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Revision 0

Seismic Reflection Investigation at the Liquid Effluent Retention Facility, 200 East Area, Hanford Site Richland, Washington

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CH2MHILL
Plateau Remediation Company
P.O. Box 1600
Richland, Washington 99352

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Program/Project: SGW

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REPORT

SEISMIC REFLECTION INVESTIGATION AT THE LERF PROJECT SITE IN RICHLAND, WASHINGTON

Contract 45109

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March 14, 2012

Project No. 113-93040

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1.0 INTRODUCTION

CH2M Hill Plateau Remediation Company (CHPRC) is focusing on the safe, environmental cleanup of the Central Plateau of the Department of Energy's (DOE's) Hanford Site. CHPRC is primarily focused on the treatment and disposal of various radioactive waste streams, groundwater, management of spent nuclear fuel, disposal or disposition of nuclear materials, and non-reactor nuclear facilities, and environmental remediation activities currently funded through DOE's Office of Environmental Management. One location where soil and groundwater remediation efforts are focused is the Liquid Effluent Retention Facility (LERF) in the 200 East Area.

Under contract 45109, Golder Associates Inc. (Golder) conducted a geophysical investigation consisting of check shot surveys, compressional wave (p-wave) reflection, shear wave (s-wave) reflection, and refraction surveying near LERF.

The scope of work involved two phases of investigation with Phase I being an initial field demonstration of the p-wave and s-wave reflection methods along two profiles approximately 1.5 km in length. Based on results of the Phase I investigation, s-wave reflection was dropped from the Phase II field investigation and replaced with seismic refraction. Phase II was based on the results of the field demonstration and consisted of an additional 5 km of surveying. This report presents the p-wave reflection and refraction results and interpretations of the geology in the vicinity of LERF.

1.1 Project Objective

This geophysical investigation is part of a broader effort using complementary geophysical methods to map the top of basalt surface, character of the upper part of the basalt, stratigraphy within the supra-basalt section, presence or absence of paleochannels, and faults within in the 200 East Area.

This geophysical survey was conducted to assist CHPRC with development of conceptual site models of the hydrogeology.

Seismic surveys were designed to investigate to depths of up to 100 m with the primary target being the character of the upper 15 m to 30 m of the underlying basalt. The top of basalt ranges from approximately 55 m to 79 m below ground surface (bgs) near the LERF. Secondary targets include describing the heterogeneity of the overlying Hanford sediments.

1.2 General Geology of Hanford Area

The general geologic setting in the 200 Areas and the Central Plateau includes basalt bedrock between approximately 152 m bgs in the south to 18 m bgs in the north, with known depth to basalt near LERF ranging from 55 m to 79 m bgs. The upper 3 m to 10 m of the basalt may be highly fractured and/or weathered, and serve as the basal or whole portion of the unconfined aquifer.

The basalt is overlain by heterogeneous glaciofluvial gravel, cobble, and sand deposits of the Hanford Formation. There is no significant hydro-stratigraphic barrier between the sedimentary units and underlying basalt. The Hanford Formation is generally characterized as three distinct facies, the lower (H1) Cold Creek Unit, a middle (H2) gravel-dominated Pasco Gravels Unit, and an upper (H3) fine-grained facies referred to as the Touchet Beds (Reidel and Fecht 2005). For the purposes of interpretation in this report, the Hanford Formation is referred to as undifferentiated sands and gravels.

Groundwater levels range from 100 m bgs in the south to 61 m bgs in the north and average about 61 m to 64 m bgs in the survey area. Often, groundwater levels are within a few meters of the bedrock surface.

Table 1-1 lists the boreholes in the vicinity of LERF that were used to understand local geologic conditions and guide interpretations of geophysical models.

Table 1-1: Geologic Control Boreholes

Well Name	NAD-83 State Plane East (m)	NAD-83 State Plane North (m)	Basalt Elevation (m)	Basalt Depth (m)	Line #	Approx. Line Distance (m)
299-E26-10	575589.0	137023.5	121.2	62.3	1	65
299-E26-11	576180.0	137134.6	122.6	60.4	8	222
299-E26-1	575231.0	137091.9	120.1	68.6	1W	8
299-E27-10	575100.3	137052.4	117.6	73.2	1W	184
299-E27-9	574917.6	137040.9	117.6	74.7	1W	168
299-E34-3	575110.3	137301.4	121.9	64.9	3w	5
299-E34-5	574643.8	137743.3	122.7	57.9	6	690
299-E34-7	575274.2	137357.7	121.8	62.5	3w	170
299-E35-1	575459.7	137465.0	122.5	60.0	3w	355
299-E35-2	575576.1	137255.1	122.7	61.0	2	83
699-47-46A	575869.8	137820.7	124.3	53.0	4	400
299-E26-79	575827.9	137051.5	119.3	63.1	1	303
699-50-53B	573655.5	138659.5	122.7	47.49	7	1715

2.0 GEOPHYSICAL METHODS

2.1 Seismic Reflection

Seismic reflection is a commonly accepted method for mapping the stratigraphic boundary between unconsolidated sediments and bedrock where the bedrock is expected to be greater than 30 m below the ground surface. This method uses a controlled energy source (e.g. weight drop and/or sledgehammer) at given locations (shot points) to inject a seismic signal into the subsurface. The seismic signal is reflected from interfaces between materials having differing acoustic characteristics such as the interface between sand and gravel. The reflected seismic signals are received by a series of geophones that are connected to a seismic cable laid on the ground in a linear configuration. The geophones are placed several inches into the ground and spaced evenly along the geophone cable.

The seismic energy source is discharged at a shot point between each of the geophones and off the ends of the line. The geophones convert the reflected acoustic energy to an electrical signal which is stored on the seismograph for later processing and analysis. The timing of the reflected acoustic energy (raw seismic data) is processed to determine the seismic velocity of the earth material through which the energy has traveled and to model the subsurface geology. Determination of seismic velocity allows for interpreted geophysical models to be generated that depict the earth in cross-section. Sharp contrasts in seismic velocity produced by contacts between various stratigraphic units can be mapped in cross section. Interpretation of the lithology is based on the seismic characteristics of the reflectors and information obtained from boreholes and/or outcrops.

2.2 Seismic Refraction

Seismic refraction is a method commonly used to map the depth to bedrock for geologic investigations when underlying bedrock is more competent (and a higher seismic velocity) than the overlying layers. The method requires a seismic energy source to introduce seismic waves into the subsurface. The seismic waves penetrate the overburden and travel along interfaces with higher seismic velocity than the layer above. Typically this is the water table or the top of the bedrock. While the seismic waves are traveling along this surface, they continually transmit seismic waves back to the ground surface where they are detected by geophones. Geophones convert the acoustic energy in the ground to an electric signal that is transmitted by the geophone cable to the seismograph. The seismograph detects the arriving electric signals with respect to time and stores the records digitally for future data processing. The seismic data is processed to determine the seismic velocity of the earth material through which the energy has traveled and to model the subsurface geology. This geophysical model depicts the earth in cross-section showing the velocity and thickness of the subsurface layers below the seismic line.

Seismic refraction data were collected using a 72-channel Geometrics GEODE seismograph. The 72 geophones were spaced at 1.5-m intervals. A PEG-40 was used as the seismic source. Generally, 11 shot points were recorded for each refraction spread. Off-end shot points were located +/- 159.75 m, +/- 106.5 m, +/- 53.25 m, and at geophones 1 and 72. Shot points internal to the refraction spread were located at geophone 18, between geophones 36 and 37, and at geophone 54.

2.3 Check Shot Survey

Check shot surveys, also known as the downhole seismic method, make direct measurements of compression and shear wave velocities between a surface seismic source and a borehole geophone. The downhole geophone is often a tri-axial component receiver and is used to detect the first arrival times of the wave train. The borehole geophone is positioned at select depths in the borehole based on the measurement interval required for the survey. The method requires a seismic energy source to introduce seismic waves into the subsurface. The seismic source is often an impact source such as a sledgehammer or other large weight drop. Geophones convert the acoustic energy in the ground to an electric signal that is transmitted by the geophone cable to the seismograph. The seismograph detects the arriving electric signals with respect to time and stores the records digitally for future data processing. The seismic data is processed to determine the seismic velocity profile of the earth material through which the energy has traveled and to model the subsurface geology.

2.4 Geo-referencing Survey Data

A real time kinematic (RTK) differential global position system was used to determine project coordinates. This system consists of a base unit that was centered on monitoring well 299-E26-10 and a rover unit that was used by the field geophysicists to measured coordinates. Refer to Table 1-1 for the coordinates of monitoring well 299-E26-10 used for the base station. Golder used two RTK GPS systems during field work, a Trimble R7 and a Hemisphere R130.

