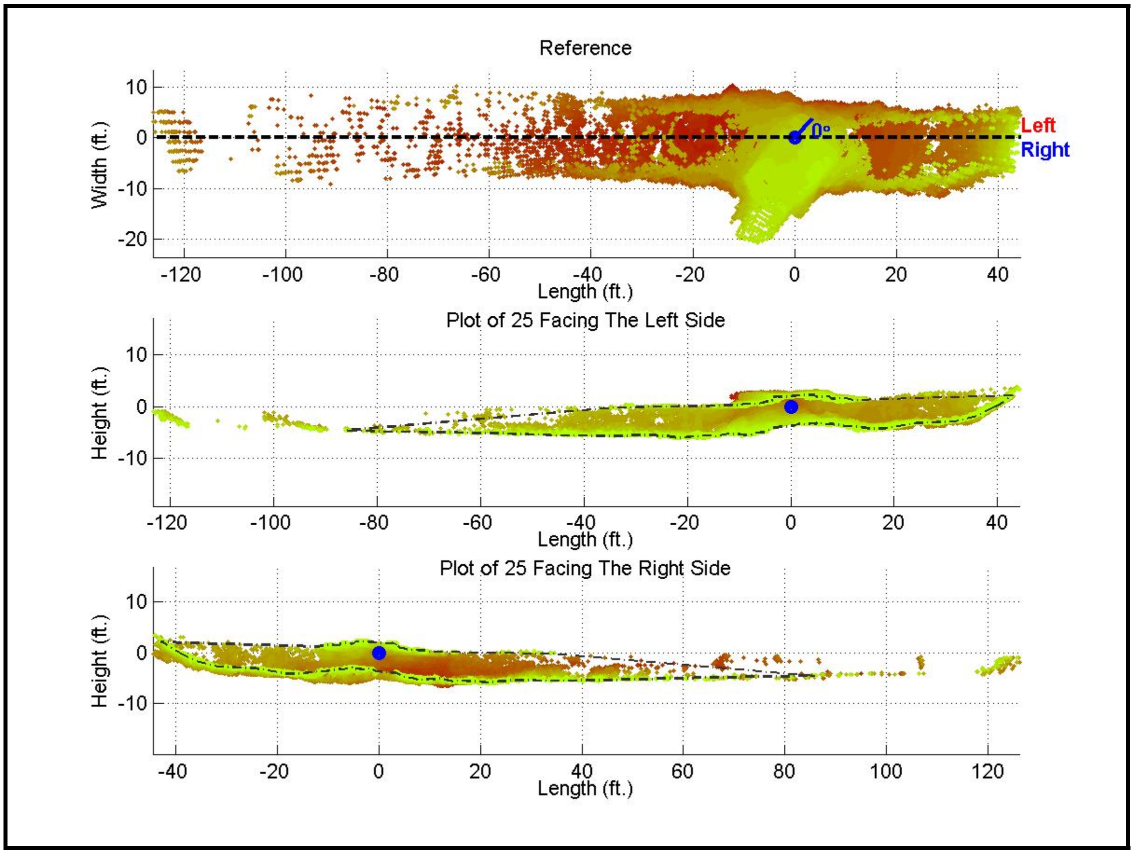
Borehole 25

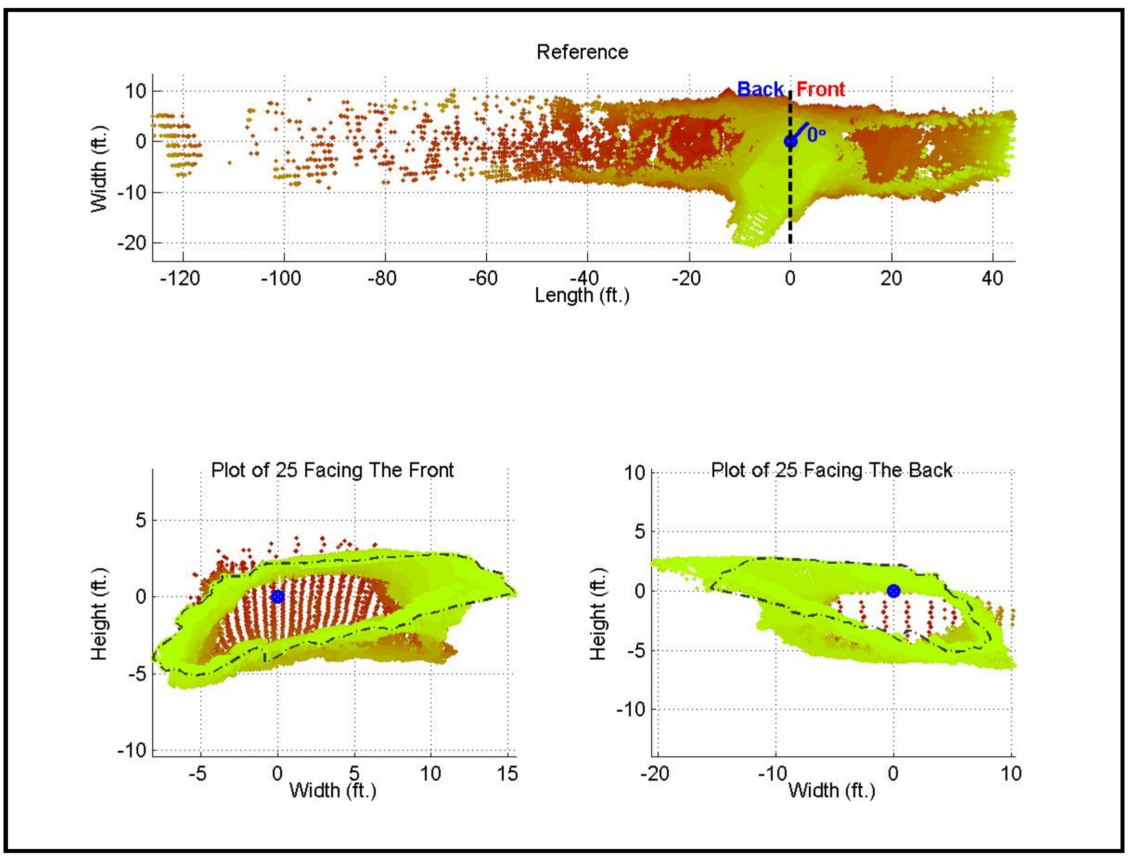
September 20, 2005

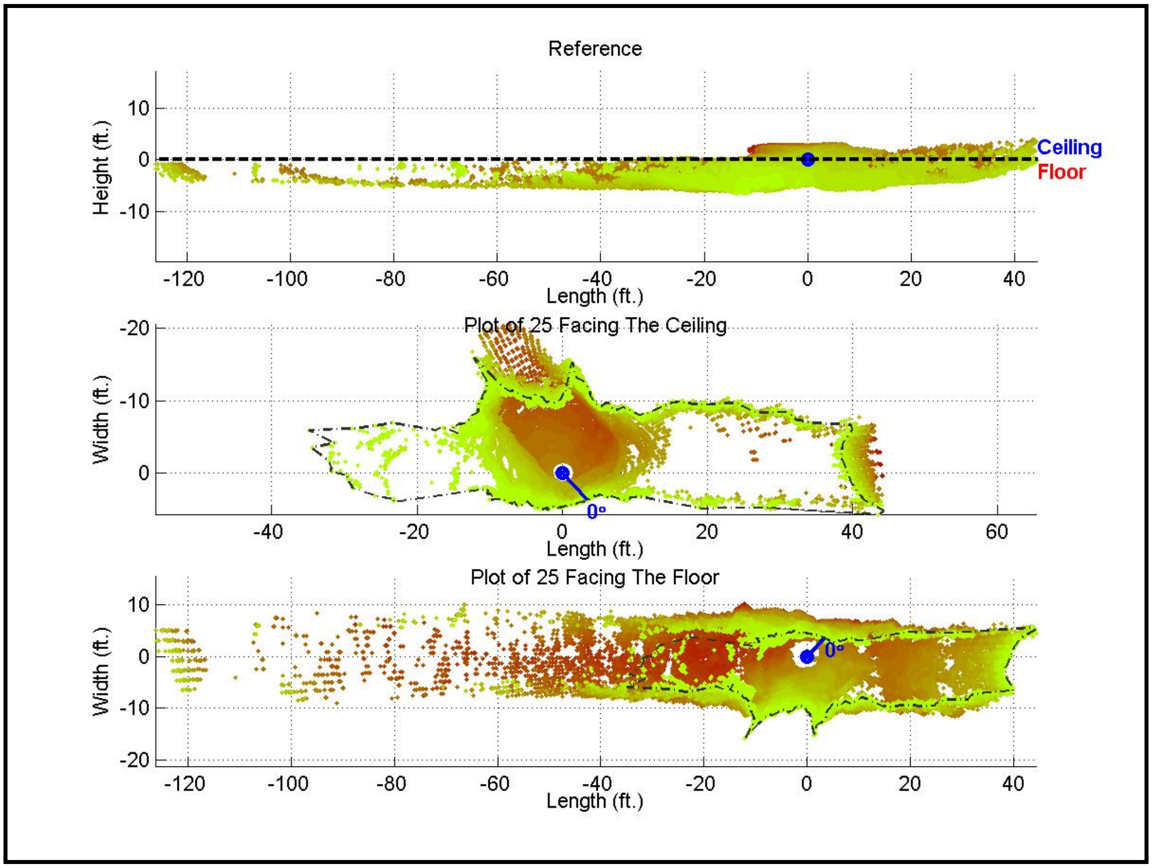
Top of void depth	29.9 ft
Bottom of void depth	36.3 ft
Volume of void	11034 cu ft
Azimuth reference	0 was directly opposite a line to hole 22


Reference Plot
Back
Front
N
0°
Left
Right
Width (ft.)
Length (ft.)
60
40
20
0
-20
-40
-60
-120
-100
-80
-60
-40
-20
0
20
40


Plot of 25 Orthographic
Height (ft.)
2
0
-2
-4
-6
10
0
-10
-20
Width (ft.)
40
20
0
-20
-40
-60
-80
-100
-120
Length (ft.)


Reference
Width (ft.)
Length (ft.)
Left
Right
0°
Plot of 25 Facing The Left Side
Height (ft.)
Length (ft.)
Plot of 25 Facing The Right Side
Height (ft.)
Length (ft.)

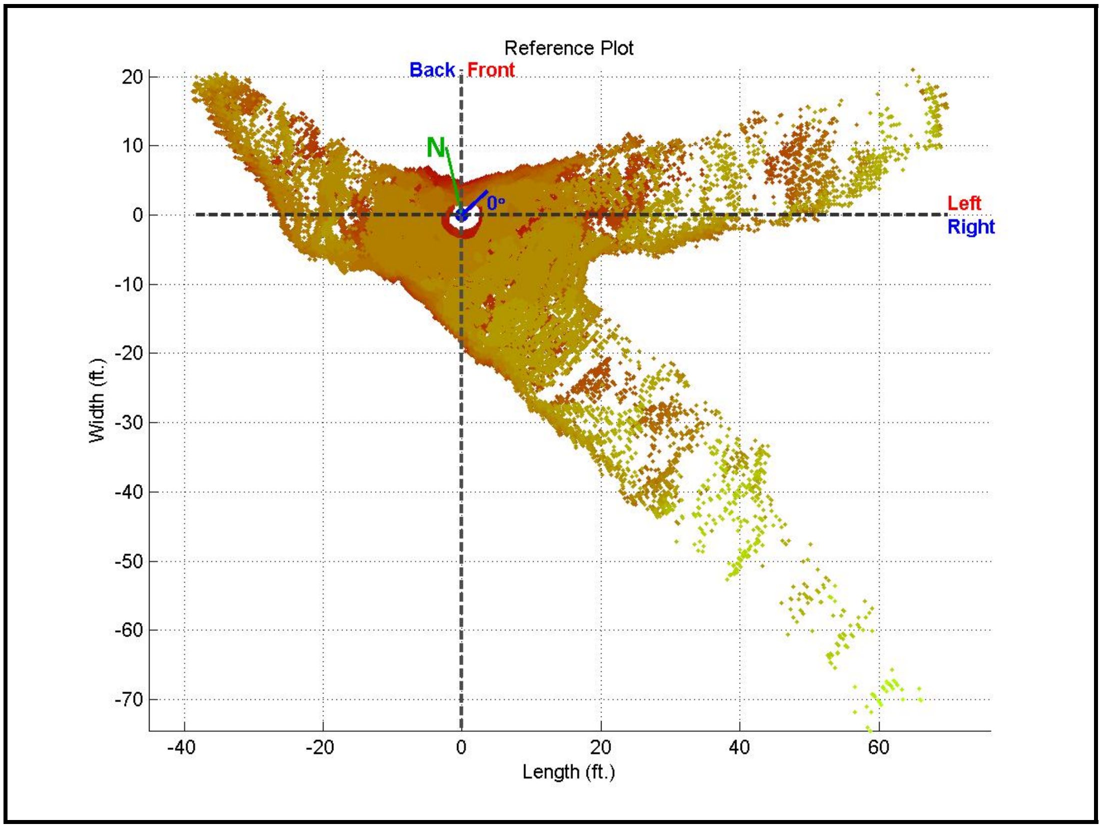

Reference
Width (ft.)
Length (ft.)
Back
Front
0°
Plot of 25 Facing The Front
Height (ft.)
Width (ft.)
Plot of 25 Facing The Back
Height (ft.)
Width (ft.)

