Final Report
Geophysical Survey
Bedrock Fracture Zone Detection
~2100 Lineal Feet of Proposed Pipeline
Carlisle, PA
Enviroscan Project Number 101722

Prepared For: Gremminger & Associates, Inc.
Prepared By: Enviroscan, Inc.
November 3, 2017

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November 3, 2017

Mr. Larry Gremminger
Gremminger & Associates, Inc.
226 South Live Oak Street
Belleville, TX 77418

RE: Geophysical Survey
Bedrock Fracture Zone Detection
~2100 Lineal Feet of Proposed Pipeline
Carlisle, PA
Enviroscan Project Number 101722

Dear Mr. Gremminger:

Pursuant to our proposal dated October 25, 2017, Enviroscan, Inc. (Enviroscan) has completed a combined seismic refraction, Multi-Spectral Analysis of Surface Waves (MASW), and electrical resistivity survey at the above-referenced site. The purpose of the survey was to map the locations of potential bedrock factures along client-designated sections of a pipeline alignment totaling ~2100 lineal feet. Fieldwork was conducted October 16 through October 23, 2017 in client-designated areas.

Site Description

The geophysical survey area was the trace of an approximate 2100-foot-long proposed pipeline route; however, due to access issues caused by densely-wooded areas and a stream, the alignment was cut to a total of ~1000 lineal feet. Section 1 was located to the east of the stream, while Section 2 was west of the stream along the cleared pipeline path – both north of the Pennsylvania Turnpike (see Figures 1 and 3). The Geologic Map of Pennsylvania (Berg, T. M., Edmunds, W. E., Geyer, A. R., and others, 1980) indicates that these two areas are located within the St. Paul Group (Osp) Formation, with a nearby contact with the Martinsburg Formation (Om) to the north and west. The St. Paul Group is characterized as a very finely crystalline limestone at the top and base, with fossiliferous limestone, chert, and dolomite making up the middle of the formation (Ibid).

Survey Methods

In order to provide the highest level of confidence and greatest cost-effectiveness, Enviroscan proposed a combined seismic refraction, MASW, and electrical resistivity survey. Seismic refraction can be used to determine the depth to bedrock and overburden thickness, as well as to show variations of the velocity of the bedrock. MASW data was used to provide information below the top of the rock, so that weathered fractures may be visible. Electrical resistivity imaging was used to map the electrical properties of the subsurface, revealing areas of fractured rock and solid bedrock.

Seismic Refraction Survey

The principles of seismic refraction are described in the accompanying Introduction to Seismic Refraction (Appendix A), and generally involve measuring the travel times of shock waves traveling from a surficial source (shot point) to a linear array of ground motion sensors (geophones). The first arrival (P-wave) travel times can be inverted to provide a cross-sectional profile of the density stratification beneath the geophone array. While seismic P-wave velocity (V_p) is – formally – inversely proportional to density, the strength of Earth materials increases with density such that in general the higher the density, the faster the P-wave velocity.

The principle of MASW is based on the dispersion of seismic surface waves. That is, the different frequency components of surface wave trains sample differing effective depths, so the surface wave train changes shape or disperses as it propagates. Therefore, the surface wave train recorded at each geophone in a linear array can be Fourier-transformed, and the velocity of individual wavelengths determined to provide S-wave velocity (V_s) as a function of frequency – which is in turn inverted to determine S-wave velocity as a function of depth at each geophone location. For numerous shot points and receivers, it is possible to construct a cross-sectional image of shear-wave velocity as a function of distance and depth. Note that MASW images (unlike seismic refraction profiles) provide information below the top of rock, so that weathered fractures may be visible.

Field Procedure

To perform the combined refraction/MASW field survey, Enviroscan completed the following specific tasks:

- Enviroscan recorded seismic records along 2 profiles oriented roughly west-east. The survey profiles are shown on the attached Figures 1 and 3.

- Recording employed a Geometrics SmartSeis 24-channel digital signal stacking seismograph and successive linear arrays of 4.5 Hertz geophones with a constant 10-foot interval.

- Seismic travel times were recorded from shots at the midpoint of every geophone pair, and extending one-half (or as far as possible) spread length beyond each array, to ensure full data coverage and highly redundant, low-noise data. The seismic energy source was a seismic slide sledge hammer, in order to generate both an impulsive source for refraction and surface waves with a wide spectral content for MASW.

- Location control (with sub-meter accuracy) was maintained for each geophone and shot point using a Topcon Hyper-SR differential global positioning system (DGPS).

- The seismic wiggle trace data from each geophone, for each shot point, was recorded on the internal hard drive of the laptop controlling the seismograph, and was downloaded daily to USB drives for backup.

Data Processing

The data were subjected to both refraction and MASW processing.

- Refraction processing employed the SeisImager (by OYO Corporation) software suite. First arrival picking was done using the automatic function in Pickwin with minor manual adjustment. Traces without clear first arrivals were typically deleted, since the data collection was highly redundant, and the missing arrivals would be more than compensated by multiple arrivals sampling the same portion of the subsurface using other shot-receiver pairs.

- The arrival time data were subjected to tomographic inversion with no a-priori layer assignments to ensure objective results. Each inversion was run for a minimum of seven iterations, and continued until the root mean square (RMS) residual between the observed travel times and those predicted for the model ceased to decline between iterations. In all cases, the RMS was less than 4 milliseconds.

- Each model was also subjected to mild horizontal smoothing (Gaussian-weighted, 70-foot window) to eliminate potential artifacts due to over-fitting of the models.

- The final seismic refraction velocity (V_p) model cross sections are shown on Figures 2 and 4 (top panel).

- The MASW data were also analyzed using SeisImager (by OYO Corporation) software suite. These are the same records used for refraction processing – which contain both the refracted P-wave first arrivals, and the later arriving surface wave trains that contain S-wave information. From the spectra, SeisImager generates dispersion curves depicting the variation of V_s with frequency, which in turn is converted to variations in V_s with depth, and distance along the profile.