3.0 SEISMIC SURVEY DESIGN

3.1 Land Streamer P-wave Seismic Reflection

Figure 1 is a map showing (in red) the locations of the compressional (p-wave) seismic reflection lines. The locations of the seismic reflection lines were determined in consultation with the CHPRC representatives. The survey was designed to image to a depth of approximately 100 m bgs. Line 1 p-wave data were collected using a spread of 72 spike-mounted geophones spaced 2 m apart. Shot points were collected at 2-m intervals from 20 m before the first geophone to 20 m beyond the last geophone of each spread, then the geophones were picked up and re-planted for collection of the next segment. This resulted in the variability of fold that is particularly noticeable in the shallow portion of the Line 1 profile. All other lines were acquired using a 72-channel land streamer and a 1.5-m geophone spacing. Data collection parameters for the reflection survey are summarized in Table 3-1.

Table 3-1: Land Streamer Seismic Reflection Acquisition Parameters

Parameter	Setting
geophone interval	1.5 m
Shot interval	1.5 m
No. of Geophones	72
Geophone frequency	40Hz
record length	700 ms
Sample interval	0.25 ms
Pre amp gain	36dB
Acquisition filters	none
File format	SEG2

The seismic reflection data set consists of ten individual Lines- 1, 1W, 2, 3, 3W, 4, 5, 7, 8, and 9. In total, 6,195 m of reflection data were acquired during this project. Table 3-2 provides the coordinates of the endpoints of each line as well as the length. Coordinates are in NAD83 WA State Plane South meters.

Table 3-2: Coordinates of Reflection lines

Line	Start	End	CMP Distance (m)	Line Distance (m)
1	575501.88 E 137021.00 N	576593.19 E 137052.33 N	1091	1091
1W	575441.63 E 137014.41 N	574959.88 E 137070.84 N	321	482
2	575501.81 E 137263.30 N	576166.38 E 137272.73 N	444	665
3	575490.13 E 137404.70 N	576198.50 E 137405.00 N	472	708

Line	Start	End	CMP Distance (m)	Line Distance (m)
3W	575458.69 E 137353.45 N	575109.38 E 137360.02 N	236	349
4	575481.63 E 137796.91 N	575770.69 E 137784.27 N	193	289
5	576207.06 E 137404.80 N	576674.81 E 137091.89	312	468
7	575533.19 E 137673.50 N	575400.38 E 138750.20 N	734	1101
8	576206.69 E 136953.80 N	576206.25 E 137404.36 N	301	451
9	575602.81 E 137050.59 N	575599.88 E 137641.33 N	395	591

3.2 Seismic Refraction

Figure 1 is a map showing the location of the refraction lines (blue). The locations of the seismic refraction lines were determined in consultation with the CHPRC representatives. The survey was designed to image to a depth of approximately 75 m bgs. All refraction data were acquired using the 72-channel land streamer and 1.5-m geophone spacing. A PEG-40 was used as the seismic source. Approximately 11 shot points were recorded for each refraction spread. Off-end shot points were located +/- 159.75 m, +/- 106.5 m, +/- 53.25 m, and at geophones 1 and 72. Shot points internal to the refraction spread were located at geophone 18, between geophones 36 and 37, and at geophone 54. Data collection parameters for the seismic refraction survey are summarized in Table 3-3.

Table 3-3: Seismic Refraction Acquisition Parameters

Parameter	Setting
geophone interval	1.5 m
Shot interval	17 - 53 m
No. of Geophones	72
Geophone frequency	40Hz
record length	700 ms

Parameter	Setting
Sample interval	0.25 ms
Pre amp gain	36dB
Acquisition filters	none
File format	SEG2

The seismic refraction data set consists of eight individual Lines- 1, 2, 3, 3W, 4, 6, 8, and 9. In total, 4,065 m of refraction data were acquired during this project. Table 3-4 provides the coordinates of the endpoints of each line as well as the length. Coordinates are in NAD83 WA State Plane South meters.

Table 3-4: Coordinates of Refraction lines

Line	Start	End	Length (m)
1	575529.13 E 137024.18 N	576619.85 E 137053.06 N	1094
1W	575441.60 E 137014.40 N	575493.44 E 137265.53 N	533
2	575501.80 E 137263.32 N	576139.46 E 137272.35 N	638
3	575490.10 E 137404.70 N	576215.00 E 137405.01 N	725
8	576206.70 E 136953.80 N	576206.18 E 137444.02 N	491
9	575602.80 E 137050.60 N	575599.98 E 137634.60 N	584

3.3 Check Shot Survey

Check shot seismic surveying was performed using a Geometrics Geode seismograph, 14 Hz GeoStuff BHG-3 tri-axial borehole geophone, and a sledgehammer with an aluminum plate and wooden plank as the source. Data collection was performed with field assistance from S.M. Stoller Corporation. Data collection parameters are summarized in Table 3-5.

Table 3-5: Check Shot Acquisition Parameters

Borehole	Depth (ft)	Seismic Method P- or S-wave	Measurement Interval (ft)	Source Offset and orientation
699-61-66	160	P	10	75 ft north
299-E26-9	199	P	10	75ft north
299-E29-11	200	P & S	10	75 ft south – P 41 ft south – S

At each borehole, the hole was first sounded using a tape measure and weight to check and confirm the depth of the open hole. Three surface p-wave geophones were placed in line at distances of 0, 10 and 20

ft from the borehole as a check on surface arrival times and trigger offset values. The geophone cable and source trigger wires were connected to the seismic system for recording the subsequent data. The geophone was lowered and raised in the borehole by S.M. Stoller Corporation field staff. The p-wave source was stationed 75 ft from the borehole. The shear wave source plank was stationed 41 ft from the borehole. The seismic shear wave source consisted of a sledgehammer horizontally striking the ends of the plank held in place with the weight of a vehicle.

3.4 S-wave Seismic Reflection

The locations of the shear wave (s-wave) seismic reflection lines, Lines 1 and 2, were determined in consultation with the CHPRC representatives. These lines are coincident with p-wave seismic reflection Lines 1 and 2. Both lines were acquired using a 72-channel land streamer and a 1.5-m geophone spacing. S-wave data were collected as P-S mode-converted data using a p-wave source and s-wave geophones. The amplitudes of such a wave are relatively low compared to the original p-wave. Data collection parameters for the s-wave reflection survey are summarized in Table 3-6.

Table 3-6: Land Streamer Shear Wave Seismic Reflection Acquisition Parameters

Parameter	Setting
geophone interval	1.5 m
Shot interval	1.5 m
No. of Geophones	72
Geophone frequency	40Hz
record length	700 ms
Sample interval	0.25 ms
Pre amp gain	36dB
Acquisition filters	none
File format	SEG2

4.0 DATA PROCESSING

4.1 P-wave Seismic Reflection

Seismic reflection data were processed using the Seismic Processing Workshop (SPW) package commercially available from Parallel Geosciences Corporation. Below are the processing steps used to produce the final depth sections presented in Figures 2 through 5.

- Assign field geometry using observer notes
- Static correction to floating datum, elevation 180 m
- Constant velocity analysis
- Normal move-out correction
- Common mid-point stack
- Predictive deconvolution
- Bandpass filter,10-40 70-120Hz
- Brute stack
- Time to depth conversion
- Depth section

4.2 Seismic refraction

Seismic refraction data were processed using SeisImager 2D PRO commercially available from Geometrics Inc. Below are the processing steps used to produce the tomographic velocity models presented in Figures 7 and 8.

- Edit source and geophone locations
- Use PickWin module to measure first arrival times
- Export file of first arrival times
- Generate initial velocity model-10 layers, 100m thick, 300-3,000 ft/sec
- Perform ray tracing to calculate travel paths
- Tomographic inversion to determine velocity model
- Export model results as x, y, z file

4.3 Check Shot

Check shot data were processed following procedures in ASTM D7400 and SGW-39020. First arrival times were measured using the PickWin module of SeisImager, similar to the process of measuring first arrival times with refraction data. These arrival times, together with the source offset and receiver depth in the borehole were used to calculate the average straight line velocity and interval velocity.

4.4 S-wave Seismic Reflection

Shear wave seismic reflection data were processed using the Seismic Processing Workshop (SPW) package commercially available from Parallel Geosciences Corporation. Below are the processing steps used to produce the brute stack sections presented in Figure 6.

- Assign field geometry using observer notes
- Static correction to floating datum, elevation 180 m
- Constant velocity analysis
- Normal move-out correction
- Common mid-point stack
- Predictive deconvolution
- Bandpass filter,10-40 70-120Hz
- Brute stack

5.0 RESULTS

The following sections briefly describe each of the seismic lines. Interpreted seismic reflection lines are presented in Figures 2 through 6. On these figures, the blue line is the interpreted basalt reflector and the red line is the interpreted supra-basalt reflector internal to the Hanford Formation, most often the contact between the fine-grained facies and the lower coarse-grained facies. The seismic reflection lines are interpreted with regard to relevant borehole logs and the check shot survey results. The interpreted seismic refraction lines are presented in Figures 7 and 8. Refraction lines are interpreted with regard to relevant borehole logs as well as the seismic reflection interpretations. Check shot survey results are presented in Appendix A.