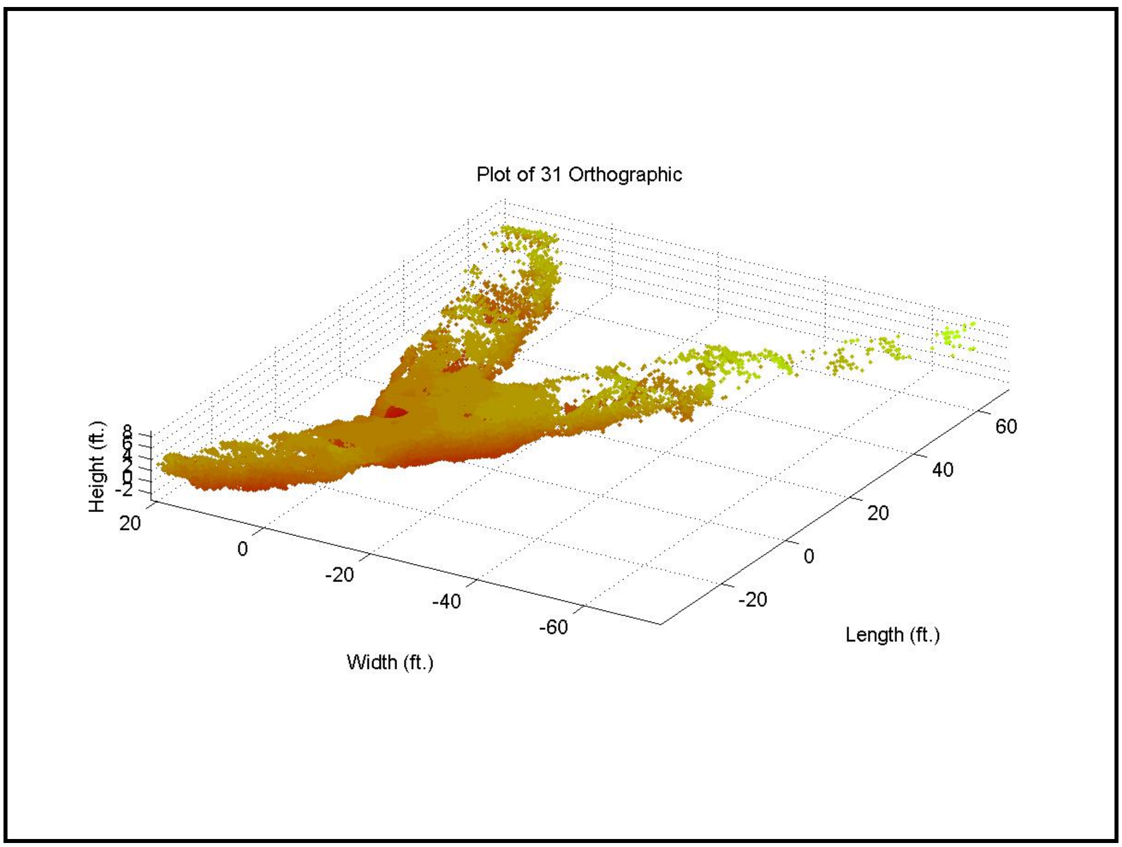


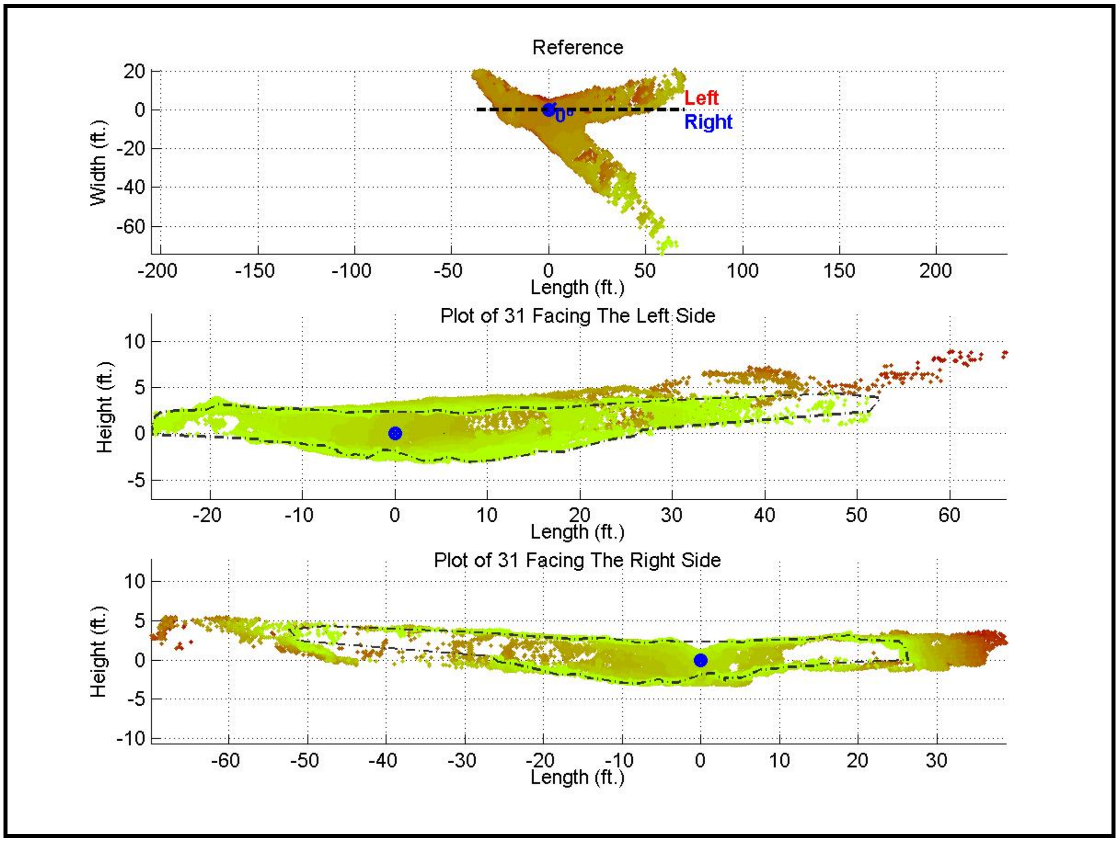
Borehole 31

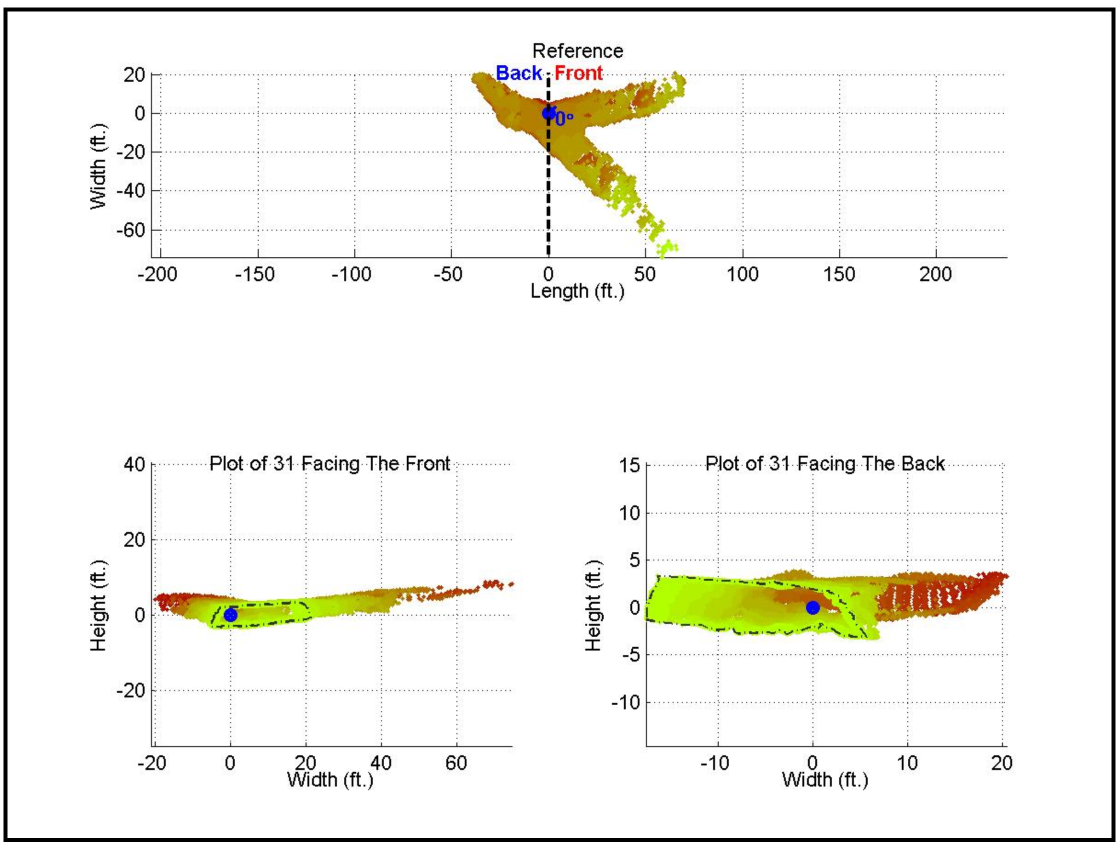
September 20, 2005

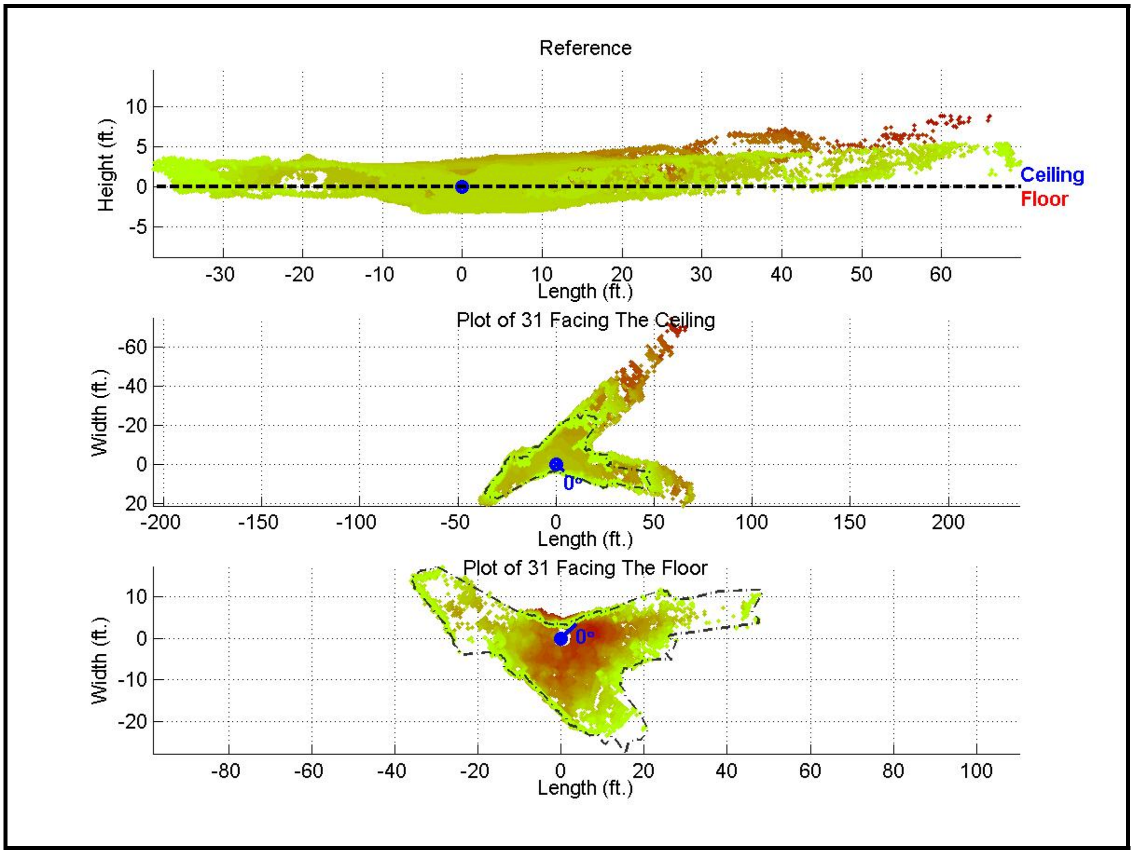
Top of void depth	36.4 ft
Bottom of void depth	40.8 ft
Volume of void	10679 cu ft
Azimuth reference	0 was aligned with the road bearing N60E


Reference Plot
Back
Front
N
0°
Left
Right
Width (ft.)
Length (ft.)
20
10
0
-10
-20
-30
-40
-50
-60
-70
-40
-20
0
20
40
60


Plot of 31 Orthographic
Height (ft.)
Width (ft.)
Length (ft.)
20
0
-20
-40
-60
60
40
20
0
-20


Reference
Left
Right
0°
Width (ft.)
Length (ft.)
Plot of 31 Facing The Left Side
Height (ft.)
Length (ft.)
Plot of 31 Facing The Right Side
Height (ft.)
Length (ft.)


Reference
Back
Front
0°
Width (ft.)
Length (ft.)
Plot of 31 Facing The Front
Height (ft.)
Width (ft.)
Plot of 31 Facing The Back
Height (ft.)
Width (ft.)