- MASW cross sections depicting variations in V_s with depth and distance were generated for each seismic profile, and are depicted on Figures 2 through 4 (middle panel).

Electrical Imaging Survey

Surface resistivity measurements involve driving an electrical current in the ground using two current electrodes at the ground surface. The apparent resistivity of the subsurface (essentially the mathematical inverse of terrain conductivity) is determined by measuring the potential difference, or voltage, between two potential electrodes with a known separation and position/orientation relative to the current electrodes. The depth and volume of the subsurface zone represented by the measured apparent resistivity is a function of the geometry of the current and potential electrodes located at the surface. The principles of electrical imaging are described in the accompanying Introduction to Electrical Imaging (Appendix B).

Using an AGI Super Sting R8/IP resistivity meter, apparent resistivity readings were collected along two profiles, mimicking the seismic arrays (Figures 1 and 3). Along each profile, electrodes were spaced at the ground surface at 10-foot intervals. The locations of profile endpoints, as well other electrodes and topography changes, were surveyed using the Topcon Hyper-SR DGPS.

The measured apparent resistivities (ρ_a) were plotted in the field as resistivity pseudosections depicting the apparent resistivity versus nominal survey depth for each profile, in order to confirm data quality. In post-field processing, the apparent resistivity pseudosections were mathematically inverted using EarthImager 2D Resistivity Software by Advanced Geosciences, Inc., to provide electrical images of true resistivity versus true depth along each profile. The 2D resistivity data are presented as a series of color contours of the true resistivity versus depth along each profile (Figures 2 and 4, bottom panel).

Results

The seismic refraction cross sections (Figures 2 and 4, top panel) indicate a generalized two-layer stratigraphic model with a rapid transition from unconsolidated materials to competent rock. The uppermost layer has averaged P-wave velocities (the **P**ressure **wave** created by the source hammer that travels through the soil and bedrock) of less than 5000 feet per second (fps), with a thickness of approximately 10 feet (shaded blue, with its lower extent bounded by a dashed black line). The deeper layer has an averaged velocity of over 9000 fps (shaded orange to red). The uppermost layer velocities are consistent with unconsolidated soils, while the bottom layer velocities are consistent with bedrock (Carmichael, R. S., 1989). Please note that the seismic profiles represent an average velocity profile, with contours representing a smoothed and gradual interface between the unconsolidated soils and rock, with rock pinnacles and cutters extending both above and below the contour lines. The seismic refraction data show a relatively consistent inferred bedrock surface with a depth of ~20 feet.

The MASW data are displayed in the middle panels of Figures 2 and 4, and depict a relatively consistent inferred bedrock surface similar to that of the refraction profiles. The MASW technique requires proper surface wave dispersion to determine velocity at multiple depths/frequencies. The collected MASW data were dominated by "higher mode" surface waves (noise), rather than the "fundamental mode" surface wave (signal). This disproportionate signal-to-noise ratio created higher RMS error, unreliable dispersion curves, and subsequently more "averaging" as lower quality data were removed. Poor wave dispersion can be the result of pinnacled rock, causing the wave front to break apart as it travels through the array. Also, shallow rock can inhibit the formation of lower frequency waves near the surface, which will decrease the sampling depth. As a result, the MASW profile contours are questionable, and therefore unreliable in determining the presence of subsurface fractures along both profiles.

The electrical imaging data (bottom panels of Figures 2 and 4) show a general depth-to-rock correlation with the seismic data at approximately 15 to 30 feet below grade. The resistivity profiles show three low-resistivity zones along the profiles within the suspected bedrock, most notably along Profile 1 (denoted by black dashed lines). The high-resistivity zones likely represent competent bedrock, while the low-resistivity zones (more conductive) in general represent weathered or fractured zones – which may indicate potential migration pathways.

In conclusion, the electrical resistivity survey identified three low-resistivity zones along the two profiles that may indicate the presence of fractures and migration pathways. Please note that the geophysical survey alone cannot predict if a suspected fracture zone will or will not be a potential fluid pathway.

Limitations

The geophysical survey described above was completed using standard and/or routinely accepted practices of the geophysical industry and equipment representing the best available technology. Enviroscan does not accept responsibility for survey limitations due to inherent technological limitations or unforeseen site-specific conditions. In particular, Enviroscan cannot make any warranties concerning the future occurrence or development of soil piping activity. However, we make every effort to identify and notify the client of such limitations or conditions.

We have enjoyed and appreciated the opportunity to have worked with you. If you have any questions, please do not hesitate to contact me.

Sincerely,
Enviroscan, Inc.

Maxwell E. Griffiths
Project Geophysicist

Technical Review By:
Enviroscan, Inc.

Felicia K. Bechtel, M.Sc., P.G.
President

Enclosures:
Figure 1: Geophysical Survey Data Coverage Profiles Section 1
Figure 2: Seismic and Electrical Resistivity Profiles Section 1
Figure 3: Geophysical Survey Data Coverage Profiles Section 2
Figure 4: Seismic and Electrical Resistivity Profiles Section 2
Appendix A: Introduction to Seismic Refraction
Appendix B: Introduction to Electrical Imaging
References

Geophysical Legend

- Electrical Resistivity Profile
- Seismic Refraction/MASW Profile

Notes:

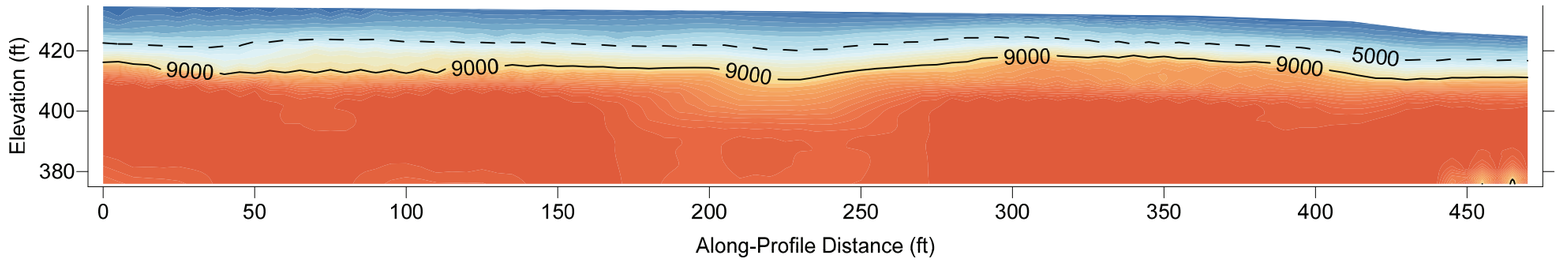
Basemap from RTK DGPS survey by Enviroscan, Inc. Google Earth Image.

