FINAL REPORT

SEISMIC REFRACTION INVESTIGATION

Bell Bend Nuclear Power Plant
Luzerne County, Pennsylvania

Report 10171-03 Rev 0

August 31, 2010

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Luzerne County, Pennsylvania

GEO*Vision* Project No. 10171

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1 INTRODUCTION

A seismic refraction survey was conducted at the Bell Bend Nuclear Power Plant in Luzerne County, Pennsylvania from May 26th to June 5th, 2010. The purpose of the seismic refraction survey was to map depth to bedrock and to characterize bedrock velocity structure. The P-wave seismic refraction technique was the primary technique used during this investigation. However, the S-wave seismic refraction technique was also tested in the field for planning purposes in the event that the P-wave method was found to be ineffective.

Subsurface geologic conditions at the site consist of a thin layer of sediments overlying shale bedrock of the Mahatango Formation. The shale unit grades from decomposed shale near the surface, which is often undifferentiated from overlying sediments, to a weathered shale and then to a competent shale at depths of about 16 to over 100 feet.

Seismic refraction data were acquired along nine lines (A1 through A5 and B1 through B4). The locations of the seismic lines were established by Paul C. Rizzo Associates, Inc. (PCRA) and surveyed at nominal 200 ft intervals by Peters Consultants, Inc. The locations of the seismic lines and boreholes in the site vicinity are provided in Figure 1.

The following sections include a discussion of methodology, equipment and field procedures, data processing, interpretation and conclusions relating to the geophysical investigation.

2 METHODOLOGY

Detailed discussions of the seismic refraction method can be found in Telford et al. (1990), Dobrin and Savit (1988) and Redpath (1973).

When conducting a seismic survey, acoustic energy is input to the subsurface by an energy source such as a sledgehammer impacting a metallic plate, weight drop, vibratory source or explosive charge. The acoustic waves propagate into the subsurface at a velocity dependent upon the elastic properties of the material through which they travel. When the waves reach an interface where the density or velocity changes significantly, a portion of the energy is reflected back to the surface and the remainder is transmitted into the lower layer. Where the velocity of the lower layer is higher than that of the upper layer, a portion of the energy is also critically refracted along the interface. Critically refracted waves travel along the interface at the velocity of the lower layer and continually refract energy back to the surface. Receivers (geophones) laid out in linear array on the surface, record the incoming refracted and reflected waves. The seismic refraction method involves analysis of the travel times of the first energy to arrive at the geophones. These first arrivals are from either the direct wave (at geophones close to the source), or critically refracted waves (at geophones further from the source).

Analysis of seismic refraction data depends upon the complexity of the subsurface velocity structure. If the subsurface target is planar in nature then the slope intercept method (Telford et al., 1990) can be used to model multiple horizontal or dipping planar layers. A minimum of one end shot is required to model horizontal layers and reverse end shots are required to model dipping planar layers. If the subsurface target is undulating (i.e. bedrock valley) then layer based analysis routines such as the generalized reciprocal method (Palmer, 1980 and 1981; Lankston and Lankston, 1986 and Lankston, 1990), reciprocal method (Hawkins, 1961) also referred to as the ABC method, Hales' method (Hales, 1958), delay time method (Wyrobek, 1956 and Gardner, 1967), time-term inversion (Scheidegger and Willmore, 1959), plus-minus method (Hagedoorn, 1959) and wavefront method (Rockwell, 1967) are required to model subsurface velocity structure. These methods generally require a minimum of 5 shot points per spread (end shots, off end shots and a center shot). If subsurface velocity structure is complex and cannot be adequately modeled using layer-based modeling techniques (i.e. complex weathering profile in bedrock, numerous lateral velocity variations), then Monte Carlo or tomographic inversion techniques (Zhang and Toksoz, 1998; Schuster and Quintus-Bosz, 1993) are required to model the seismic refraction data. These techniques require a high shot density; typically every 2 to 6 stations/geophones. Generally, these techniques cannot effectively take advantage of off-end shots to extend depth of investigation, so longer profiles are required.

Errors in seismic refraction models can be caused by velocity inversions, hidden layers or lateral velocity variations. At sites with steeply dipping or highly irregular bedrock surfaces, out of plane refractions (refractions from structures to the side of the line rather than from beneath the line) may severely complicate modeling. A velocity inversion is a geologic layer with a lower seismic velocity than an overlying layer. Critical refraction does not occur along such a layer because velocity has to increase with depth for critical refraction to occur. This type of layer, therefore, cannot be recognized or modeled and depths to underlying layers would be overestimated. A hidden layer is a layer with a velocity increase, but of sufficiently small thickness relative to the velocities of overlying and underlying layers, that refracted arrivals do not arrive at the geophones before those from the deeper, higher velocity layer. Because the seismic refraction method generally only involves the interpretation of first arrivals, a hidden layer cannot be recognized or modeled and depths to underlying layers would be underestimated. Saturated sediments, overlying high velocity bedrock can be a hidden layer under many field conditions. However, saturated sediments generally have a much higher velocity than unsaturated sediments, typically in the 5,000 to 7,000 ft/s range, and can occasionally be interpreted as a second arrival when the layer does not give rise to a first arrival. A subsurface velocity structure that increases as a function of depth rather than as discrete layers will also cause depths to subsurface refractors to be underestimated, in a manner very similar to that of the hidden layer problem. Lateral velocity variations that are not adequately addressed in the seismic models will also lead to depth errors. Tomographic imaging techniques can often resolve the complex velocity structures associated with hidden layers, velocity gradients and lateral velocity variations. However, in the event of an abrupt increase in velocity at a geologic horizon, the velocity model generated using tomographic inversion routines will smooth the horizon with velocity being underestimated at the interface and possibly overestimated at depth.

3 EQUIPMENT AND FIELD PROCEDURES

The seismic data acquisition system consisted of two 24-channel Geometrics Geode signal enhancement seismographs combined to form a 48-channel system and a laptop computer running Geometrics Seismodule Controller Software (Geometrics Multiple Geode OS, Controller Version 9.14.0.0©). The seismograph calibration procedure and calibration records are included as Appendix A.

Other geophysical equipment for the P-wave refraction survey consisted of 10 Hz vertical geophones, refraction cable with 15 to 25-foot takeouts, a truck mounted accelerated weight drop (AWD), a downhole percussion firing rod (DPFR) with 500 grain loads, a 20 lb sledgehammer, an aluminum plate, Geometrics hammer switches and a trigger cable. Additional geophysical equipment for the S-wave refraction testing consisted of 10 Hz horizontal geophones and a 20 lb sledgehammer with a horizontal traction plank. Photographs of geophysical equipment used during this investigation are presented in Figure 2.

The seismic refraction survey was conducted in accordance with the seismic refraction procedure included as Appendix B. Each seismic line consisted of two or three spreads of 48 geophones, spaced 10 feet apart, aligned in a linear array. A minimum 130 ft overlap was used between adjacent spreads. Horizontal and vertical control for the seismic lines was established at the site by Peters Consultants, Inc. The location of the survey control established by Peters Consultants is presented in Table 1 and tied to the seismic line stationing. The locations of the seismic refraction lines are shown in Figure 1. The seismic line geometry is presented as Table 2. All geophone locations were measured using a 300-foot tape measure and 200 foot station marks were placed by Peters Consultants. Relative elevations along each seismic line were surveyed using a Sokkia C300 automatic level. Relative elevations were converted to true elevation using survey data provided by Peters Consultants. If leveled elevations did not match the surveyed station markers within 0.3 feet, then the section was leveled again with a closed loop. Using this method, several surveyed station marks were determined to not be within the 0.3 feet project tolerance. In these cases, the survey stakes were not used to determine relative and true elevations for the seismic lines.

Up to 24 shot point locations were occupied on each spread: off-end shots where possible, end shots and multiple interior shot points nominally located between every fourth geophone. Vegetation, topography and surface structure limited the placement and the source of some of the shot points.

The AWD was used in all shots accessible to a 4WD truck and the DPFR or the 20 lb sledgehammer was used for the remaining shots. The final seismic record at each shot point was the result of stacking 3 to 15 shots to increase the signal to noise ratio. The data were saved to an internal hard drive. Data files were named with the sequential line, spread and shot number and a ".dat" extension (i.e. data file 14115.dat is the seismic record from line A4, spread 1, shot 15). Seismic refraction field logs are included as Appendix C.

4 DATA PROCESSING

Seismic refraction data were modeled using the tomographic analysis technique available in the SeisImager™ Plotrefa software package, developed by Oyo Corporation. Refraction tomography techniques are often able to resolve complex velocity structure (e.g. velocity gradients) that can be observed in bedrock weathering profiles. Layer based modeling techniques such as the GRM are not able to accurately model the velocity gradients that can be observed in weathered bedrock. The GRM method was, however, used to confirm velocity ranges in the tomographic models.

Tomographic inversion techniques will model a smooth velocity gradient even if a sharp velocity boundary exists. For this site, velocity gradients are assumed to be present within weathered bedrock and, therefore, tomographic inversion routines are the most appropriate data modeling technique. However, borehole velocity logging indicates that there may be a relatively sharp contact between weathered and competent bedrock.

The first step in data processing consisted of picking the arrival time of the first energy received at each geophone (first arrival) for each shot point. The first arrivals on each seismic record are either a direct arrival from a compressional (P) wave traveling in the uppermost layer or a refracted arrival from a subsurface interface where there is a velocity increase. First-arrival times were selected using the automatic and manual picking routines in the software package SeisImager™ (Oyo Corporation). These first arrival times were saved in an ASCII file containing shot location, geophone locations and associated first arrival time. Errors in the first arrival times were variable with error generally increasing with distance from the shot point. First arrival picking errors probably averaged about 1 ms with error probably less than 0.5 ms at geophone locations near the shot point and up to 2 ms at distal geophone locations.

Data quality was affected by factors such as: weather, on site activity and geologic conditions. For certain lines, data acquisition was delayed for noise due to rain and continued when rain ceased or lessened to acceptable limits. Poor source coupling in soft soils in some areas may have increased noise at some shot locations. The AWD was used in all locations accessible by truck. Shot locations not accessible by truck ,utilized a lower energy 20 lb sledgehammer source or DPFR, which resulted in more noise on the seismic records.

Preliminary layer based analysis was conducted with the GRM computer program VIEWSEIS (Kassenaar, 1989-1992). First arrival and elevation data were entered into the software package and time-distance plots for the forward and reverse shots were generated. Forward shots are shot points where energy travels from geophone 1 to 48. Energy travels in the opposite direction for reverse shots and interior shots have both forward and reverse components. The first arrival data for all the shot points were then assigned to the layer from which they were refracted. Typically, three to four layers were assigned to the travel time data. The upper two layers corresponded to unsaturated sediment units and the lower two layers corresponded to weathered and competent rock, respectively. The travel time data refracted from the intermediate and high velocity layers were then phantomed (shifted in time) to line up with the travel-time data associated with the zero-offset end shot, therefore forming a single travel-time curve for each refractor along the line. This method was employed for both forward and reverse shots according to the procedures outlined in Lankston and Lankston (1986) and Redpath (1973). During this process it was noted that velocity gradients were present beneath many of the seismic lines with velocity in some units increasing as a function of depth. It was, therefore, determined that tomographic methods were most appropriate for modeling the seismic refraction data acquired during this investigation. The preliminary GRM models were, however, used to determine realistic velocity ranges for the various geologic units.

After loading the seismic refraction first arrival and elevation data into SeisImager, tomographic analysis was conducted as outlined in the following steps. An initial model was generated using parameters outlined by the processor. The initial model had 20 layers with the top of the bottom layer at a depth of about 150 ft. Velocity increased with depth from 1,750 ft/s at the surface to 14,000 at a depth of 65 to 150 ft. The velocity models were extended to permit the use of off end shot points during the inversion. A minimum of 20 to 30 iterations of non-linear raypath inversion were then implemented to improve the fits of the travel time curves to near-surface sediments/rock. Two modeling iterations were conducted: one with velocity constrained to increase with depth during the inversion process and the other with no velocity constraints. Final tomographic velocity models for each seismic line were exported as ASCII files and imported into the Geosoft Oasis montaj® v7 mapping system where the velocity models were gridded, contoured and annotated for presentation.

5 INTERPRETATION

5.1 Overview

5.1.1 Review of Geologic and Borehole Geophysical Data

Subsurface geologic conditions at the site consist of a thin layer of sediments overlying shale bedrock of the Mahatango Formation. The shale unit grades from decomposed shale near the surface, which is often undifferentiated from overlying sediments, to a weathered shale and then to a competent shale at depth.

Geologic logs from boreholes drilled in the vicinity of the seismic lines were provided by PCRA for review. GEO*Vision* previously completed borehole velocity logging of three boreholes (G-401, G-423 and G-426), reported separately (GEO*Vision*, 2010). Boreholes G-401, G-423 and G-426 were drilled specifically for the geophysical logging and are located adjacent to boreholes B-401, B-423 and B-426 as shown in Figure 1. Review of the geologic boring logs for B-401, B-423 and B-426 and geophysical velocity logs for G-401, G-423 and G-426 revealed a good relationship between P- and S-wave velocities and the rock quality designation (RQD) and fracture density (FD).

A comparison of P-wave velocity, RQD and FD for B-401/G-401 is presented as Figure 3. Competent shale is clearly evident in this figure at an elevation of about 658 ft (depth of 89.5 ft) where RQD abruptly increases to 92%, FD abruptly decreases to FD3 and P-wave velocity abruptly increases to over 12,000 ft/s. RQD and FD range from 75 to 100% and FD0 to FD3 in the competent rock to the bottom of the borehole at an elevation of 328 ft, respectively. P-wave velocity ranges from about 12,000 to 16,700 ft/s in the competent rock to the bottom of the borehole at an elevation of about 340 ft. There is a complex weathering profile in the shale above and elevation of 658 ft and very good correlation between RQD, FD and seismic velocity. Within the decomposed and weathered shale, P-wave velocity generally increases with depth from 3,400 ft/s at an elevation of 741 ft to 9,800 ft/s at an elevation of 701 ft, decreases with depth to 6,000 ft/s at an elevation 677 ft and then increases with depth to an elevation of 658 ft where significantly higher velocity competent shale is encountered. The P-wave velocity of the decomposed and weathered shale is below 10,000 ft/s. The seismic refraction method is typically unable to image velocity inversions and the presence of such structures will lead to overestimated depths of underlying refractors. However, if the velocity inversion is of limited lateral extent, high resolution seismic refraction imaging (i.e. high shot density and small geophone spacing) with the use of tomographic inversion routines may be able to detect the possible presence of the velocity inversions although the velocity structure may still not be accurately imaged.

A comparison of P-wave velocity, RQD and FD for B-423/G-423 is presented as Figure 4. Competent shale is clearly evident in this figure at an elevation of about 695 ft (depth of 29 ft) where RQD abruptly increases to 84%, FD abruptly decreases to FD5 and P-wave velocity abruptly increases to over 12,000 ft/s. With the exception of several zones typically less than 10 ft thick, RQD and FD range from 70 to 100% and FD0 to FD5 in the competent rock to the bottom of the borehole at an elevation of about 501 ft, respectively. P-wave velocity ranges from about 13,300 to 17,100 ft/s in the competent rock to the bottom of the borehole at an elevation of about 479 ft. There is significantly more variation in RQD and FD within the competent rock unit in B-423 than in B-401 and B-426. Additionally, there is not generally a good correlation between RQD, FD and P-wave velocity within the competent shale unit. The geophysical and geologic logging were conducted in adjacent, but different, boreholes and, depending upon the attitude of the bedding and fracturing, may have been sampling different materials at a constant elevation. At the location of B-423, there is only a thin weathering zone in the shale with P-wave velocity in the 5,300 to 6,100 ft/s range between a depth of 18 and 21 ft and then increasing with depth to 10,300 ft/s at a depth of 30 ft, immediately above the competent rock unit. The RQD of the weathered shale is less than 37% and the FD of the weathered shale is FD5, or greater.

A comparison of P-wave velocity, RQD and FD for B-426/G-426 is presented as Figure 5. Competent shale is clearly evident in this figure at an elevation of about 685 ft (depth of 60 ft) where RQD abruptly increases to 96%, FD abruptly decreases to FD1 and P-wave velocity abruptly increases to over 12,000 ft/s. RQD and FD typically range from 80 to 100% and FD0 to FD4, respectively, in the competent rock to the bottom of the borehole at an elevation of about 522 ft. P-wave velocity ranges from about 13,300 to 17,100 ft/s in the competent rock to the bottom of the borehole at elevation of about 504 ft. At the location of B-426, there is 60 ft thick weathering zone in the shale with P-wave velocity in the 2,800 to 8,800 ft/s range with velocity generally increasing with depth. The RQD of the weathered shale is less than 40 % and the FD of the weathered shale is FD5, or greater.

The geophysical logs for boreholes G-401, G-423 and G-426 and review of borehole geologic logs indicate that the depth to competent rock is quite variable across the site. The borehole velocity logs indicate that the shale has a complex and variable weathering profile and that there may often be a relatively abrupt contact between weathered and competent shale. The complex weathering profile in the shale dictated that tomographic inversion routines were more applicable than layer based modeling routines for seismic refraction modeling. Borehole logs in the vicinity of the seismic lines (Figure 1) were reviewed to obtain estimates of the depths/elevations of decomposed, weathered and competent shale for correlation with the seismic refraction models. Based on correlation of the borehole velocity logs with geologic logs and review of multiple additional borehole geologic logs, a decision was made to define the depth of competent rock as the depth at which RQD was greater than 80% or RDQ was greater than 70% for more than 5 ft and FD was less than or equal to FD5. Interpretation of borehole geologic data is summarized in Table 3. The interpreted top of decomposed and weathered shale is based on geologic descriptions in the borehole logs. An additional weathered shale unit is interpreted as the depth at which RQD > 0% and the competent shale is interpreted as discussed above. It should be noted that interpretation of some of the shale weathering horizons from the borehole logs is somewhat subjective. Interpretation of most of the borehole logs was straight forward with a clear distinction between weathered and competent shale. However, interpretation of some borehole logs (B-412, B-413, B-415, B-429, B430, B-431 and B-432) was more complicated with clear indications of highly weathered zones underlying thin zones of more competent rock. In these cases, the deeper competent rock unit was generally considered the top of competent rock and was the uppermost unit that satisfied the competent rock criteria discussed above. The most complex bedrock may be in the vicinity of boreholes B-431 and B-432, which lie on seismic line A-3. Competent shale in these boreholes was interpreted at depths of 99 and 105 ft, respectively. However, thin layers of possibly competent rock (RQD >70) were observed in the boreholes as shallow 34 and 45 ft, respectively indicating that velocity inversions are a distinct possibility between a depth of 35 and 100 ft in the vicinity of these boreholes.

5.1.2 Seismic Refraction Survey

Preliminary modeling of the seismic refraction data was also conducted using the layer based GRM method, but not finalized due to the difficulty modeling the weathered shale unit. The GRM modeling did, however, provide accurate constraints on the seismic velocity of the upper sediment units and the competent bedrock. The GRM models indicated the presence of a thin soil layer with P-wave velocity in the 1,500 ft/s range underlain by an undifferentiated layer of stiffer soil, residual soil and decomposed shale with P-wave velocity in the 3,000 ft/s range. This layer is underlain by decomposed shale and weathered shale units, which cannot accurately be characterized using layer based modeling techniques. The preliminary GRM models indicate that P-wave velocity of the competent bedrock is nominally in the 14,000 to 16,000 ft/s range, which is consistent with the borehole velocity logs.

The test S-wave seismic refraction lines were not long enough to reliably image the top of the competent shale unit and processing of these data was, therefore, not finalized.

Review of the borehole velocity logs and boring logs, as discussed above, revealed the presence of complex velocity structure and the possibility of velocity inversions in the weathered shale unit at the site. Therefore, the seismic refraction data were modeled using the tomographic inversion technique with and without a velocity constraint that forced an increase in velocity with depth in the seismic models. It should be noted, that although tomographic inversion techniques may have the ability of identifying areas with localized velocity inversions, they typically cannot accurately model the true velocity structure in such cases. If a velocity inversion occurs over a wide area (i.e. beneath the entire line) it is not detectible with the seismic refraction method.