5.1 Seismic Reflection Lines

5.1.1 Line 1 Reflection

Figure 2 presents the interpreted Line 1 p-wave profile. Line 1 is an east to west oriented line located along the southern boundary of the study area. This line is 1,091 meters long. Planted geophones were used for Line 1 rather than the land streamer to help expedite the field data collection schedule. The components of the land streamer were not immediately available when field work began.

The reflector interpreted as the top of basalt is weak and discontinuous. The interpreted basalt reflector is consistent with the reported basalt elevation in boreholes 299-E26-10 and 299-E26-79. The basalt reflector strength is highly variable, primarily due to fold coverage associated with acquisition. This line was not collected as a common offset line, and as such, there is variable fold coverage that creates artifacts masking the basalt reflector. No paleochannels or faults are interpreted on this line. There does appear to be depression on the interpreted basalt surface at a line distance of 1365 m.

5.1.2 Line 2 Reflection

Figure 2 presents the interpreted Line 2 p-wave profile. Line 2 is 665 meters long. The reflector interpreted as the top of basalt is fairly well defined and consistent with the reported basalt elevation in borehole 299-E35-2. There is a depression, possibly a small paleochannel, in the bedrock surface at distance 1,435 m. The reflection character above this depression is consistent with sand and gravel deposits. There is also a mound-like feature between distances 1,270 m and 1,340 m. The character of the basalt reflector suggests the top of the basalt surface is competent and not heavily fractured west of line distance 1,400 m, but is likely a weathered or fractured flow top to the east of 1,400 m. There is no evidence suggesting the presence of faults on this line.

The red line on the figure is interpreted as a supra-basalt reflector internal to the undifferentiated sands and gravels of the Hanford Formation. The reflectors internal to the Hanford Formation on the west end

of the profile suggest a cross-bedding type character to the sediments that is not seen on any of the other seismic sections.

5.1.3 Line 3 Reflection

Figure 2 presents the interpreted Line 3 reflection profile. Line 3 is situated west to east through the center of the study area. This profile is 708 m long. There is a strong reflector, shown in blue on the figure that is interpreted as the top of basalt. There are no boreholes located close enough to seismic Line 3 for a direct comparison with known geology. There are two depressions, possibly a small paleochannels, in the bedrock surface at line distances 1,140 and 1,310 m. There is no evidence suggesting the presence of faults on this line.

The undulating reflectors above the basalt reflector on the east end of the profile suggest typical glaciofluvial deposition of sand, gravel and cobbles associated with the Hanford Formation sands and gravels.

5.1.4 Line 1W Reflection

Figure 3 presents the interpreted Line 1W reflection profile. Line 1W is 482 meters long and located immediately west of Canton Avenue and in-line with Line 1. The reflector interpreted as the top of basalt is coherent east of line distance 1,200 m, but has incoherent to chaotic character west of line distance 1,200 m. Data west of line distance 1,200 is degraded, likely due to wind noise and heavy equipment traffic. The interpreted basalt surface is consistent with the reported basalt elevation in borehole 299-E27-10. There is a depression on the bedrock surface between distances 1140 m and 1190 m that is interpreted as a possible paleochannel.

The upper reflector is interpreted as a stratigraphic contact within the undifferentiated Hanford Formation sands and gravels. This reflector is gently undulating. There also appears to be an incised channel in the sands and gravels that is centered at distance 1280 m.

5.1.5 Line 3W Reflection

Figure 3 presents the interpreted Line 3W reflection profile. Line 3W is 349 m long. The reflector interpreted as the top of basalt is strong and continuous east of distance 1,150 m and highly variable west of distance 1,150 m. This reflector has a character very similar to the basalt reflector on Line 1W. The elevation of the interpreted basalt reflector on Line 3W is consistent with the reported basalt elevation in borehole 299-E34-7.

This is a poorly-defined reflector on the west half of the line that is interpreted as a stratigraphic contact within undifferentiated Hanford Formation. This reflector appears to pinch out at distance 1,170 m. There are no interpretable reflectors above the basalt reflector on the eastern half of Line 3W.

5.1.6 Line 4 Reflection

Figure 3 presents the interpreted Line 4 reflection profile. Line 4 is 289 m long and is the northern-most east-to-west line. This line is approximately 300 m shorter than first planned due to fire-danger considerations that restricted our access.

The reflector interpreted as the basalt reflector is relatively high amplitude and continuous. There are no boreholes located sufficiently close to Line 4. The lower reflector is interpreted as the top of basalt and shows a character similar to the basalt reflector interpreted on other lines. The basalt reflector dips gently to the east. There is no evidence of paleochannels or faults on Line 4.

5.1.7 Line 5 Reflection

Figure 4 presents the interpreted Line 5 reflection profile. Line 5 is 468 m long. Line 5 is the only line oriented northwest to southeast. There are no nearby boreholes to guide the interpretation of the reflectors. The basalt reflector dips to the southeast. There are no paleochannels interpreted on this line. However, there is a potential fault located at line distance 1,070 m. There appears to be an offset in the basalt reflector, but no apparent offset in the reflectors above the top of basalt. The package of reflectors, representing the Pasco Gravels, above the basalt reflector is unusually continuous and high amplitude, and thickens to the southeast. Only nearby Line 8 has a package of reflectors with similar character.

5.1.8 Line 8 Reflection

Figure 4 presents the interpreted Line 8 reflection profile. Line 8 is 451 meters long and is oriented south to north along the east boundary of the LERF perimeter road. The lower reflector is interpreted as the top of basalt. There is a small depression on the basalt reflector between distance 1,060 m and 1,120 m. The interpreted basalt reflector is consistent with the reported basalt elevation in borehole 299-E26-11.

The package of reflectors, representing the undifferentiated Hanford Formation, are consistent with those observed on Line 5, but don't exhibit thickening to the south.

5.1.9 Line 9 Reflection

Figure 4 presents the interpreted Line 9 reflection profile. Line 9 is 591 meters long and is oriented south to north along the access road on the west side of the LERF basins. The lower reflector is interpreted as the top of basalt. This is a continuous but incoherent reflector. It is possible the character of the reflector is due to the gap in seismic coverage due to the presence of a road. Safety reasons required leaving a gap in coverage. There is a small depression on the basalt reflector between distance 1,220 m and 1,290 m. The interpreted basalt reflector is consistent with the reported basalt elevation in boreholes 299-E26-9 and 299-E35-2.

There are few continuous reflectors above the basalt reflector. This can be interpreted as a package of uniform sediments. It is difficult to interpret a stratigraphic contact within the undifferentiated Hanford Formation on this line. The interpreted reflector is weak and discontinuous along the line.

5.1.10 Line 7 Reflection

Figure 5 presents the interpreted Line 7 reflection profile. Line 7 is 1,101 meters long and is oriented south to north at the northern end of the project area. The lower reflector is interpreted as the top of basalt. This is a continuous but incoherent reflector. It is possible the character of the reflector is due to the nature of the flow top, being heavily fractured or variably weathered. The basalt reflector is very flat lying over a relatively long distance. The interpreted basalt reflector is consistent with the reported basalt elevation in borehole 699-50-53B.

There are several continuous reflectors above the basalt reflector. These can be interpreted as a package of flat-lying uniform sands and gravels of the Hanford Formation.

5.1.11 Bay Geophysical 12th Avenue Reflection

Figure 5 presents the reprocessed and interpreted Bay Geophysical 12th Avenue reflection profile. This line is approximately 2,805 m long. The input files for this line are the raw .segY files provided by CHPRC.

The reflector is interpreted as the top of basalt. This is a continuous and generally coherent reflector. There appears to be depression, possibly a paleochannels at line distance 3,215 m, just east of the location where borehole 699-47-50 projects onto this seismic line. The interpreted seismic bedrock elevation matches reasonably well with the reported bedrock elevation reported on the lithologic log.

There are no obvious reflectors above the basalt reflector. These can be interpreted as a package of massive, uniform sands and gravels that don't show much layering.

5.1.12 Bay Geophysical Canton Avenue Reflection

Figure 5 presents the reprocessed and interpreted Bay Geophysical Canton Avenue reflection profile. This line is approximately 3,320 m long. The input files for this line are the raw .segY files provided by CHPRC. The observer notes recorded during data acquisition indicate heavy traffic volume that had a negative impact on data quality.