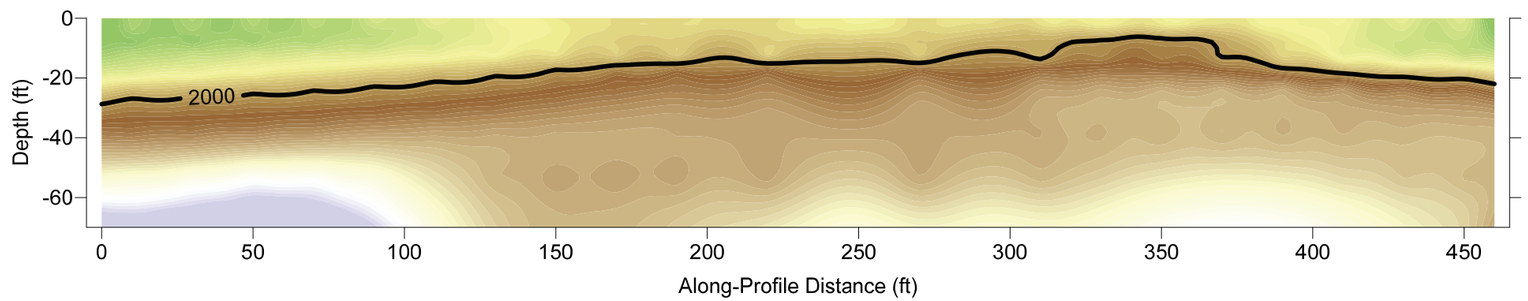
Scale (ft)

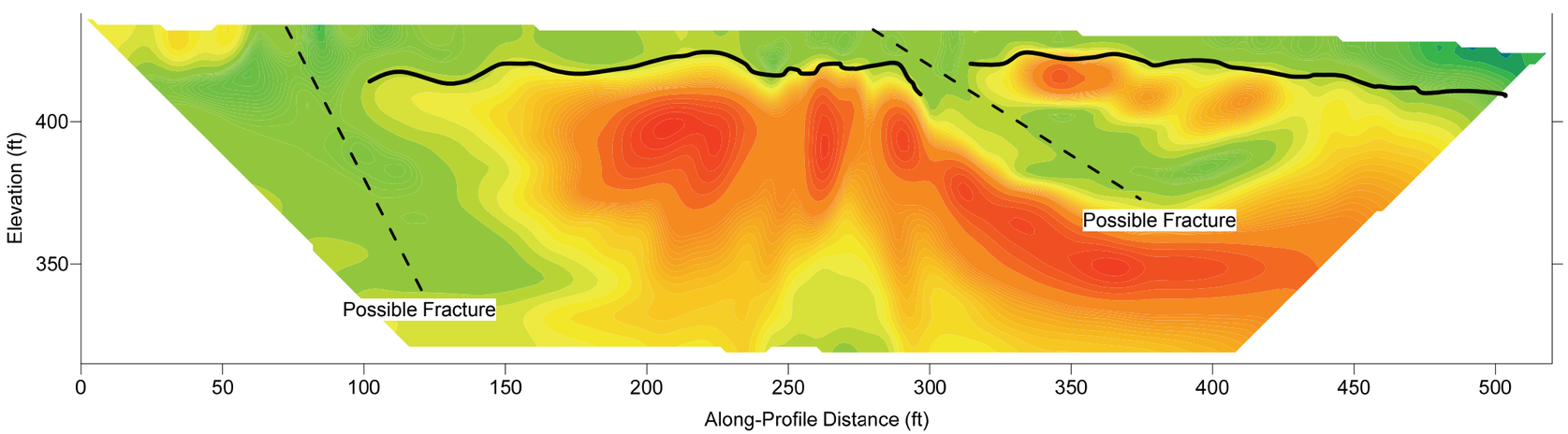
0 25 50 75 100

Prepared by:	Title:	Project Location:	Figure
Enviroscan, Inc. 1051 Columbia Ave. Lancaster PA 17603 717-396-8922 www.enviroscan.com	**Geophysical Survey Data Coverage Area 1**	**Proposed Sunoco Pipeline Carlisle, PA**	1
		Project Number: 101722 / Revision/Issue: 11/3/2017	
		Original Scale: 1" = 50' / Survey Ending Date: 10/31/2017	Drawn by: MEG / Approved by: FKB

East ⟶







Compressional (P-Wave) Velocity (fps)

500 5000 9500 14000 18500

Shear (S-Wave) Velocity (fps)

1000 1650 2300 2950 3600

Resistivity (ohm*m)

2 5 8 26 58 89 312 629 947 3647 6824 10000

Inferred Bedrock Surface ———

Notes:

Seismic data from Geometrics 48-channel Geode System, 10-foot geophone spacing, 10-foot shot spacing.

Resistivity from AGI SuperSting resistivity meter, 53 electrodes, dipole-dipole array.