Seismic models for Lines A1 to A5 with and without the velocity constraints are presented as Figures 6a/6b to 10a/10b, respectively. Seismic models for Lines B1 to B4 with and without the velocity constraints are presented as Figures 11a/11b to 14a/14b, respectively. A common color scheme is used on all images with cyan-green, green-yellow, and red-magenta color transitions occurring at velocities of about 4,000, 6,000 and 12,000 ft/s, respectively. With the exception of line A3, the alternate velocity models are very similar at velocity contours above 11,000 ft/s.

The approximate locations of the top of the decomposed, weathered and competent shale identified in boreholes within 50 ft of the seismic lines is included on the seismic models to aid with interpretation. Two possible weathered shale units are identified; one based on geologic description (WS1) and the other based on the depth at which RQD exceeds 0% (WS2), as shown on Table 3. The locations of the 4,000, 6,000 and 12,000 ft/s contours from intersecting lines are also shown on the seismic models for discussion. There is a distinct possibility at this site that velocity structure may be slightly different at intersecting lines because of the complex velocity structure of the weathered shale. Additionally, bedding and fracture attitudes relative to the seismic line orientation may have a significant impact on modeled seismic velocity structure. For example, a seismic line parallel to the strike of dipping layers could be strongly influenced by a high velocity dipping layer adjacent to the line. Alternatively, seismic lines perpendicular to strike will characterize the average velocity structure of all the geologic layers.

Interpreted top of decomposed, weathered and competent shale contacts are shown on the seismic models for discussion. Interpretation of the top of decomposed and weathered shale units involved identification of a smooth surface that reasonably satisfied borehole observations, tracked a small range of velocity contours and was consistent with intersecting lines. Because of the highly variable weathering profile across the site it was not necessary to tract the same velocity range from line to line. The decomposed shale contact was generally interpreted within the 3,500 to 4,500 ft/s velocity range. Identification of the top of decomposed shale was highly subjective because the unit was not clearly identified in all boreholes and often had similar properties to overlying residual soils. The top of the weathered shale contact was generally identified in the 5,000 to 6,000 ft/s velocity range and typically fell somewhere between the WS1 and WS2 weathered shale units identified in boreholes.

Interpretation of the top of competent rock was complicated by the highly variable weathering profile in the weathered shale unit across the site, which would result in the competent shale unit not necessarily tracking a constant velocity contour across the site. The maximum P-wave velocity observed for weathered shale in the limited velocity logging is in the 9,000 to 10,000 ft/s range and competent shale is expected to typically have P-wave velocity in the 14,000 to 16,000 range; therefore, the competent bedrock contact on the seismic models is expected to be in the intermediate 11,000 to 13,000 ft/s range. The interpretation of the approximate top of competent rock involved identification of a relatively smooth surface that reflected the overall velocity structure in the seismic model; was within 5 ft of the competent rock identified in the borehole(s); located between the 12,000 ft/s velocity contours at the intersections of the seismic lines; tracked general trends of seismic velocity contours between line intersections and boreholes; consistent with intersecting lines and generally within the expected 11,000 to 13,000 ft/s velocity range on both models.

5.2 Seismic Refraction Line A1

The seismic refraction models for Line A1 with and without the increase in velocity with depth constraint are presented as Figures 6a and 6b, respectively.

Seismic line A1 intersects Lines B1, B2, B3 and B4 at positions of 138.7, 307.4, 465.3 and 609.9 ft on Line A1, respectively. Three boreholes (B-409, B-410 and B-411) are located within 28 ft of the seismic line at positions of 199.4, 307.1 and 436.6 ft, respectively, as shown on Figure 1 and the seismic models (Figures 6a and 6b).

The 4,000, 6,000 and 12,000 ft/s velocity contours from intersecting seismic lines; location of decomposed, weathered and competent shale units interpreted from the geologic logs of boreholes located on or near the seismic line (Table 3); and the interpreted top of the three shale units are shown on the figures for discussion.

The seismic models for line A1 with (Figure 6a) and without (Figure 6b) the increase in depth velocity constraint are very similar at velocity contours above 11,000 ft/s. At the intersection of this seismic line with lines B1 to B4, the elevations of the 4,000 and 6,000 ft/s contours on the respective models are within about 5 ft. There is about a 20 to 33 ft elevation difference in the 12,000 ft/s velocity contour at the intersection of line A1 and lines B1 to B4, with Figure 6b having slightly better agreement at the line intersections. The 12,000 ft/s velocity contour on intersecting lines B1 to B4 typically corresponds to velocities in the 11,000 to 14,000 ft/s range on line A1, which are generally within the expected velocity range for the competent shale contact. Figure 6b indicates that velocity structure near the 12,000 ft/s contour and in the vicinity of the line intersections may be somewhat complex, which would explain the differences at the line intersections.

At the location of the three boreholes (B-409, B-410 and B-411) near the seismic line, the top of decomposed shale and upper weathered shale are located in the 3,500 to 4,000 and 4,500 to 5,500 ft/s velocity ranges, respectively. The interpreted competent rock contact in the boreholes is located between the 10,750 and 11,750 ft/s velocity contours on both Figures 6a and 6b.

The top of decomposed and weathered shale is interpreted along the top of the 4,000 and 6,000 ft/s contours, which are almost equivalent on the alternate models presented as Figures 6a and 6b. The interpreted top of competent rock, as shown on Figures 6a and 6b, generally tracks velocity contours in the 11,500 to 13,500 ft/s range while satisfying the criteria discussed in Section 5.1.2. Lateral variability of the weathering within the weathered shale unit is expected to cause slight variation in the velocity associated with competent shale along the seismic line. There is about a 50 ft variation in the elevation of the interpreted competent rock unit beneath line A1 with competent rock occurring at the lowest elevations between about 300 and 400 ft.

5.3 Seismic Refraction Line A2

The seismic refraction models for Line A2 with and without the increase in velocity with depth constraint are presented as Figures 7a and 7b, respectively.

Seismic line A2 intersects Lines B1, B2, B3 and B4 at positions of 138.5, 307.4, 464.5 and 609.9 ft, respectively. Six boreholes (B-416, B-417, B-418, B-419, B-424 and B-425) are located within 45 ft of the seismic line at positions of 138.5, 242.1, 354.7, 429.7, 610.1 and 671.2 ft, respectively, as shown on Figure 1 and the seismic models (Figures 7a and 7b).

The 4,000, 6,000 and 12,000 ft/s velocity contours from intersecting seismic lines; location of decomposed, weathered and competent shale units interpreted from the geologic logs of boreholes located on or near the seismic line (Table 3); and the interpreted top of the three shale units are shown on the figures for discussion.

The seismic models for line A2 with (Figure 7a) and without (Figure 7b) the increase in depth velocity constraint are very similar. At the intersection of this seismic line with lines B1 to B4, the elevations of the 4,000 and 6,000 ft/s contours on the respective models are within about 5 ft. There is about a 1 to 22 ft elevation difference in the 12,000 ft/s velocity contour at the intersection of line A2 with lines B1 to B4. The 12,000 ft/s velocity contour on intersecting lines B1 to B4 typically corresponds to velocities in the 12,000 to 13,750 ft/s range on line A2, which are generally within the expected velocity range for the competent shale contact. There is no significant difference in the velocity structure presented as Figures 7a and 7b, respectively.

At the location of the six boreholes (B-416, B-417, B-418, B-419, B-424 and B-425) near the seismic line, the top of decomposed shale and upper weathered shale are located in the 4,000 to 5,000 and 5,000 to 6,500 ft/s velocity ranges, respectively. The interpreted competent rock contact in the boreholes is located between the 10,750 and 13,750 ft/s velocity contours on both Figures 7a and 7b.

The top of decomposed and weathered shale is interpreted in the 4,000 to 4,500 and 6,000 to 6,500 ft/s velocity ranges, respectively. The alternate models presented as Figures 7a and 7b are almost identical over these velocity ranges. The interpreted top of competent rock, as shown on Figures 7a and 7b, satisfies the criteria discussed in Section 5.1.2 and tracks velocity contours in the 11,500 to 12,000 ft/s range west of 450 ft and deepens to the 13,500 to 14,000 velocity range east of 500 ft. Both alternate velocity models show a deepening of competent rock east of 450 ft and the change in seismic velocity associated with competent rock indicates a change in the weathering characteristics of the upper shale units between the two sides of the seismic line. There is about a 35 ft variation in the elevation of the interpreted competent rock unit beneath line A2 with competent rock occurring at the lowest elevations between about 550 and 750 ft, an area well characterized by two boreholes (B-424 and B-425).

5.4 Seismic Refraction Line A3

The seismic refraction models for Line A3 with and without the increase in velocity with depth constraint are presented as Figures 8a and 8b, respectively.

Seismic line A3 intersects Lines B1, B2, B3 and B4 at positions of 138.9, 307.5, 466.1 and 610.0 ft, respectively. Six boreholes (B-403, B-401, B-405, B-430, B-431 and B-432) are located within 1 ft of the seismic line at positions of 217.8, 308.1, 398.5, 567.7, 698.0 and 844.7 ft, respectively, as shown on Figure 1 and the seismic models (Figures 8a and 8b).

The 4,000, 6,000 and 12,000 ft/s velocity contours from intersecting seismic lines; location of decomposed, weathered and competent shale units interpreted from the geologic logs of boreholes located on or near the seismic line (Table 3); and the interpreted top of the three shale units are shown on the figures for discussion.

The seismic models for line A3 with (Figure 8a) and without (Figure 8b) the increase in depth velocity constraint are very similar at velocity contours above 9,000 ft/s, but significantly different below. At the intersection of this seismic line with lines B1 to B4, the elevations of the 4,000 and 6,000 ft/s contours on the respective models are within about 1 and 5 and 1 and 10 ft, respectively. There is about a 9 to 16 ft elevation difference in the 12,000 ft/s velocity contour at the intersection of line A3 and lines B1 to B4, with Figure 8b having slightly better agreement at the line intersections. The 12,000 ft/s velocity contour on intersecting lines B1 to B4 typically corresponds to velocities in the 11,000 to 15,000 ft/s range on line A3, which are generally within the expected velocity range for the competent shale contact. Figure 8b indicates that velocity structure below the 9,000 ft/s contour may be somewhat complex, which would explain the differences at the line intersections.

At the location of the six boreholes (B-403, B-401, B-405, B-430, B-431 and B-432) near the seismic line, the top of decomposed shale and upper weathered shale are located in the 3,000 to 3,500 and 4,500 to 7,000 ft/s velocity ranges, respectively. The interpreted competent rock contact in the boreholes is located between the 11,000 and 12,250 ft/s velocity contours on both Figures 8a and 8b.

The top of decomposed and weathered shale is interpreted in the 4,000 to 5,000 and 6,000 to 7,000 ft/s velocity ranges, respectively. The alternate models presented as Figures 8a and 8b are almost identical over these velocity ranges. The interpreted top of competent rock, as shown on Figures 8a and 8b, satisfies the criteria discussed in Section 5.1.2 and generally tracks velocity contours in the 11,000 to 13,000 ft/s range. The velocity model for line A3 generated using no velocity constraints (Figure 8b) indicates that localized velocity inversions may be present in the 250 to 400 and 600 to 800 ft ranges beneath the seismic line. The possibility of such velocity structure is supported by borehole and geophysical logs in B-401 and G-401, respectively and borehole logs for B-430, B-431 and B-432. The potential for such velocity structure on this seismic line, prompted generation of alternate velocity models (increase in velocity with depth and no velocity constraints) for all seismic lines that generally turned out to be redundant with the exception of line A3 and to a lesser degree, line A1. Although tomographic inversion routines can often detect localized velocity inversions, it is generally not possible to accurately image the velocity structure. Velocity inversions that are continuous beneath the entire seismic line cannot be detected by the seismic refraction method. There is about a 65 ft variation in the elevation of the interpreted competent rock unit beneath line A3 with competent rock occurring at the lowest elevations between about 250 and 500 ft.

5.5 Seismic Refraction Line A4

The seismic refraction models for Line A4 with and without the increase in velocity with depth constraint are presented as Figures 9a and 9b, respectively.

Seismic line A4 intersects Lines B1, B2, B3 and B4 at positions of 139.1, 307.5, 467.9 and 610.0 ft, respectively. Three boreholes (B-428, B-429 and B-433) are located within 5 ft of the seismic line at positions of 85.7, 147.5 and 589.8 ft, respectively, as shown on Figure 1 and the seismic models (Figures 9a and 9b).

The 4,000, 6,000 and 12,000 ft/s velocity contours from intersecting seismic lines; location of decomposed, weathered and competent shale units interpreted from the geologic logs of boreholes located on or near the seismic line (Table 3); and the interpreted top of the three shale units are shown on the figures for discussion.

The seismic models for line A4 with (Figure 9a) and without (Figure 9b) the increase in depth velocity constraint are very similar. At the intersection of this seismic line with lines B1 to B4, the elevations of the 4,000, 6,000 ft/s and 12,000 contours on the respective models are within about 5 ft. The 12,000 ft/s velocity contour on intersecting lines B1 to B4 typically corresponds to velocities in the 11,000 to 12,000 ft/s range on line A4, which are within the expected velocity range for the competent shale contact. There is no significant difference in the velocity structure presented as Figures 7a and 7b, respectively.

At the location of the three boreholes (B-428, B-429 and B-433) near the seismic line, the top of decomposed shale and upper weathered shale are located in the 3,500 to 4,000 and 6,000 to 6,500 ft/s velocity ranges, respectively. The interpreted competent rock contact in the boreholes is located between the 11,250 and 12,250 ft/s velocity contours on both Figures 9a and 9b.

The top of decomposed and weathered shale is interpreted as closely tracking the 4,000 and 6,000 ft/s velocity contours, respectively. The interpreted top of competent rock, as shown on Figures 9a and 9b, satisfies the criteria discussed in Section 5.1.2 and tracks velocity contours in the 11,500 to 12,000 ft/s range over the entire line. There is excellent correlation between the line A4 seismic model, intersecting seismic models and borehole geologic interpretation indicating that the weathering profile in the shale is relatively uniform along the line. There is about a 30 ft variation in the elevation of the interpreted competent rock unit beneath line A4 with competent rock occurring at the lowest elevations at each end of the seismic line.

5.6 Seismic Refraction Line A5

The seismic refraction models for Line A5 with and without the increase in velocity with depth constraint are presented as Figures 10a and 10b, respectively.

Seismic line A5 intersects Lines B1, B2, B3 and B4 at positions of 78.2, 246.8, 406.3 and 549.3 ft, respectively. Three boreholes (B-426, B-427 and B-406) are located within 29 ft of the seismic line at positions of 25.8, 88.3 and 246.8 ft, respectively, as shown on Figure 1 and the seismic models (Figures 10a and 10b).

The 4,000, 6,000 and 12,000 ft/s velocity contours from intersecting seismic lines; location of decomposed, weathered and competent shale units interpreted from the geologic logs of boreholes located on or near the seismic line (Table 3); and the interpreted top of the three shale units are shown on the figures for discussion.

The seismic models for line A5 with (Figure 10a) and without (Figure 10b) the increase in depth velocity constraint are very similar. At the intersection of this seismic line with lines B1 to B4, the elevations of the 4,000, 6,000 ft/s and 12,000 contours on the respective models are within about 5 ft. The 12,000 ft/s velocity contour on intersecting lines B1 to B4 typically corresponds to velocities in the 11,500 to 12,500 ft/s range on line A5, which are within the expected velocity range for the competent shale contact. There is no significant difference in the velocity structure presented as Figures 10a and 10b, respectively.

At the location of the three boreholes (B-426, B-427 and B-406) near the seismic line, the top of decomposed shale and upper weathered shale are located in the 2,000 to 3,000 and 3,500 to 4,500 ft/s velocity ranges, respectively. The interpreted competent rock contact in the boreholes is located between the 11,250 and 12,250 ft/s velocity contours on both Figures 10a and 10b.

The top of decomposed and weathered shale is interpreted in the 3,500 to 4,000 and 5,000 to 6,000 ft/s velocity ranges, respectively. The interpreted top of competent rock, as shown on Figures 10a and 10b, satisfies the criteria discussed in Section 5.1.2 and tracks velocity contours in the 11,750 to 12,000 ft/s range over the entire line. There is excellent correlation between the line A5 seismic model, intersecting seismic models and borehole geologic interpretation indicating that the weathering profile in the shale is relatively uniform along the line. There is about a 40 ft variation in the elevation of the interpreted competent rock unit beneath line A5 with competent rock occurring at the lowest elevations west of 500 ft.

5.7 Seismic Refraction Line B1

The seismic refraction models for Line B1 with and without the increase in velocity with depth constraint are presented as Figures 11a and 11b, respectively.

Seismic line B1 intersects Lines A2, A1, A3, A5 and A4 at positions of 210.1, 348.1, 486.2, 679.7 and 828.7 ft, respectively. Six boreholes (B-416, B-414, B-408, B-407, B-427 and B-429) are located within 15 ft of the seismic line at positions of 165.8, 265.2, 422.0, 546.7, 679.8 and 828.5 ft, respectively, as shown on Figure 1 and the seismic models (Figures 11a and 11b).

The 4,000, 6,000 and 12,000 ft/s velocity contours from intersecting seismic lines; location of decomposed, weathered and competent shale units interpreted from the geologic logs of boreholes located on or near the seismic line (Table 3); and the interpreted top of the three shale units are shown on the figures for discussion.

The seismic models for line B1 with (Figure 11a) and without (Figure 11b) the increase in depth velocity constraint are very similar at velocity contours above 12,000 ft/s. At the intersection of this seismic line with lines A1 to A5, the elevations of the 4,000 and 6,000 ft/s contours on the respective models are within about 5 ft. There is about a 1 to 24 ft elevation difference in the 12,000 ft/s velocity contour at the intersection of line B1 and lines A1 to A5, with Figure 11b having slightly better agreement at the line intersections. The 12,000 ft/s velocity contour on intersecting lines A1 to A5 typically corresponds to velocities in the 10,750 to 12,000 ft/s range on line B1, which are generally within the expected velocity range for the competent shale contact.

At the location of the six boreholes (B-416, B-414, B-408, B-407, B-427 and B-429) near the seismic line, the top of decomposed shale and upper weathered shale are located in the 2,250 to 4,250 and 3,500 to 6,000 ft/s velocity ranges, respectively. The interpreted competent rock contact in the boreholes is located between the 10,000 and 12,500 ft/s velocity contours on both Figures 11a and 11b.

The top of decomposed and weathered shale is interpreted in the 3,500 to 4,000 and 5,000 to 6,000 ft/s velocity ranges, respectively. The interpreted top of competent rock, as shown on Figures 11a and 11b, satisfies the criteria discussed in Section 5.1.2 and tracks velocity contours in the 11,500 to 12,500 ft/s range over the entire line. There is excellent correlation between the line B1 seismic model, intersecting seismic models and borehole geologic interpretation south of 300 ft and north of 650 ft indicating that the weathering profile in the shale is relatively uniform along these segments of the line. Correlation of the seismic models with intersecting lines and borehole geologic data is more difficult in the central portion of the line indicating a more complex weathering profile in the uppermost shale units in this area. There is about a 70 ft variation in the elevation of the interpreted competent rock unit beneath line B1 with competent rock occurring at the lowest elevations between 350 and 600 ft.

5.8 Seismic Refraction Line B2

The seismic refraction models for Line B2 with and without the increase in velocity with depth constraint are presented as Figures 12a and 12b, respectively.

Seismic line B2 intersects Lines A2, A1, A3, A5 and A4 at positions of 210.2, 348.1, 486.3, 679.8 and 828.8 ft, respectively. Seven boreholes (B-418, B-410, B-404, B-401, B-402, B-406 and B-420) are located within 48 ft of the seismic line at positions of 210.8, 320.1, 394.5, 486.4, 578.2, 650.7 and 763.1 ft, respectively, as shown on Figure 1 and the seismic models (Figures 12a and 12b).