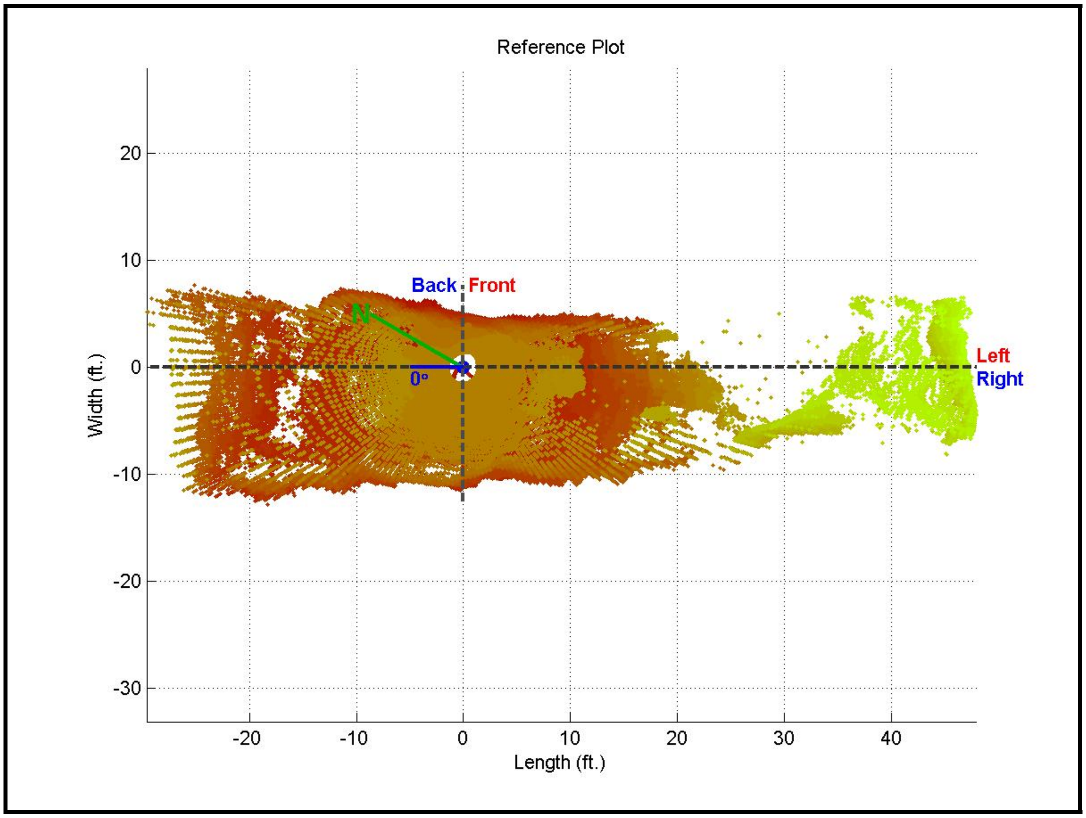


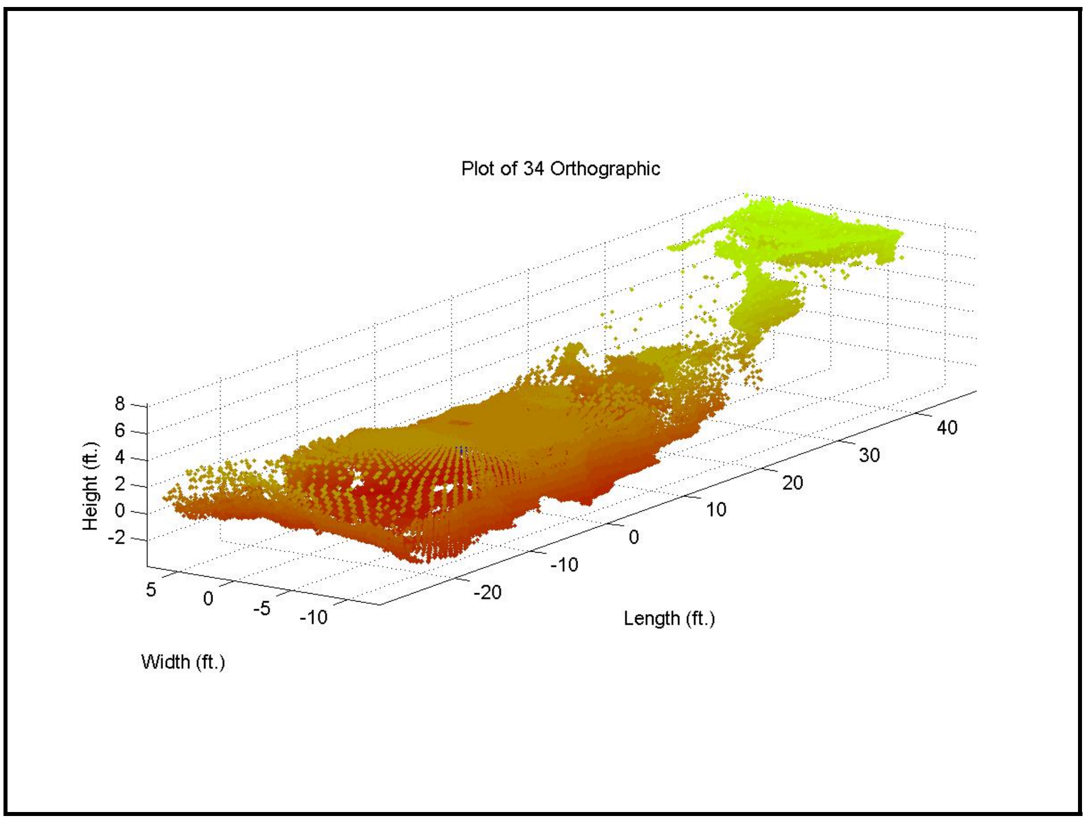
Borehole 34

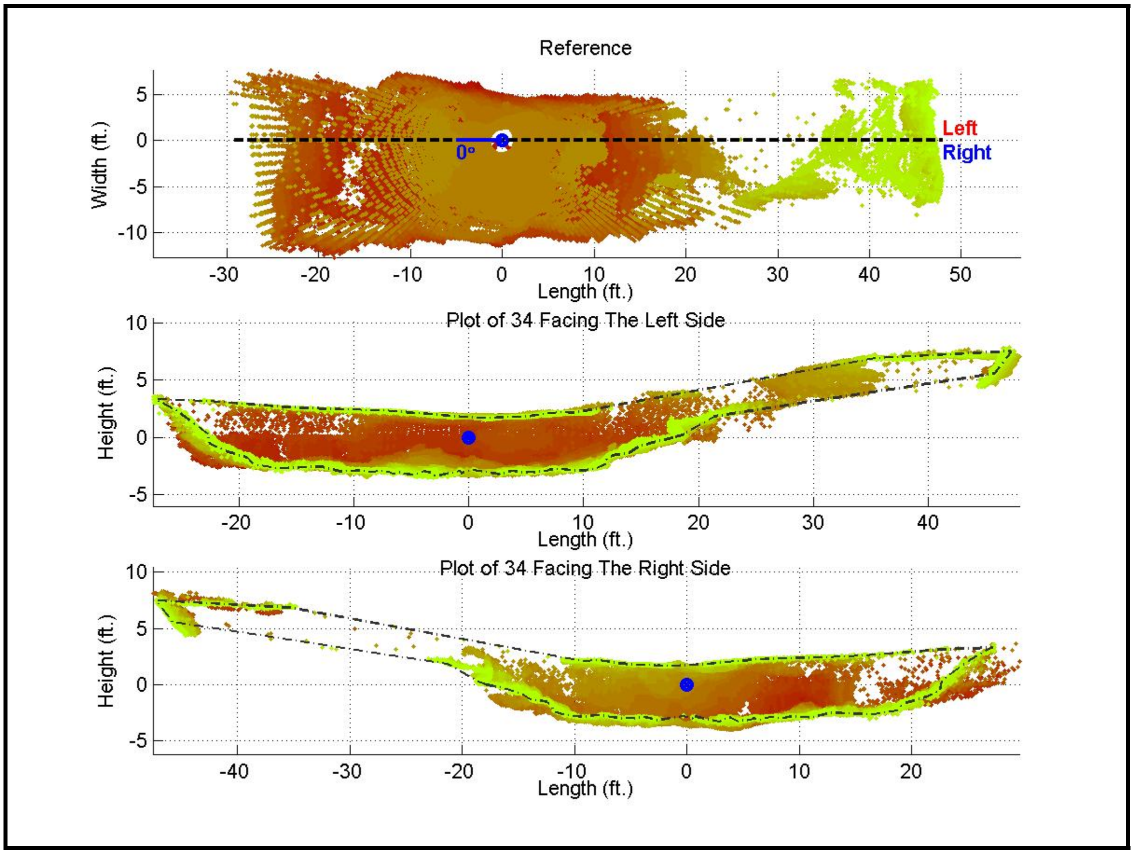
September 21, 2005

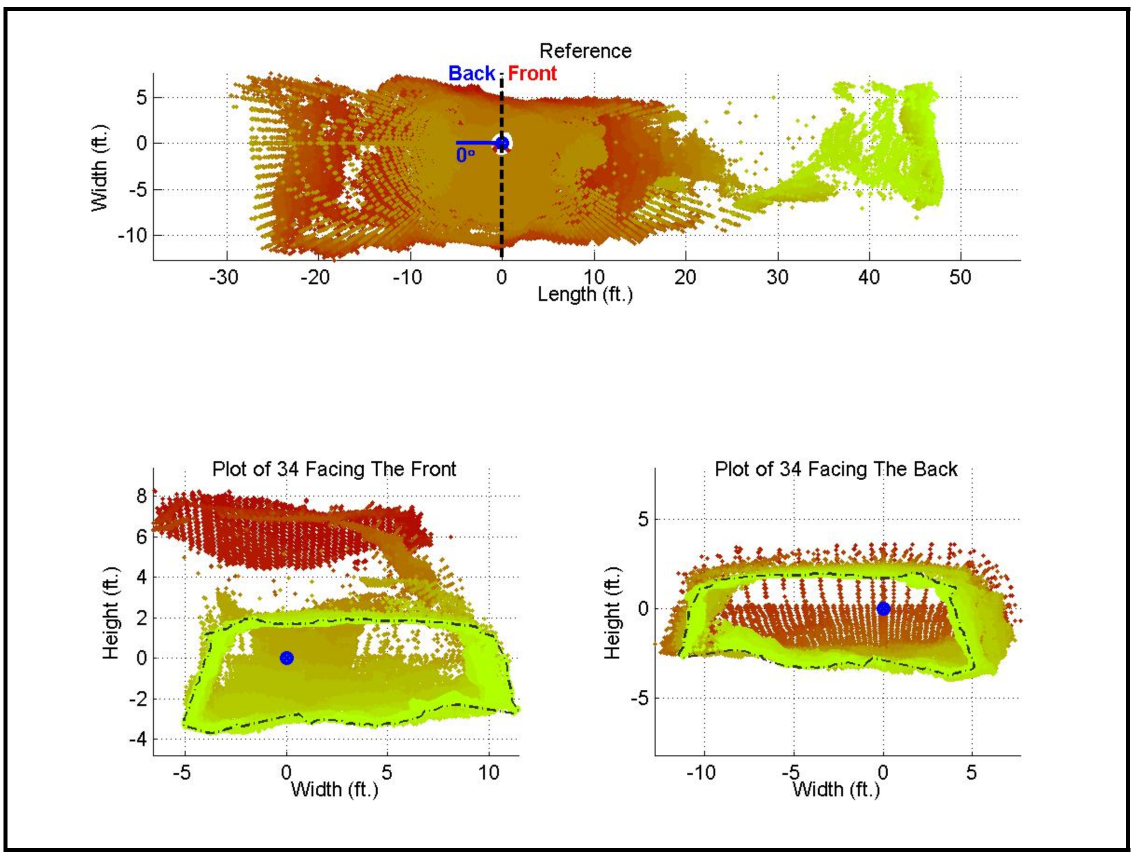
Top of void depth	36.2 ft
Bottom of void depth	41.6 ft
Volume of void	4297.9701 cu ft

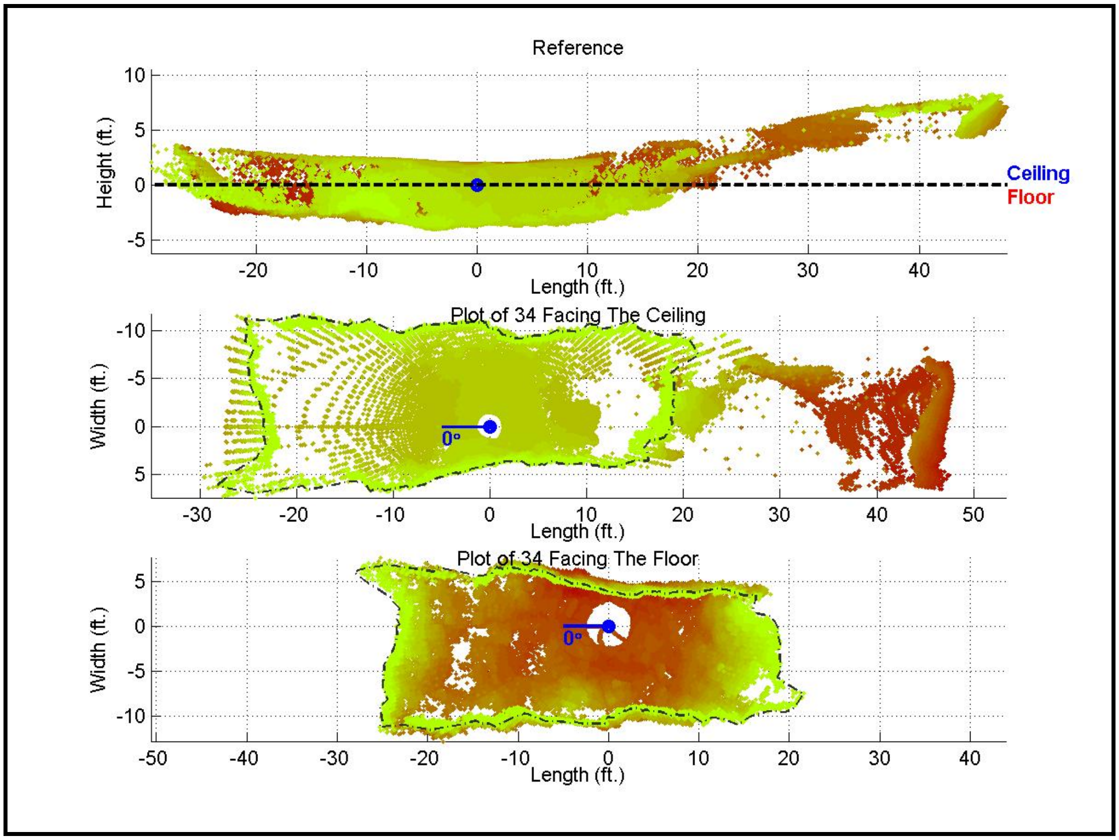
Azimuth reference 0 was to be aligned with same bearing reference used for hole 31 however a blunder in matching the mechanical linkage resulted in a 90 degree shift in the reference.


Reference Plot
Back
Front
N
0°
Left
Right
Width (ft.)
Length (ft.)
20
10
0
-10
-20
-30
-20
-10
0
10
20
30
40


Plot of 34 Orthographic
Height (ft.)
8
6
4
2
0
-2
5
0
-5
-10
Width (ft.)
-20
-10
0
10
20
30
40
Length (ft.)


Reference
Width (ft.)
Length (ft.)
Left
Right
0°
Plot of 34 Facing The Left Side
Height (ft.)
Length (ft.)
Plot of 34 Facing The Right Side
Height (ft.)
Length (ft.)


Reference
Back
Front
0°
Width (ft.)
Length (ft.)
Plot of 34 Facing The Front
Height (ft.)
Width (ft.)
Plot of 34 Facing The Back
Height (ft.)
Width (ft.)



Composite Plot and Survey

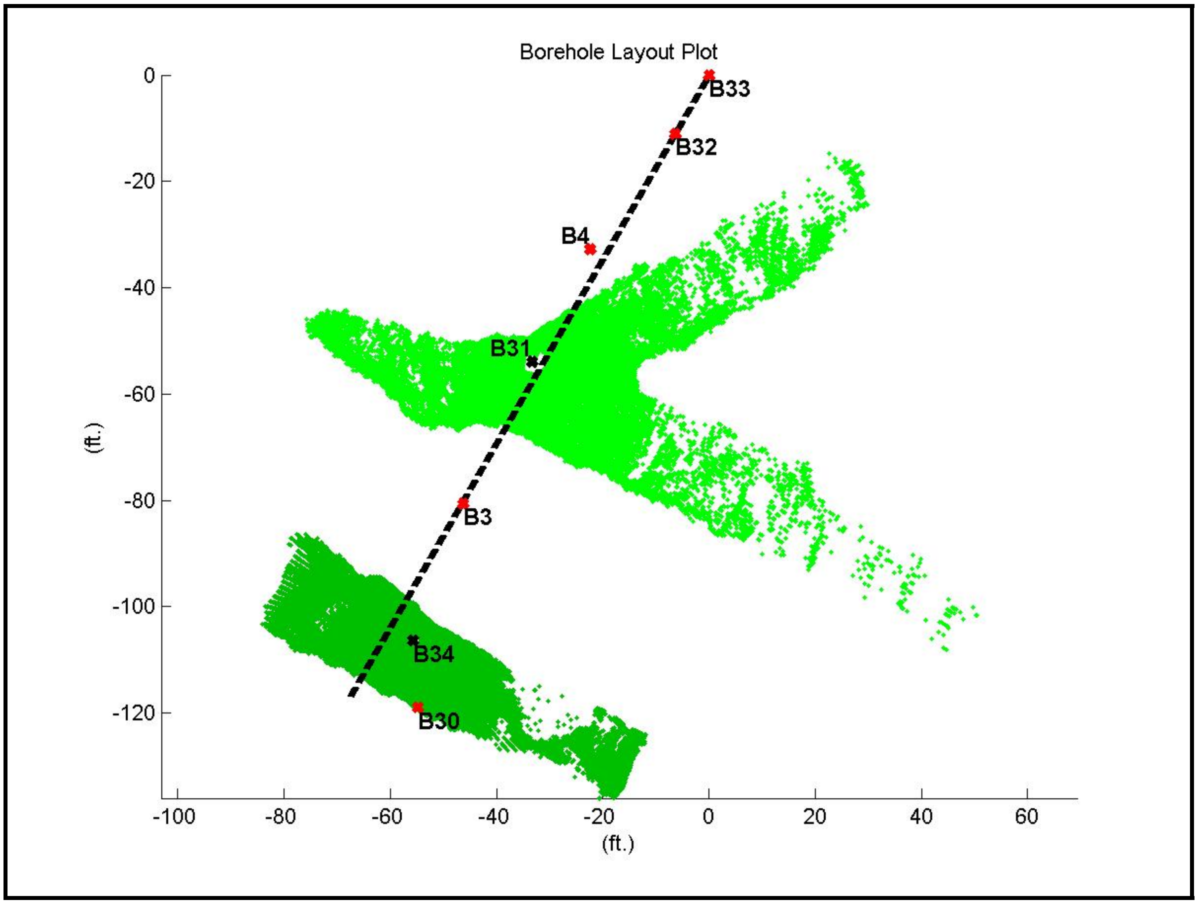
Several holes were drilled in the vicinity of boreholes 31 and 34. Following the Ferret work in hole 34 a localized layout survey was conducted in order to explain the coal and void records from the drilling logs. The survey and the resulting plot follows:

Hole Layout
September21,2005
Pine Ridge Coal Company
Lots Branch Impoundment

Hole #	Length	90 offset	direction	finding
B-33	0	On Line	x	coal
B-32	12'-9"	On Line	x	coal
B-4	39'-6"	(-36")	<	coal
B-31	63'-4"	(-22")	<	void
B-3	93'	3"	>	coal
B-34	120'	5'	>	void
B-30	130'-6"	12'	>	coal

x on line
< toward lake
> toward hillside

Bearing of tape measure 240 degrees from compass



Summary

The Lots Branch Impoundment void exploration provided a great opportunity for Workhorse Technologies, LLC to show the strength of Ferret's mapping capabilities. The voids accessed in the 4 boreholes at the site clearly define the localized pieces of the old coal mines.

Acknowledgements

Thank you to Bill Johnson of D'Appalonia and MSHA for your invaluable support, orientation, and expertise in the field.

Thank you to D'Appolonia and MSHA for this opportunity.

Electronic Data Files index
Index to the Electronic Data

The data and analysis is summarized in this written report however the electronic files accompanying this report contain the complete data sets, models and images relaying our investigation.

The electronic data is presented in several forms:

- 3 dimensional point files - Point files are a listing of coordinates that define the individual point measurements from a scan or model. These files are in a .txt form and a read me file document explains the form of the data. (x,y,z), or (horizontal angle, vertical angle, distance)
- 3 dimensional point cloud models – These files consist of a plot in space of all the collected data points and the resulting model is referred to as a point cloud. See Figure 4. The files are listed in a .wrl format and can be viewed by VRML web based data viewers such as Cortona found at www.parallelgraphics.com See Figure 5.