Prepared by:	Title:	Project Location:	Figure
ENVIROSCAN, INC. **Enviroscan, Inc.** 1051 Columbia Ave. Lancaster PA 17603 717-396-8922 www.enviroscan.com	**Seismic and Electrical Resistivty Profiles Area 1**	**Proposed Sunoco Pipeline Carlisle, PA**	2

Project Number	Revision/Issue	Original Scale	Survey Ending Date	Drawn by:	Approved by:
101722	11/3/2017	1" = 50'	10/31/2017	MEG	FKB

N

Geophysical Legend

- Electrical Resistivity Profile
- Seismic Refraction/MASW Profile

Scale (ft)

0 25 50 75 100

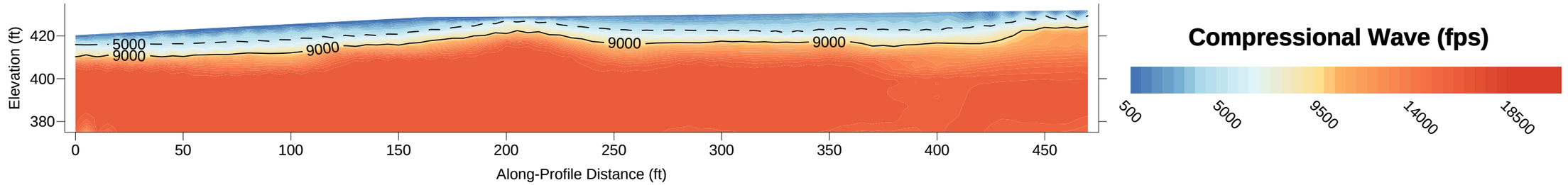
Notes:

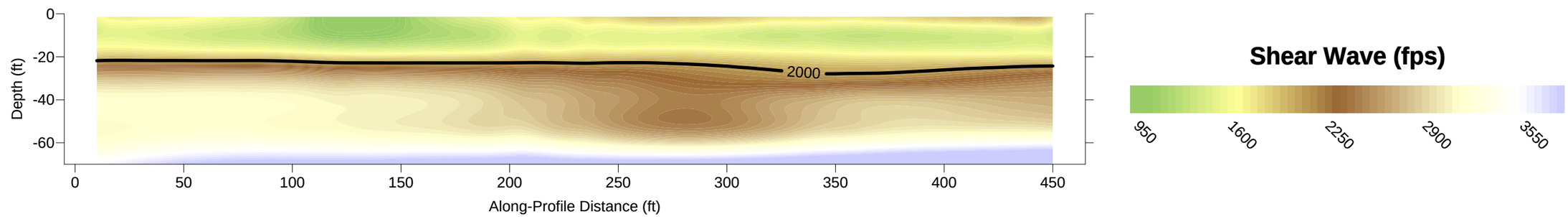
Basemap from RTK DGPS survey by Enviroscan, Inc. Google Earth Image.

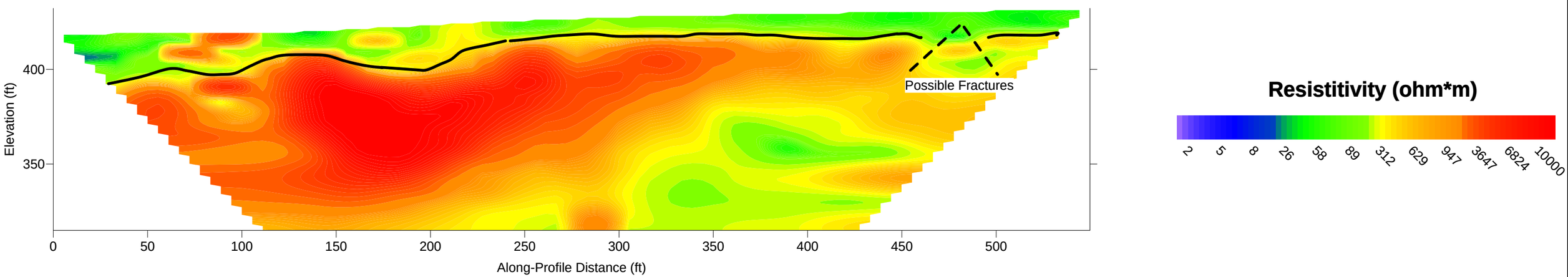
Prepared by:	Title:	Project Location:	Figure
Enviroscan, Inc. 1051 Columbia Ave. Lancaster PA 17603 717-396-8922 www.enviroscan.com	**Geophysical Survey Data Coverage Area 2**	**Proposed Sunoco Pipeline Carlisle, PA**	3

Project Number	Revision/Issue	Original Scale	Survey Ending Date	Drawn by:	Approved by:
101722	11/3/2017	1" = 50'	10/31/2017	MEG	FKB

East ⟶







Inferred Bedrock Surface ———

Notes:

Seismic data from Geometrics 48-channel Geode System, 10-foot geophone spacing, 10-foot shot spacing.

Resistivity from AGI SuperSting resistivity meter, 56 electrodes, dipole-dipole array.

Prepared by:	Title:	Project Location:	Figure
Enviroscan, Inc. 1051 Columbia Ave. Lancaster PA 17603 717-396-8922 www.enviroscan.com	**Electrical Resitivity & Seismic Profiles**	**Proposed Sunoco Pipeline Carlisle, PA**	4

Project Number	Revision/Issue	Original Scale	Survey Ending Date	Drawn by:	Approved by:
101722	11/3/2017	1" = 50'	10/31/2017	MEG	FKB

Appendix A

Introduction to Seismic Refraction

Introduction to Seismic Refraction

By

Timothy D. Bechtel, Ph.D., P.G.

Energy

Mechanical elastic (seismic) waves generated by a hammer blow, weight drop, or explosion.

Sensitivity

Sensitive to elastic properties or moduli – generally strongly correlated with density.

Basic Equipment

Recording Seismograph (generally 24 or more channels); Geophones (one for each channel); Geophone cable; Hammer or weight plus strike plate or explosives; Trigger switch.

Common Applications

Determination of the depth and dip of soil horizons and bedrock surfaces. Recent processing advances allow some detection and delineation of discrete targets.