The 4,000, 6,000 and 12,000 ft/s velocity contours from intersecting seismic lines; location of decomposed, weathered and competent shale units interpreted from the geologic logs of boreholes located on or near the seismic line (Table 3); and the interpreted top of the three shale units are shown on the figures for discussion.

The seismic models for line B2 with (Figure 12a) and without (Figure 12b) the increase in depth velocity constraint are very similar. At the intersection of this seismic line with lines A1 to A5, the elevations of the 4,000 and 6,000 ft/s contours on the respective models are within about 5 ft. There is about a 2 to 15 ft elevation difference in the 12,000 ft/s velocity contour at the intersection of line B2 and lines A1 to A5. The 12,000 ft/s velocity contour on intersecting lines A1 to A5 typically corresponds to velocities in the 12,000 to 14,000 ft/s range on line B2, which are generally within the expected velocity range for the competent shale contact.

At the location of the seven boreholes (B-418, B-410, B-404, B-401, B-402, B-406 and B-420) near the seismic line, the top of decomposed shale and upper weathered shale are located in the 2,000 to 4,000 and 3,500 to 5,500 ft/s velocity ranges, respectively. The interpreted competent rock contact in the boreholes is located between the 9,000 and 13,500 ft/s velocity contours on both Figures 12a and 12b.

The top of decomposed and weathered shale is interpreted in the 3,500 to 4,000 and 5,000 to 6,000 ft/s velocity ranges, respectively. The interpreted top of competent rock, as shown on Figures 12a and 12b, satisfies the criteria discussed in Section 5.1.2 and generally tracks velocity contours in the 11,500 to 13,000 ft/s range over the entire line. There is generally good correlation between the line B2 seismic model, intersecting seismic models and borehole geologic interpretation along this seismic line indicating that the weathering profile in the shale may be relatively uniform. There is about a 90 ft variation in the elevation of the interpreted competent rock unit beneath line B2 with competent rock occurring at the lowest elevations between 300 and 550 ft.

5.9 Seismic Refraction Line B3

The seismic refraction models for Line B3 with and without the increase in velocity with depth constraint are presented as Figures 13a and 13b, respectively.

Seismic line B3 intersects Lines A2, A1, A3, A5 and A4 at positions of 210.3, 348.2, 486.4, 679.9 and 828.9, respectively. Five boreholes (B-419, B-411, B-412, B-413 and B-421) are located within 36 ft of the seismic line at positions of 210.8, 329.7, 416.5, 556.7 and 763.0 ft, respectively, as shown on Figure 1 and the seismic models (Figures 13a and 13b).

The 4,000, 6,000 and 12,000 ft/s velocity contours from intersecting seismic lines; location of decomposed, weathered and competent shale units interpreted from the geologic logs of boreholes located on or near the seismic line (Table 3); and the interpreted top of the three shale units are shown on the figures for discussion.

The seismic models for line B3 with (Figure 13a) and without (Figure 13b) the increase in depth velocity constraint are very similar. At the intersection of this seismic line with lines A1 to A5, the elevations of the 4,000 and 6,000 ft/s contours on the respective models are within about 5 ft. There is about a 2 to 20 ft elevation difference in the 12,000 ft/s velocity contour at the intersection of line B3 and lines A1 to A5. The 12,000 ft/s velocity contour on intersecting lines A1 to A5 typically corresponds to velocities in the 10,500 to 14,000 ft/s range on line B3, which are generally within the expected velocity range for the competent shale contact.

At the location of the five boreholes (B-419, B-411, B-412, B-413 and B-421) near the seismic line, the top of decomposed shale and upper weathered shale are located in the 3,000 to 4,250 and 4,000 to 5,500 ft/s velocity ranges, respectively. The interpreted competent rock contact in the boreholes is located between the 11,250 and 12,500 ft/s velocity contours on both Figures 13a and 13b.

The top of decomposed and weathered shale is interpreted in the 3,500 to 4,000 and 5,000 to 6,000 ft/s velocity ranges, respectively. The interpreted top of competent rock, as shown on Figures 13a and 13b, satisfies the criteria discussed in Section 5.1.2 and tracks velocity contours in the 11,500 to 12,250 ft/s range over the entire line. There is generally good correlation, particularly at the southern and northern ends of the line, between the line B3 seismic model, intersecting seismic models and borehole geologic interpretation indicating that the weathering profile in the shale may be relatively uniform. There is about a 90 ft variation in the elevation of the interpreted competent rock unit beneath line B3 with competent rock occurring at the lowest elevations between 300 and 600 ft.

5.10 Seismic Refraction Line B4

The seismic refraction models for Line B4 with and without the increase in velocity with depth constraint are presented as Figures 14a and 14b, respectively.

Seismic line B4 intersects Lines A2, A1, A3, A5 and A4 at positions of 210.4, 348.2, 486.5, 680.0 and 829.0 ft, respectively. Four boreholes (B-422, B-424, B-430 and B-433) are located within 43 ft of the seismic line at positions of 54.5, 202.8, 485.9 and 824.1 ft, respectively, as shown on Figure 1 and the seismic models (Figures 14a and 14b).

The 4,000, 6,000 and 12,000 ft/s velocity contours from intersecting seismic lines; location of decomposed, weathered and competent shale units interpreted from the geologic logs of boreholes located on or near the seismic line (Table 3); and the interpreted top of the three shale units are shown on the figures for discussion.

The seismic models for line B4 with (Figure 14a) and without (Figure 14b) the increase in depth velocity constraint are very similar at velocity contours above 12,000 ft/s. At the intersection of this seismic line with lines A1 to A5, the elevations of the 4,000 and 6,000 ft/s contours on the respective models are within about 3 to 8 and 3 to 10 ft, respectively. There is about a 0 to 27 ft elevation difference in the 12,000 ft/s velocity contour at the intersection of line B4 and lines A1 to A5, with Figure 14b having slightly better agreement at the line intersections. The 12,000 ft/s velocity contour on intersecting lines A1 to A5 typically corresponds to velocities in the 11,000 to 13,000 ft/s range on line B4, which are generally within the expected velocity range for the competent shale contact.

At the location of the four boreholes (B-422, B-424, B-430 and B-433) near the seismic line, the top of decomposed shale and upper weathered shale are located in the 3,500 to 5,000 and 4,000 to 5,500 ft/s velocity ranges, respectively. The interpreted competent rock contact in the boreholes is located at a velocity of 6,500 ft/s near B-422, a much lower velocity than expected for competent rock, and between 12,000 and 13,000 ft/s near the remaining boreholes on both Figures 14a and 14b. Competent shale in borehole B-423, located about 50 ft from the seismic line and near borehole B-422, is about 13 ft deeper than in B-422 and correlates to a velocity of about 10,000 ft/s. The seismic model may overestimate depth to competent rock in the vicinity of borehole B-422 because of the absence of weathered shale. Alternatively, the shallow competent rock encountered in B-422 may not have sufficient spatial extent to be imaged by the seismic refraction survey. It should be noted that borehole B-422 is the only borehole in the vicinity of the seismic lines, in which competent shale was encountered immediately beneath only several feet of decomposed shale.

The top of decomposed and weathered shale is interpreted in the 3,500 to 4,000 and 5,000 to 6,000 ft/s velocity ranges, respectively. The interpreted top of competent rock, as shown on Figures 11a and 11b, satisfies the criteria discussed in Section 5.1.2 and tracks velocity contours in the 11,500 to 12,500 ft/s range over the entire line. There is excellent correlation between the line B4 seismic model, intersecting seismic models and borehole geologic interpretation north of 600 ft indicating that the weathering profile in the shale is relatively uniform along this segment of the line. Correlation of the seismic models with intersecting lines and borehole geologic data is more difficult in southern and central portions of the line indicating a more complex weathering profile in the uppermost shale units in this area. There is about a 90 ft variation in the elevation of the interpreted competent rock unit beneath line B1 with competent rock occurring at the lowest elevations between 200 and 600 ft.

5.11 Contour Maps of Seismic Horizons

Elevation contour maps of the interpreted top of decomposed, weathered and competent shale are included as Figures 15 to 17, respectively. These contour maps were generated using the horizons presented on the seismic models. The elevation contour map of the top of competent shale (Figure 17) was generated using both the seismic models (Figures 6 to 14) and borehole data presented in Table 3.

The interpreted elevations of the top of decomposed and weathered shale (Figures 15 and 16) generally parallel surface topography at the site. The interpreted elevation of the competent shale (Figure 17) is highest in the northern portion of the site, and forms an east-west to southeast-northwest trending depression in the central portion of the site with elevation increasing again to the south. The accuracy of the interpreted competent shale contour map may be as good as 5 ft in the vicinity in the southern and northern portions of the site where the competent shale is shallower and 10 ft in the central portion of the site where the shale is deeper and the weathering profile more complex.

6 CONCLUSIONS

A seismic refraction survey was conducted in Luzerne County, Pennsylvania at the Bell Bend Nuclear Power Plant. The purpose of the survey was to map bedrock depth and velocity structure beneath nine (9) P-wave seismic refraction lines at locations selected by PCRA. The locations of the seismic lines, designated A1 to A5 and B1 to B4 and nearby boreholes are presented in Figure 1.

Subsurface geologic conditions at the site consist of a thin layer of sediments overlying shale bedrock of the Mahatango Formation. The shale unit grades from a decomposed shale near the surface to a weathered shale and then to a competent shale at depth.

Review of borehole geologic logs and three PS suspension velocity logs (Figures 3 to 5) indicated that there was a possibility of localized velocity inversions in the weathered rock. The maximum P-wave velocity observed in the velocity logs for weathered shale is about 10,000 ft/s and P-wave velocity nominally varies from about 14,000 to 16,000 ft/s in competent shale. Although the seismic refraction method cannot image velocity inversions that are continuous, it is often possible to identify localized velocity inversions using tomographic inversion techniques. Therefore, two models were generated for each seismic line, one where velocity was constrained to increase with depth and the other without velocity constraints. Seismic models for Lines A1 to A5 with and without the velocity constraints are presented as Figures 6a/6b to 10a/10b, respectively. Seismic models for Lines B1 to B4 with and without the velocity constraints are presented as Figures 11a/11b to 14a/14b, respectively. The alternate velocity models for each seismic line are very similar, with the exception of Line A3, which imaged possible velocity inversions, and to a lesser degree Line A1. It should be noted that the seismic lines intersecting lines A1 and A3 (B1 to B4) were unable to detect the velocity inversion indicating that it may be of very limited spatial extent in the south to north direction.

Geologic contacts identified in borehole geologic logs and the location of the 4,000, 6,000 and 12,000 ft/s velocity contours are shown on the seismic models to facilitate interpretation. Interpreted geologic contacts in boreholes near the seismic lines are summarized in Table 3. Interpretations were made of the approximate tops of decomposed, weathered and competent shale. The top of decomposed shale was typically interpreted in the 3,500 to 4,500 ft/s velocity range. The seismic velocity of this unit is often similar to that of overlying sediments. The top of weathered shale was typically interpreted in the 5,000 to 6,000 ft/s velocity range. The top of the competent shale was typically interpreted in the 11,000 to 13,500 ft/s velocity range. In many areas with shallower competent shale and probable uniform weathering of the uppermost shale units, the competent shale unit was interpreted in the 11,500 to 12,500 ft/s range and is expected to be quite accurate. In areas, with a significantly thicker weathered shale unit, interpretation was complicated by probable lateral variability of the weathering profile in the uppermost shale unit. Potential velocity inversions, supported by geologic data and geophysical logs, were also identified in the vicinity of Lines A1 and A3, further complicating interpretation. The elevation of the competent shale unit was found to vary by as much as 90 ft across the survey area.

Contour maps of the interpreted top of decomposed, weathered and competent shale units are presented as Figures 15 to 17, respectively. The interpreted elevations of the top of decomposed and weathered shale (Figures 15 and 16) generally parallel surface topography at the site. The top of competent shale forms an east-west to southeast-northwest trending depression in the central portion of the site with elevation increasing to the north and south.

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8 CERTIFICATION

All geophysical data, analysis, interpretations, conclusions, and recommendations in this document have been prepared under the supervision of and reviewed by a **GEO*Vision*** California Professional Geophysicist.

Reviewed by

08/08/10

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Date

∗ This geophysical investigation was conducted under the supervision of a California Professional Geophysicist using industry standard methods and equipment. A high degree of professionalism was maintained during all aspects of the project from the field investigation and data acquisition, through data processing interpretation and reporting. All original field data files, field notes and observations, and other pertinent information are maintained in the project files and are available for the client to review for a period of at least one year.

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

TABLES

Table 1: Seismic Line Locations

Line	Stake Designation	Location on Line (ft)	Northing	Easting	Elevation
A1	1	0.0	339,957.31	2,404,837.47	717.1
A1	2	200.0	339,975.89	2,405,036.60	735.0
A1	3	400.0	339,994.47	2,405,235.74	754.8
A1	4	600.0	340,013.06	2,405,434.87	771.2
A1	5	789.1	340,030.63	2,405,623.19	776.4
A2	1	0.0	339,819.88	2,404,850.35	719.8
A2	2	200.0	339,838.46	2,405,049.48	735.6
A2	3	400.0	339,857.03	2,405,248.62	746.4
A2	4	600.0	339,875.61	2,405,447.75	746.9
A2	5	789.1	339,893.18	2,405,636.07	744.8
A3	1	109.0	340,104.87	2,404,933.10	724.2
A3	2	200.0	340,113.32	2,405,023.72	735.0
A3	3	400.0	340,131.90	2,405,222.85	758.0
A3	4	600.0	340,150.49	2,405,421.99	777.3
A3	5	800.0	340,169.07	2,405,621.12	790.2
A3	6	1000.0	340,187.65	2,405,820.26	767.1
A3	7	1084.1	340,195.47	2,405,903.99	750.7
A4	1	60.8	340,441.43	2,404,853.24	747.7
A4	2	200.0	340,454.37	2,404,991.89	763.8
A4	3	400.0	340,472.95	2,405,191.03	780.0
A4	4	600.0	340,491.53	2,405,390.16	793.7
A4	5	710.3	340,501.78	2,405,500.00	800.5
A5	1	0.0	340,293.07	2,404,867.08	741.5
A5	2	200.0	340,311.66	2,405,066.22	767.8
A5	3	4000	340,330.24	2,405,265.35	783.1
A5	4	600.0	340,348.82	2,405,464.49	794.6
A5	5	649.6	340,353.43	2,405,513.84	797.4

Notes: 1. Pennsylvania State Plane Coordinate System, NAD83 (CORS96), North, NAVD88.
2. Data provided by PCRA.

Table 1: Seismic Line Locations (continued)

Line	Stake Designation	Location on Line (ft)	Northing	Easting	Elevation
B1	1	0.0	339,623.54	2,405,007.66	714.3
B1	2	200.0	339,822.69	2,404,989.20	729.6
B1	3	400.0	340,021.84	2,404,970.75	727.7
B1	4	600.0	340,220.98	2,404,952.30	740.2
B1	5	800.0	340,420.13	2,404,933.84	754.8
B1	6	855.7	340,475.59	2,404,928.70	757.9
B2	1	0.0	339,639.14	2,405,175.93	718.9
B2	2	200.0	339,838.27	2,405,157.34	740.1
B2	3	400.0	340,037.41	2,405,138.76	744.3
B2	4	600.0	340,236.54	2,405,120.18	765.3
B2	5	800.0	340,435.68	2,405,101.60	775.6
B2	6	1000.9	340,635.70	2,405,082.93	782.1
B3	1	0.0	339,653.53	2,405,331.27	716.3
B3	2	200.0	339,852.76	2,405,313.73	747.1
B3	3	400.0	340,051.99	2,405,296.19	762.5
B3	4	600.0	340,251.22	2,405,278.65	776.9
B3	5	800.0	340,450.45	2,405,261.11	784.6
B3	6	1000.1	340,650.74	2,405,243.47	787.5
B4	1	0.0	339,667.05	2,405,477.14	716.5
B4	2	200.0	339,866.18	2,405,458.55	744.7
B4	3	400.0	340,065.32	2,405,439.97	772.7
B4	4	600.0	340,264.45	2,405,421.39	787.2
B4	5	800.0	340,463.59	2,405,402.81	793.9
B4	6	1001.2	340,663.92	2,405,384.11	792.0

Notes:
1. Pennsylvania State Plane Coordinate System, NAD83 (CORS96), North, NAVD88.
2. Data provided by PCRA.

Table 2: Seismic Line Geometry

Line	Geophone Spacing (ft)	Spread 1 Start (ft)	Spread 1 End (ft)	Spread 2 Start (ft)	Spread 2 End (ft)	Spread 3 Start (ft)	Spread 3 End (ft)
A1	10	0	470	320	790	N/A	N/A
A2	10	0	470	320	790	N/A	N/A
A3	10	100	570	340	810	580	1050
A4	10	60	530	240	710	N/A	N/A
A5	10	0	470	180	650	N/A	N/A
B1	10	0	470	240	710	430	900
B2	10	190	660	530	1000	N/A	N/A
B3	10	0	470	240	710	480	950
B4	10	0	470	240	710	480	950

Table 3: Borehole Geology Summary

Borehole	Ground Surface Elevation (feet)	Depth - Interpreted Top of Decomposed Shale (ft)	Elevation - Interpreted Top of Decomposed Shale (ft)	Depth - Interpreted Top of Weathered Shale (ft)	Elevation - Interpreted Top of Weathered Shale (ft)	Depth RQD > 0 (ft)	Elevation RQD > 0 (ft)	Depth - Interpreted Top of Competent Shale (ft)	Elevation - Interpreted Top of Competent Shale (ft)	Comments (RQD%-FD)
B-401	747.68	16	731.68	19.42	728.26	24.5	723.18	89.5	658.18	92%-FD3
B-402	761.79	1.5	760.29	25	736.79	25	736.79	95	666.79	70%-FD5, 80%-FD4 at 100'
B-403	737.56	7.5	730.06	19.9	717.66	21.8	715.76	75.6	661.96	100% -FD0, 74%-FD5 at 80.6'
B-404	744.44	12	732.44	17.75	726.69	40.15	704.29	95.15	649.29	92%-FD0
B-405	757.56	14	743.56	14	743.56	14	743.56	99	658.56	100%-FD4
B-406	771.88	3	768.88	11	760.88	11	760.88	75	696.88	100%-FD3
B-407	734.19	16.5	717.69	25.5	708.69	30.5	703.69	70.5	663.69	76%-FD4, 76%-FD0 at 73.5'
B-408	728.44			24.42	704.02	39.5	688.94	79.5	648.94	89%-FD1
B-409	735.15	9	726.15	17.5	717.65	30.5	704.65	70.5	664.65	82%-FD3, <70% @ 75.5'-95.5', 100%-FD2 @ 95.5'
B-410	744.85	11.5	733.35	17.5	727.35	24.8	720.05	79.8	665.05	72%-FD3, 92%-FD2 at 84.8'
B-411	758.15	16.15	742	23.45	734.7	44.9	713.25	79.9	678.25	100%-FD5
B-412	763.35	12	751.35	22	741.35	22	741.35	99.4	663.95	86%-FD5, 77%-FD5 @ 89.4'-94.4', 68%-FD5 @ 94.4'-99.4'
B-413	772.2	4.5	767.7	9	763.2	14	758.2	109	663.2	76%-FD2, 80%-FD5 @ 74'-79', <70% @ 79'-109'
B-414	730.32	10.7	719.62	16.5	713.82	34.25	696.07	39.25	691.07	82%-FD5, 94%-FD4 @ 44.25'
B-415	739.64	3	736.64	15.5	724.14	15.5	724.14	80.5	659.14	10%-FD4, 74%-FD5 @ 45.5'-50.5', <70%-FD5 @ 50.5'-60.5', 70%-FD5 60.5'-65.5', <70%-FD5/FD4 @ 65.5'-80.5', 100%-FD4 @ 80.5'-85.5', <70%-FD4-FD9 @ 85.5'-115.5', 83%-FD3 or better below 117'
B-416	728.86	15	713.86	25	703.86	30	698.86	45	683.86	100%-FD3
B-417	734.74	15.05	719.69	20	714.74	34.2	700.54	39.2	695.54	100%-FD0
B-418	744.2			20	724.2	34.5	709.7	44.5	699.7	100%-FD0
B-419	748.14	19.8	728.34	23.75	724.39	26.4	721.74	51.4	696.74	78%-FD5, 94%-FD3 at 56.4'
B-420	778.81			15.6	763.21	15.6	763.21	64.6	714.21	77%-FD3, 100%-FD3 @ 74.6'
B-421	783.85	6	777.85	15.4	768.45	15.4	768.45	70.2	713.65	74%-FD4, 74%-FD6 @ 69.4', 100%-FD1 @ 74.4'
B-422	724.95	12.9	712.05					16	708.95	90%-FD3
B-423	724.06			11.5	712.56	13.2	710.86	29	695.06	84%-FD5, 84%-FD3 @ 30.2'
B-424	745.4	18	727.4	23.4	722	23.4	722	89.7	655.7	71%-FD5, 75%-FD4 @ 94.7'
B-425	744.91	21.75	723.16	23.9	721.01	36.25	708.66	89.9	655.01	72%-FD5, 19% @ 23.9' but only 2.5' thick
B-426	745.2	7.5	737.7	20	725.2	44.9	700.3	59.9	685.3	96%-FD5, 26% @ 20' but only 5' thick
B-427	753.97	2.65	751.32	12.7	741.27	13.7	740.27	58.7	695.27	96%-FD5
B-428	750.57	12.5	738.07	18.17	732.4	18.17	732.4	45.8	704.77	74%-FD3, 98%-FD0 @ 50.8'
B-429	757.19			21	736.19	21	736.19	45	712.19	84%-FD5, 78%-FD5 @ 35'-40', 60%-FD5 @ 40'-45', 58%-FD5/FD1 @ 50'-55' then 100%-FD1 below 55'
B-430	775.32	12.5	762.82	21.8	753.52	24.8	750.52	94.7	680.62	84%-FD4, 74%-FD4 @ 84.7'-89.7', 68%-FD4 89.7'-94.7
B-431	783.22	12.9	770.32	20.3	762.92	20.3	762.92	99.2	684.02	84%-FD6/FD4, 73%-FD6 @ 34.2'-39.2', 74%-FD5 @ 39.2'-44.2', <60%-FD5/FD6 @ 44.2'-84.2', 76%-FD6 @ 84.2'-89.2', 78%-FD6 @ 89.2'-94.2', 30%-FD6 @ 94.2'-99.2'