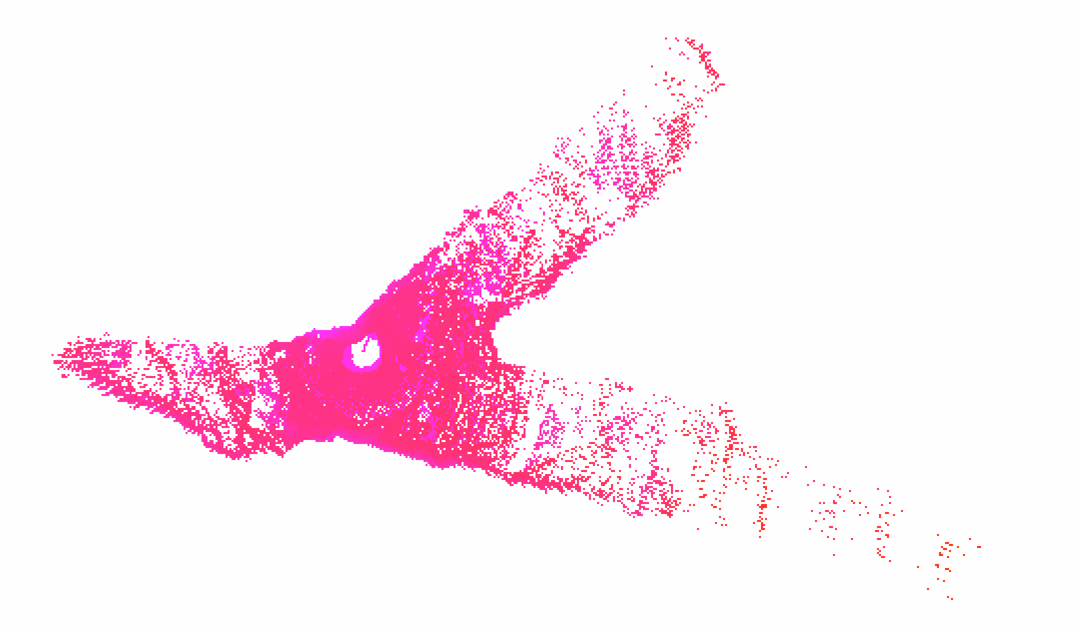


Figure 4: point cloud image from hole 31

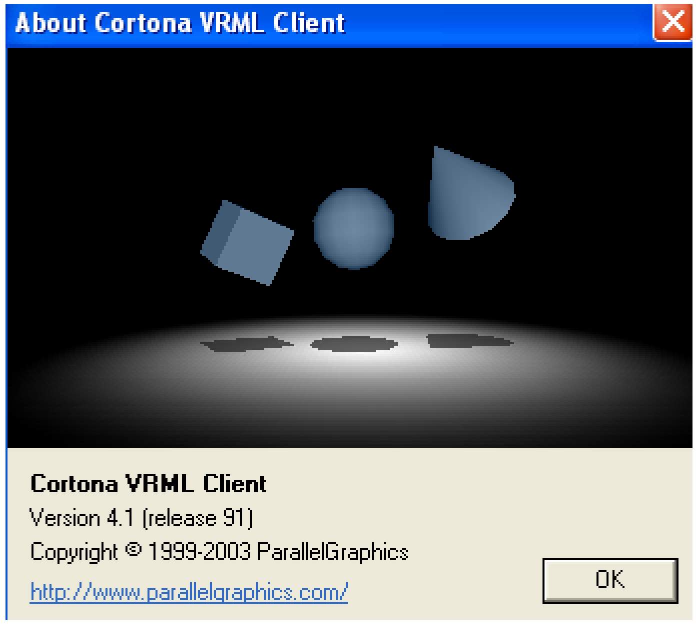
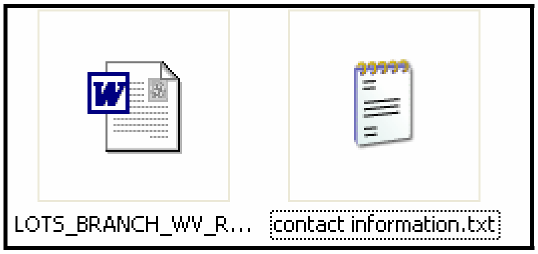
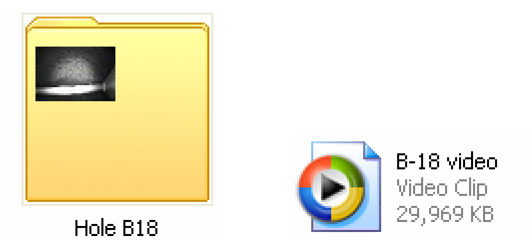


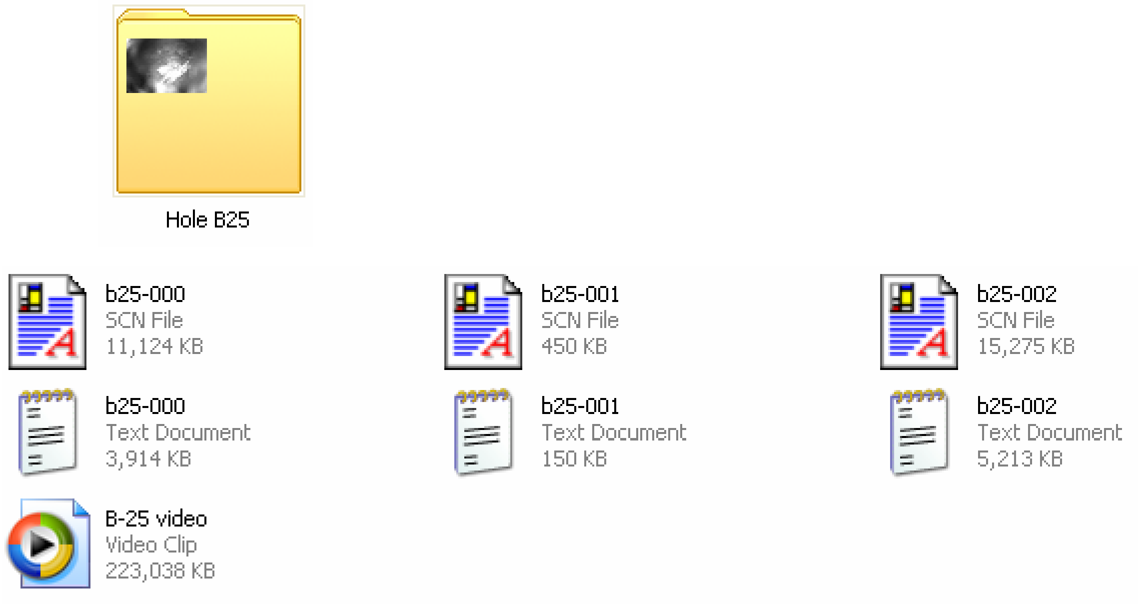
Figure 5: Cortona VRML viewer

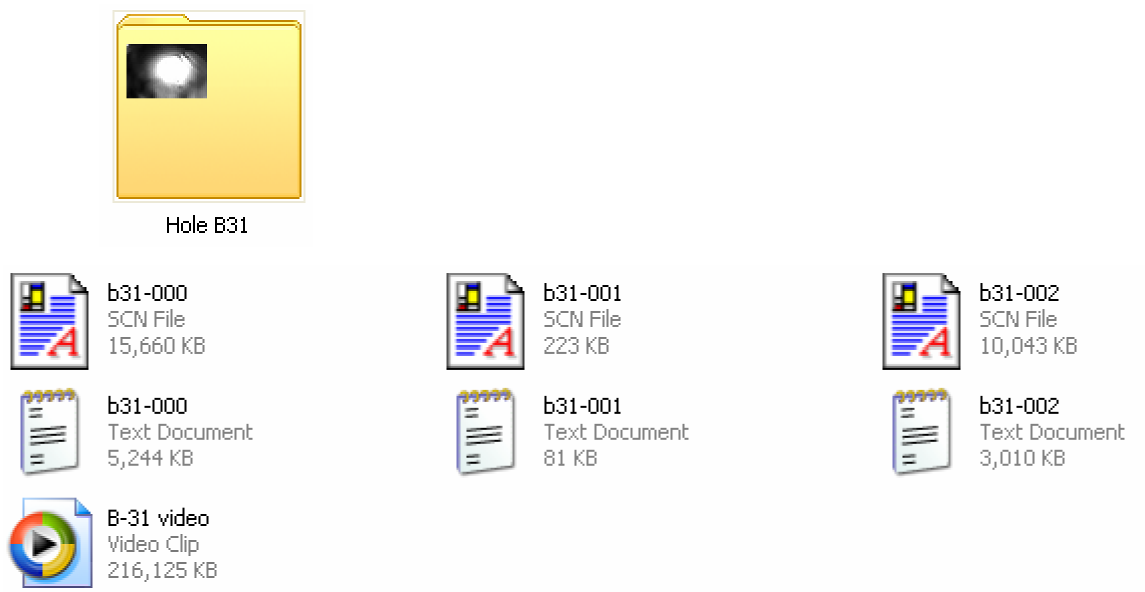
- 2 dimensional plots – Plots of data in a single plane are presented in a .jpg format.
- Movies – Movies are compressed .avi files. To view these movies you will need to install DivX Codec by running DivXPlay.exe found on the disc. (for Windows XP). At http://www.divxmovies.com/codec/ you can find installs for other operating systems
- Scans - Individual scans are recorded in the field as a .scn file. This is Workhorse's raw data format and no viewer is provided

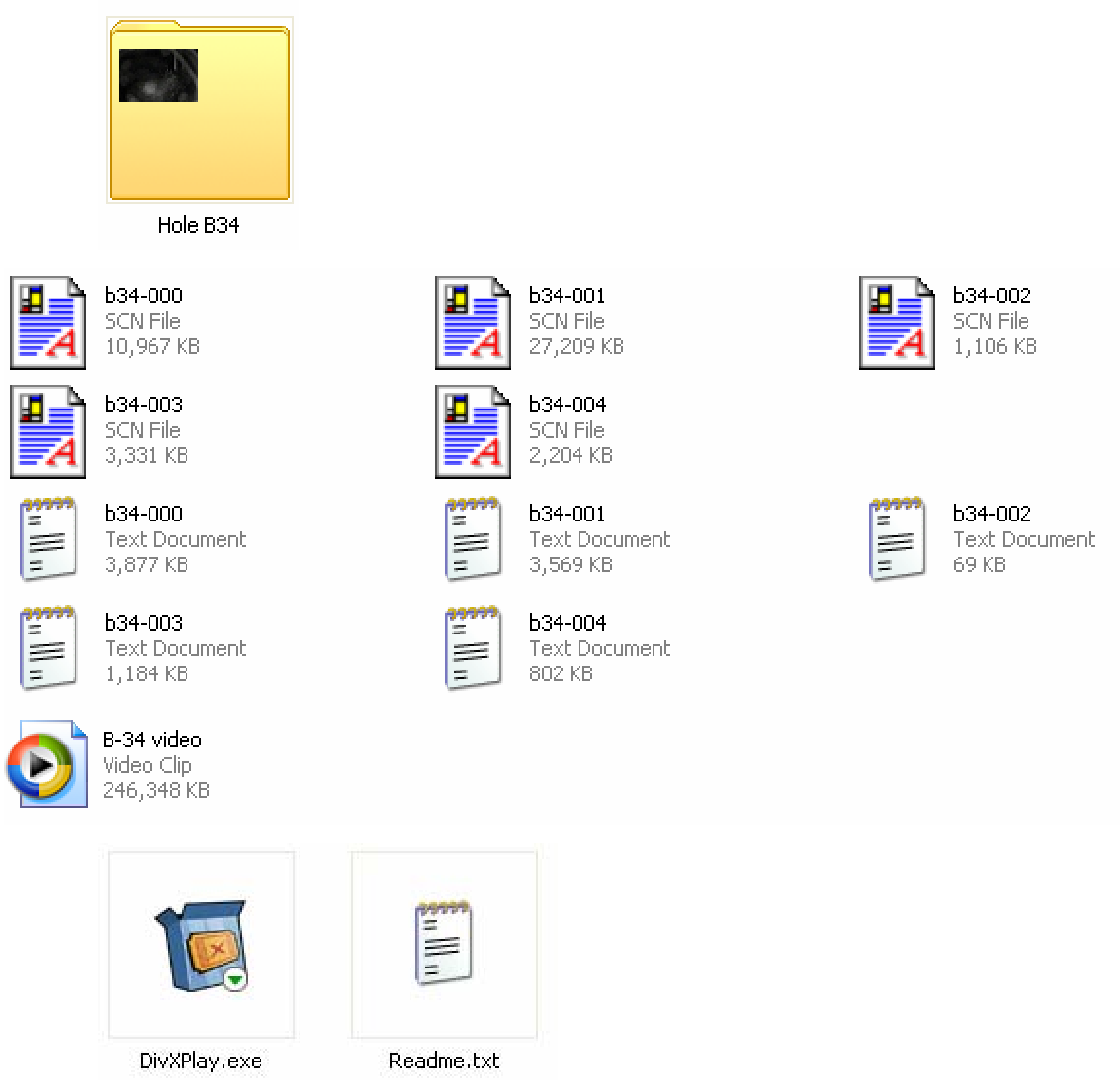
Following is the index of the files found on the accompanying DVD.

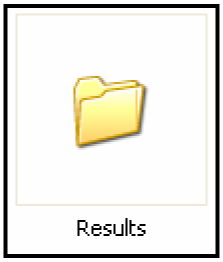


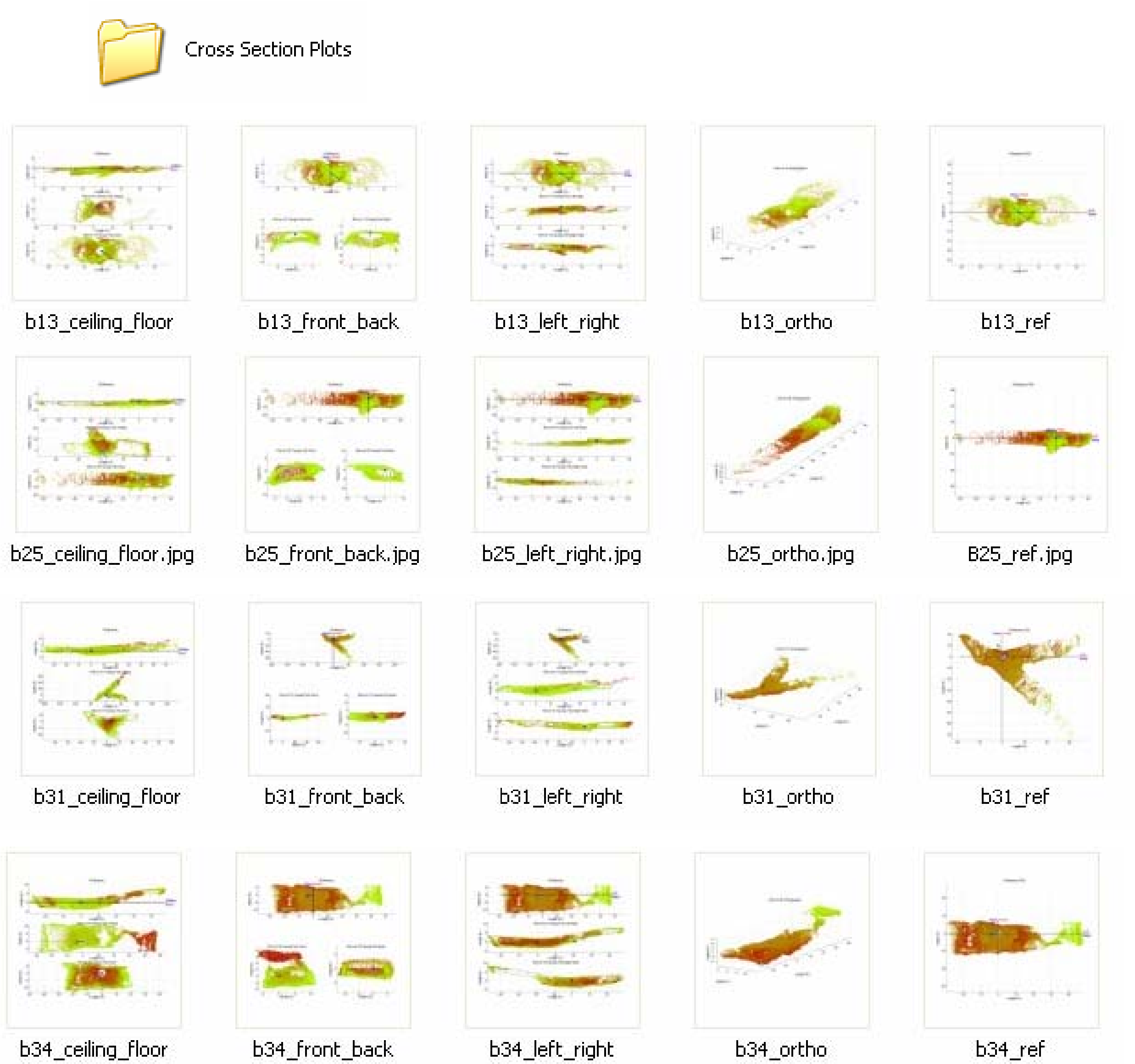



Hole B25
b25-000
SCN File
11,124 KB
b25-001
SCN File
450 KB
b25-002
SCN File
15,275 KB
b25-000
Text Document
3,914 KB
b25-001
Text Document
150 KB
b25-002
Text Document
5,213 KB
B-25 video
Video Clip
223,038 KB