Principles

In a uniform isotropic earth, the shock wave from a blow or explosion at the surface travels outward and downward in a hemispherical wave front like a three-dimensional ripple from a pebble in a still pond. At any point on the wave front, a straight line from the shock source to the wave front depicts the path of the seismic wave, and is called a ray path (see Figure SR-1). In reality, there are several independent shock waves; the fast-moving primary, compressional or P wave front; the slower moving secondary, shear or S wave (both of which form hemispherical wavefronts); and several disk-like wave fronts that travel only along the surface of the earth (called surface waves or ground roll). For the purposes of most seismic refraction surveys, only the fastest moving wave front — the P wave — is considered. S-wave refraction is used in selected circumstances where complete determination of elastic moduli is desired – particularly when it may be desirable to eliminate the effects of water saturation.

In a layered earth, the hemispherical P shock wave defined by the radially distributed P ray paths are deflected according to the laws of optics (Snell's Law) at interfaces between materials with differing seismic velocities (i.e. densities or elastic properties). Figure SR-2 depicts the deflection of ray paths due to an increase in P velocity at a bedding plane. The type of deflection that a ray path will undergo is dependent upon the angle at which it strikes the interface, and falls into one of four categories:

1) Some direct rays (green in Figures SR-2 and SR-3) travel parallel to the ground surface at the seismic velocity of the upper layer, do not strike the underlying interface, and consequently are not deflected.

2) Reflected rays (purple in Figures SR-2 and SR-3) arise where direct rays strike the interface, and a portion of the energy is reflected symmetrically back towards the surface.

3) The portion of the energy of the incident direct wave that is not reflected upward is refracted, or bent as it crosses the interface – making refracted waves in the lower layer (red in Figures SR-2 and SR-3).

4) At a precise angle called the critical angle, the incident ray is refracted directly along the interface, and travels at the higher seismic velocity of the lower layer (see Critically Refracted Wave in Figure SR-3). As this critically refracted or head wave races along beneath the interface, it generates a secondary elastic disturbance that travels back to the surface along ray paths that define a wave front analogous to the bow wake of a ship. These returning rays again travel at the slower velocity of the upper layer.

To perform a refraction survey, a linear array of ground motion sensors or geophones is spaced out from the seismic source or shot point, forming a geophone spread. Each geophone is connected to a separate channel in a seismograph which records a wiggle trace representing the ground motion resulting from the passage of the various seismic rays.

As depicted in the time-distance (T-X) curve in Figure SR-4, the layered earth structure can be determined by analyzing the seismographic wiggle traces. At distances close to the seismic source, the first wiggle or ground motion (the first arrival after the shot) is due to passage of the direct wave travelling at the velocity of the upper layer. Reflected waves arrive later since they have by definition traveled a greater distance at the same velocity (additional later wiggles are caused by passage of the more slowly travelling S and surface waves). Beyond a distance dictated by the critical angle, the first arrival of seismic energy represents the head wave of the critically refracted ray. These refracted rays also by definition travel a greater distance than the direct wave. However, along part of their path, they have traveled at the higher velocity of the underlying more consolidated layer. At greater

distances from the shot point, where the path length in the higher velocity layer becomes significant, the head wave arrivals actually race past the direct wave and become the first arrival (see labeled crossover in Figure SR-4). By extension, it can be shown that if a third layer with even greater velocity lies at greater depth, the head wave from this layer will become the first arrival at a sufficient distance from the shot point.

In conventional seismic refraction, only the first P wave arrivals can be reliably selected on a wiggle trace record. The later reflected P wave arrivals are generally obscured by the slower-travelling S and surface waves, and the very slow air blast or sound wave from the shot. To interpret a seismic refraction record, the first arrival travel times are measured for each wiggle trace and plotted at the appropriate point on a time-distance (T-X) curve (see Figure SR-4). In a plane-layered earth, these first arrivals define a series of line segments, each representing a discrete layer. The seismic velocity of each layer is simply the reciprocal of the slope of the associated line segment. The thickness of each layer can be calculated from the distances where the line segments intersect. The mathematics for these calculations are easily derived, and can be found in any introductory geophysics text.

True geologic strata are rarely perfectly horizontal. The effect of a dipping interface on a travel time curve cannot be recognized using a single shot point. Calculations based on a T-X curve from a single shot point should always be considered as producing apparent depths to interfaces and apparent seismic velocities for all but the uppermost layer. To determine the true depths and dips of interfaces and the true seismic velocities, it is necessary to reverse the seismic line; that is, move the shot point to a location at or beyond the farthest geophone in the spread, and repeat the shot. The calculation of true depths, dips and velocities from reversed seismic lines is also readily performed.

Capabilities

Conventional seismic refraction can yield accurate measurements of depths and attitudes of soil horizons, groundwater tables, and other relatively distinct and planar strata. Modern computer analysis of multi-fold seismic refraction data (i.e. with many and overlapping shot points) can provide delineation of undulating or even irregular (as opposed to simply planar) interfaces. The latest generation of computer processing techniques require very high-fold data, but in favorable conditions, are capable of resolving even discrete targets such as foundation elements, tunnels or cavities, and can resolve gradational boundaries as well as distinct interfaces. The seismic P-wave velocities of materials are generally an indication of relative density or compaction. S-wave refraction data (collected using specialized geophones, shock sources and field procedures) can provide S-

wave velocities that bear a well-constrained empirical relationship to standard penetration test (SPT) N values and therefore bearing capacity. For surveys where matching P- and S-wave velocities are determined, the dynamic elastic moduli of subsurface materials can be calculated (including Poisson's Ration, Young's or Bulk Modulus, and Shear Modulus or Rigidity).

Limitations

Seismic data is collected at spaced geophones, and therefore does not provide continuous profile data. If geophones are spaced too widely, thin layers can be missed entirely.

Conventional refraction interpretations are only accurate where the velocity of strata increase with depth. Velocity inversions not only alter the data, but are particularly insidious since the presence of a low velocity zone at depth is not apparent in first arrival data. The latest generation of computer processing techniques do allow detection and delineation of laterally restricted low velocity zones (e.g. tunnels, cavities, gravel lenses, etc.).

Sharp or dramatic interface relief such as limestone pinnacles cannot always be resolved even with very tight geophone spacing. Therefore, refraction profiles of expectedly irregular interfaces should be assumed to represent somewhat smoothed versions of actual relief (see e.g. Figure SR-5).