Borehole	Ground Surface Elevation (feet)	Depth - Interpreted Top of Decomposed Shale (ft)	Elevation - Interpreted Top of Decomposed Shale (ft)	Depth - Interpreted Top of Weathered Shale (ft)	Elevation - Interpreted Top of Weathered Shale (ft)	Depth RQD > 0 (ft)	Elevation RQD > 0 (ft)	Depth - Interpreted Top of Competent Shale (ft)	Elevation - Interpreted Top of Competent Shale (ft)	Comments (RQD%-FD)
B-432	789.49	22.5	766.99	28	761.49	28	761.49	105	684.49	82%-FD4, 78%-FD5 @ 45'-50', <60%-FD5/FD6 @ 50'-95', 73%-FD5/FD4 @ 95'-100', 60%-FD4 @ 100'-105'
B-433	792.77	15.5	777.27	35	757.77	35	757.77	75	717.77	92%-FD4
PMT-401	759.09					29.8	729.29	92.8	666.29	100%-FD1
PMT-402	729.82							80	649.82	94%-FD3
MW-403	801.97							73	728.97	100%-FD0
MW-404	735.42							69	666.42	75%-FD4, 95%-FD0 @71'
MW-407	735.42							41	694.42	94%-FD2, competent rock may be slightly shallower

Note: Competent Rock defined as (RQD > 80%)or (RQD >= 70% for more than 5 ft and Fracture Density <= FD5)

FIGURES

Legend

Seismic Refraction Line

B1-1 Survey control established for seismic refraction survey

MW406 Location of borehole / monitoring well

NOTES:
1. STATE PLANE COORDINATE SYSTEM
PA NORTH, NAD 83, US FEET

0 80 160 240
Feet

GEOVision geophysical services	FIGURE 1 SITE MAP
Date: 8-31-10 GV Project: 10171 Developed by: A. Martin Drawn by: T Rodriguez Approved by: A Martin File Name: 10171-1.MXD	BELL BEND NUCLEAR POWER PLANT LUZERNE COUNTY, PENNSYLVANIA PREPARED FOR PAUL C. RIZZO ASSOCIATES, INC.

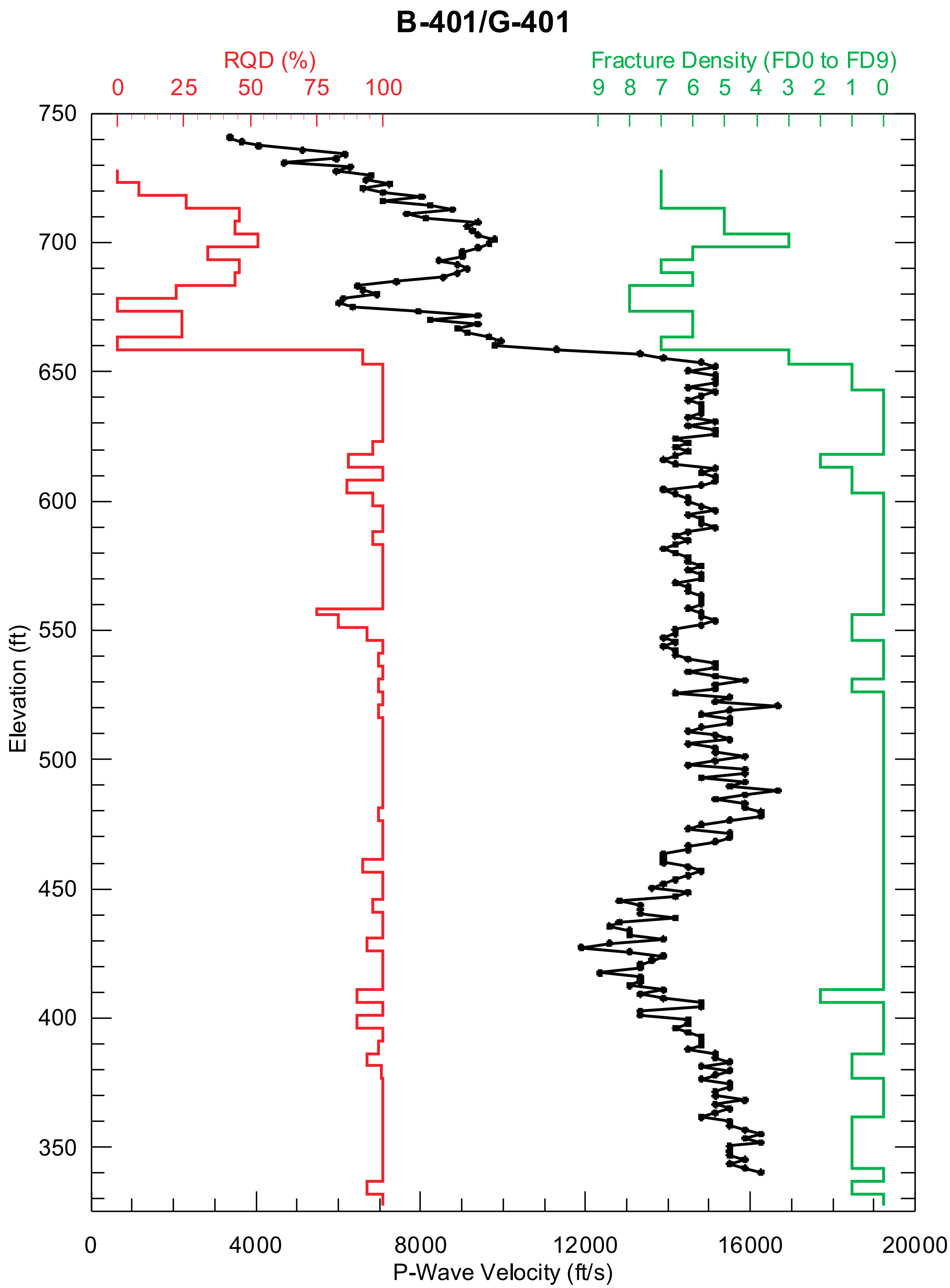
Seismic Data Acquisition System

Typical Seismic Line

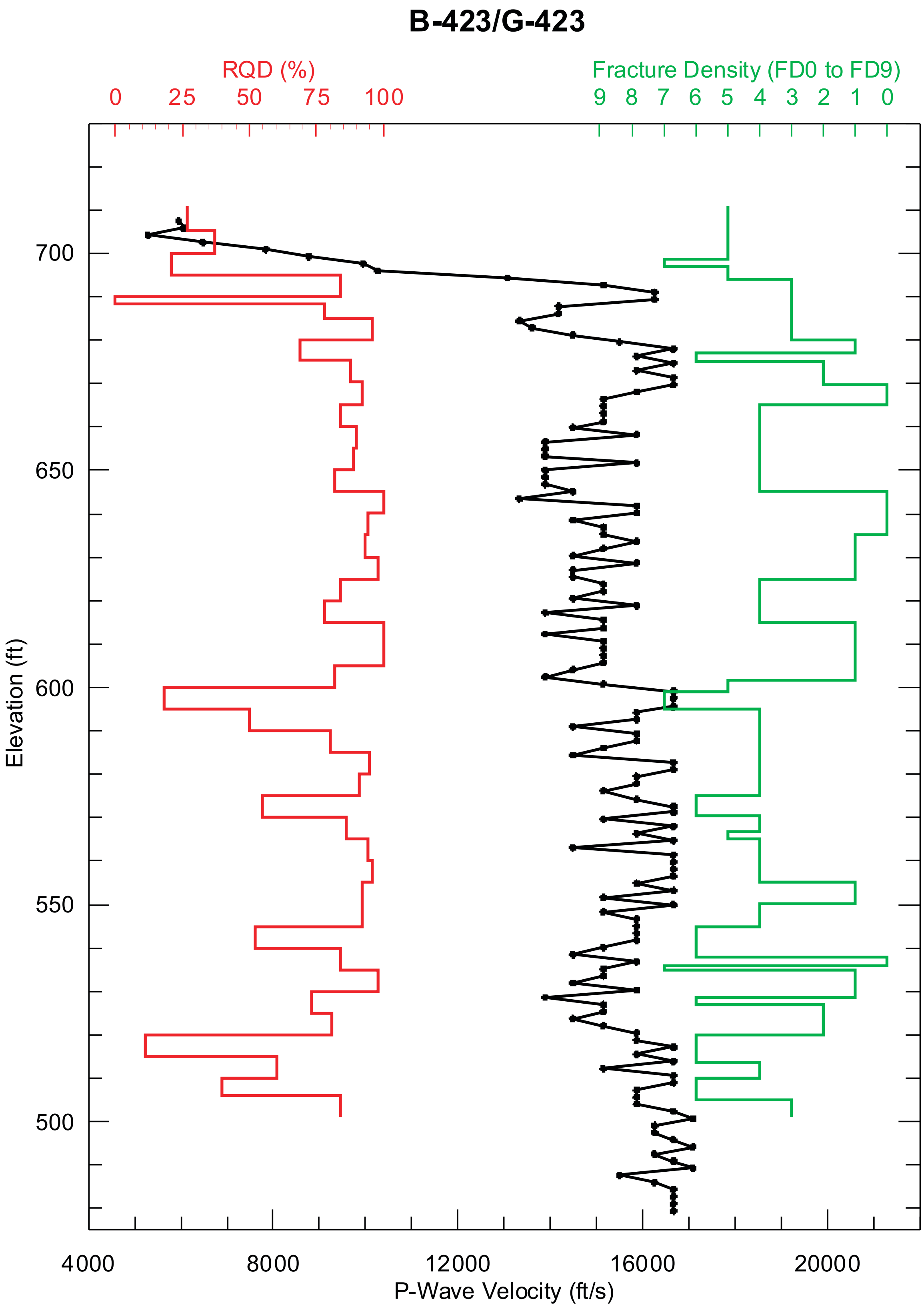
Accelerated Weight Drop

Downhole Percussion Firing Rod

GEOVision geophysical services	FIGURE 2 PHOTOGRAPHS OF SEISMIC EQUIPMENT
Project # 10171 Date: AUG 4, 2010 Drawn By: E FELDMAN	BELL BEND NUCLEAR POWER PLANT LUZERNE COUNTY, PENNSYLVANIA
Approved By: Antony J Martin File R:\...Project Files\2010\10171 Bell Bend NPP\Figures\Figure2.cdr	PREPARED FOR PAUL C. RIZZO ASSOCIATES, INC.



GEOVision geophysical services	FIGURE 3 GEOPHYSICAL LOG & BOREHOLE PARAMETERS BOREHOLE B-401/G-401
Project # 10171 Date: AUG 5, 2010 Drawn By: E FELDMAN	BELL BEND NUCLEAR POWER PLANT LUZERNE COUNTY, PENNSYLVANIA
Approved By: [signature] File R:\...Project Files\2010\10171 Bell Bend NPP\figures\Figure3.cdr	PREPARED FOR PAUL C. RIZZO ASSOCIATES, INC.



GEOVision geophysical services	FIGURE 4 GEOPHYSICAL LOG & BOREHOLE PARAMETERS BOREHOLE B-423/G-423
Project # 10171 Date: AUG 5, 2010 Drawn By: E FELDMAN	BELL BEND NUCLEAR POWER PLANT LUZERNE COUNTY, PENNSYLVANIA
Approved By:	PREPARED FOR PAUL C. RIZZO ASSOCIATES, INC.
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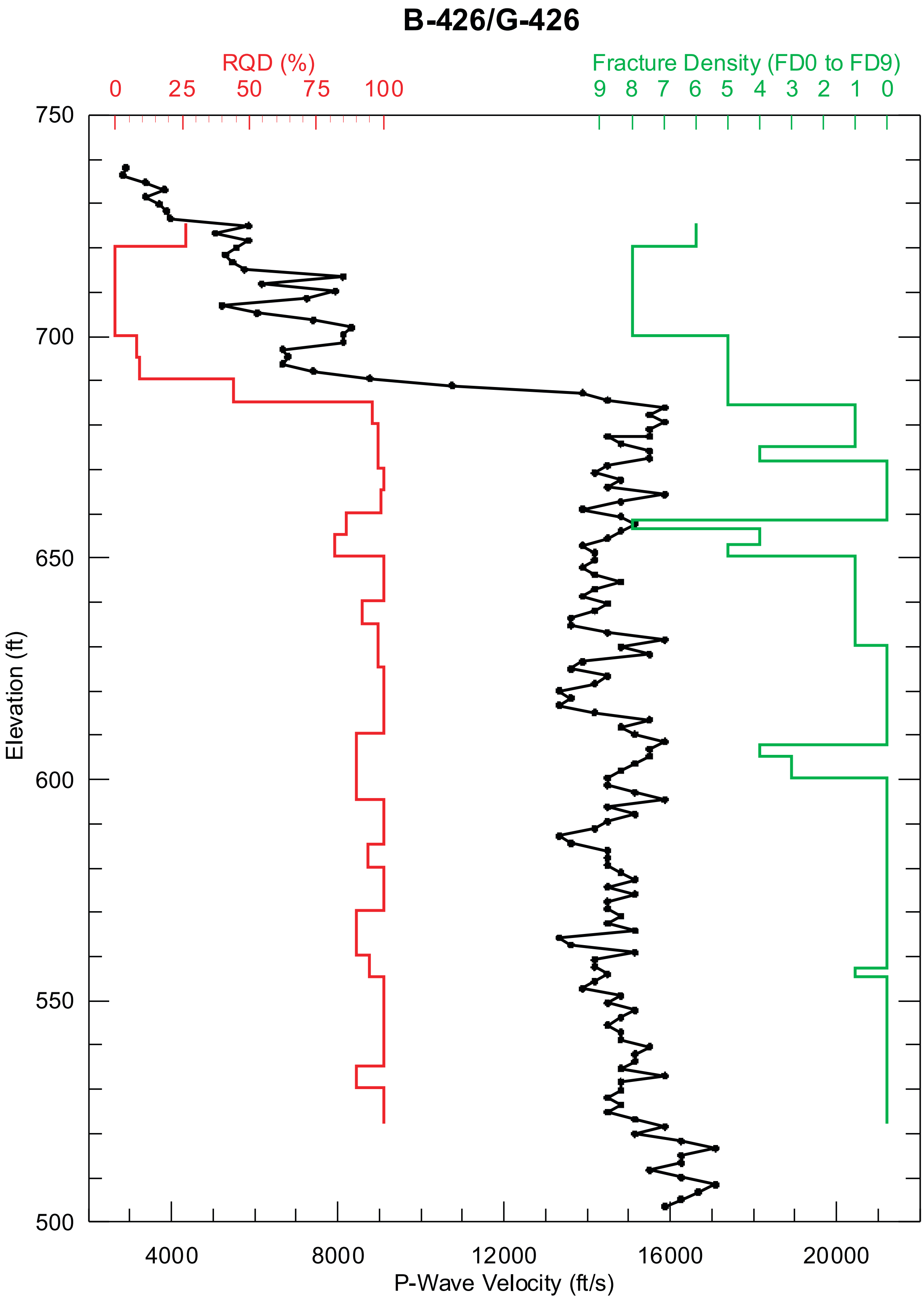
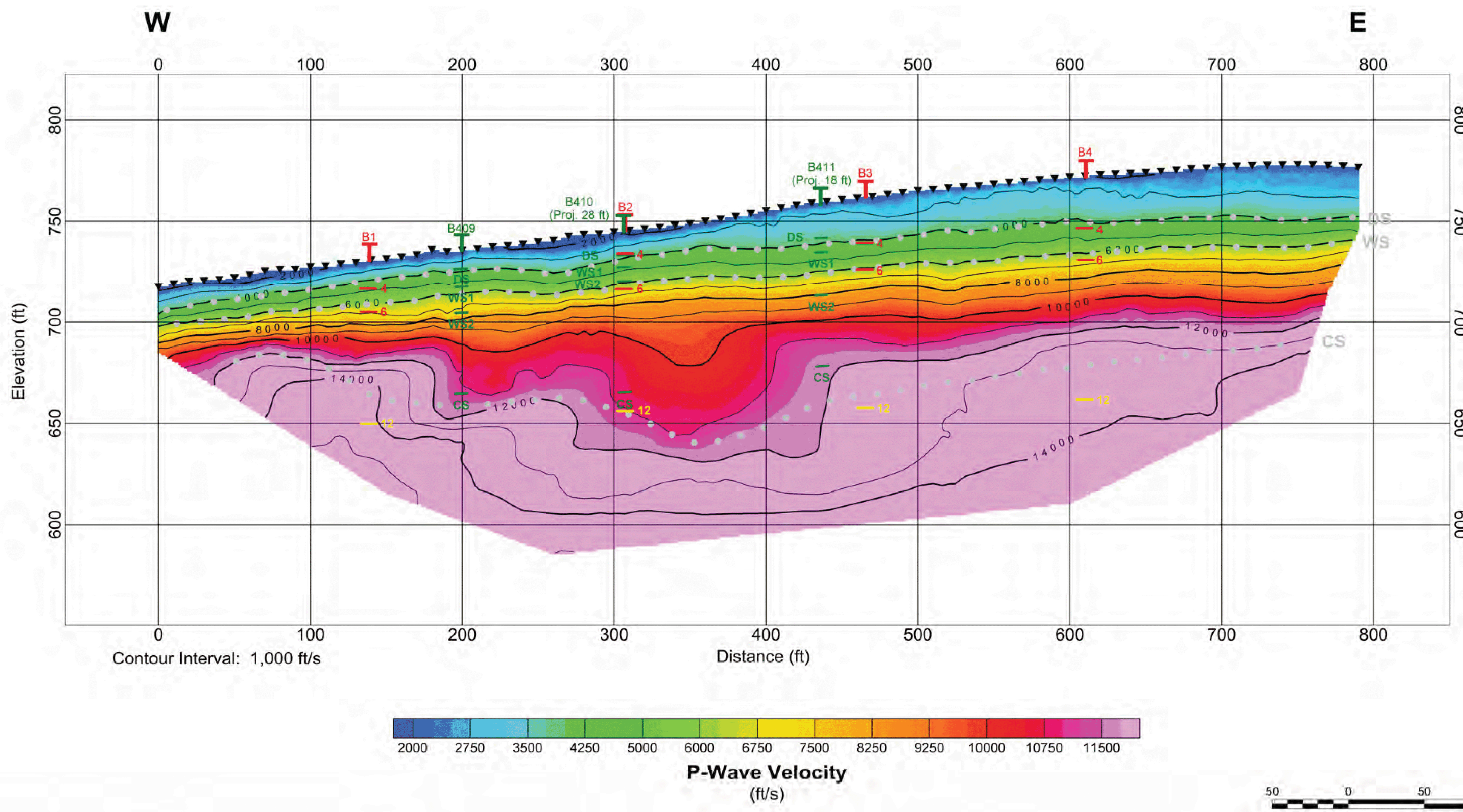


GEOVision geophysical services	FIGURE 5 GEOPHYSICAL LOG & BOREHOLE PARAMETERS BOREHOLE B-426/G-426
Project # 10171 Date: AUG 5, 2010 Drawn By: E FELDMAN	BELL BEND NUCLEAR POWER PLANT LUZERNE COUNTY, PENNSYLVANIA
Approved By: Antony J Martin File R:\...Project Files\2010\10171 Bell Bend NPP\figures\Figure5.cdr	PREPARED FOR PAUL C. RIZZO ASSOCIATES, INC.