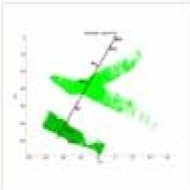

Hole B31
b31-000
SCN File
15,660 KB
b31-001
SCN File
223 KB
b31-002
SCN File
10,043 KB
b31-000
Text Document
5,244 KB
b31-001
Text Document
81 KB
b31-002
Text Document
3,010 KB
B-31 video
Video Clip
216,125 KB


Hole B34
b34-000
SCN File
10,967 KB
b34-001
SCN File
27,209 KB
b34-002
SCN File
1,106 KB
b34-003
SCN File
3,331 KB
b34-004
SCN File
2,204 KB
b34-000
Text Document
3,877 KB
b34-001
Text Document
3,569 KB
b34-002
Text Document
69 KB
b34-003
Text Document
1,184 KB
b34-004
Text Document
802 KB
B-34 video
Video Clip
246,348 KB
DivXPlay.exe
Readme.txt


Results


Cross Section Plots
b13_ceiling_floor
b13_front_back
b13_left_right
b13_ortho
b13_ref
b25_ceiling_floor.jpg
b25_front_back.jpg
b25_left_right.jpg
b25_ortho.jpg
B25_ref.jpg
b31_ceiling_floor
b31_front_back
b31_left_right
b31_ortho
b31_ref
b34_ceiling_floor
b34_front_back
b34_left_right
b34_ortho
b34_ref

Extra Plots



Layout

Point Files

B13_pts B25_pts B31_pts B34_pts Readme

Volume Estimates

Readme
Text Document
1 KB

volumes
Text Document
1 KB

VRML Files

B31_B34 BH13 BH25 BH31 BH34

APPENDIX B
FORWARD MODELING OF THE RESPONSE OF THE TDEM TECHNIQUE TO MINE WORKINGS

APPENDIX B
FORWARD MODELING OF THE RESPONSE OF THE TDEM TECHNIQUE TO MINE WORKINGS

For any geophysical technique to be effective, the target of interest must have a physical contrast with surrounding material such that it can be distinguished. For the purpose of modeling coal mine workings, the assumption has been made that the mine is at least partially flooded. As discussed in the results of the Lots Branch survey, the TDEM technique is oriented towards the identification of conductive bodies. Where dry workings were surveyed, it was not practical to distinguish the workings from the surrounding rock. In areas where it is probable that partially flooded conditions were present, the TDEM results showed some correlation to the DC resistivity results, but the TDEM results do not have the same degree of depth resolution. Because the amount of water in the workings at Lots Branch at the time of the survey is not precisely known, it is not practical to simulate TDEM theoretical response. Accordingly, to better appreciate the potential of this technique, fully flooded workings have been considered. In particular, forward modeling has focused on simulating conditions previously encountered by D'Appolonia at the Weisner Hollow tailings impoundment site in Jefferson County, Pennsylvania, as this site offer the possibility to review a case history of the TDEM technique obtained from flooded workings.

Forward modeling of conditions at the Weisner Hollow site was made with MOTEM, forward modeling software created and made available by Geonics Ltd., the equipment manufacturer, to determine the TDEM response of specified subsurface features. MOTEM is a forward modeling program which lets you calculate transient EM response profiles for simplified models of conductivity structures, and compare with field measurements. MOTEM can model background response with:

- A uniformly conducting earth (HHS - Homogeneous half-space);
- A thin, infinite conductive layer at depth in a resistive background (Thin sheet).

Discrete conductors can be modeled with the responses for:

- A sphere in free space;
- A wire loop late stage approximation to a thin rectangular plate in free space;
- Wire loop and filament approximations for thick bodies and channeled currents.

MOTEM allows for the combination of several structural elements. The program simply adds the individual responses without accounting for interactions, but the element parameters can be adjusted to give a reasonable fit to the field measurements and provide a feeling for the type of conductivity structures that may be involved. Both surface and borehole modeling are supported.

Based on resistivity surveys previously conducted at the site, the minimum background resistivity was modeled to be 250 ohm-meters. The resistivity value used for the flooded mine workings was 8 ohm-meters. Model constraints from DC resistivity modeling indicate that the mine water should be close to 1,200 µS/cm conductivity (8 ohm-meters), as this value best fits with a model that is close to the actual results from the DC resistivity profile. The depth to the workings is approximately 20 meters. The model data were generated based on a multi-turn transmitter loop set out as a 5-meter square with a 2 amp current, the same as used in the field experiment.

The theoretical response of the mine workings as determined by the forward modeling (for the first 10 channels) is shown on Figure B1. The peak response is more than an order of magnitude greater than the background responses and it is expected that the flooded mine workings would be observable in the field data.

To evaluate the change of response with depth, a second model was run where the same target was located at a depth of 40 meters (130 feet), as shown on Figure B1. The response is still several times background. The model does not include noise so, depending on the signal-to-noise ratio, the actual field data may not show such a strong anomaly, but the mine workings appear potentially to be detectable.

The actual profile obtained from the Weisner Hollow tailings impoundment site is provided on Figure B2. The equipment used for the TDEM measurements was the same as used at Lots Branch: a Geonics PROTEM-47, which uses a TEM-47 transmitter with a PROTEM receiver. The eight-turn TEM-47 transmitter loop 5m on a side was moved in tandem with the receiver unit at 5 meter increments along the profile lines. The PROTEM-47 receiver was place on the ground and leveled with a bubble level at a distance of 15 meters in front of the transmitter loop. Figure 2 compares the final processed data from the TEMIX program converted to resistivity and contoured across the profile with the same profile obtained with the DC resistivity technique. Both the DC resistivity and TDEM profiles are identically color-coded to values of ground resistivity.

The strongest resistivity low at the elevation of the Lower Kittanning Coal identified from the TDEM results corresponds to the position of the known flooded entry tunnels, similar to the results from the DC resistivity surveying. Relatively low resistivity values at the elevation of the coal are also found immediately north of the entry tunnels where the profile skirts the edge of flooded mine workings, similar to the DC resistivity results. Differences between the TDEM and DC resistivity results are observed with the apparently low resistivity values encountered at the surface with the TDEM measurements. This low resistivity layer is not believed to exist and is interpreted to be due to the inability of the TDEM measurements to resolve near surface electrical properties. The resistivity low of unknown origin at a distance of 50 feet on the DC resistivity profile is not observed from the TDEM measurements. There is also a difference in apparent resistivity below the Lower Kittanning Coal between the two methods that does not have an obvious explanation. In spite of the differences, the TDEM technique at this location is believed to provide useful imaging of the flooded mine workings. Based on the theoretical modeling, TDEM appears to have the potential to image flooded mine workings at a depth greater than would be practical with the DC resistivity technique.