Seismic records can contain noise due to heavy machinery vibrations, vehicular traffic, and sometimes even wind or distant earthquakes. Care must be taken to identify potential sources of seismic noise prior to beginning a survey.

The effective survey depth is limited to approximately 1/5 of the greatest shotpoint to geophone distance. Therefore, very deep surveys may require impractically long lines (requiring consideration of other geophysical techniques such as seismic reflection).

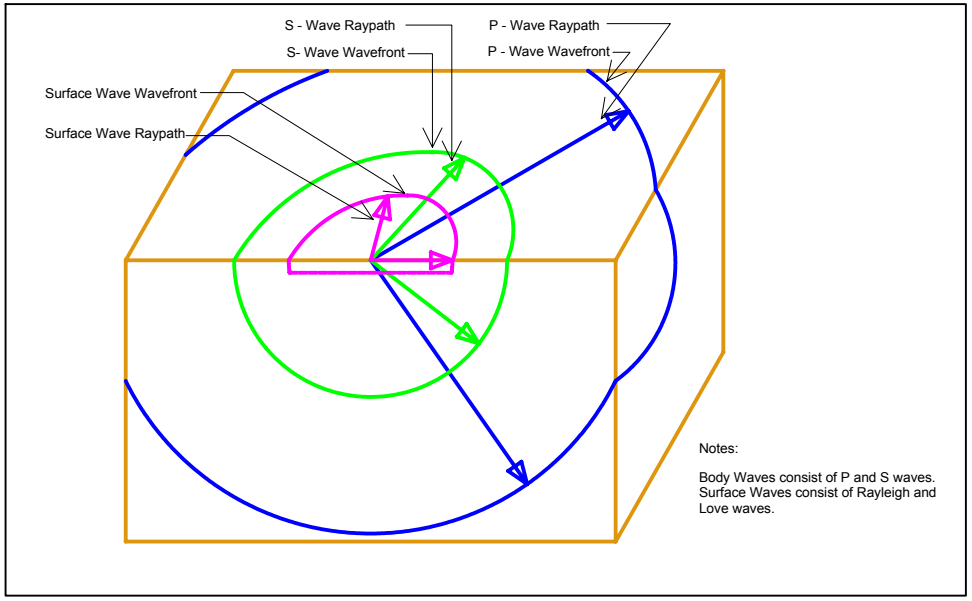