LEGEND

▼ Geophone Location	DS	Borehole Interpreted Decomposed Shale	4	4,000 ft/s Contour on Intersecting Line
T Line Intersection	WS1	Borehole Interpreted Weathered Shale	6	6,000 ft/s Contour on Intersecting Line
	WS2	Borehole Interpreted Weathered Shale with RQD > 0	12	12,000 ft/s Contour on Intersecting Line
T Borehole Location	CS	Borehole Interpreted Competent Shale		

Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

GEOVision geophysical services

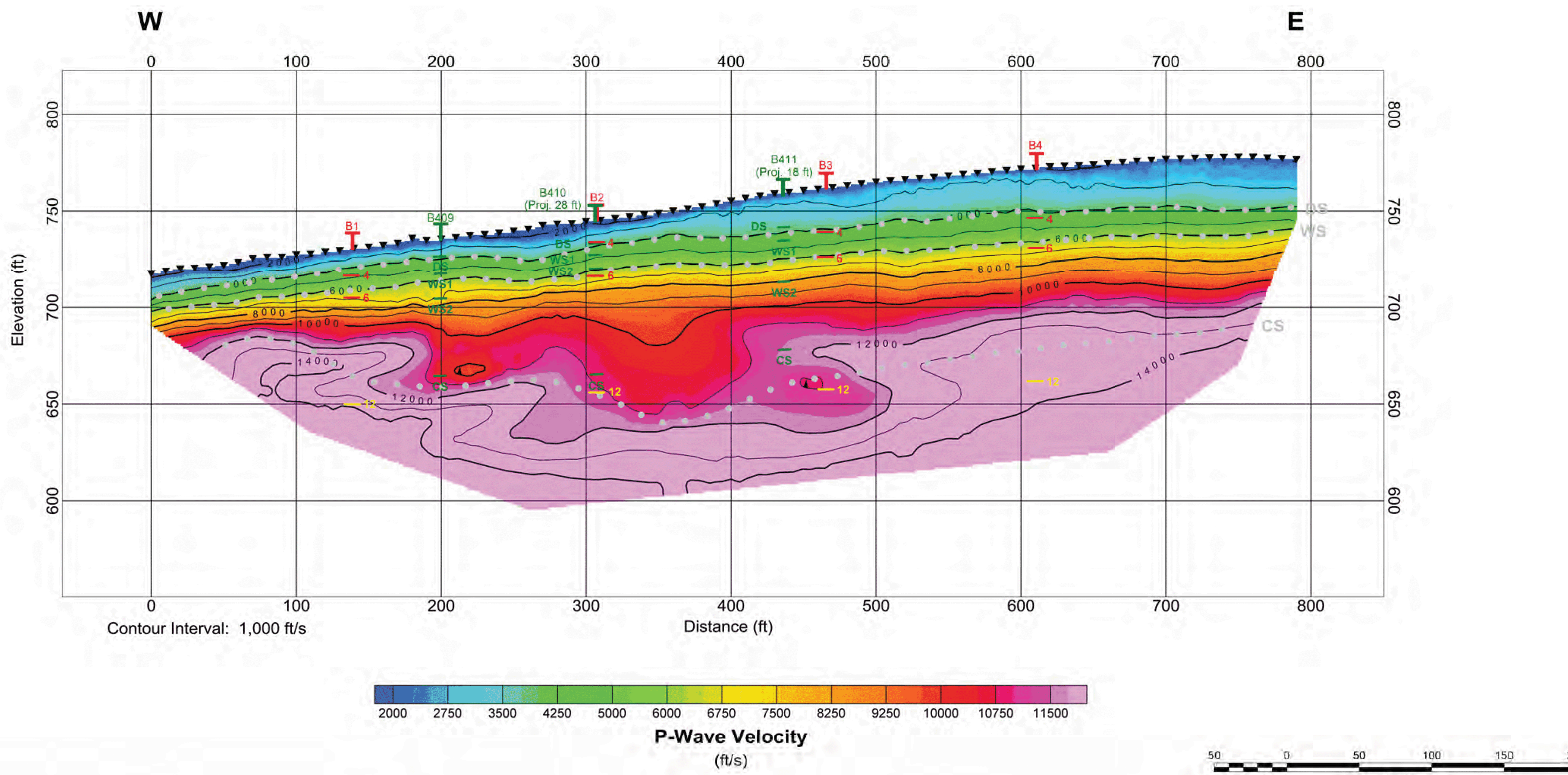
Figure 6A

Line A1 - Seismic Tomography Model with Velocity Constraints

Bell Bend Nuclear Power Plant
Luzerne County, Pennsylvannia

Prepared for Paul C. Rizzo Associates, Inc.

Project No. 10171



LEGEND

▼ Geophone Location	DS Borehole Interpreted Decomposed Shale	4 4,000 ft/s Contour on Intersecting Line
T Line Intersection	WS1 Borehole Interpreted Weathered Shale	6 6,000 ft/s Contour on Intersecting Line
T Borehole Location	WS2 Borehole Interpreted Weathered Shale with RQD > 0	12 12,000 ft/s Contour on Intersecting Line
	CS Borehole Interpreted Competent Shale	

Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

GEOVision geophysical services

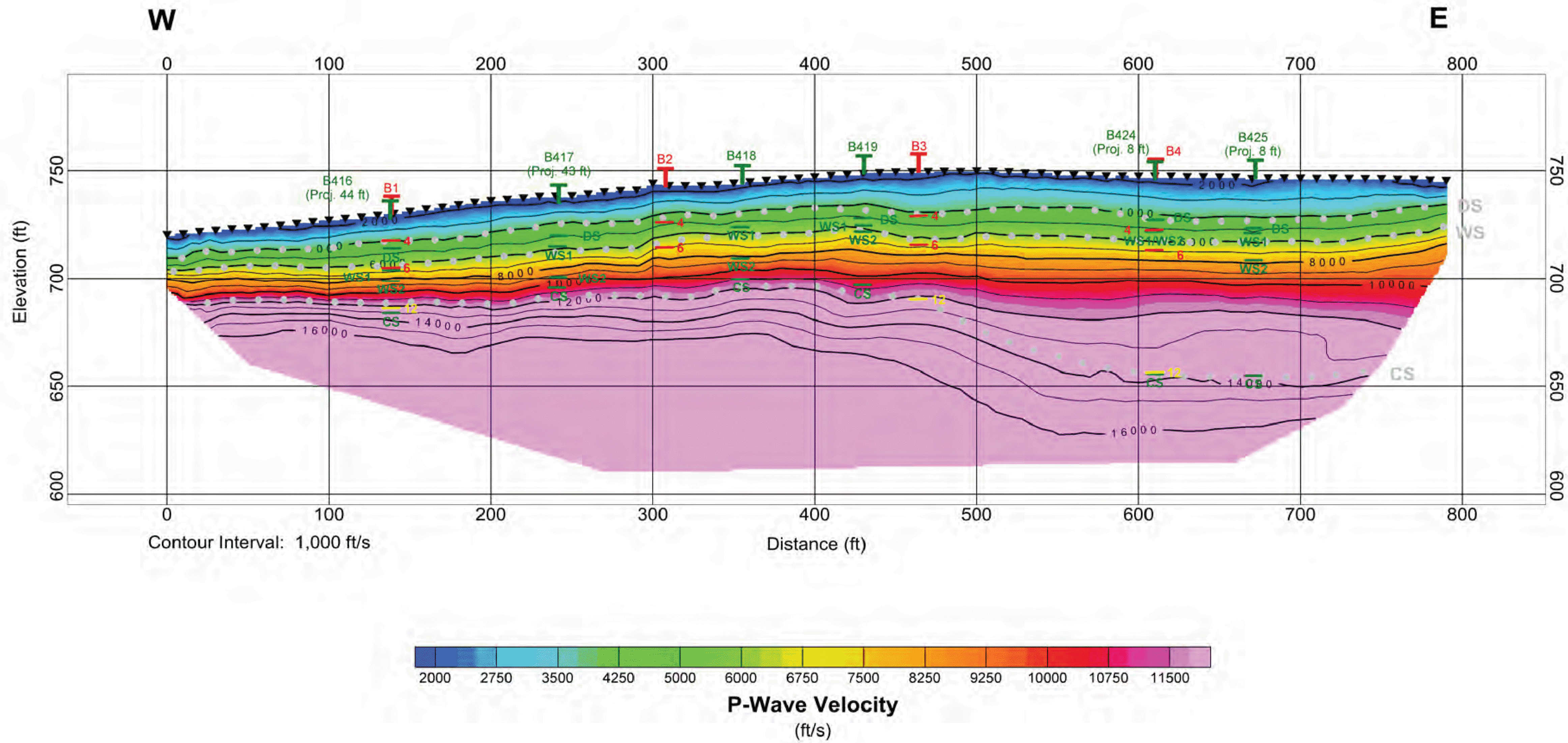
Figure 6B

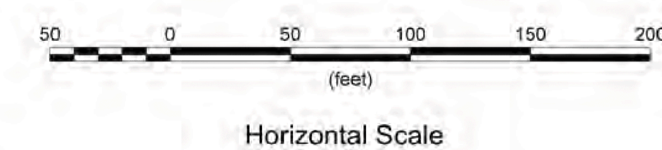
Line A1 - Seismic Tomography Model without Velocity Constraints

Bell Bend Nuclear Power Plant
Luzerne County, Pennsylvannia

Prepared for Paul C. Rizzo Associates, Inc.

Project No. 10171





LEGEND

▼	Geophone Location
T	Line Intersection
T	Borehole Location
— DS	Borehole Interpreted Decomposed Shale
— WS1	Borehole Interpreted Weathered Shale
— WS2	Borehole Interpreted Weathered Shale with RQD > 0
— CS	Borehole Interpreted Competent Shale
— 4	4,000 ft/s Contour on Intersecting Line
— 6	6,000 ft/s Contour on Intersecting Line
— 12	12,000 ft/s Contour on Intersecting Line
• • •	Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

GEOVision geophysical services

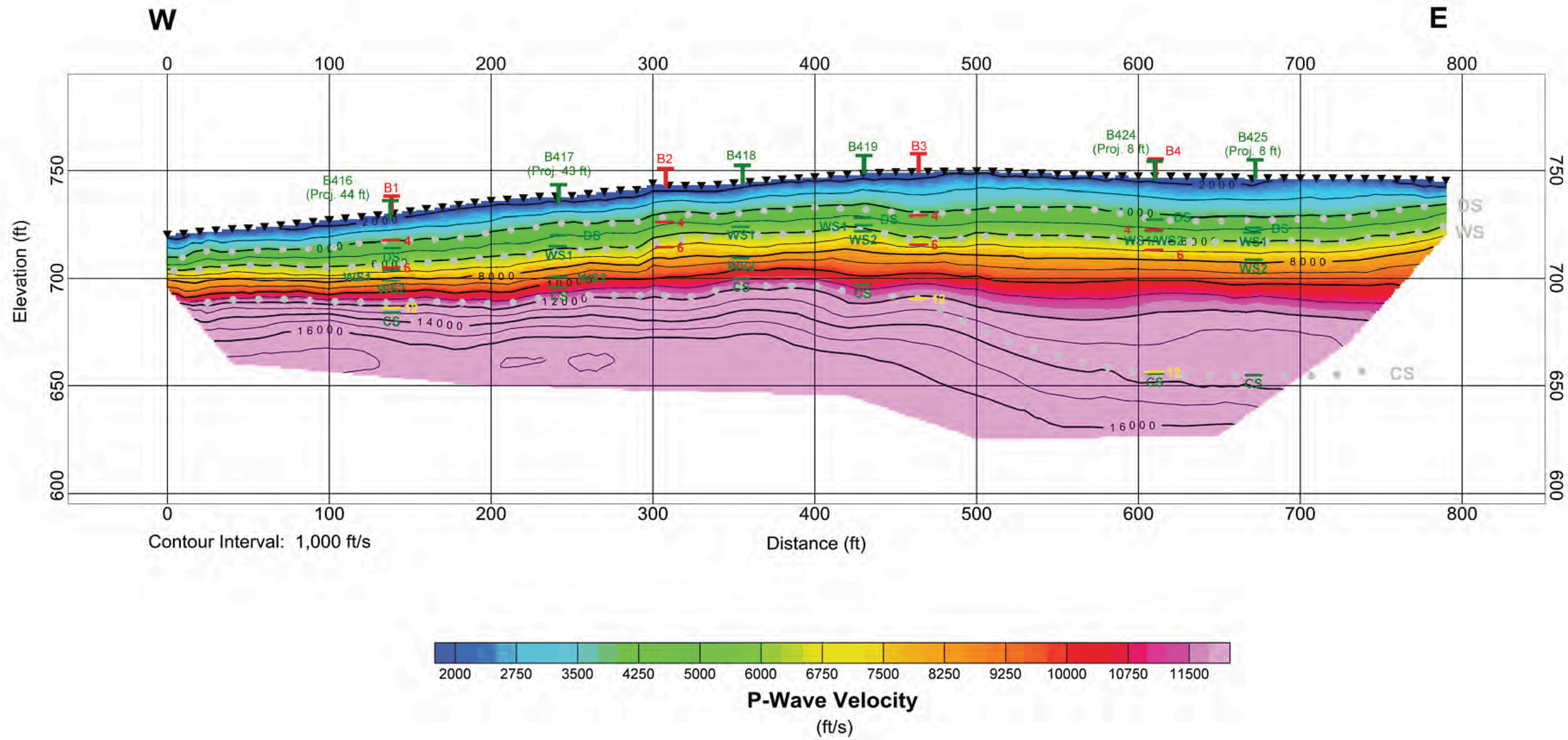
Figure 7A

Line A2 - Seismic Tomography Model with Velocity Constraints

Bell Bend Nuclear Power Plant
Luzerne County, Pennsylvannia

Prepared for Paul C. Rizzo Associates, Inc.

Project No. 10171



50 0 50 100 150 200
(feet)
Horizontal Scale

LEGEND

▼ Geophone Location	— DS Borehole Interpreted Decomposed Shale	— 4 4,000 ft/s Contour on Intersecting Line	
T Line Intersection	— WS1 Borehole Interpreted Weathered Shale	— 6 6,000 ft/s Contour on Intersecting Line	
	— WS2 Borehole Interpreted Weathered Shale with RQD > 0	— 12 12,000 ft/s Contour on Intersecting Line	
T Borehole Location	— CS Borehole Interpreted Competent Shale		

• • • Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

GEOVision geophysical services

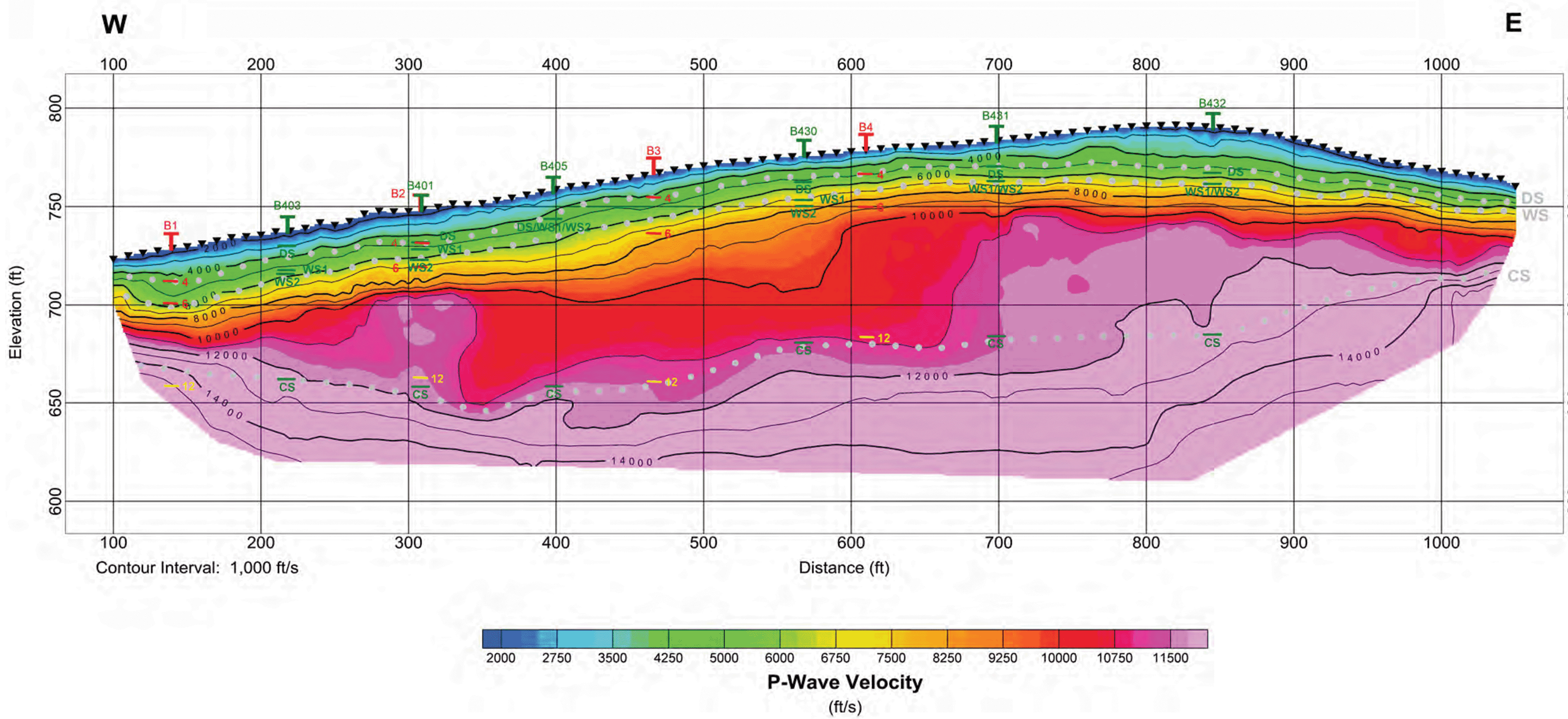
Figure 7B

Line A2 - Seismic Tomography Model without Velocity Constraints

Bell Bend Nuclear Power Plant
Luzerne County, Pennsylvannia

Prepared for Paul C. Rizzo Associates, Inc.