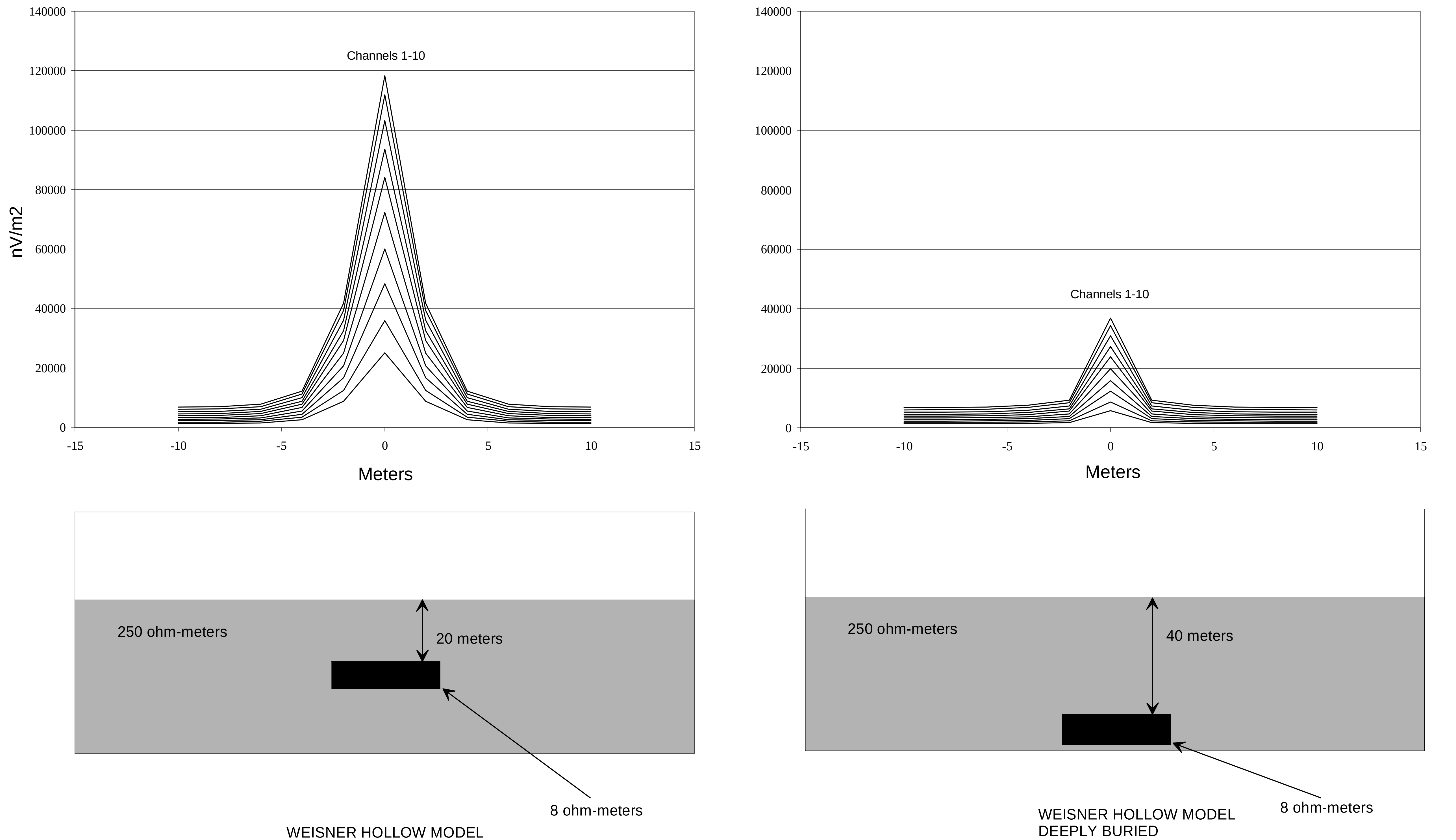


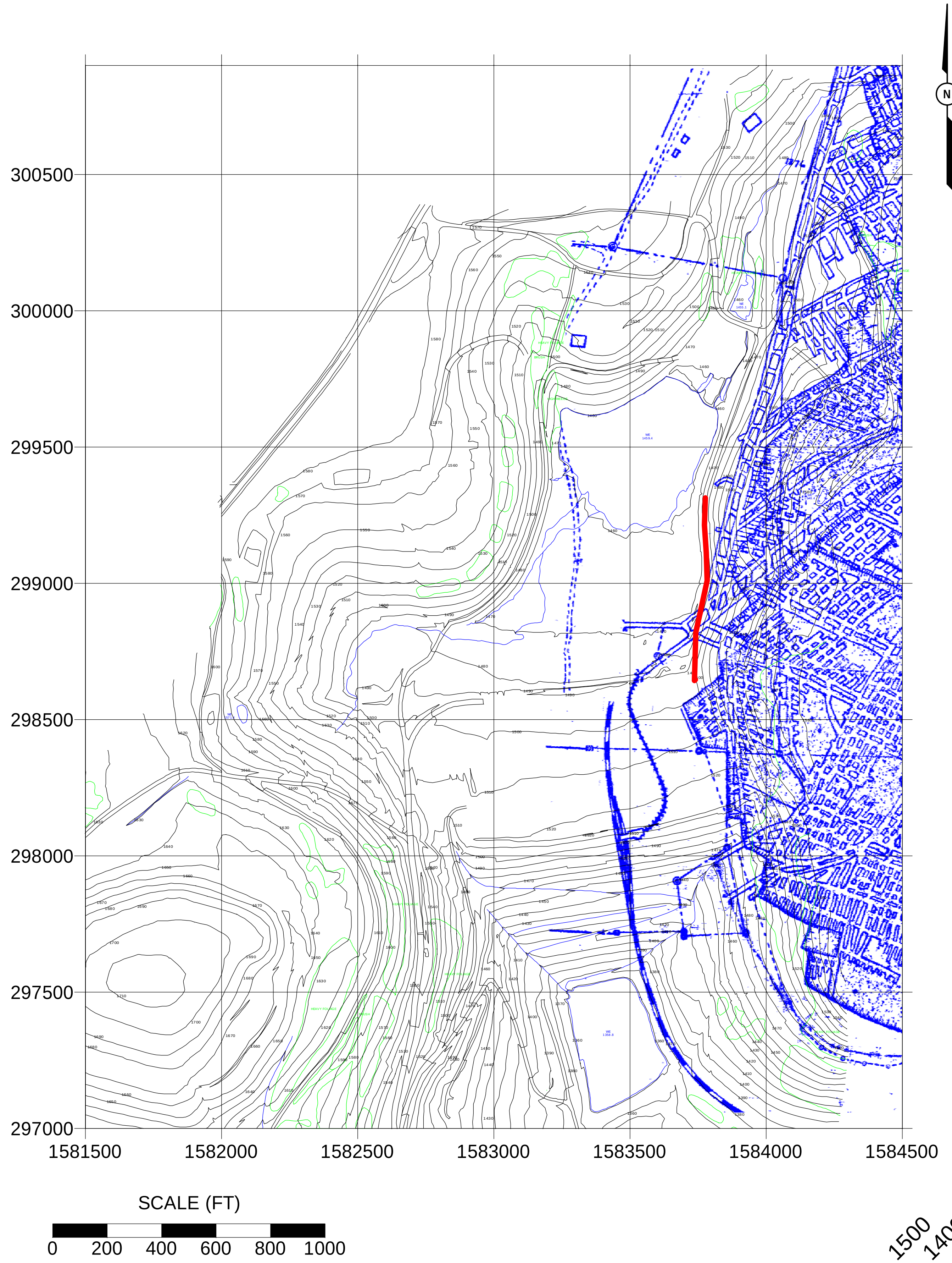
FIGURE B1

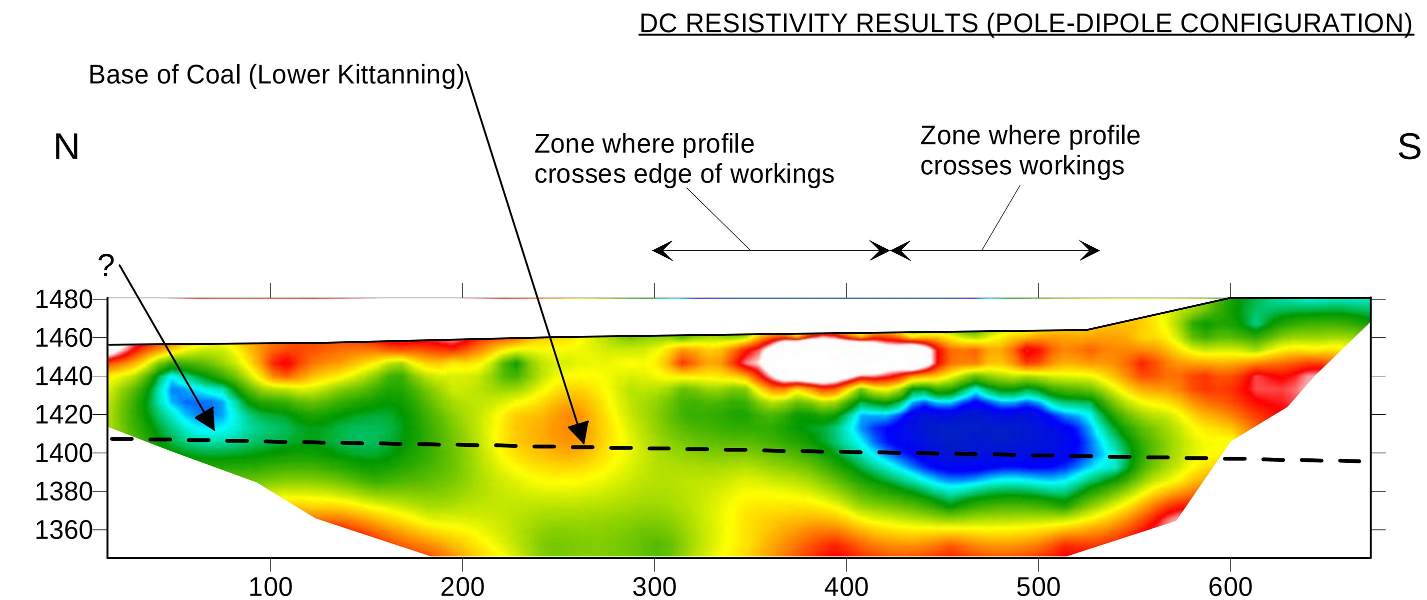
MODELING TDEM RESPONSE
OVER FLOODED MINE WORKINGS

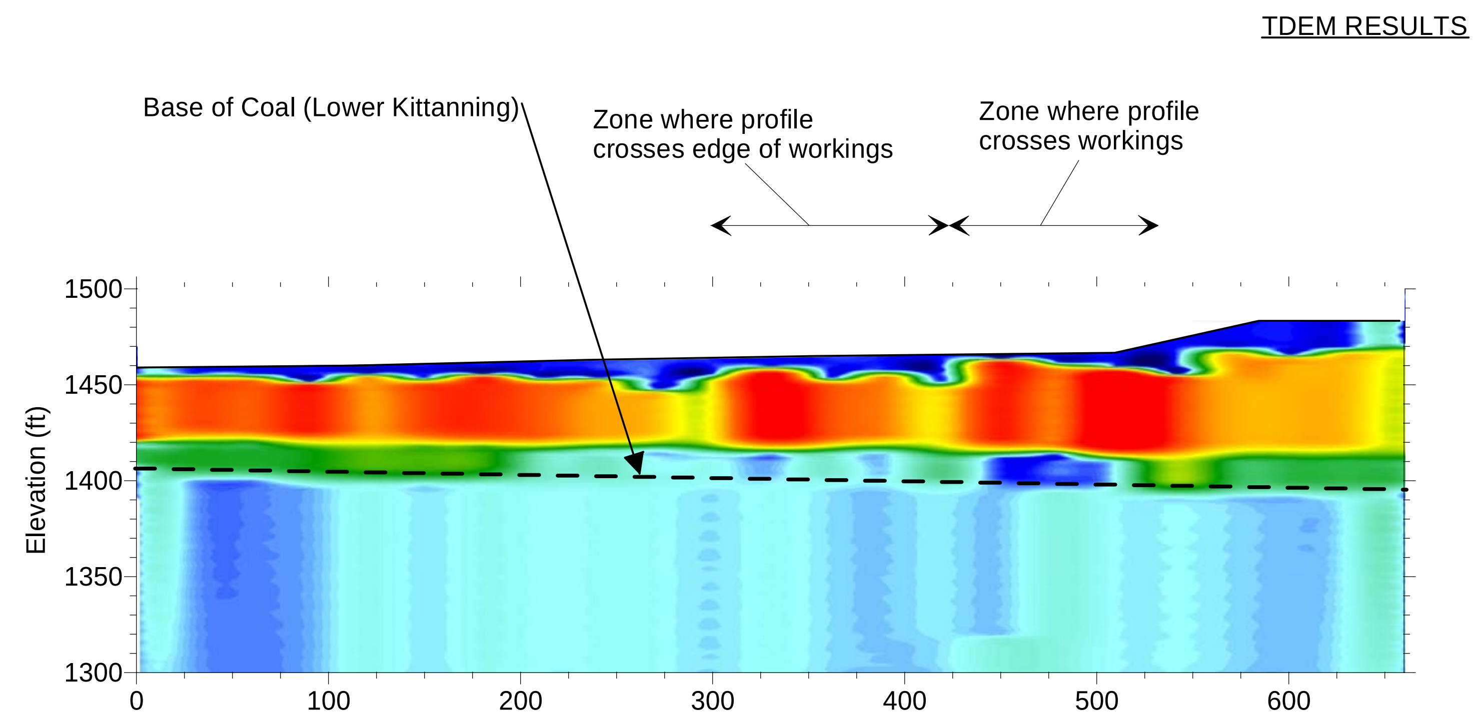
PREPARED FOR

MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON, VIRGINIA

D'APPOLONIA







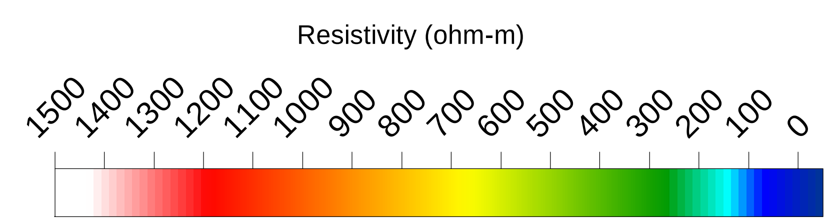


FIGURE B2

COMPARISON OF DC RESISTIVITY AND TDEM PROFILES
OVER FLOODED MINE WORKINGS
WEISNER HOLLOW TAILINGS IMPOUNDMENT
JEFFERSON COUNTY, PENNSYLVANIA

PREPARED FOR

MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON, VIRGINIA

D'APPOLONIA

APPENDIX C
BORING LOGS AND GROUTING SCHEMATIC

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-1
	SHEET NO. 1 of 2	DATE STARTED 09-17-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-17-05
DRILLING METHOD Hetager track-mounted Rotary Drill with NX rock core (Wireline)	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)/ % REC.	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1540.57 GROUND WATER EL. 1533.46	COMMENTS:
0–5				**4-INCH DIAMETER CASING ADVANCED TO 4.9' THROUGH WEATHERED SANDSTONE** **4.9'**	
5	R-1	2.6 (100%)	8	SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)**	
10	R-2	5.0 (100%)	86		
15	R-3	5.0 (100%)	100		
20	R-4	5.0 (100%)	100		
25	R-5	4.8 (98%)	90		
30	R-6	5.0 (100%)	100		

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1) UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	**PROJECT NO.** 031019	**BORING NO.** B-1
	SHEET NO. 2 of 2	**DATE STARTED** 09-17-05
BORING LOCATION SEE FIGURE	**FIELD SUPERVISOR** R. Short	**DATE COMPLETED** 09-17-05
DRILLING METHOD Hetager track-mounted Rotary Drill with NX rock core (Wireline)	**CHECKED BY** W. Johnson	**DATE CHECKED** 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)/ % REC.	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1540.57 GROUND WATER EL. 1533.46	COMMENTS:
	R-6 (CONT)	5.0 (100%)	100	SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **34.5'**	
35	R-7	5.0 (100%)	68	UNWEATHERED BROKEN TO UNBROKEN MEDIUM HARD DARK GRAY **SILTY SHALE** WITH BLACK COAL LENSES **36.9'**	
				SLIGHTLY WEATHERED VERY BROKEN SOFT TO MEDIUM HARD **BLACK COAL** **37.7'**	
40	R-8	5.0 (100%)	74	UNWEATHERED BROKEN TO UNBROKEN MEDIUM HARD DARK GRAY **SILTY SHALE** WITH BLACK COAL LENSES **42.9'**	
45	R-9	4.7 (94%)	0	SLIGHTLY WEATHERED VERY BROKEN TO BROKEN SOFT TO MEDIUM HARD **BLACK COAL** **(LEWISTON COAL FORMATION)** **49.8'**	
50	R-10	5.0 (100%)	56	UNWEATHERED UNBROKEN MEDIUM HARD GRAY **SANDSTONE** **(COALBURG SANDSTONE FORMATION)**	
55				**BOTTOM OF BORING B-1 AT 52.5'**	
60					

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

[(1)]UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	**PROJECT NO.** 031019	**BORING NO.** B-2
	SHEET NO. 1 of 1	**DATE STARTED** 09-16-05
BORING LOCATION SEE FIGURE	**FIELD SUPERVISOR** R. Short	**DATE COMPLETED** 09-16-05
DRILLING METHOD Driltech 40D Air Rotary Drill	**CHECKED BY** W. Johnson	**DATE CHECKED** 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1540.27 GROUND WATER EL. 1494.12	COMMENTS:
10 20 30				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** **32.2'**	
40				INTERBEDDED UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** **41.2'**	**NO AIR LOST**
				SLIGHTLY WEATHERED SOFT BLACK **COAL** **(LEWISTON COAL FORMATION)** **46.5'**	
				INTERBEDDED SLIGHTLY WEATHERED SOFT BLACK **COAL** AND SLIGHTLY WEATHERED MEDIUM HARD DARK GRAY **SHALE** **48.3'**	
50				UNWEATHERED HARD GRAY **SANDSTONE** **(COALBURG SANDSTONE FORMATION)**	
60				**BOTTOM OF B-2 AT 49.5'**	

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

[(1)]UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-3
	SHEET NO. 1 of 1	DATE STARTED 09-15-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-15-05
DRILLING METHOD Driltech 40D Air Rotary Drill	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1517.70 GROUND WATER EL. 1475.50	COMMENTS:
0–31.0				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** **31.0'**	
31.0–32.0				SLIGHTLY WEATHERED SOFT BLACK **COAL** **32.0'**	
32.0–39.1				UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** **39.1'**	**NO AIR LOST**
39.1–44.2				SLIGHTLY WEATHERED SOFT BLACK **COAL** **(LEWISTON COAL FORMATION)** **44.2'**	
44.2–46.5				INTERBEDDED SLIGHTLY WEATHERED SOFT BLACK **COAL** AND SLIGHTLY WEATHERED MEDIUM HARD DARK GRAY **SHALE** **46.5'**	
46.5–49.5				UNWEATHERED HARD GRAY **SANDSTONE** **(COALBURG SANDSTONE FORMATION)**	
				BOTTOM OF B-3 AT 49.5'	

Depth scale: 10, 20, 30, 40, 50, 60

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

[1] UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-4
	SHEET NO. 1 of 1	DATE STARTED 09-15-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-15-05
DRILLING METHOD Driltech 40D Air Rotary Drill	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1516.74 GROUND WATER EL. 1474.54	COMMENTS:
10				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE**	
				(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)	
20				**(HOMEWOOD SANDSTONE FORMATION)**	
30				30.7'	
				SLIGHTLY WEATHERED SOFT BLACK **COAL** 32.5'	
				UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL**	**NO AIR LOST**
40				39.8'	
				SLIGHTLY WEATHERED SOFT BLACK **COAL** **(LEWISTON COAL FORMATION)** 45.0'	
				SLIGHTLY WEATHERED MEDIUM HARD DARK GRAY **SHALE** 46.5'	
50				UNWEATHERED HARD GRAY **SANDSTONE** **(COALBURG SANDSTONE FORMATION)**	
				BOTTOM OF B-4 AT 49.5'	
60					

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

[1]UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	**PROJECT NO.** 031019	**BORING NO.** B-5
	SHEET NO. 1 of 2	**DATE STARTED** 09-16-05
BORING LOCATION SEE FIGURE	**FIELD SUPERVISOR** R. Short	**DATE COMPLETED** 09-17-05
DRILLING METHOD Hetager track-mounted Rotary Drill with NX rock core (Wireline)	**CHECKED BY** W. Johnson	**DATE CHECKED** 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)/ % REC.	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1517.89 GROUND WATER EL. 1485.79	COMMENTS:
5				**4-INCH DIAMETER CASING ADVANCED TO 5.7' THROUGH WEATHERED SANDSTONE** **5.7'**	
	R-1	1.3 (100%)	92	SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)**	
10	R-2	5.0 (100%)	72		
15	R-3	5.0 (100%)	90		
20	R-4	5.0 (100%)	100		
25	R-5	5.0 (100%)	100		
30	R-6	5.0 (100%)	58	**29.5'**	
				UNWEATHERED VERY BROKEN SOFT **BLACK COAL** **29.8'**	

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

[1]UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-5
	SHEET NO. 2 of 2	DATE STARTED 09-16-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-17-05
DRILLING METHOD Hetager track-mounted Rotary Drill with NX rock core (Wireline)	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)/ % REC.	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1517.89 GROUND WATER EL. 1485.79	COMMENTS:
	R-6 (CONT)	5.0 (100%)	58	INTERBEDDED UNWEATHERED BROKEN TO UNBROKEN MEDIUM HARD DARK GRAY **SILTY SHALE** WITH SOFT **BLACK COAL** **32.9'**	
35	R-7	5.0 (100%)	70	UNWEATHERED BROKEN TO SLIGHTLY BROKEN MEDIUM HARD DARK GRAY **SILTY SHALE** **37.7'**	
40	R-8	5.0 (100%)	0	SLIGHTLY WEATHERED VERY BROKEN TO BROKEN SOFT TO MEDIUM HARD **BLACK COAL** **(LEWISTON COAL FORMATION)** **43.0'**	
				SLIGHTLY WEATHERED VERY BROKEN MEDIUM HARD DARK GRAY **SHALE** AND SOFT **BLACK COAL** **44.0'**	
45	R-9	4.8 (96%)	58	UNWEATHERED UNBROKEN HARD GRAY **LIMESTONE**	
50				**BOTTOM OF BORING B-5 AT 47.0'** UNWEATHERED UNBROKEN MEDIUM HARD GRAY **SANDSTONE** **(COALBURG SANDSTONE FORMATION)**	
55					
60					