The reflector is interpreted as the top of basalt. The section between line distances 1,200 and 2,000 m shows a very strong, coherent reflector. This area is interpreted as representing competent bedrock with very few fractures. The interpreted bedrock reflector is much more subtle over the remaining portion of the line. The interpreted seismic bedrock elevation matches reasonably well with the reported bedrock elevation for well 299-E26-8.

There are no obvious reflectors above the basalt reflector that could be interpreted as layers within the overlying sand and gravel sequence.

5.2 Shear Wave Seismic Reflection

S-wave seismic reflection results were generally poor. This is likely due to the relatively small input energy from the P-wave seismic source. It is possible that s-wave reflection could prove to be a suitable method at LERF if an s-wave vibratory source is used rather than an impact source. It was decided by the project team to discontinue s-wave reflection in favor of p-wave seismic refraction. P-wave refraction was chosen because it helps understand the velocity structure of the materials below LERF, but also because first arrival energy was crisp and coherent in the seismic reflection records.

5.2.1 Line 1 S-wave Reflection

Figure 6 presents the interpreted Line 1 s-wave profile. Line 1 is 1,081 m long and coincident with the location of the Line 1 p-wave reflection profile. There is no strong continuous basalt reflector like there is in the p-wave data. There are several discontinuous segments of reflectors interpreted as being within the Touchet Beds. No reflectors are interpreted in the Pasco Gravels or the underlying basalt.

5.2.2 Line 2 S-wave Reflection

Figure 6 presents the interpreted Line 2 s-wave profile. Line 2 is 520 meters long and coincident with the location of the Line 2 p-wave reflection profile. There is no strong continuous reflector like the reflector in the p-wave data for Line 2. Around a line distance of 1,150, there is a shallow packet of strong, coherent reflectors that appear to represent stratigraphy within the shallow unconsolidated sediments of the Touchet Beds.

5.3 Seismic Refraction

5.3.1 Line 1 Refraction

Figure 7 presents the interpreted Line 1 refraction profile. Line 1 is 1,118 m long and coincident with the location of the Line 1 p-wave reflection profile. There are three layers interpreted in this section, the basalt bedrock, Pasco Gravels, and the Touchet Beds. The seismic velocity of the basalt is greater than approximately 2,200 m/s. The seismic velocity of the Pasco Gravel layer is interpreted to be between 1,200 and 2,200 m/s. The seismic velocity of the Touchet Beds in interpreted to be less than 1,200 m/s.

5.3.2 Line 2 Refraction

Figure 7 presents the interpreted Line 2 p-wave profile. Line 2 is 639 m long. There are three layers interpreted in this section, the basalt bedrock, Pasco Gravels, and the Touchet Beds. The seismic velocity of the basalt is greater than approximately 2,200 m/s. The seismic velocity of the Pasco Gravel

layer is interpreted to be between 1,200 and 2,200 m/s. The seismic velocity of the Touchet Beds in interpreted to be less than 1,200 m/s.

5.3.3 Line 3 Refraction

Figure 7 presents the interpreted Line 3 p-wave profile. Line 3 is 725 m long. There are three layers interpreted in this section, the basalt bedrock, Pasco Gravels, and the Touchet Beds. The seismic velocity of the basalt is greater than approximately 2,200 m/s. The seismic velocity of the Pasco Gravel layer is interpreted to be between 1,200 and 2,200 m/s. The seismic velocity of the Touchet Beds in interpreted to be less than 1,200 m/s.

5.3.4 Line 1W Refraction

Figure 8 presents the interpreted Line 8 p-wave profile. Line 8 is 533 m long. There are three layers interpreted in this section, the basalt bedrock, Pasco Gravels, and the Touchet Beds. The seismic velocity of the basalt is greater than approximately 2,200 m/s. The seismic velocity of the Pasco Gravel layer is interpreted to be between 1,200 and 2,200 m/s. The seismic velocity of the Touchet Beds in interpreted to be less than 1,200 m/s.

5.3.5 Line 8 Refraction

Figure 5 presents the interpreted Line 1 s-wave profile. Line 1 is 492 m long. There are three layers interpreted in this section, the basalt bedrock, Pasco Gravels, and the Touchet Beds. The seismic velocity of the basalt is greater than approximately 2,200 m/s. The seismic velocity of the Pasco Gravel layer is interpreted to be between 1,200 and 2,200 m/s. The seismic velocity of the Touchet Beds in interpreted to be less than 1,200 m/s.

5.3.6 Line 9 Refraction

Figure 6 presents the interpreted Line 2 s-wave profile. Line 2 is 586 m long. There are three layers interpreted in this section, the basalt bedrock, Pasco Gravels, and the Touchet Beds. The seismic velocity of the basalt is greater than approximately 2,200 m/s. The seismic velocity of the Pasco Gravel layer is interpreted to be between 1,200 and 2,200 m/s. The seismic velocity of the Touchet Beds in interpreted to be less than 1,200 m/s.

5.4 Check Shot

Check shot results are presented in Figure 9 and Appendix A. The results from boreholes 299-E26-9 and 299-E26-11 are compared to the seismic reflection sections from Lines 9 and 8 respectively. There is good general agreement in the results as there is a large increase in velocity at the depth where there is a reflector within the Pasco Gravels. The s-wave results for 299-E26-11 are suspect, likely due to a relatively low energy seismic source and environmental noise. None of the wells reached bedrock and there is no check shot data from within the bedrock. The range of velocities between 1,000 and 4,500 ft/s

determined from the check shot surveys is consistent with the velocity analysis performed during seismic reflection processing and the interpreted refraction models.

6.0 CONCLUSIONS

There is excellent consistency between the seismic reflection, seismic refraction, and the check shot survey results. There appears to be three geologic layers present, the Columbia River Basin Group Basalt, Pasco Gravels of the Hanford Formation, and Touchet Beds of the Hanford Formation. The velocity profiles from check shot surveying are similar to the velocity analysis results performed as part of the seismic reflection processing. The seismic reflection interpretations of the basalt bedrock are a good match to existing borehole control. The same is also true for the seismic refraction profiles.

The character of the basalt reflector is fairly variable across the various survey lines. There are areas where the character is continuous and coherent and interpreted as representing competent bedrock with very little weathering or fracturing. There are also areas where the bedrock reflector is weak and discontinuous and interpreted as possibly representing a flow top that is fractured or heavily weathered. A potential fault was identified on the northwest end of Line 5. This area should be investigated further with reflection lines oriented northwest to southeast.

The tomographic models from refraction surveying show the same general stratigraphy as the seismic reflection, but with less vertical resolution. The irregular contour patterns within the tomographic model could represent lateral variations in the composition of the unconsolidated sediments.

Figure 10 is a summary of the interpreted top of basalt. Bedrock elevations are contoured using a contour interval of 5 m. There are no prominent paleochannels interpreted on this map. There are incidental depressions at various locations on the basalt reflectors, but none appear to extend from one line to another.

7.0 LIMITATIONS OF GEOPHYSICAL METHODS

Golder services will be conducted in a manner consistent with that level of care and skill ordinarily exercised by other members of the geophysical community currently practicing under similar conditions subject to the time limits, and financial and physical constraints applicable to the services. Seismic reflection and refraction are remote sensing geophysical methods that may not detect all subsurface features of interest, including faults, fractures, and stratigraphic horizons.

8.0 REFERENCES

Reidel, S.P., K.R. Fecht, 2005 Geology of the Integrated Disposal Facility Trench, Pacific Northwest National Laboratory document PNNL-15237.