Project No. 10171



Horizontal Scale
50 0 50 100 150 200
(feet)

LEGEND

- ▼ Geophone Location
- T Line Intersection
- T Borehole Location
- DS Borehole Interpreted Decomposed Shale
- WS1 Borehole Interpreted Weathered Shale
- WS2 Borehole Interpreted Weathered Shale with RQD > 0
- CS Borehole Interpreted Competent Shale
- 4 4,000 ft/s Contour on Intersecting Line
- 6 6,000 ft/s Contour on Intersecting Line
- 12 12,000 ft/s Contour on Intersecting Line
- • • • Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

GEOVision geophysical services

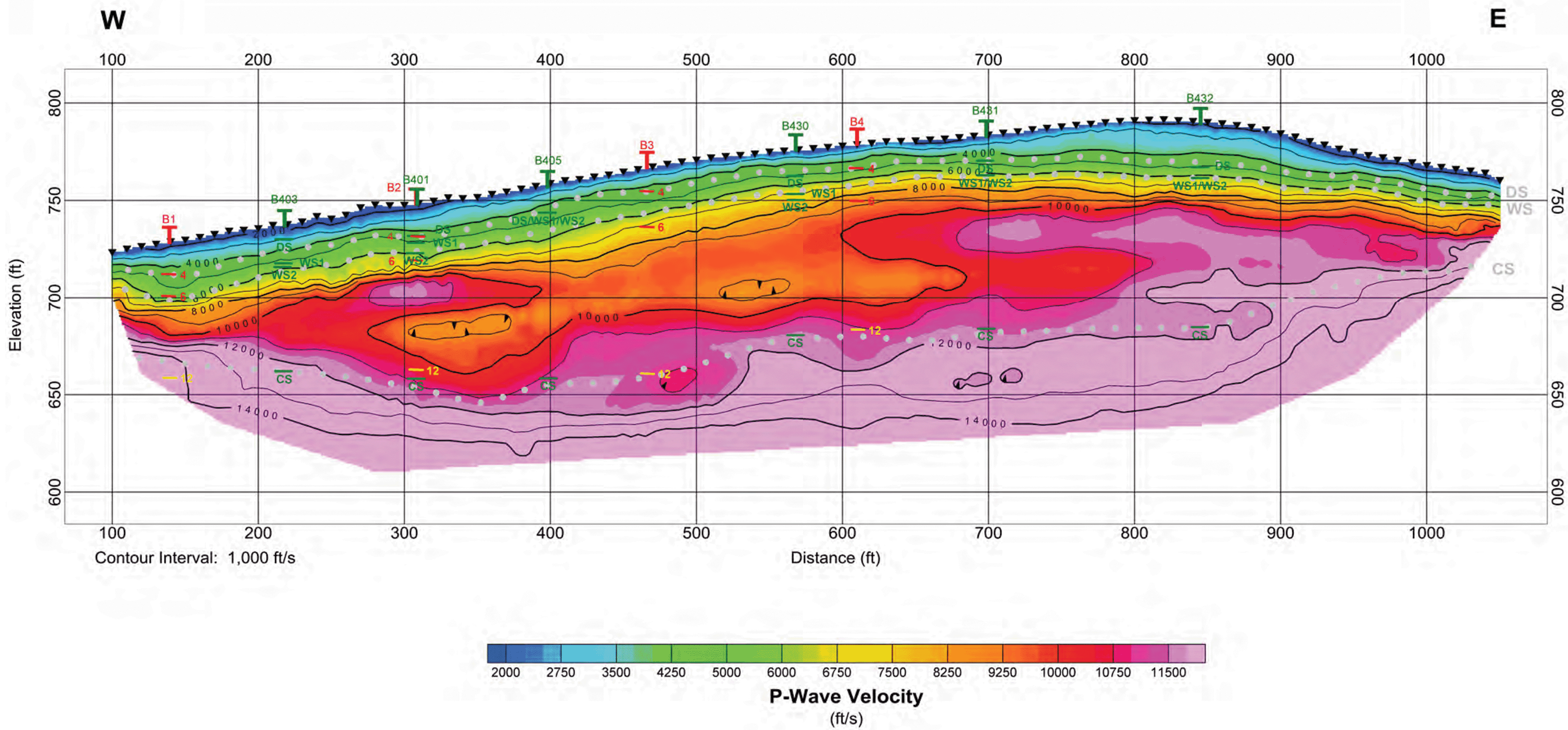
Figure 8A

Line A3 - Seismic Tomography Model with Velocity Constraints

Bell Bend Nuclear Power Plant
Luzerne County, Pennsylvania

Prepared for Paul C. Rizzo Associates, Inc.

Project No. 10171



50 0 50 100 150 200
(feet)
Horizontal Scale

LEGEND

▼	Geophone Location	— DS	Borehole Interpreted Decomposed Shale
T	Line Intersection	— WS1	Borehole Interpreted Weathered Shale
		— WS2	Borehole Interpreted Weathered Shale with RQD > 0
T	Borehole Location	— CS	Borehole Interpreted Competent Shale

— 4 4,000 ft/s Contour on Intersecting Line
— 6 6,000 ft/s Contour on Intersecting Line
— 12 12,000 ft/s Contour on Intersecting Line

• • • Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

GEOVision geophysical services

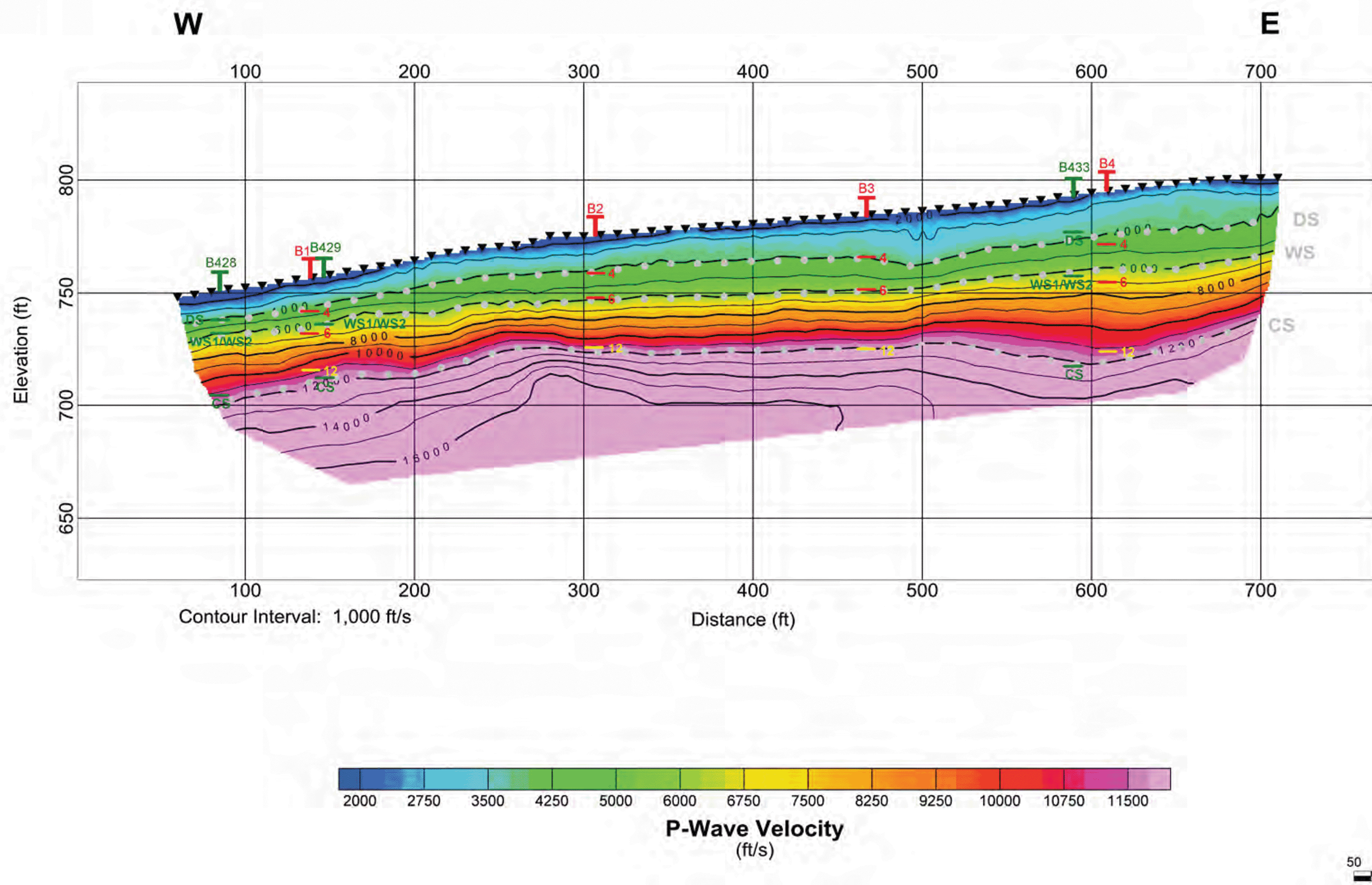
Figure 8B

Line A3 - Seismic Tomography Model without Velocity Constraints

Bell Bend Nuclear Power Plant
Luzerne County, Pennsylvania

Prepared for Paul C. Rizzo Associates, Inc.

Project No. 10171



LEGEND

- ▼ Geophone Location
- T Line Intersection
- T Borehole Location
- DS Borehole Interpreted Decomposed Shale
- WS1 Borehole Interpreted Weathered Shale
- WS2 Borehole Interpreted Weathered Shale with RQD > 0
- CS Borehole Interpreted Competent Shale
- 4 4,000 ft/s Contour on Intersecting Line
- 6 6,000 ft/s Contour on Intersecting Line
- 12 12,000 ft/s Contour on Intersecting Line
- Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

GEOVision geophysical services

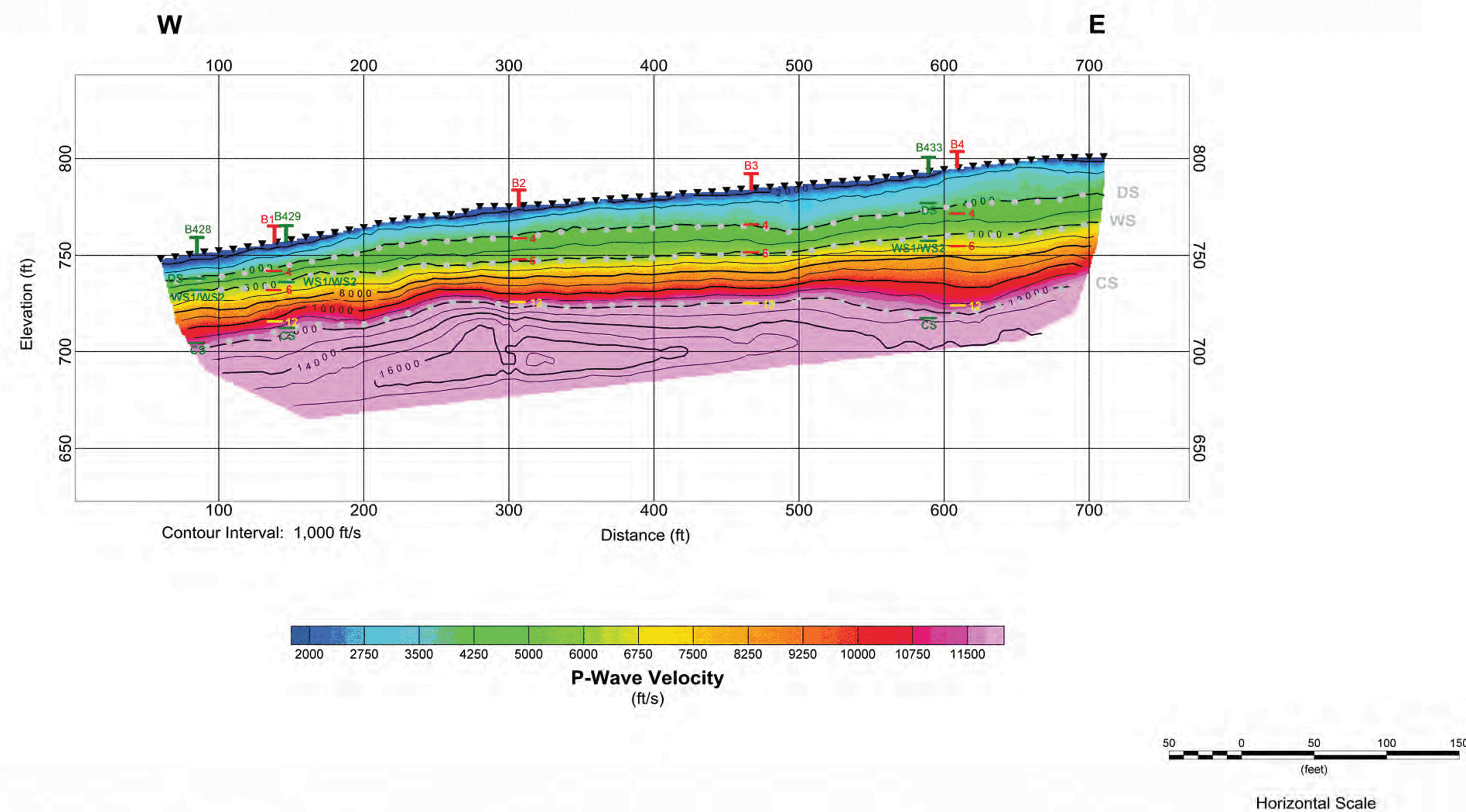
Figure 9A

Line A4 - Seismic Tomography Model with Velocity Constraints

Bell Bend Nuclear Power Plant
Lucerne County, Pennsylvannia

Prepared for Paul C. Rizzo Associates, Inc.

Project No. 10171



LEGEND

Geophone Location	DS Borehole Interpreted Decomposed Shale	4 4,000 ft/s Contour on Intersecting Line
Line Intersection	WS1 Borehole Interpreted Weathered Shale	6 6,000 ft/s Contour on Intersecting Line
Borehole Location	WS2 Borehole Interpreted Weathered Shale with RQD > 0	12 12,000 ft/s Contour on Intersecting Line
	CS Borehole Interpreted Competent Shale	

Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

GEOVision geophysical services

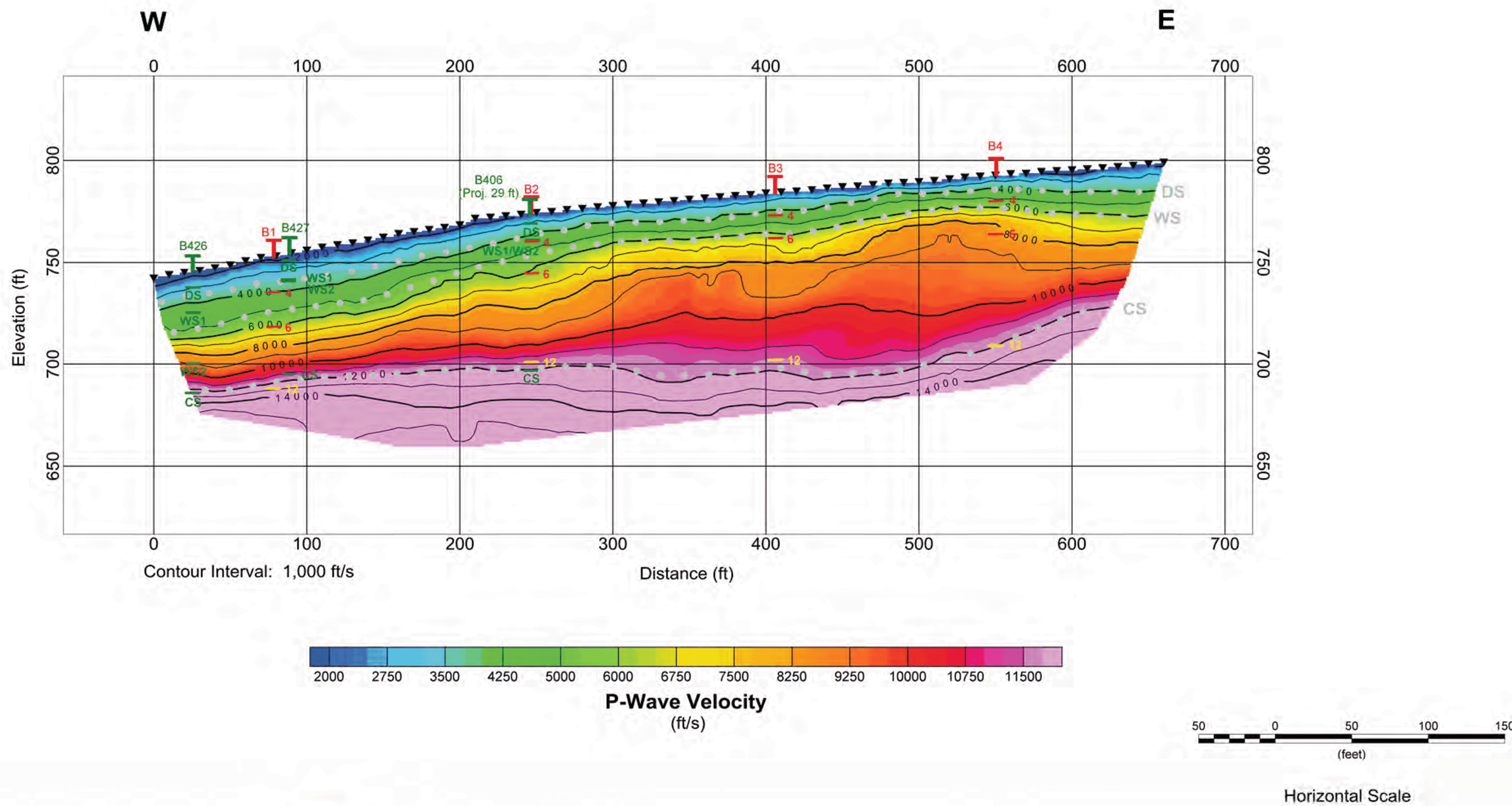
Figure 9B

Line A4 - Seismic Tomography Model without Velocity Constraints

Bell Bend Nuclear Power Plant
Lucerne County, Pennsylvannia

Prepared for Paul C. Rizzo Associates, Inc.