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1)UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	**PROJECT NO.** 031019	**BORING NO.** B-6
	SHEET NO. 1 of 1	**DATE STARTED** 09-15-05
BORING LOCATION SEE FIGURE	**FIELD SUPERVISOR** R. Short	**DATE COMPLETED** 09-15-05
DRILLING METHOD Driltech 40D Air Rotary Drill	**CHECKED BY** W. Johnson	**DATE CHECKED** 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1530.36 GROUND WATER EL. 1488.26	COMMENTS:
10				HIGHLY TO SLIGHTLY WEATHERED SOFT TO MEDIUM HARD REDDISH-BROWN **SHALE** — 10.5'	
20, 30				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** — 34.5'	
				SLIGHTLY WEATHERED SOFT BLACK **COAL** — 35.5'	
				SLIGHTLY WEATHERED MEDIUM HARD GRAY **SHALE** WITH COAL LENSES — 37.0'	
				SLIGHTLY WEATHERED SOFT BLACK **COAL** — 38.0'	
40				SLIGHTLY WEATHERED MEDIUM HARD GRAY **SHALE** WITH COAL LENSES **(SANDY AREAS)** — 42.0'	**AIR RETURN LOST: 42.7'**
				SLIGHTLY WEATHERED SOFT BLACK **COAL** — 42.7'	**VOID NOT OPEN ENOUGH TO MONITOR**
				AIR-FILLED VOID — 43.7'	
50				**MINE SPOIL-FILLED VOID** — 50.2'	**BORING CAVED IN AFTER REMOVING BIT**
				UNWEATHERED HARD GRAY **LIMESTONE**	
60				**BOTTOM OF B-6 AT 54.5'**	

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

[1]UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-7
	SHEET NO. 1 of 1	DATE STARTED 09-15-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-15-05
DRILLING METHOD Driltech 40D Air Rotary Drill	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1529.20 GROUND WATER EL. 1488.30	COMMENTS:
0–31.2				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** **31.2'**	
				SLIGHTLY WEATHERED SOFT BLACK **COAL** **31.9'**	
				UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** **36.3'**	**MINE TEMPERATURE 70.2°F**
				MINE SPOIL-FILLED VOID **40.5'**	**AIR RETURN LOST: 36.3'**
				AIR-FILLED VOID **42.7'**	**VOID NOT OPEN ENOUGH TO MONITOR**
				MINE SPOIL-FILLED VOID **47.0'**	**BORING CAVED IN AFTER REMOVING BIT**
				UNWEATHERED HARD GRAY **LIMESTONE**	
				BOTTOM OF B-7 AT 49.5'	

Depth scale: 10, 20, 30, 40, 50, 60

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1)UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-8
	SHEET NO. 1 of 1	DATE STARTED 09-15-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-15-05
DRILLING METHOD Driltech 40D Air Rotary Drill	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

SURFACE EL. 1529.17 — GROUND WATER EL. 1487.66

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL	COMMENTS:
0–32.7				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** — **32.7'**	
				UNWEATHERED SOFT GRAY **SHALE** AND SOFT BLACK **COAL** — **33.8'**	
				SLIGHTLY WEATHERED SOFTBLACK **COAL** — **34.8'**	
				INTERBEDDED SIGHTLY WEATHERED SOFT DARK GRAY **SHALE,** SOFT GRAY **CLAYSTONE** AND SOFT BLACK **COAL** — **39.7'**	**AIR RETURN LOST: 42.5'**
				SLIGHTLY WEATHERED SOFT BLACK **COAL** **(LEWISTON COAL FORMATION)** — **42.5'**	**VOID NOT OPEN ENOUGH TO MONITOR**
				AIR-FILLED VOID — **42.8'**	
				SLIGHTLY WEATHERED SOFT BLACK **COAL AND MINE SPOIL** — **45.0'**	
				SLIGHTLY WEATHERED SOFT DARK GRAY **CLAYSTONE** AND MEDIUM HARD CARBONACEOUS **SHALE** — **48.5'**	**BORING CAVED IN AFTER REMOVING BIT**
				UNWEATHERED HARD GRAY **LIMESTONE**	
				BOTTOM OF B-8 AT 49.5'	

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1) UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	**PROJECT NO.** 031019	**BORING NO.** B-9
	SHEET NO. 1 of 1	**DATE STARTED** 09-16-05
BORING LOCATION SEE FIGURE	**FIELD SUPERVISOR** R. Short	**DATE COMPLETED** 09-16-05
DRILLING METHOD Driltech 40D Air Rotary Drill	**CHECKED BY** W. Johnson	**DATE CHECKED** 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1504.25 GROUND WATER EL. 1458.90	COMMENTS:
0–27.8				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** **27.8'**	
27.8–37.3				INTERBEDDED UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** **37.3'**	
37.3–43.4				SLIGHTLY WEATHERED SOFT BLACK **COAL** **(LEWISTON COAL FORMATION)** **43.4'**	**NO AIR LOST** **MINE TEMPERATURE 74.8°F**
43.4–49.5				UNWEATHERED HARD GRAY **SANDSTONE** **(COALBURG SANDSTONE FORMATION)**	
				BOTTOM OF B-9 AT 49.5'	

Depth scale: 10, 20, 30, 40, 50, 60

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1) UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	**PROJECT NO.** 031019	**BORING NO.** B-11
	SHEET NO. 1 of 1	**DATE STARTED** 09-16-05
BORING LOCATION SEE FIGURE	**FIELD SUPERVISOR** R. Short	**DATE COMPLETED** 09-16-05
DRILLING METHOD Driltech 40D Air Rotary Drill	**CHECKED BY** W. Johnson	**DATE CHECKED** 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1502.86 — GROUND WATER EL. DRY	COMMENTS:
0–26.3				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** **26.3'**	
26.3–32.4				INTERBEDDED UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** **32.4'**	
32.4–39.1				**AIR-FILLED VOID** **39.1'**	**AIR RETURN LOST: 32.4'**
39.1–42.7				UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** **42.7'**	**MINE TEMPERATURE 82.1°F**
42.7–45.0				UNWEATHERED HARD GRAY **SANDSTONE** **(COALBURG SANDSTONE FORMATION)**	
45.0				**BOTTOM OF B-11 AT 45.0'**	

Depth scale: 10, 20, 30, 40, 50, 60

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1) UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-12
	SHEET NO. 1 of 1	DATE STARTED 09-19-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-19-05
DRILLING METHOD Driltech 40D Air Rotary Drill	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1504.63 GROUND WATER EL. DRY	COMMENTS:
0–22.0				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** **22.0'**	
22.0–32.0				INTERBEDDED UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** **32.0'**	
32.0–38.2				SLIGHTLY WEATHERED SOFT BLACK **COAL** **(LEWISTON COAL FORMATION)** **38.2'**	**NO AIR RETURN LOST**
38.2–40.3				UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** **40.3'**	**MINE TEMPERATURE 65.9°F**
40.3–42.5				UNWEATHERED HARD GRAY **SANDSTONE** **(COALBURG SANDSTONE FORMATION)**	
				BOTTOM OF B-12 AT 42.5'	

Depth scale: 10, 20, 30, 40, 50, 60

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1)UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-13
	SHEET NO. 1 of 1	DATE STARTED 09-19-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-19-05
DRILLING METHOD Driltech 40D Air Rotary Drill	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1505.51 GROUND WATER EL. 1464.91	COMMENTS:
0–25.5				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** **25.5'**	
25.5–31.2				**AIR-FILLED VOID** **31.2'**	**AIR RETURN LOST: 25.5'**
31.2–40.3				**MINE SPOIL-FILLED VOID** **40.3'**	**MINE TEMPERATURE 72.6°F**
40.3–42.0				UNWEATHERED HARD GRAY **SANDSTONE** **(COALBURG SANDSTONE FORMATION)**	
				BOTTOM OF B-13 AT 42.0'	

Depth scale: 10, 20, 30, 40, 50, 60

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1)UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	**PROJECT NO.** 031019	**BORING NO.** B-14
	SHEET NO. 1 of 1	**DATE STARTED** 09-19-05
BORING LOCATION SEE FIGURE	**FIELD SUPERVISOR** R. Short	**DATE COMPLETED** 09-19-05
DRILLING METHOD Driltech 40D Air Rotary Drill	**CHECKED BY** W. Johnson	**DATE CHECKED** 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1535.63 GROUND WATER EL. DRY	COMMENTS:
0–4.0				**MINE SPOIL FILL FOR ROADWAY STABILIZATION** (4.0')	
4.0–46.7 (10, 20, 30, 40)				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** (46.7')	
46.7–53.8 (50)				INTERBEDDED UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** (53.8')	**NO AIR RETURN LOST**
53.8–59.5				SLIGHTLY WEATHERED SOFT BLACK **COAL** **(LEWISTON COAL FORMATION)** (59.5')	
59.5–60 (60)				SLIGHTLY WEATHERED MEDIUM HARD GRAY **SILTY SHALE** **BOTTOM OF B-14 AT 60.0'**	

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1)UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-15
	SHEET NO. 1 of 1	DATE STARTED 09-19-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-19-05
DRILLING METHOD Driltech 40D Air Rotary Drill	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1536.24 GROUND WATER EL. DRY	COMMENTS:
0–4.0				**MINE SPOIL FILL FOR ROADWAY STABILIZATION** 4.0'	
10, 20, 30, 40				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** 46.3'	
50				INTERBEDDED UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** 52.2'	
				SLIGHTLY WEATHERED SOFT BLACK **COAL** **(LEWISTON COAL FORMATION)** 58.5'	**NO AIR RETURN LOST**
60				SLIGHTLY WEATHERED MEDIUM HARD GRAY **SILTY SHALE** **BOTTOM OF B-15 AT 60.0'**	

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1)UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-16
	SHEET NO. 1 of 3	DATE STARTED 09-17-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-17-05
DRILLING METHOD Hetager track-mounted Rotary Drill with NX rock core (Wireline)	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

SURFACE EL. 1536.50 — GROUND WATER EL. 1503.20

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)/ % REC.	ROCK RQD (%)	DESCRIPTION OF MATERIAL	COMMENTS:
0–4.5				**4-INCH DIAMETER CASING ADVANCED TO 4.5' THROUGH MINE SPOIL ROADWAY FILL**	
5	R-1	3.0 (100%)	73	**(SHALY AREAS TO 5.2')**	
10	R-2	5.0 (100%)	96	UNWEATHERED UNBROKEN MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE**	
15	R-3	5.0 (100%)	97	**(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)**	
20	R-4	5.0 (100%)	100	**(HOMEWOOD SANDSTONE FORMATION)**	
25	R-5	5.0 (100%)	90		
30	R-6	5.0 (100%)	97		

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1)UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	**PROJECT NO.** 031019	**BORING NO.** B-16
	SHEET NO. 2 of 3	**DATE STARTED** 09-18-05
BORING LOCATION SEE FIGURE	**FIELD SUPERVISOR** R. Short	**DATE COMPLETED** 09-18-05
DRILLING METHOD Hetager track-mounted Rotary Drill with NX rock core (Wireline)	**CHECKED BY** W. Johnson	**DATE CHECKED** 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)/ % REC.	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1536.50 GROUND WATER EL. 1503.20	COMMENTS:
	R-6 (CONT)	5.0 (100%)	97	SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS** **SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** **38.6'**	
35	R-7	5.0 (100%)	100		
40	R-8	3.3 (66%)	42	COMPLETELY WEATHERED VERY BROKEN SOFT DECOMPOSED RED **SANDSTONE AND CLAYSTONE** **41.1'**	
				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS** **SANDSTONE** **(HOMEWOOD SANDSTONE FORMATION)** **45.3'**	
45	R-9	5.0 (100%)	54	INTERBEDDED SLIGHTLY WEATHERED VERY BROKEN SOFT TO MEDIUM HARD DARK GRAY **SILTY SHALE** AND **BLACK COAL** **51.2'**	
50	R-10	5.0 (100%)	56		
55	R-11	5.0 (100%)	10	SLIGHTLY WEATHERED VERY BROKEN SOFT **BLACK COAL** **(LEWISTON COAL FORMATION)** **57.4'**	
60	R-12	4.7 (100%)	55	SLIGHTLY WEATHERED BROKEN TO SLIGHTLY BROKEN MEDIUM HARD GRAY **SILTY SHALE**	

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

[1]UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-16
	SHEET NO. 3 of 3	DATE STARTED 09-18-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-18-05
DRILLING METHOD Hetager track-mounted Rotary Drill with NX rock core (Wireline)	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)/ % REC.	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1536.50 GROUND WATER EL. 1503.20	COMMENTS:
	R-12 (CONT)	4.7 (100%)	55	SLIGHTLY WEATHERED BROKEN TO SLIGHTLY BROKEN MEDIUM HARD GRAY **SILTY SHALE**	
				BOTTOM OF BORING B-16 AT 62.2'	
65					
70					
75					
80					
85					
90					

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1)UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-17
	SHEET NO. 1 of 1	DATE STARTED 09-19-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-19-05
DRILLING METHOD Driltech 40D Air Rotary Drill	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1537.06 GROUND WATER EL. DRY	COMMENTS:
0–4.0				**MINE SPOIL FILL FOR ROADWAY STABILIZATION** 4.0'	
4.0–44.9 (10, 20, 30, 40)				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** 44.9'	
44.9–51.0 (50)				INTERBEDDED UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** 51.0'	
51.0–57.1				SLIGHTLY WEATHERED SOFT BLACK **COAL** **(LEWISTON COAL FORMATION)** 57.1'	**NO AIR RETURN LOST**
57.1–60 (60)				SLIGHTLY WEATHERED MEDIUM HARD GRAY **SILTY SHALE** **BOTTOM OF B-17 AT 60.0'**	

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1)UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	**PROJECT NO.** 031019	**BORING NO.** B-18
	SHEET NO. 1 of 1	**DATE STARTED** 09-20-05
BORING LOCATION SEE FIGURE	**FIELD SUPERVISOR** R. Short	**DATE COMPLETED** 09-20-05
DRILLING METHOD Driltech 40D Air Rotary Drill	**CHECKED BY** W. Johnson	**DATE CHECKED** 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1542.70 GROUND WATER EL. DRY	COMMENTS:
0–4.0				**MINE SPOIL FILL FOR ROADWAY STABILIZATION** 4.0'	
4.0–53.4				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** 53.4'	
53.4–57.4				INTERBEDDED UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** 57.4'	**AIR RETURN LOST: 57.4'**
57.4–61.5				**AIR-FILLED VOID TO 61.5'** **BOTTOM OF BORING B-18 AT 61.5'**	

Depth scale: 10, 20, 30, 40, 50, 60

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1)UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-20
	SHEET NO. 1 of 1	DATE STARTED 09-16-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-16-05
DRILLING METHOD Driltech 40D Air Rotary Drill	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1509.20 GROUND WATER EL. 1460.25	COMMENTS:
0–30.3				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** **30.3'**	
30.3–39.9				INTERBEDDED UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** **39.9'**	**NO AIR LOST**
39.9–44.6				SLIGHTLY WEATHERED SOFT BLACK **COAL** **(LEWISTON COAL FORMATION)** **44.6'**	**MINE TEMPERATURE 60.8°F**
44.6–45.8				INTERBEDDED SLIGHTLY WEATHERED SOFT BLACK **COAL** AND SLIGHTLY WEATHERED MEDIUM HARD DARK GRAY **SHALE** **45.8'**	
45.8–49.5				UNWEATHERED HARD GRAY **SANDSTONE** **(COALBURG SANDSTONE FORMATION)**	
50–60				**BOTTOM OF B-20 AT 49.5'**	

Depth scale: 10, 20, 30, 40, 50, 60

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1)UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	**PROJECT NO.** 031019	**BORING NO.** B-22
	SHEET NO. 1 of 1	**DATE STARTED** 09-16-05
BORING LOCATION SEE FIGURE	**FIELD SUPERVISOR** R. Short	**DATE COMPLETED** 09-16-05
DRILLING METHOD Driltech 40D Air Rotary Drill	**CHECKED BY** W. Johnson	**DATE CHECKED** 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1503.79 GROUND WATER EL. 1457.74	COMMENTS:
0–33.2'				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** **33.2'**	
33.2'–41.3'				INTERBEDDED UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** **41.3'**	**NO AIR LOST**
41.3'–45.9'				SLIGHTLY WEATHERED SOFT BLACK **COAL** **(LEWISTON COAL FORMATION)** **45.9'**	**MINE TEMPERATURE 69.8°F**
45.9'–48.2'				INTERBEDDED SLIGHTLY WEATHERED SOFT BLACK **COAL** AND SLIGHTLY WEATHERED MEDIUM HARD DARK GRAY **SHALE** **48.2'**	
48.2'–49.5'				UNWEATHERED HARD GRAY **SANDSTONE** **(COALBURG SANDSTONE FORMATION)**	
				BOTTOM OF B-22 AT 49.5'	