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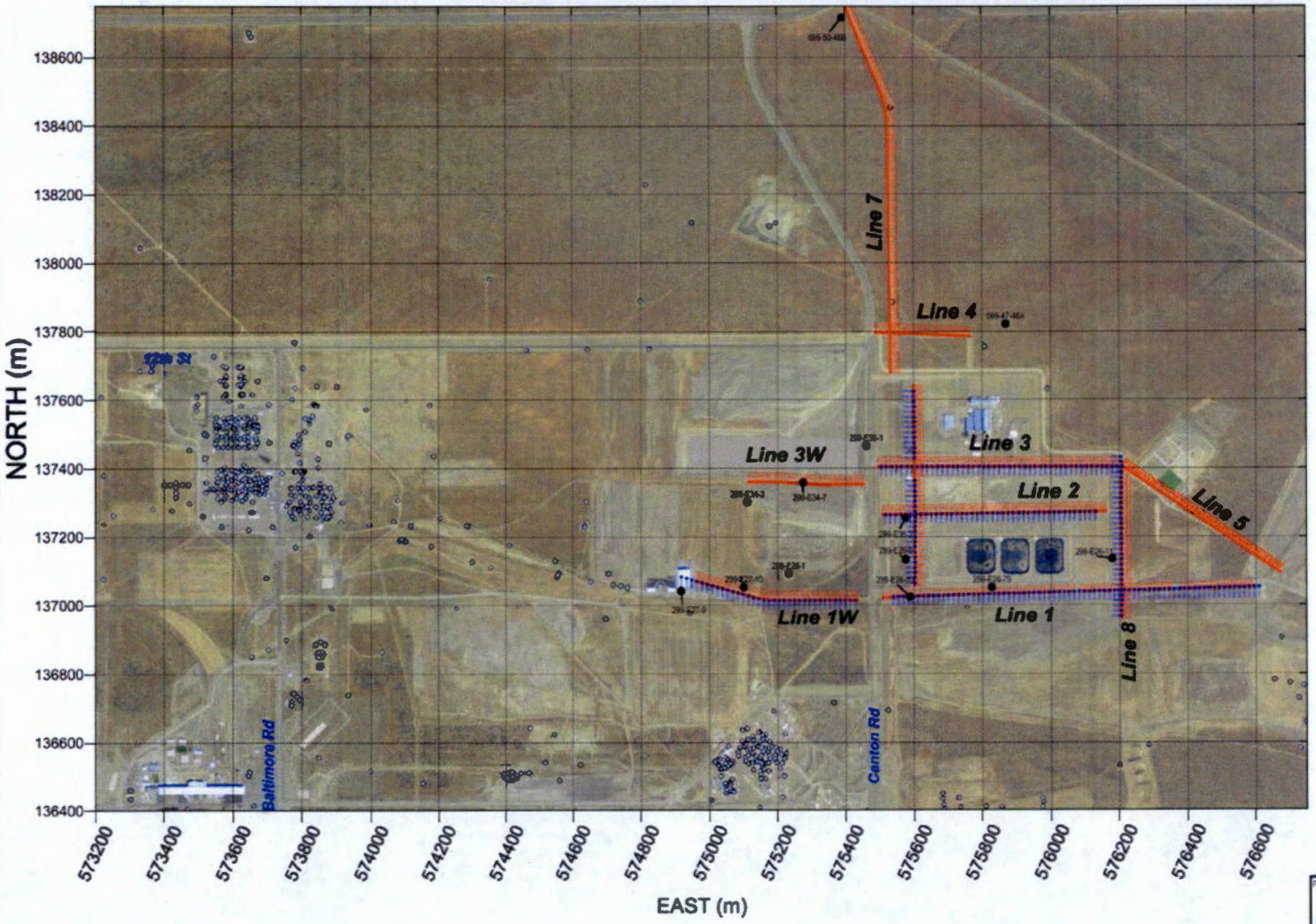
Standard Guide for Using the Seismic-Reflection Method for Shallow Subsurface Investigation, ASTM Designation: D7128-05, American Society for Testing and Materials. 2005.

Standard Test Methods for Downhole Seismic Testing, ASTM Designation: D7400-08, American Society for Testing and Materials. 2008.

FIGURES



LEGEND

- Seismic Reflection Line with CMP Location Label
- Seismic Refraction Line with Line Location Label
- Basalt Well Location shown on Seismic Figures

NOTES:

1. Seismic reflection and refraction data collected June -August 2011.
2. Seismic data collected using 72 channel Geometrics GEODE system.
3. Seismic data processed using SeisImager Pro and SPW software.
4. Base Map provided by CHPRC,
5. Horizontal datum is WA State Plane South meters, NAD83.
6. Survey objective is to map help map the top of basalt bedrock.

PROJECT

CONTRACT 45109
LERF GEOPHYSICAL SURVEY
HANFORD 200 EAST AREA

TITLE

200 EAST - LERF GEOPHYSICAL SURVEY SEISMIC REFLECTION AND REFRACTION LINE LOCATIONS

Golder Associates

PROJECT No.	113-93040.200		FILE No. —	
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REVIEW	ML	1/31/12		

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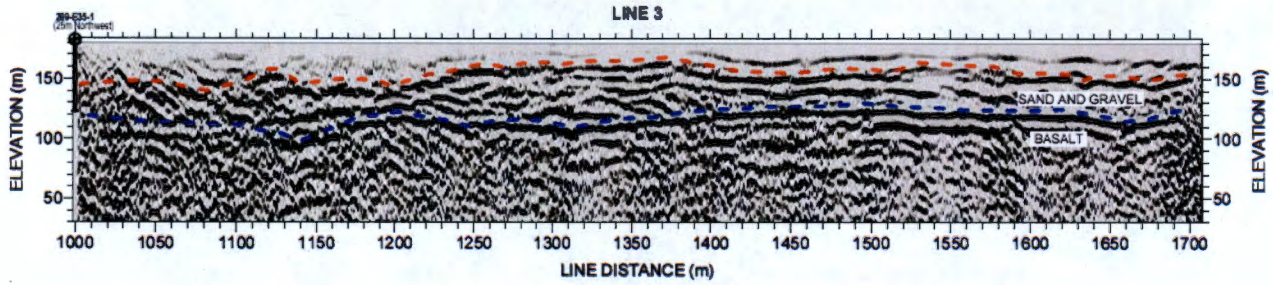

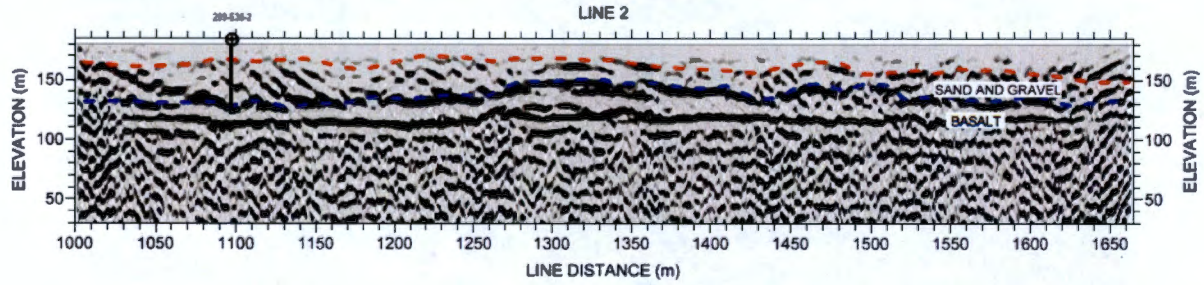

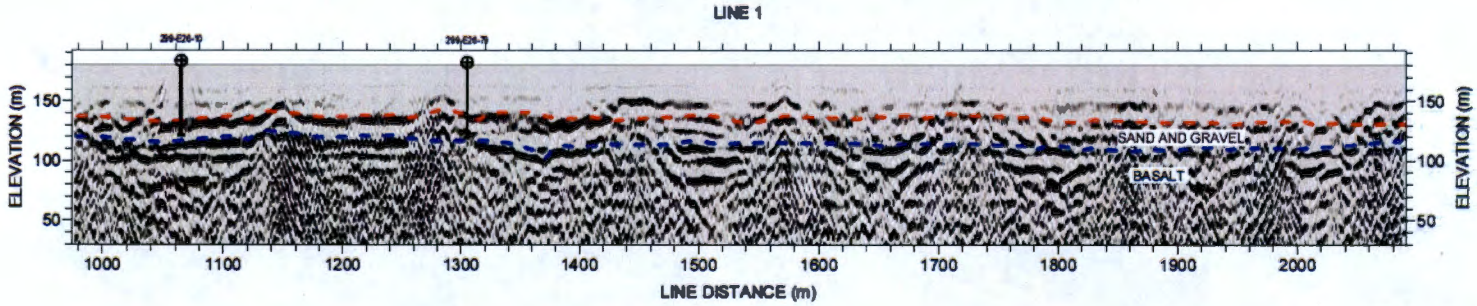

NOTES:
1. Seismic reflection data collected in June and July 2011.
2. Seismic reflection data collected using 72 channel streamer with 40 Hz geophones.
3. Seismic reflection data processed using SPW software from Parallel Geosciences.
4. Base map and survey locatons provided by CHPRC.
5. Survey objective is to map help map the top of basalt bedrock.