Project No. 10171



LEGEND

▼ Geophone Location	— DS Borehole Interpreted Decomposed Shale	— 4	4,000 ft/s Contour on Intersecting Line
T Line Intersection	— WS1 Borehole Interpreted Weathered Shale	— 6	6,000 ft/s Contour on Intersecting Line
T Borehole Location	— WS2 Borehole Interpreted Weathered Shale with RQD > 0	— 12	12,000 ft/s Contour on Intersecting Line
	— CS Borehole Interpreted Competent Shale		

Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

Project No. 10171

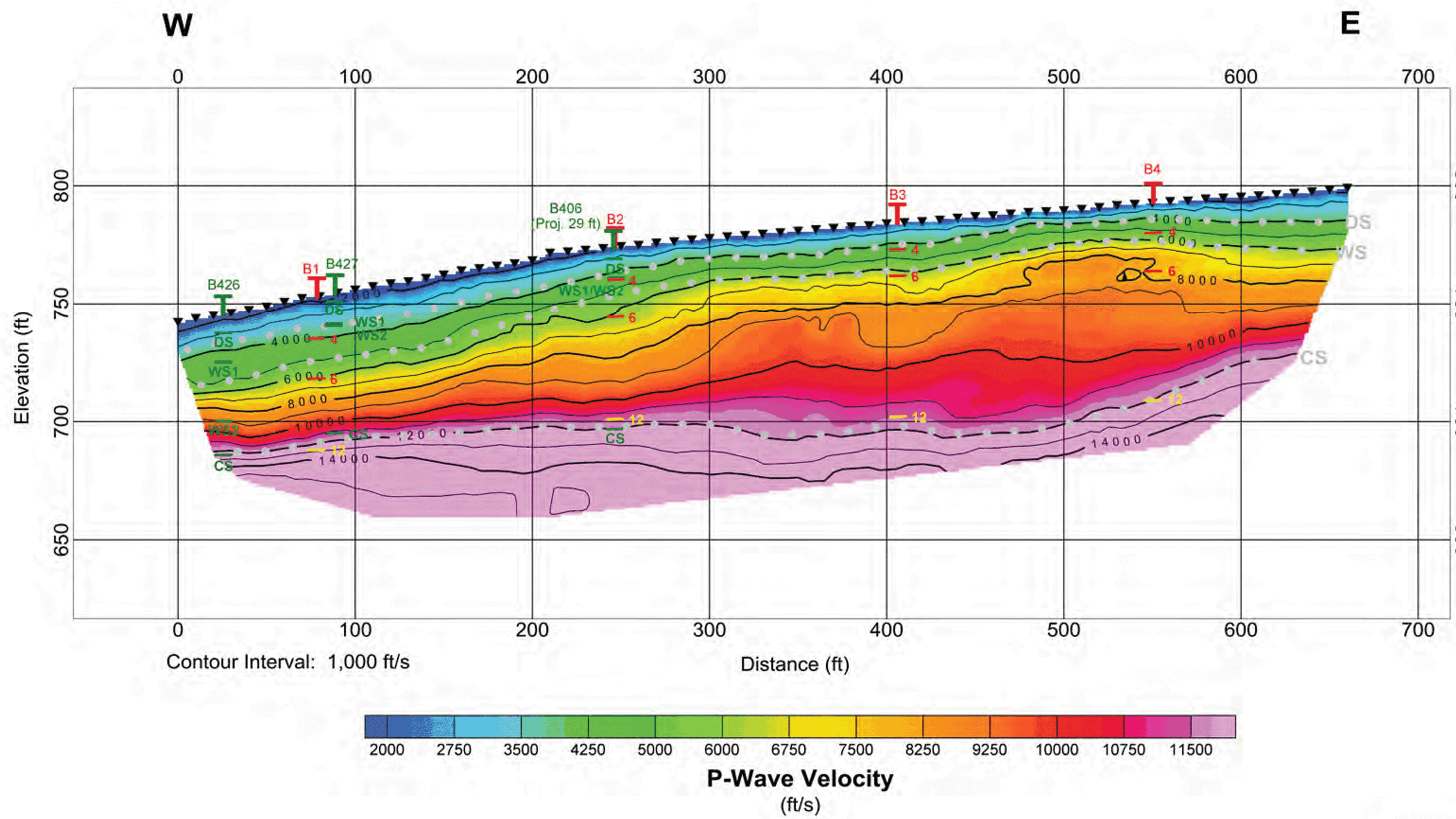
GEOVision geophysical services

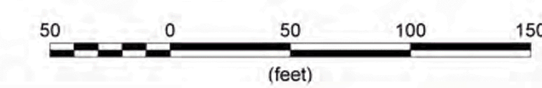
Figure 10A

Line A5 - Seismic Tomography Model with Velocity Constraints

Bell Bend Nuclear Power Plant
Luzerne County, Pennsylvannia

Prepared for Paul C. Rizzo Associates, Inc.





Horizontal Scale

LEGEND

▼	Geophone Location	DS	Borehole Interpreted Decomposed Shale	4	4,000 ft/s Contour on Intersecting Line
T	Line Intersection	WS1	Borehole Interpreted Weathered Shale	6	6,000 ft/s Contour on Intersecting Line
		WS2	Borehole Interpreted Weathered Shale with RQD > 0	12	12,000 ft/s Contour on Intersecting Line
T	Borehole Location	CS	Borehole Interpreted Competent Shale		

Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

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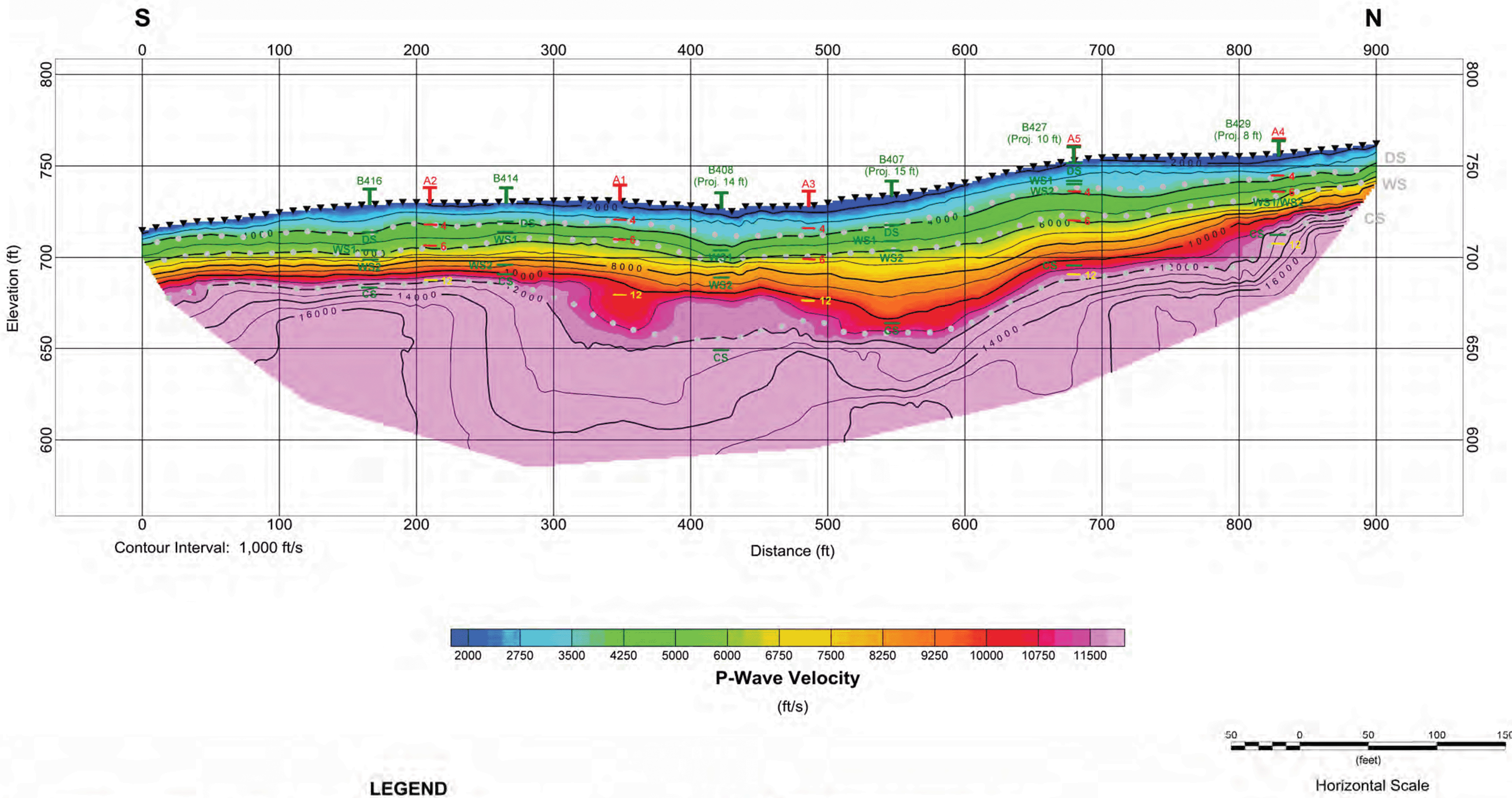
Figure 10B

Line A5 - Seismic Tomography Model without Velocity Constraints

Bell Bend Nuclear Power Plant
Luzerne County, Pennsylvannia

Prepared for Paul C. Rizzo Associates, Inc.

Project No. 10171



LEGEND

▼ Geophone Location	— DS Borehole Interpreted Decomposed Shale		— 4 4,000 ft/s Contour on Intersecting Line
T Line Intersection	— WS1 Borehole Interpreted Weathered Shale		— 6 6,000 ft/s Contour on Intersecting Line
	— WS2 Borehole Interpreted Weathered Shale with RQD > 0		— 12 12,000 ft/s Contour on Intersecting Line
T Borehole Location	— CS Borehole Interpreted Competent Shale		

Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

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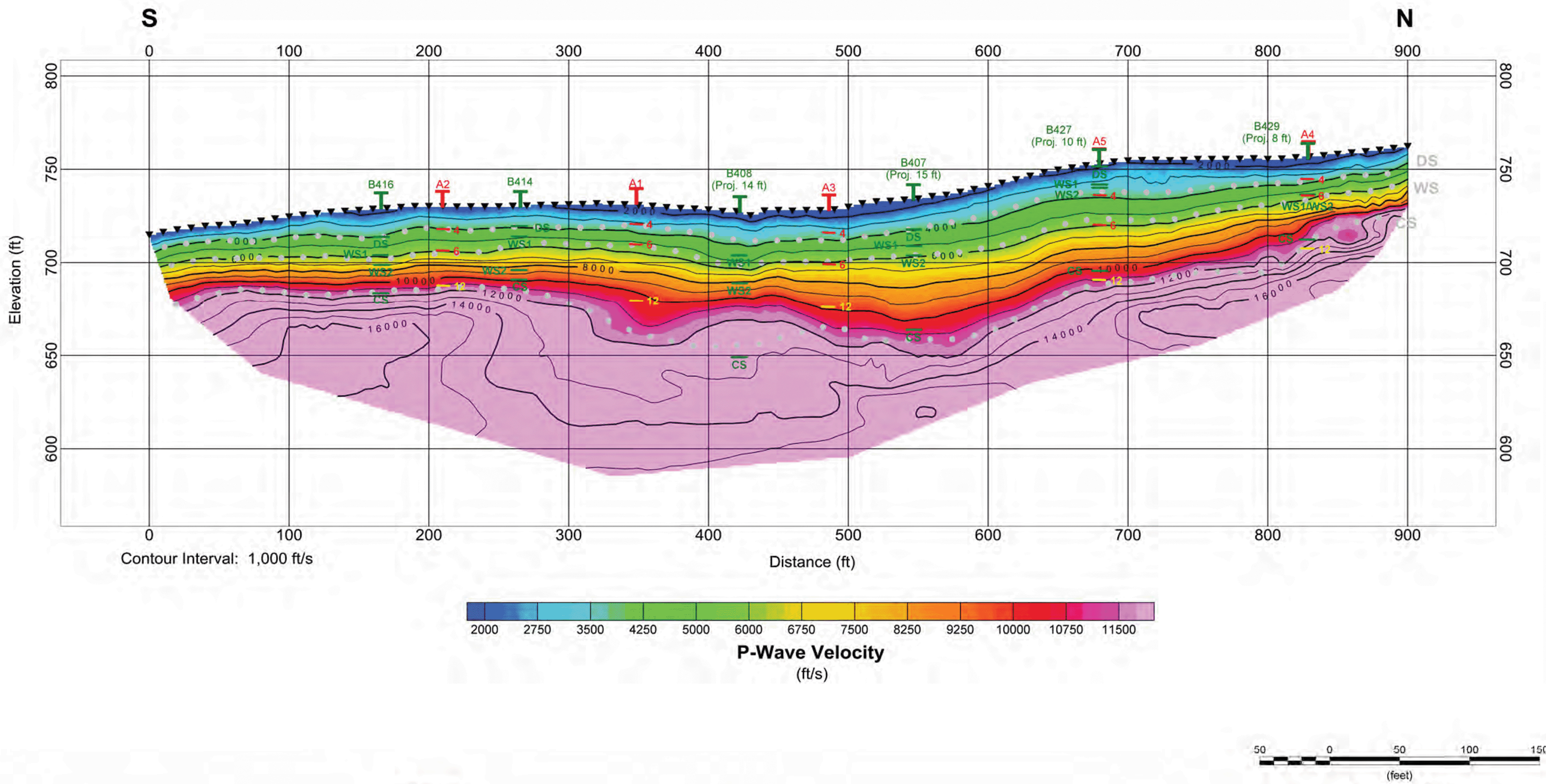
Figure 11A

Line B1 - Seismic Tomography Model with Velocity Constraints

Bell Bend Nuclear Power Plant
Luzerne County, Pennsylvannia

Prepared for Paul C. Rizzo Associates, Inc.

Project No. 10171



LEGEND

▼ Geophone Location	DS Borehole Interpreted Decomposed Shale	4	4,000 ft/s Contour on Intersecting Line
T Line Intersection	WS1 Borehole Interpreted Weathered Shale	6	6,000 ft/s Contour on Intersecting Line
	WS2 Borehole Interpreted Weathered Shale with RQD > 0	12	12,000 ft/s Contour on Intersecting Line
T Borehole Location	CS Borehole Interpreted Competent Shale		

Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

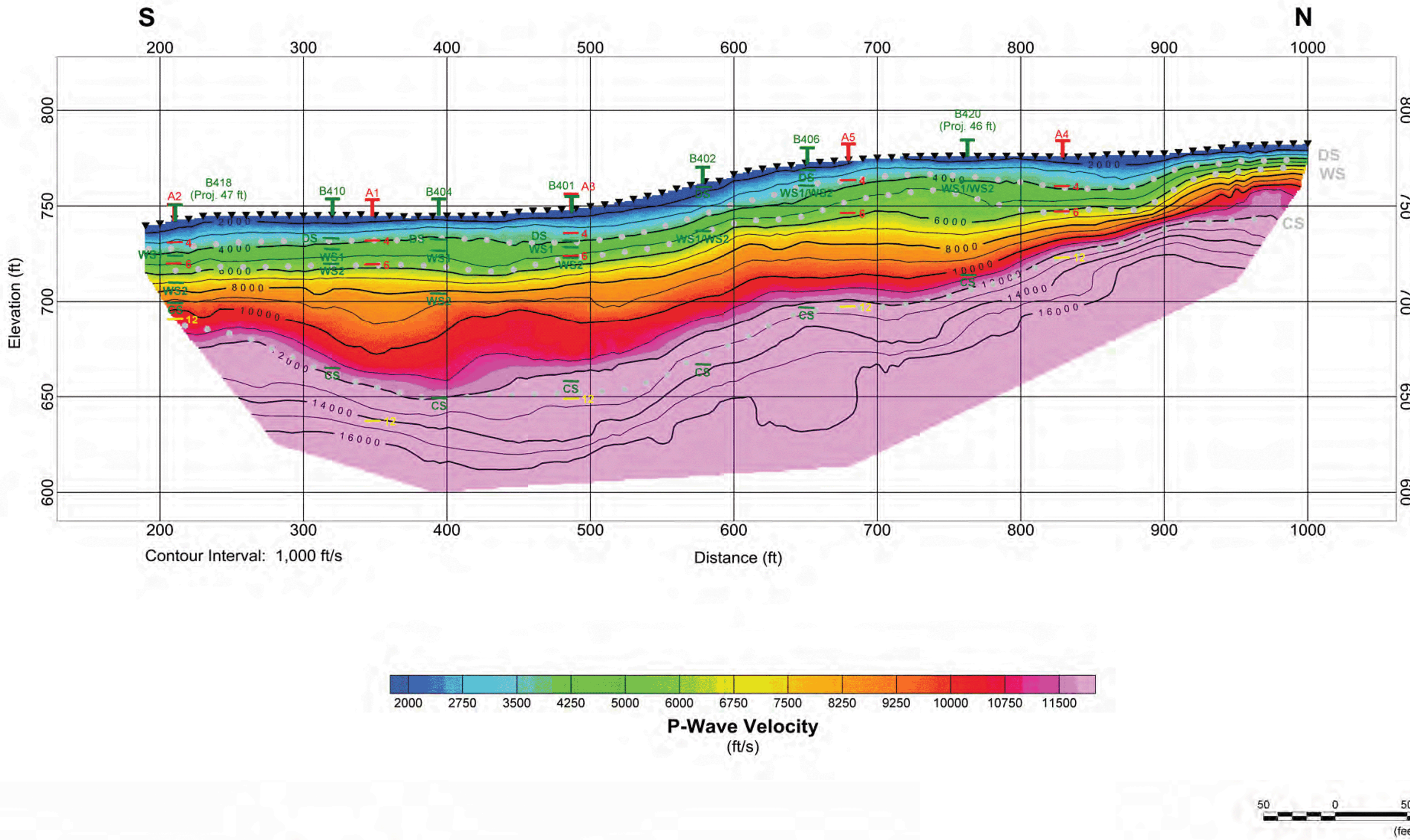
Figure 11B

Line B1 - Seismic Tomography Model without Velocity Constraints

Bell Bend Nuclear Power Plant
Luzerne County, Pennsylvannia

Prepared for Paul C. Rizzo Associates, Inc.

Project No. 10171



LEGEND

▼ Geophone Location
T Line Intersection
T Borehole Location

— DS Borehole Interpreted Decomposed Shale
— WS1 Borehole Interpreted Weathered Shale
— WS2 Borehole Interpreted Weathered Shale with RQD > 0
— CS Borehole Interpreted Competent Shale

— 4 4,000 ft/s Contour on Intersecting Line
— 6 6,000 ft/s Contour on Intersecting Line
— 12 12,000 ft/s Contour on Intersecting Line

• • • • Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

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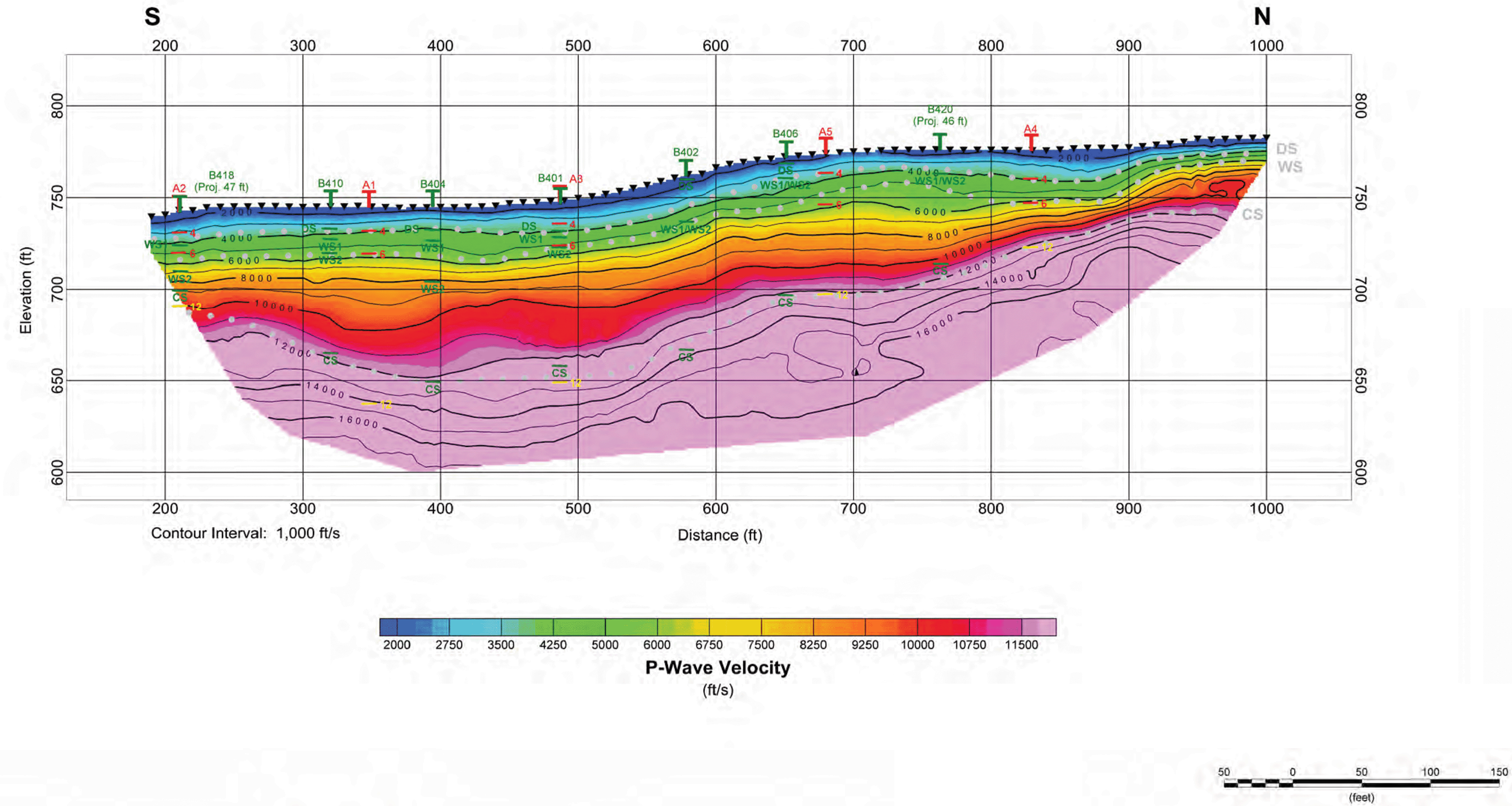
Figure 12A

Line B2 - Seismic Tomography Model with Velocity Constraints

Bell Bend Nuclear Power Plant
Luzerne County, Pennsylvannia

Prepared for Paul C. Rizzo Associates, Inc.