Depth scale: 10, 20, 30, 40, 50, 60

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1)UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-23
	SHEET NO. 1 of 2	DATE STARTED 09-20-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-20-05
DRILLING METHOD Driltech 40D Air Rotary Drill	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1540.50 GROUND WATER EL. 1475.17	COMMENTS:
				MINE SPOIL FILL FOR ROADWAY STABILIZATION 4.0'	
10 20 30 40 50				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** 52.6'	
				INTERBEDDED UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** 59.3'	**NO AIR RETURN LOST**
60				SLIGHTLY WEATHERED SOFT BLACK **COAL** **(LEWISTON COAL FORMATION)**	

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

[(1)]UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	**PROJECT NO.** 031019	**BORING NO.** B-23
	SHEET NO. 2 of 2	**DATE STARTED** 09-20-05
BORING LOCATION SEE FIGURE	**FIELD SUPERVISOR** R. Short	**DATE COMPLETED** 09-20-05
DRILLING METHOD Driltech 40D Air Rotary Drill	**CHECKED BY** W. Johnson	**DATE CHECKED** 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1540.50 GROUND WATER EL. 1475.17	COMMENTS:
				SL SLIGHTLY WEATHERED SOFT BLACK **COAL** **(LEWISTON COAL FORMATION)** **67.1'**	
				SLIGHTLY WEATHERED MEDIUM HARD GRAY **SILTY SHALE**	
70				**BOTTOM OF BORING B-23 AT 68.5'**	
80					
90					
100					
110					
120					

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1)UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-25
	SHEET NO. 1 of 1	DATE STARTED 09-20-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-20-05
DRILLING METHOD Driltech 40D Air Rotary Drill	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1501.53 GROUND WATER EL. 1462.83	COMMENTS:
0–25.5				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** **25.5'**	
25.5–30.8				INTERBEDDED UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** **30.8'**	
30.8–38.8				**AIR-FILLED VOID**	**RETURN AIR LOST: 30.8'**
				BOTTOM OF B-25 AT 38.8'	

Depth scale: 10, 20, 30, 40, 50, 60

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1)UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-28
	SHEET NO. 1 of 1	DATE STARTED 09-19-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-19-05
DRILLING METHOD Driltech 40D Air Rotary Drill	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1507.82 GROUND WATER EL. DRY	COMMENTS:
0–28.5				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** **28.5'**	
28.5–36.0				INTERBEDDED UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** **36.0'**	**NO AIR RETURN LOST**
36.0–40.7				SLIGHTLY WEATHERED SOFT BLACK **COAL** **(LEWISTON COAL FORMATION)** **40.7'**	**MINE TEMPERATURE 77.7°F**
40.7–45.0				UNWEATHERED HARD GRAY **SANDSTONE** **(COALBURG SANDSTONE FORMATION)**	
45.0				**BOTTOM OF B-28 AT 45.0'**	

Depth scale: 10, 20, 30, 40, 50, 60

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1) UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	**PROJECT NO.** 031019 **SHEET NO.** 1 of 2	**BORING NO.** B-29 **DATE STARTED** 09-19-05
BORING LOCATION SEE FIGURE	**FIELD SUPERVISOR** R. Short	**DATE COMPLETED** 09-19-05
DRILLING METHOD Hetager track-mounted Rotary Drill with NX rock core (Wireline)	**CHECKED BY** W. Johnson	**DATE CHECKED** 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)/ % REC.	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1488.14 GROUND WATER EL. NA	COMMENTS:
5 10				**4-INCH DIAMETER CASING ADVANCED TO 13.8' THROUGH COARSE COAL REFUSE**	
15	R-1	3.7 (100%)	71	SLIGHTLY WEATHERED TO UNWEATHERED BROKEN TO UNBROKEN MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** WITH SHALE AND COAL STREAKS **17.5'**	
20	R-2	4.9 (98%)	74	MODERATELY WEATHERED VERY BROKEN SOFT TO MEDIUM HARD DARK GRAY **SHALE** **18.1'** SLIGHTLY WEATHERED VERY BROKEN SOFT **BLACK COAL** **18.6'** INTERBEDDED UNWEATHERED UNBROKEN MEDIUM HARD GRAY **SANDSTONE AND SILTY SHALE**	
25	R-3	5.0 (100%)	86	**26.9'**	
30	R-4	5.0 (100%)	16	SLIGHTLY WEATHERED VERY BROKEN TO BROKEN SOFT **BLACK COAL (LEWISTON COAL FORMATION)**	

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

[1] UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-29
	SHEET NO. 2 of 2	DATE STARTED 09-19-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-19-05
DRILLING METHOD Hetager track-mounted Rotary Drill with NX rock core (Wireline)	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)/ % REC.	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1488.14 GROUND WATER EL. NA		COMMENTS:
	R-4 (CONT)	5.0 (100%)	16	SLIGHTLY WEATHERED VERY BROKEN TO BROKEN SOFT **BLACK COAL** **(LEWISTON COAL FORMATION)**	**31.5'**	
				UNWEATHERED VERY BROKEN MEDIUM HARD GRAY **SHALE**	**32.0'**	
				SLIGHTLY WEATHERED VERY BROKEN TO BROKEN SOFT **BLACK COAL**	**33.0'**	
35	R-5	4.8 (96%)	84	UNWEATHERED UNBROKEN MEDIUM HARD GRAY **SILTY SHALE**		
				BOTTOM OF BORING B-29 AT 37.5'		
40						
45						
50						
55						
60						

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1) UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	**PROJECT NO.** 031019 **SHEET NO.** 1 of 1	**BORING NO.** B-30 **DATE STARTED** 09-16-05
BORING LOCATION SEE FIGURE	**FIELD SUPERVISOR** R. Short	**DATE COMPLETED** 09-16-05
DRILLING METHOD Driltech 40D Air Rotary Drill	**CHECKED BY** W. Johnson	**DATE CHECKED** 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1518.23 GROUND WATER EL. 1476.43	COMMENTS:
0–31.8				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** **31.8'**	
31.8–32.2				SLIGHTLY WEATHERED SOFT BLACK **COAL** **32.2'**	
32.2–38.8				UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** **38.8'**	**NO AIR LOST**
38.8–43.8				SLIGHTLY WEATHERED SOFT BLACK **COAL** **(LEWISTON COAL FORMATION)** **43.8'**	
43.8–46.0				INTERBEDDED SLIGHTLY WEATHERED SOFT BLACK **COAL** AND SLIGHTLY WEATHERED MEDIUM HARD DARK GRAY **SHALE** **46.0'**	
46.0–50.0				UNWEATHERED HARD GRAY **SANDSTONE** **(COALBURG SANDSTONE FORMATION)**	
50–60				**BOTTOM OF B-30 AT 50.0'**	

Depth scale: 10, 20, 30, 40, 50, 60

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

[1]UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	**PROJECT NO.** 031019	**BORING NO.** B-31
	SHEET NO. 1 of 1	**DATE STARTED** 09-20-05
BORING LOCATION SEE FIGURE	**FIELD SUPERVISOR** R. Short	**DATE COMPLETED** 09-20-05
DRILLING METHOD Driltech 40D Air Rotary Drill	**CHECKED BY** W. Johnson	**DATE CHECKED** 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1516.98 GROUND WATER EL. DRY	COMMENTS:
0–30.5				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** **30.5'**	
30.5–31.5				SLIGHTLY WEATHERED SOFT BLACK **COAL** **31.5'**	
31.5–37.0				INTERBEDDED UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** **37.0'**	
37.0–43.0				**AIR-FILLED VOID**	**RETURN AIR LOST: 37.0'**
				BOTTOM OF B-31 AT 43.0'	

Depth scale: 10, 20, 30, 40, 50, 60

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

[1]UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	**PROJECT NO.** 031019	**BORING NO.** B-32
	SHEET NO. 1 of 1	**DATE STARTED** 09-20-05
BORING LOCATION SEE FIGURE	**FIELD SUPERVISOR** R. Short	**DATE COMPLETED** 09-20-05
DRILLING METHOD Driltech 40D Air Rotary Drill	**CHECKED BY** W. Johnson	**DATE CHECKED** 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1516.53 — GROUND WATER EL. 1476.83	COMMENTS:
0–30.4				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** **30.4'**	
30.4–31.5				SLIGHTLY WEATHERED SOFT BLACK **COAL** **31.5'**	
31.5–37.0				UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** **37.0'**	
37.0–43.6				SLIGHTLY WEATHERED SOFT BLACK **COAL** **(LEWISTON COAL FORMATION)**	**NO AIR LOST** **MINE TEMPERATURE 59.8°F**
				BOTTOM OF B-32 AT 43.6'	

Depth scale: 10, 20, 30, 40, 50, 60

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

[(1)] UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA	PROJECT NO. 031019	BORING NO. B-33
	SHEET NO. 1 of 1	DATE STARTED 09-21-05
BORING LOCATION SEE FIGURE	FIELD SUPERVISOR R. Short	DATE COMPLETED 09-21-05
DRILLING METHOD Driltech 40D Air Rotary Drill	CHECKED BY W. Johnson	DATE CHECKED 10-03-05

DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1516.40 GROUND WATER EL. 1477.15	COMMENTS:
0–30.1				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** **30.1'**	
30.1–31.5				SLIGHTLY WEATHERED SOFT BLACK **COAL** **31.5'**	
31.5–38.4				UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** **38.4'**	
38.4–45.1				SLIGHTLY WEATHERED SOFT BLACK **COAL** **(LEWISTON COAL FORMATION)**	**NO AIR LOST** **MINE TEMPERATURE 59.0°F**
				BOTTOM OF B-33 AT 45.1'	

Depth scale: 10, 20, 30, 40, 50, 60

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1)UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.

DEMONSTRATION PROJECT-MINE VOID DETECTION DC RESISTIVITY AND TDEM TECHNIQUES LOT'S BRANCH SLURRY IMPOUNDMENT SITE PRENTER, WEST VIRGINIA		**PROJECT NO.** 031019	**BORING NO.** B-34
		SHEET NO. 1 of 1	**DATE STARTED** 09-21-05
BORING LOCATION SEE FIGURE		**FIELD SUPERVISOR** R. Short	**DATE COMPLETED** 09-21-05
DRILLING METHOD	Driltech 40D Air Rotary Drill	**CHECKED BY** W. Johnson	**DATE CHECKED** 10-03-05

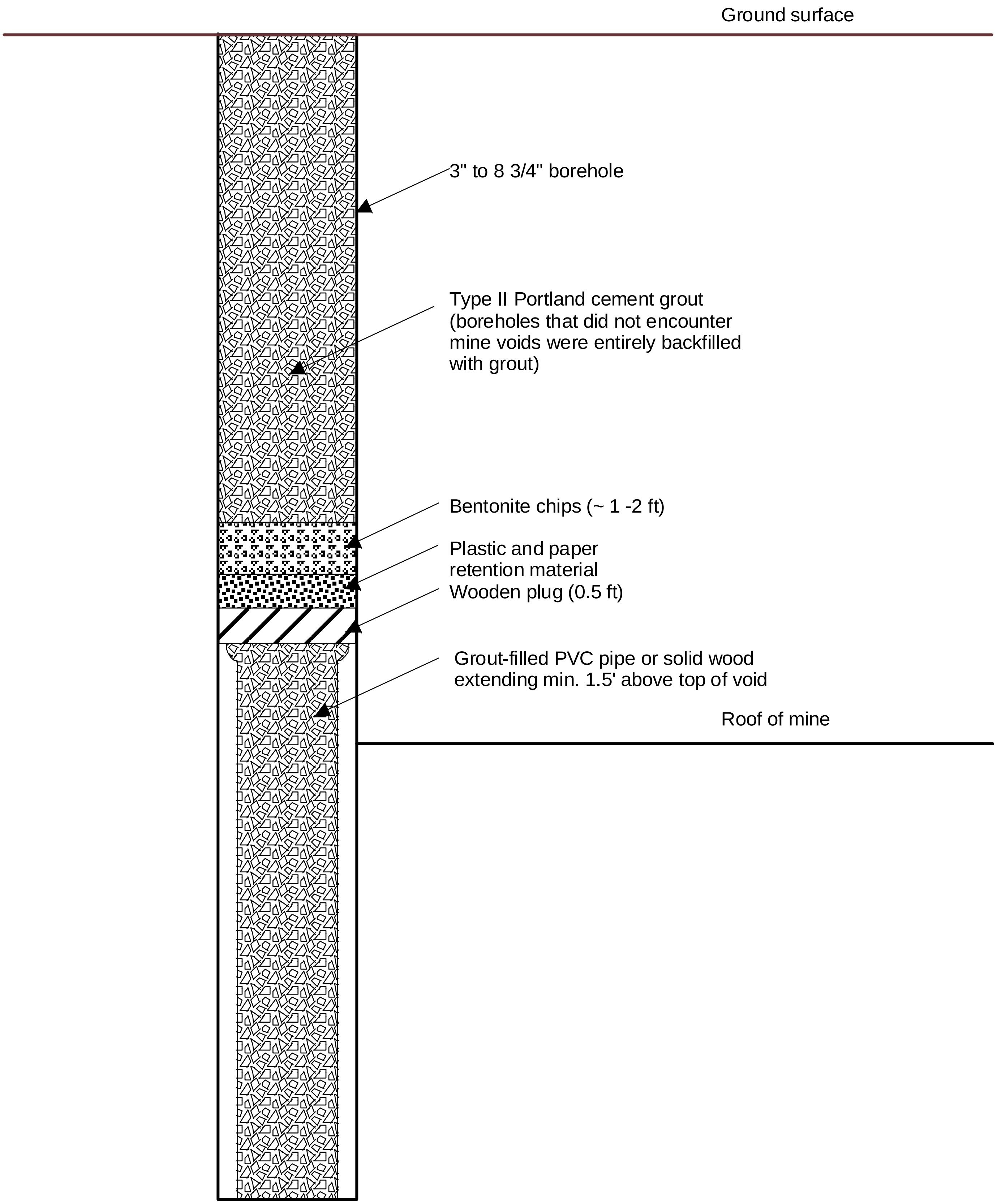
DEPTH (FT)	SAMPLE NO. OR TYPE AND RUN NO.	REC. (FT)	ROCK RQD (%)	DESCRIPTION OF MATERIAL SURFACE EL. 1518.24 GROUND WATER EL. 1475.74	COMMENTS:
0–31.3				SLIGHTLY WEATHERED TO UNWEATHERED MEDIUM HARD BROWN AND GRAY **MICACEOUS SANDSTONE** **(ISOLATED DARK GRAY CARBONACEOUS SHALE AND BLACK COAL STREAKS)** **(HOMEWOOD SANDSTONE FORMATION)** **31.3'**	
31.3–32.0				SLIGHTLY WEATHERED SOFT BLACK **COAL** **32.0'**	
32.0–37.9				UNWEATHERED SOFT TO MEDIUM HARD GRAY **SHALE** AND SOFT BLACK **COAL** **37.9'**	**RETURN AIR LOST: 36.9'**
37.9–42.7				**AIR-FILLED VOID**	
				BOTTOM OF B-33 AT 42.7'	

Depth scale: 10, 20, 30, 40, 50, 60

THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES. IN SITU, THE TRANSITION MAY BE GRADUAL.

D'APPOLONIA

(1)UNCONFINED COMPRESSIVE STRENGTHS FOR SOIL SAMPLES BASED ON POCKET PENETROMETER TESTS. UNCONFINED COMPRESSIVE STRENGTHS FOR INTACT ROCK CORE BASED ON POINT LOAD TESTS.



GROUTING SCHEMATIC
(Not to scale)