PROJECT
CONTRACT 45109
LERF GEOPHYSICAL SURVEY
HANFORD 200 EAST AREA

TITLE
200 EAST - LERF GEOPHYSICAL SURVEY
SEISMIC REFLECTION RESULTS
LINES 1, 2 & 3 P-WAVE DEPTH SECTIONS

Golder Associates

PROJECT No.	113-93040.200		FILE No. —	
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CHECK	ML	1/31/12		
REVIEW	ML	1/31/12		

WEST

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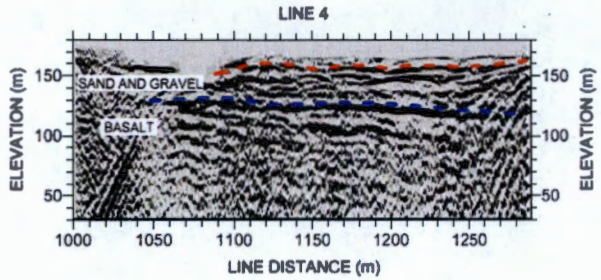

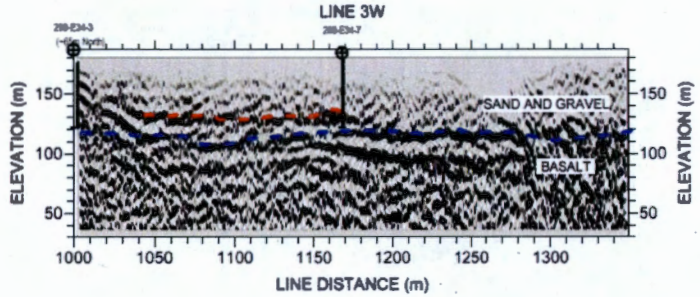

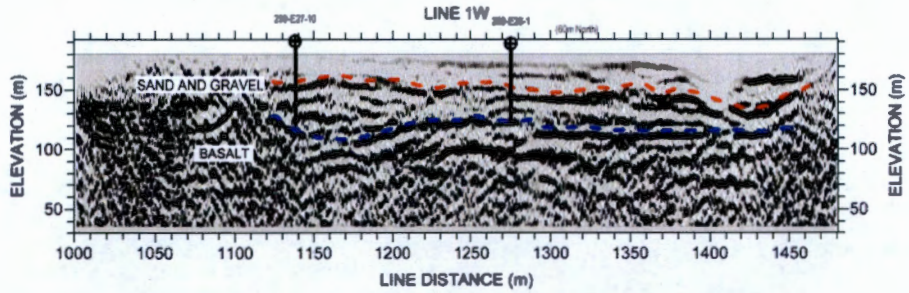

NOTES:
1. Seismic reflection data collected in June and July 2011.
2. Seismic reflection data collected using 72 channel streamer with 40 Hz geophones.
3. Seismic reflection data processed using SPW software from Parallel Geosciences.
4. Base map and survey locatons provided by CHPRC.
5. Survey objective is to map help map the top of basalt bedrock.

PROJECT
CONTRACT 45109
LERF GEOPHYSICAL SURVEY
HANFORD 200 EAST AREA

TITLE
200 EAST - LERF GEOPHYSICAL SURVEY
SEISMIC REFLECTION RESULTS
LINES 1W, 3W & 4 P-WAVE DEPTH SECTIONS

Golder Associates

PROJECT No.	113-93040.200		FILE No. —	
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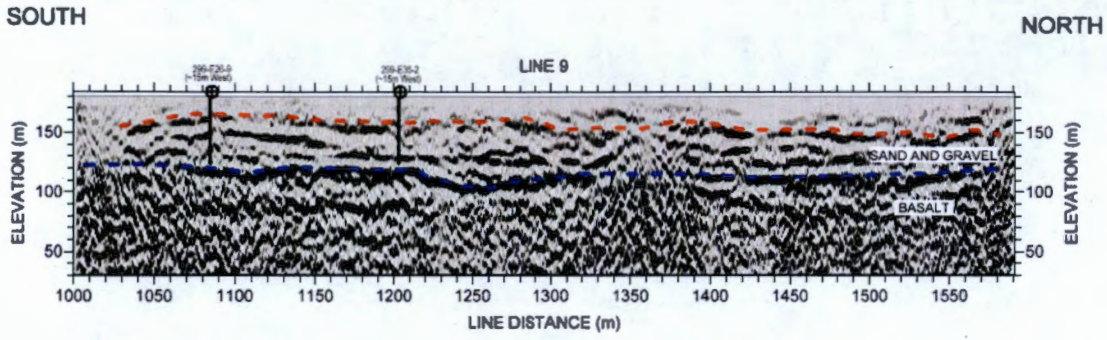

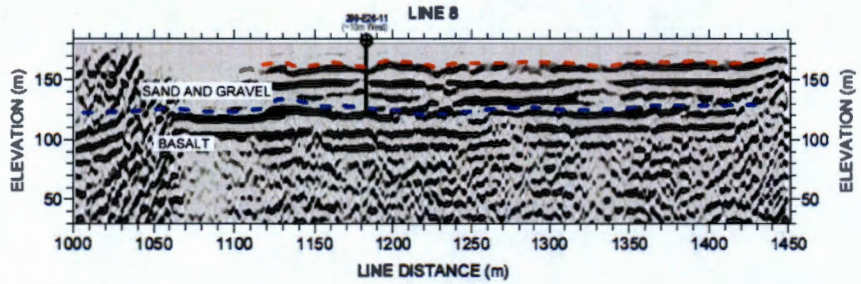

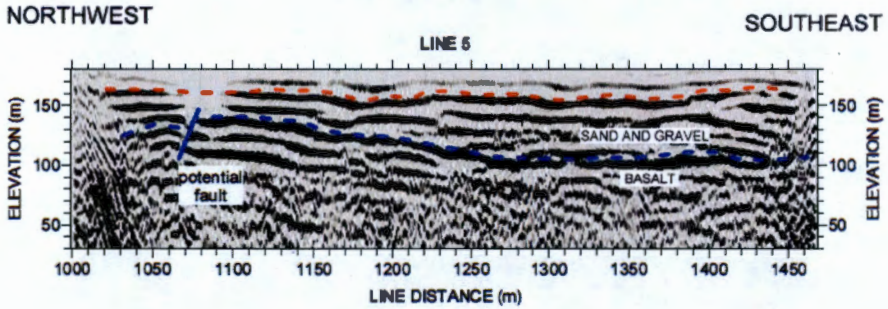

NOTES:
1. Seismic reflection data collected in June and July 2011.
2. Seismic reflection data collected using 72 channel streamer with 40 Hz geophones.
3. Seismic reflection data processed using SPW software from Parallel Geosciences.
4. Base map and survey locatons provided by CHPRC.
5. Survey objective is to map help map the top of basalt bedrock.

PROJECT
CONTRACT 45109
LERF GEOPHYSICAL SURVEY
HANFORD 200 EAST AREA

TITLE
200 EAST - LERF GEOPHYSICAL SURVEY
SEISMIC REFLECTION RESULTS
LINES 5, 8 & 9 P-WAVE DEPTH SECTIONS

Golder Associates

PROJECT No.	113-93045.200		FILE No.	--
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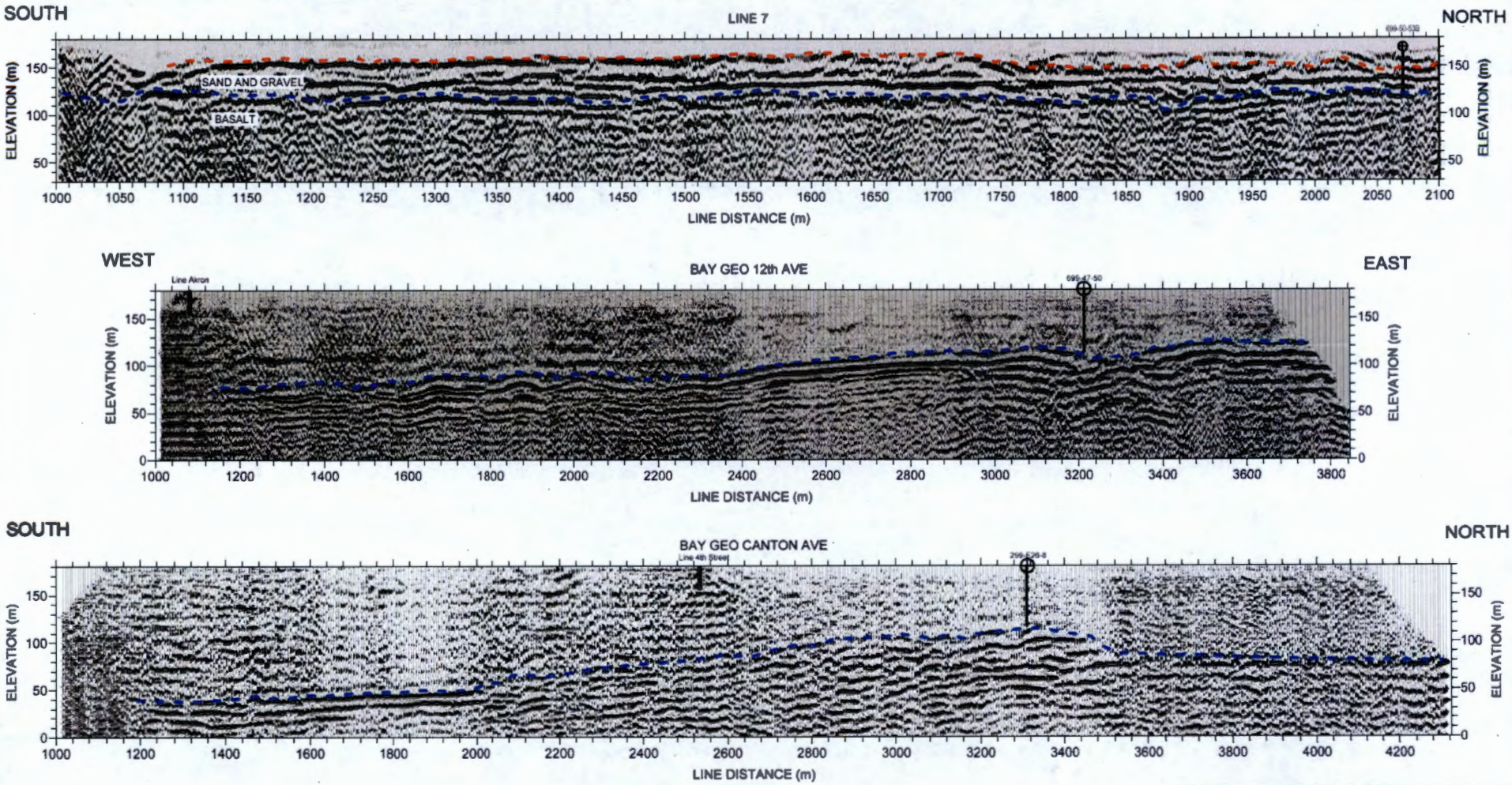