Project No. 10171



LEGEND

▼ Geophone Location	— DS Borehole Interpreted Decomposed Shale	— 4	4,000 ft/s Contour on Intersecting Line
T Line Intersection	— WS1 Borehole Interpreted Weathered Shale	— 6	6,000 ft/s Contour on Intersecting Line
T Borehole Location	— WS2 Borehole Interpreted Weathered Shale with RQD > 0	— 12	12,000 ft/s Contour on Intersecting Line
	— CS Borehole Interpreted Competent Shale		

• • • • Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

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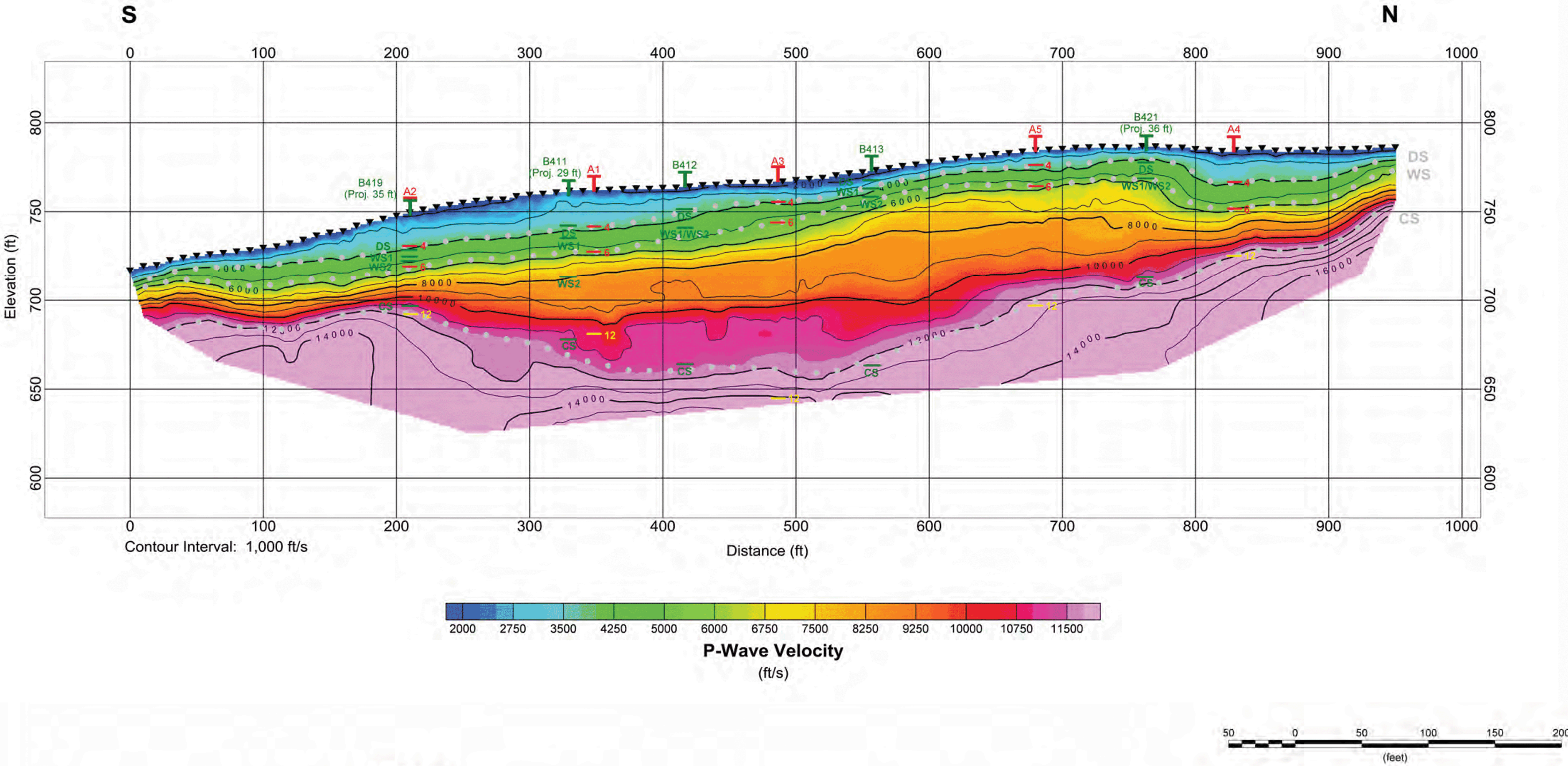
Figure 12B

Line B2 - Seismic Tomography Model without Velocity Constraints

Bell Bend Nuclear Power Plant
Luzerne County, Pennsylvannia

Prepared for Paul C. Rizzo Associates, Inc.

Project No. 10171



LEGEND

- ▼ Geophone Location
- T Line Intersection
- T Borehole Location
- DS Borehole Interpreted Decomposed Shale
- WS1 Borehole Interpreted Weathered Shale
- WS2 Borehole Interpreted Weathered Shale with RQD > 0
- CS Borehole Interpreted Competent Shale
- 4 4,000 ft/s Contour on Intersecting Line
- 6 6,000 ft/s Contour on Intersecting Line
- 12 12,000 ft/s Contour on Intersecting Line
- Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

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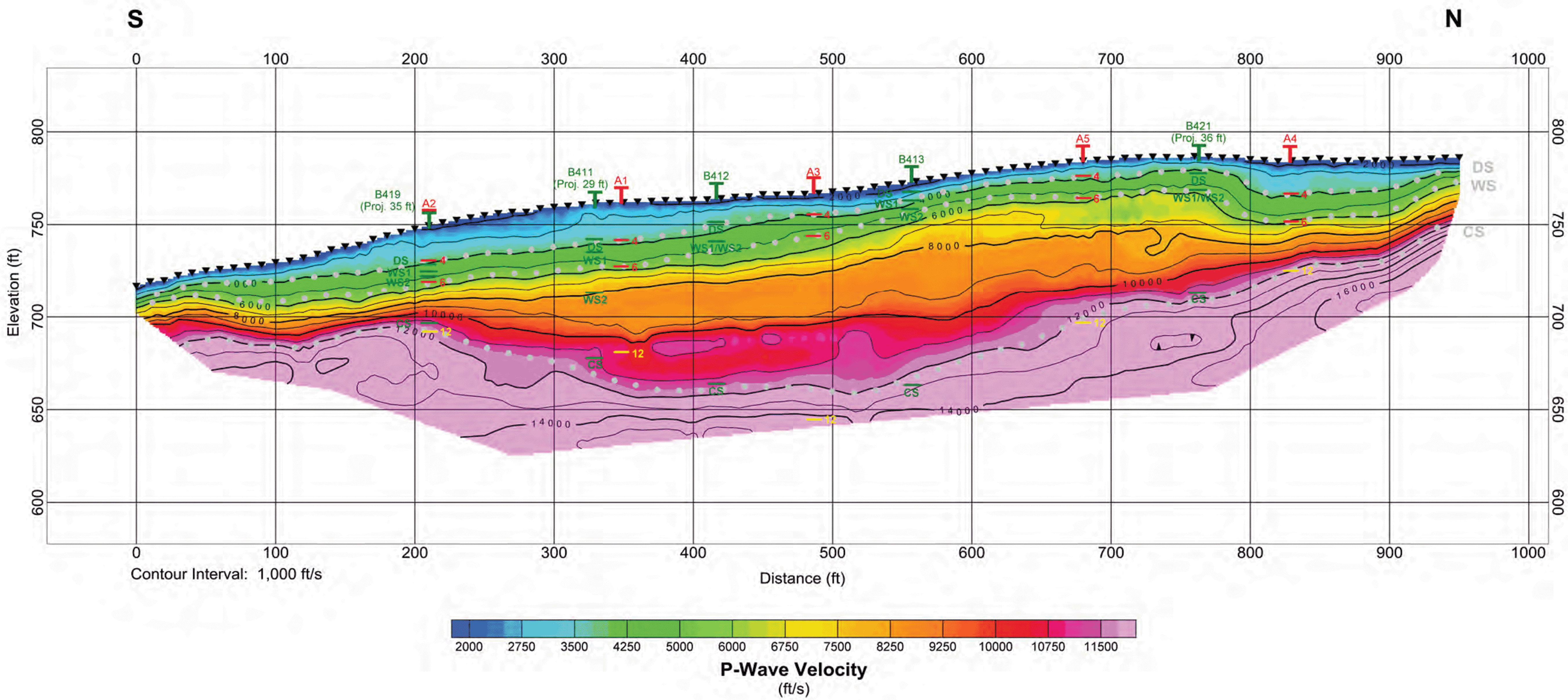
Figure 13A

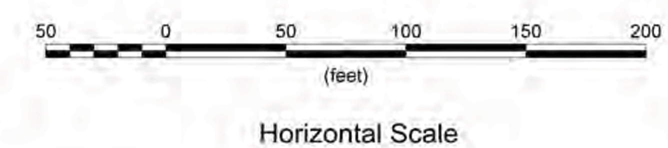
Line B3 - Seismic Tomography Model with Velocity Constraints

Bell Bend Nuclear Power Plant
Luzerne County, Pennsylvania

Prepared for Paul C. Rizzo Associates, Inc.

Project No. 10171





LEGEND

- ▼ Geophone Location
- T Line Intersection
- T Borehole Location
- DS Borehole Interpreted Decomposed Shale
- WS1 Borehole Interpreted Weathered Shale
- WS2 Borehole Interpreted Weathered Shale with RQD > 0
- CS Borehole Interpreted Competent Shale
- 4 4,000 ft/s Contour on Intersecting Line
- 6 6,000 ft/s Contour on Intersecting Line
- 12 12,000 ft/s Contour on Intersecting Line
- Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

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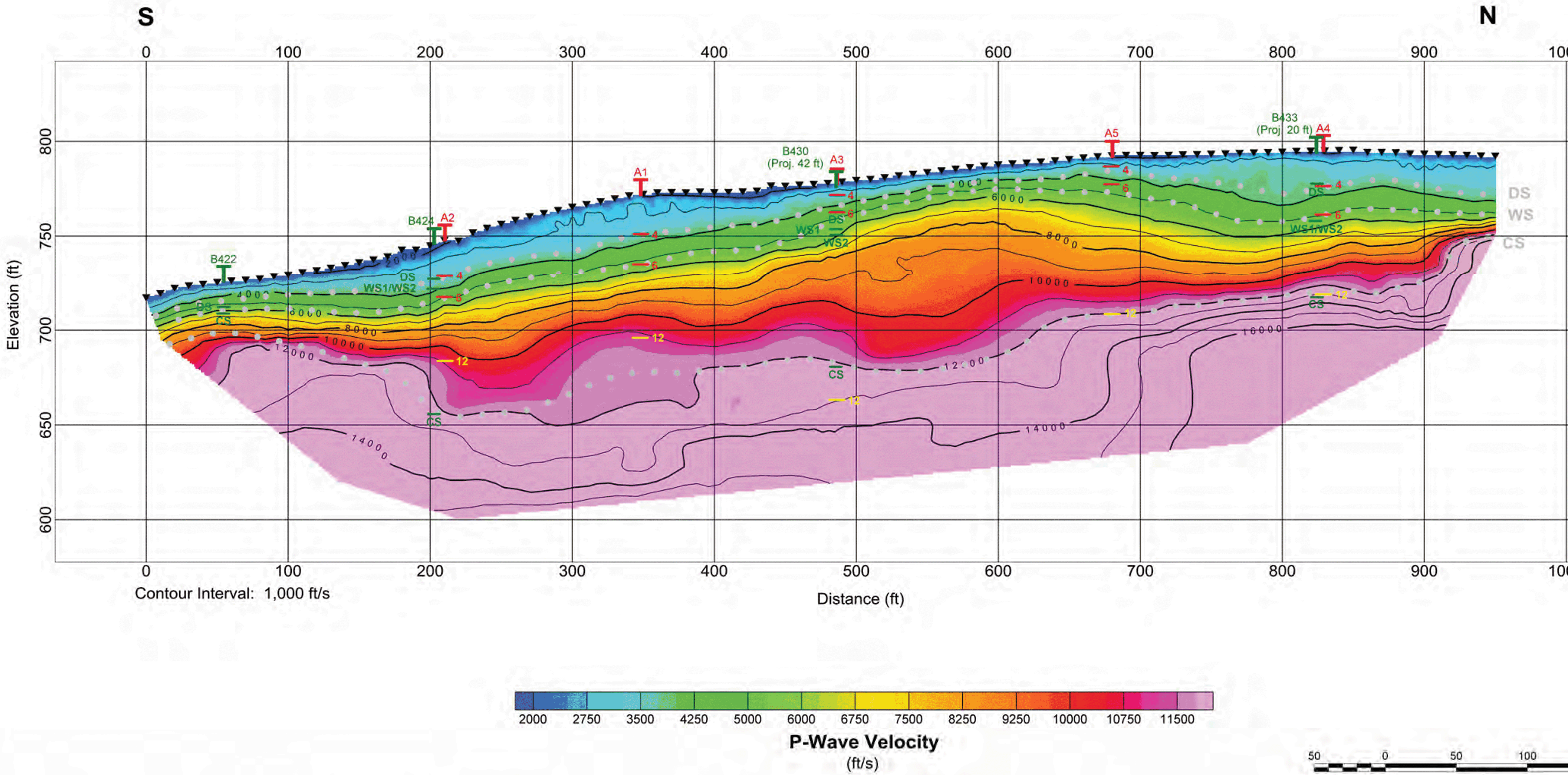
Figure 13B

Line B3 - Seismic Tomography Model without Velocity Constraints

Bell Bend Nuclear Power Plant
Luzerne County, Pennsylvannia

Prepared for Paul C. Rizzo Associates, Inc.

Project No. 10171



LEGEND

- ▼ Geophone Location
- T Line Intersection
- T Borehole Location
- DS Borehole Interpreted Decomposed Shale
- WS1 Borehole Interpreted Weathered Shale
- WS2 Borehole Interpreted Weathered Shale with RQD > 0
- CS Borehole Interpreted Competent Shale
- 4 4,000 ft/s Contour on Intersecting Line
- 6 6,000 ft/s Contour on Intersecting Line
- 12 12,000 ft/s Contour on Intersecting Line
- Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

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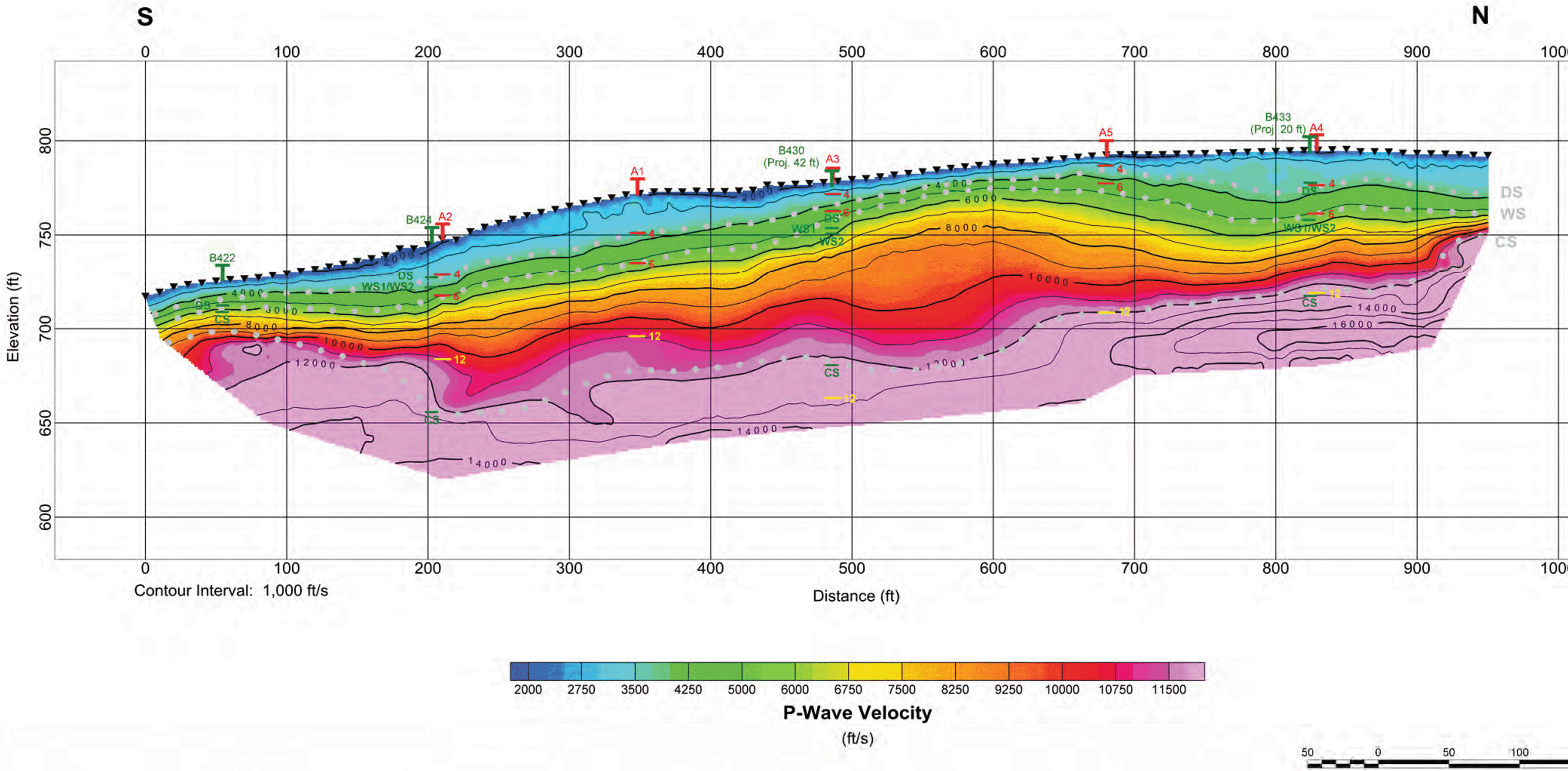
Figure 14A

Line B4 - Seismic Tomography Model with Velocity Constraints

Bell Bend Nuclear Power Plant
Luzerne County, Pennsylvania

Prepared for Paul C. Rizzo Associates, Inc.

Project No. 10171



LEGEND

▼ Geophone Location	— DS Borehole Interpreted Decomposed Shale	— 4 4,000 ft/s Contour on Intersecting Line
T Line Intersection	— WS1 Borehole Interpreted Weathered Shale	— 6 6,000 ft/s Contour on Intersecting Line
T Borehole Location	— WS2 Borehole Interpreted Weathered Shale with RQD > 0	— 12 12,000 ft/s Contour on Intersecting Line
	— CS Borehole Interpreted Competent Shale	

• • • Interpreted Geologic Horizon (DS = Decomposed Shale, WS = Weathered Shale, CS = Competent Shale)

Note: Borehole intersections are marked with projected distances if greater than 5 ft from the line. All projected distances are rounded to the nearest foot.

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Figure 14B

Line B4 - Seismic Tomography Model without Velocity Constraints

Bell Bend Nuclear Power Plant
Luzerne County, Pennsylvannia

Prepared for Paul C. Rizzo Associates, Inc.

Project No. 10171