Figure SR-1 **Seismic Wave Types** Rev. 01/2001

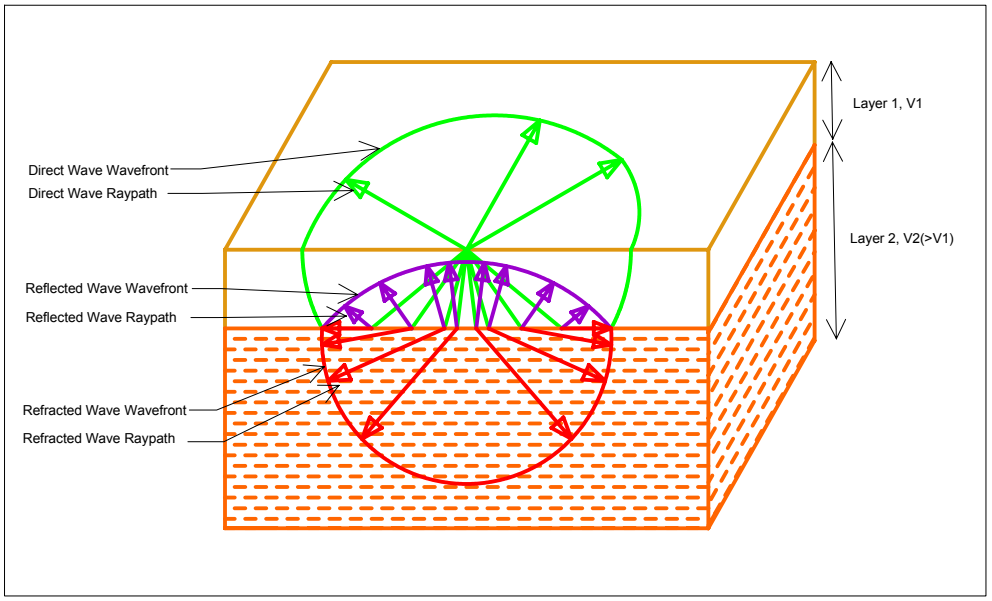


Figure SR-2 **Effect of Layering on Body Wave Raypath** Rev. 01/2001

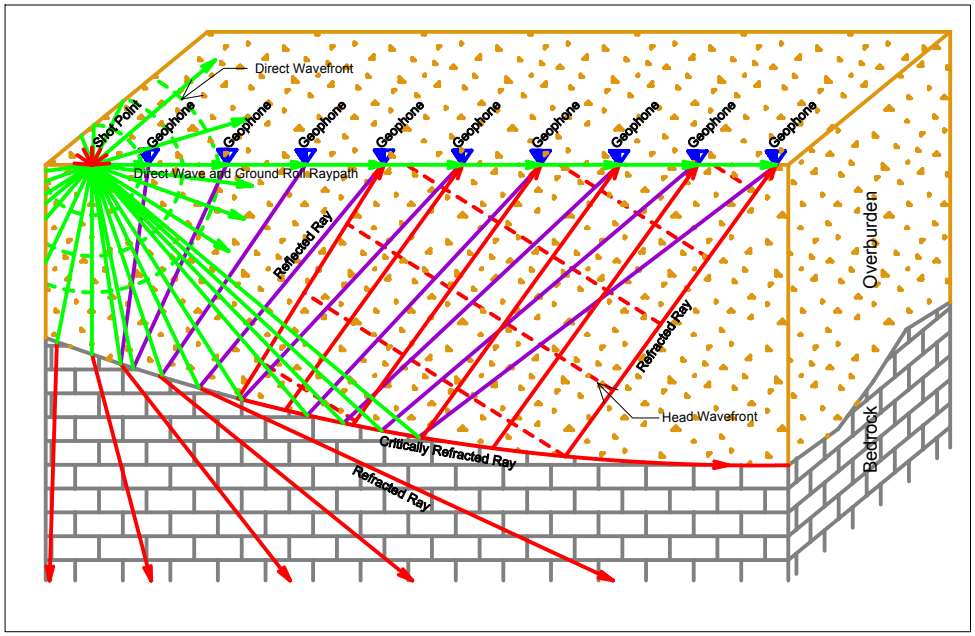


Figure SR-3 **Seismic Ray Path Geometry** Rev. 01/2001

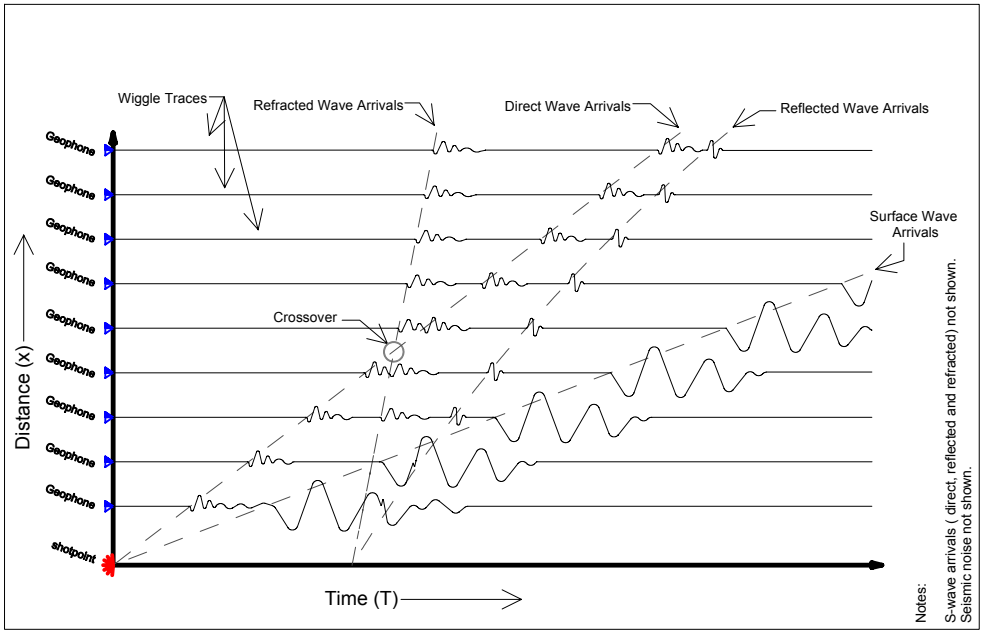


Figure SR-4 **Idealized Seismic Record and T- X Graph** Rev. 01/2001

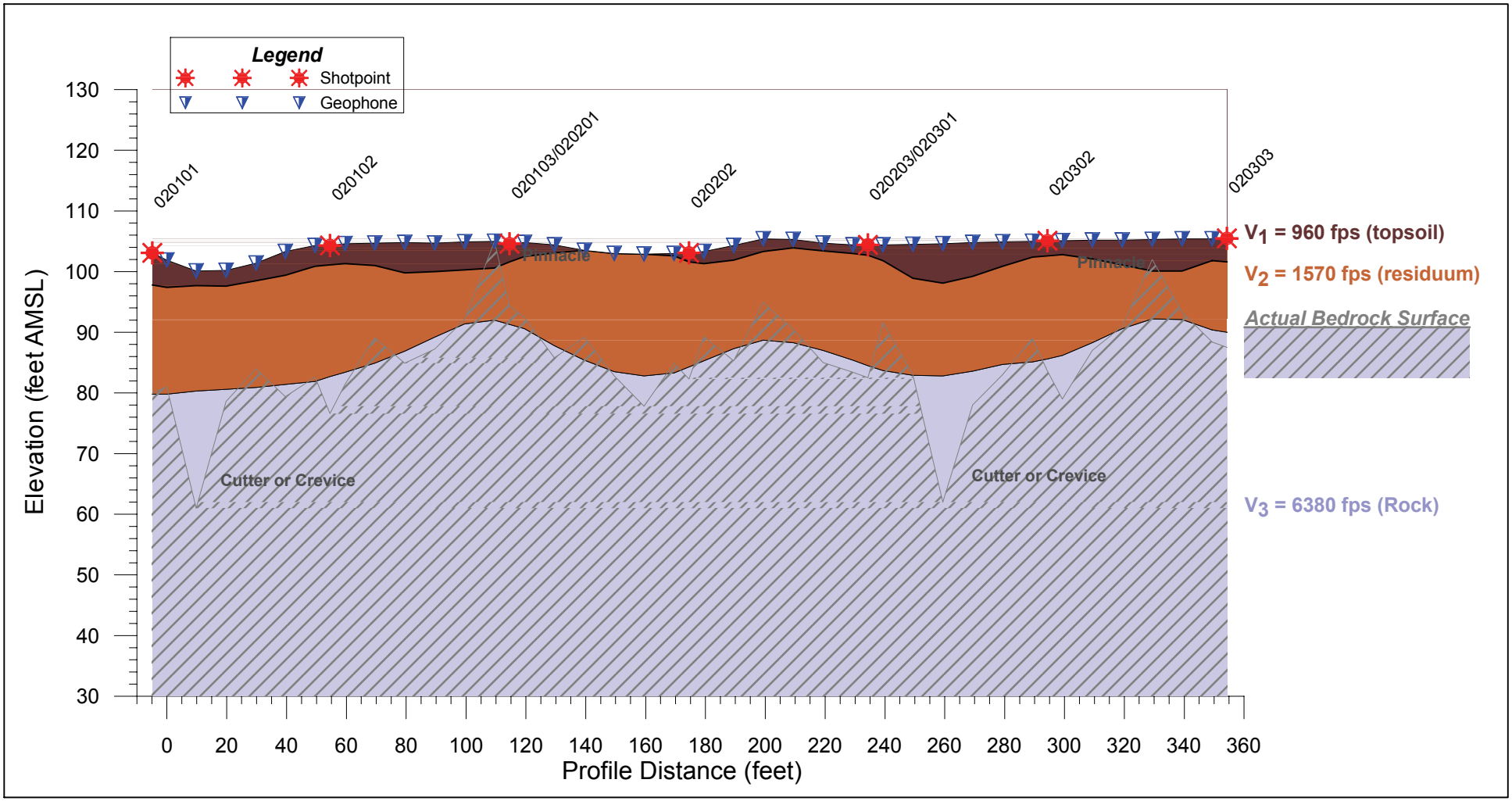


Figure SR-5 **Example Karst Terrane Seismic Profile** **Revised 01/2001**

ENVIROSCAN, INC.