NOTES:
1. Seismic reflection data collected in June and July 2011.
2. Seismic reflection data collected using 72 channel streamer with 40 Hz geophones.
3. Seismic reflection data processed using SPW software from Parallel Geosciences.
4. Base map and survey locatons provided by CHPRC.
5. Survey objective is to map help map the top of basasit bedrock.
6. Bay Geophysical data for Canton Ave section provided by CHPRC.
7. Bay Geophysical data is presented at different horizontal scale than Line 7.

PROJECT
CONTRACT 45109
LERF GEOPHYSICAL SURVEY
HANFORD 200 EAST AREA

TITLE
200 EAST - LERF GEOPHYSICAL SURVEY
SEISMIC REFLECTION RESULTS
BAY GEO & LINE 7 P-WAVE DEPTH SECTIONS

Golder Associates

PROJECT No.	113-93040.200		FILE No.	—
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REVIEW	ML	1/31/12		

WEST

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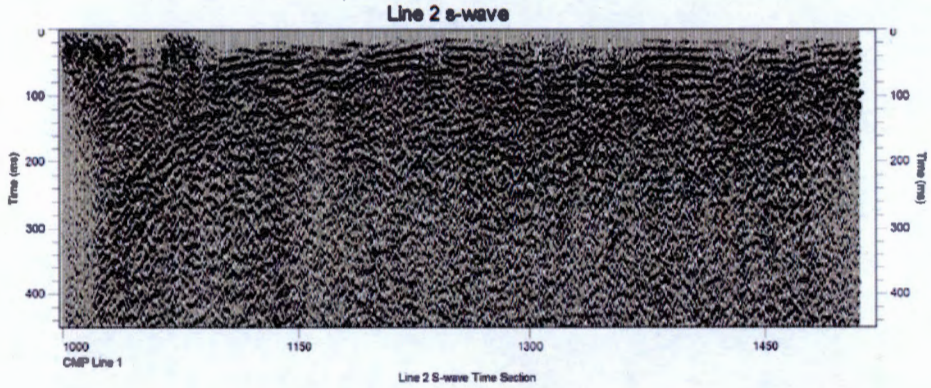

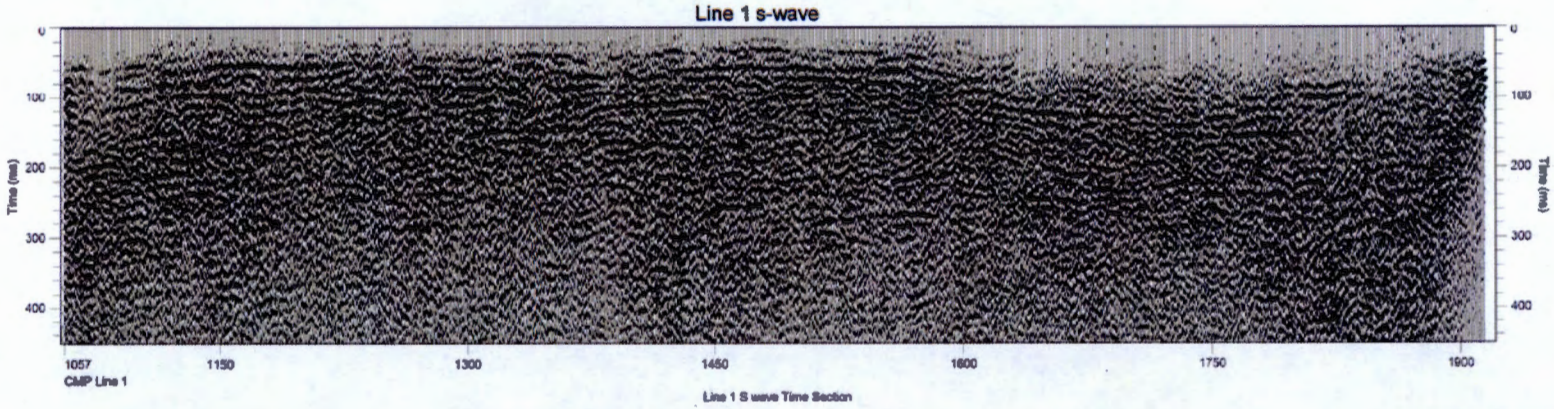

NOTES:

1. Seismic reflection data collected in June and July 2011.
2. Seismic reflection data collected using 72 channel streamer with 40 Hz geophones.
3. Seismic reflection data processed using SPW software from Parallel Geosciences.
4. Base map and survey locatons provided by CHPRC.
5. Survey objective is to map help map the top of basalt bedrock.

PROJECT

CONTRACT 45109
LERF GEOPHYSICAL SURVEY
HANFORD 200 EAST AREA

TITLE

200 EAST - LERF GEOPHYSICAL SURVEY
PHASE 1 SEISMIC RESULTS
LINES 1& 2 – S-WAVE BRUTE STACK

Golder Associates

PROJECT No.	133-93040.200		FILE No.	–
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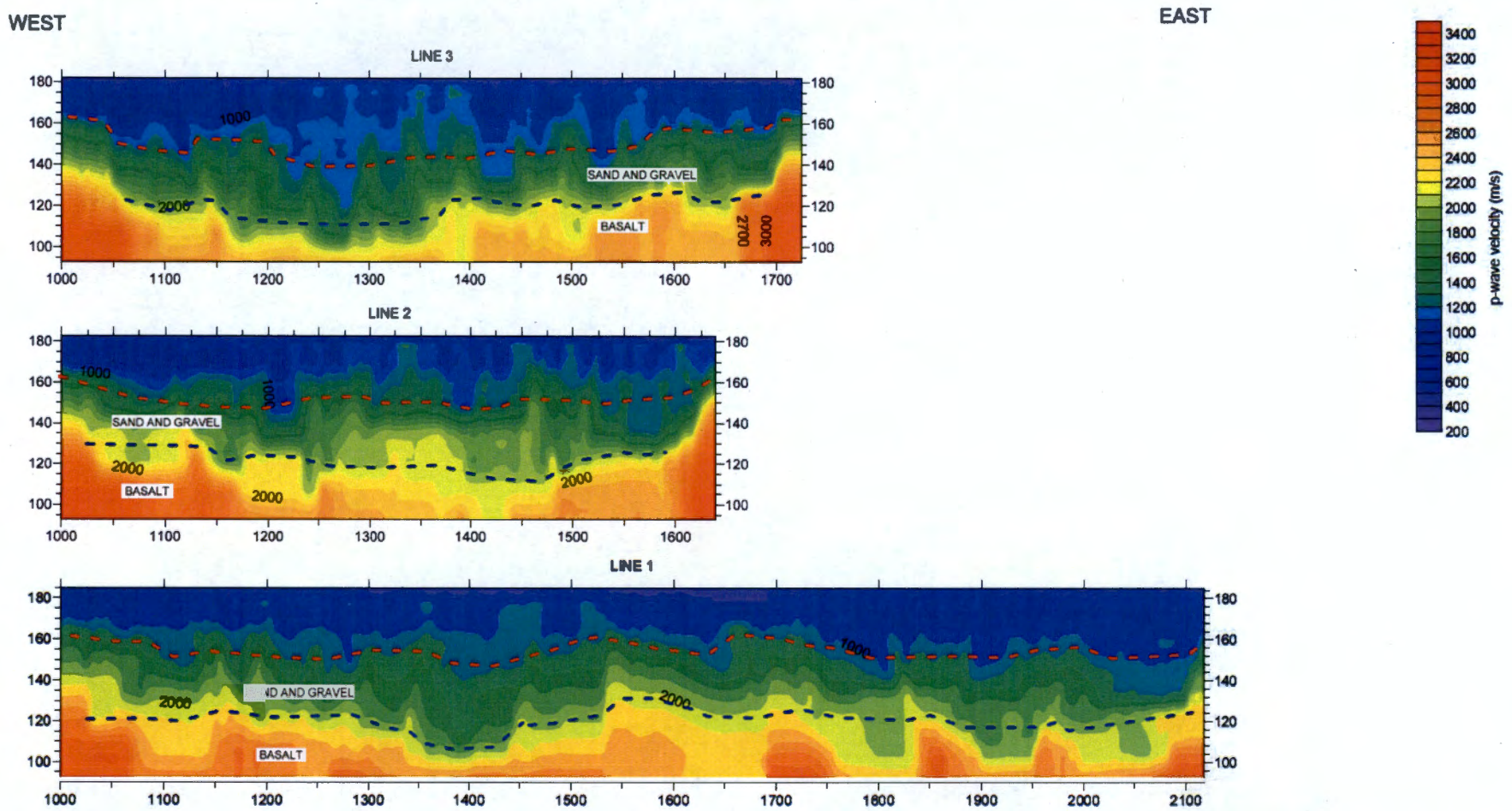
FIGURE 6