Appendix B

Introduction to Electrical Imaging

Introduction to Electrical Imaging

by

Timothy D. Bechtel, Ph.D., P.G.

Energy

Electrical currents injected into the subsurface between electrodes pushed into the ground surface or non-intrusive, protected capacitors.

Sensitivity

Detects changes in electrical resistivity (the inverse of conductivity).

Basic Equipment

Either (traditional "steel spike electrode" method):

Steel spike electrodes (called current electrodes) connected by wires to a current source (to inject current), and steel spike electrodes (called voltage electrodes) connected to a microvolt meter (to measure the surficial distribution of electrical potentials). Note that current and voltage electrodes differ only by that to which they are connected (i.e. current source or microvolt meter, respectively.) Modern systems use arrays of electrodes (connected to multi-channel cables and an automated electrode-switching/recording system) to take measurements from electrodes at different locations and spacings (which adjusts the survey depth and resolution). Electrodes are hand-pushed into the ground surface along desired survey profiles.

Or (innovative "capacitively-coupled electrode" method):

Straight-wire capacitors which are capable of driving subsurface electrical currents and measuring surface potentials. The wire lengths and the distance between wires can be varied to adjust the survey depth and resolution. Capacitors are encased in torpedo-like protectors between the wire lengths, and the entire array (similar to a swimming rope with flotation buoys) is hand- or vehicle-towed along desired survey profiles.

Common Applications

Electrical imaging produces color-contour cross sections (commonly called electrical images) of subsurface electrical resistivity variations. These images can depict a target that has a different electrical resistivity from its surroundings, such as: buried wastes (pits, trenches, etc.); conductive groundwater plumes; resistive hydrocarbon plumes; foundation elements; water-bearing or mineralized faults or fractures; clay seams in bedrock; soil moisture anomalies; soil voids; clay layers bounded by sand or sand lenses bounded by clay; the top of competent (non-water-bearing) rock.

Principles

Electrical imaging can be performed by driving a harmless, very low amperage (e.g. 1 milliamp) DC electrical current in the ground between two steel spike electrodes. The depth to which the current flows is dictated by the separation of the two electrodes, and by the resistivity of subsurface materials. The flow of electrical current is mapped by measuring the electrical potential at various points of the ground surface using a very high impedance microvolt meter. Data suitable for determining a cross-sectional electrical image can be collected by taking many voltage readings with differing current electrode separations (i.e. different effective measurement depths) using different current electrode positions and voltage electrode positions (i.e. different locations along a profile). A two-dimensional image or cross-section is produced by employing electrodes in a linear array. Three-dimensional images (or color-contoured blocks of data) can be calculated using multiple linear arrays or grids of electrodes. The field-measured voltages, together with associated electrode positions, are mathematically inverted to provide the statistically best-fitting model of the subsurface resistivity distribution.

Electrical imaging can also be performed using straight-wire capacitors to drive currents and measure voltages. In this case, the length of the transmitter wire and the separation between the transmitter and receiver wires dictate the effective survey depth. Two- or three-dimensional data is collected by varying the lengths and separations of the transmitter and receiver capacitor wires for a given survey profile (i.e. the same profile is traversed several times using different wire lengths and separations).

Capabilities

Electrical imaging can detect and delineate a target that has a different electrical resistivity from its surroundings. Particularly good targets for electrical imaging include: electrically conductive clay seams, and water-bearing or mineralized faults or fractures in resistive bedrock; electrically resistive hydrocarbon plumes in moist electrically conductive soils; highly conductive electrolytic groundwater plumes (e.g. leachate or saltwater intrusion); highly conductive or resistive wastes buried in "normal" soils; soil moisture anomalies (e.g. dam seepage or incipient sinkholes).

Where site conditions allow, capacitively-coupled electrode systems can collect greater quantities of data in a given time (or at a given cost) than the traditional steel spike systems. The capacitive systems can also be used on asphalt pavement (where steel spike systems would require drilling many electrode holes).

Limitations

Electrical resistivities of differing materials have wide and overlapping ranges, making it impossible to positively identify a subsurface material based on its resistivity alone. For instance, profiling of the top-of-rock can be done by electrical imaging, but it is often difficult to specify exactly what resistivity contour corresponds with the top of rock (particularly where there is a weathering or saprolite zone). Since electrical resistivity (unlike seismic velocity) does not correlate with rippability or density, it is not typically the method of choice for rock profiling.

Based largely on a single well-publicized incident, electrical imaging has been promoted (by others) as a method for detecting bedrock cavities. However, since an air-filled cavity and competent rock are both electrical resistors, many cavities are not detectable using electrical methods (in this case, gravity would be the method of choice since air and competent rock have very different densities).

Electrical imaging data is susceptible to interference from underground utilities that capture and channel the subsurface current flow. This can be minimized in two-dimensional surveys by orienting the trace of an image perpendicular to any existing utilities.

Capacitively-coupled electrode systems suffer loss of signal penetration depth in highly conductive terranes. In addition, they are difficult to use in rugged or brushy terrain.

Survey depths using steel spike electrode systems can be limited by high contact resistances between the spikes and highly resistive surficial material.

References

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