NOTES:
1. Seismic refraction data collected in July and August 2011.
2. Seismic refraction data collected using 72 channel streamer with 40 Hz geophones.
3. Seismic refraction data processed using SeisImager software from Geometrics.
4. Base map and survey locatons provided by CHPRC.
5. Survey objective is to map help map the top of basalt bedrock.

PROJECT
CONTRACT 45109
LERF GEOPHYSICAL SURVEY
HANFORD 200 EAST AREA

TITLE
200 EAST - LERF GEOPHYSICAL SURVEY
SEISMIC REFRACTION RESULTS
LINES 1 2 & 3 VELOCITY MODELS

Golder Associates

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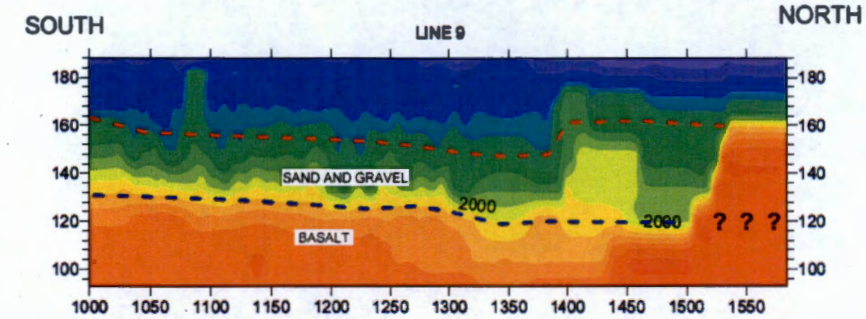

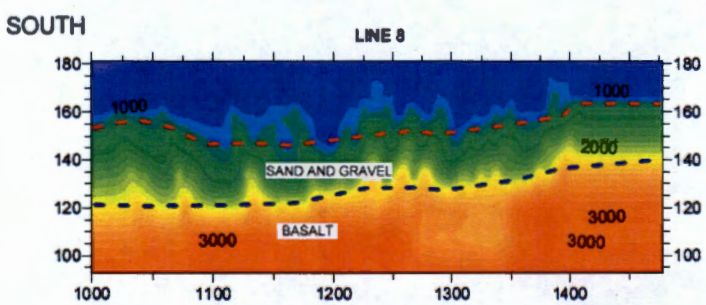

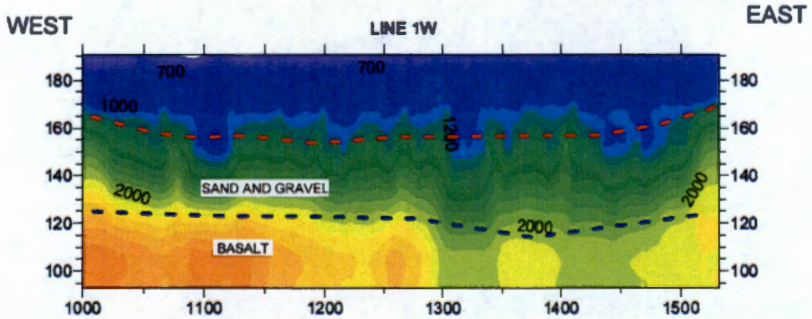

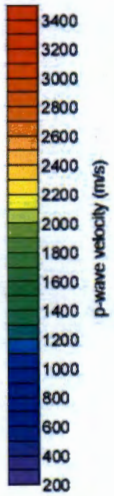

NOTES:
1. Seismic refraction data collected in July and August 2011.
2. Seismic refraction data collected using 72 channel streamer with 40 Hz geophones.
3. Seismic refraction data processed using SeisImager software from Geometrics.
4. Base map and survey locatons provided by CHPRC.
5. Survey objective is to map help map the top of basalt bedrock.

PROJECT
CONTRACT 45109
LERF GEOPHYSICAL SURVEY
HANFORD 200 EAST AREA

TITLE
200 EAST - LERF GEOPHYSICAL SURVEY
SEISMIC REFRACTION RESULTS
LINES 1W 8 & 9 VELOCITY MODELS

Golder Associates

PROJECT No.	113-93045.200		FILE No.	—
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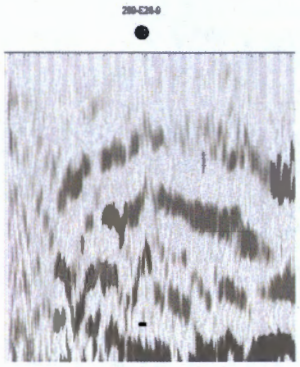

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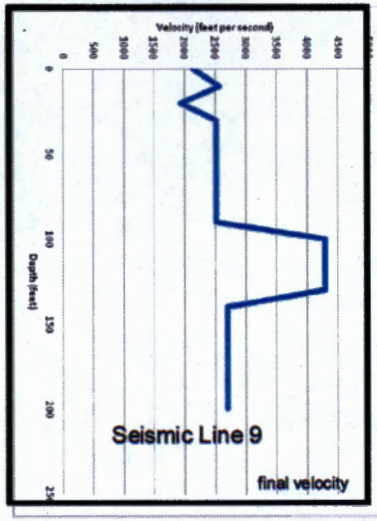

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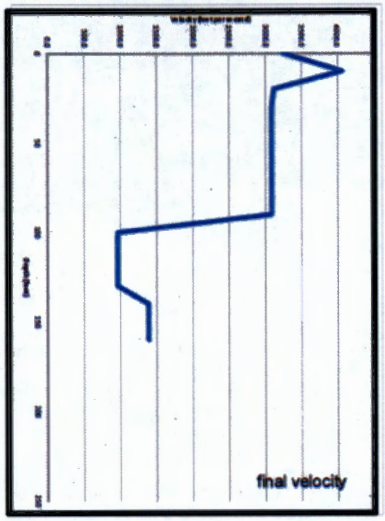

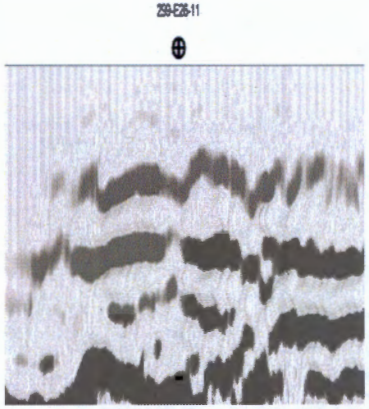

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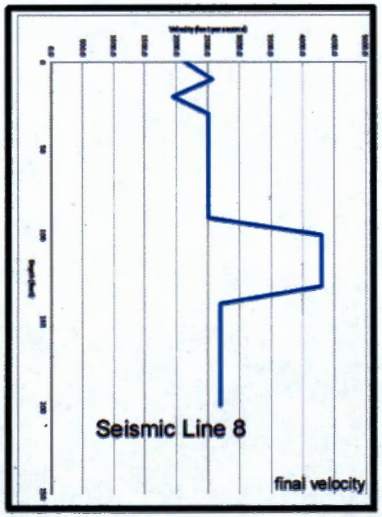
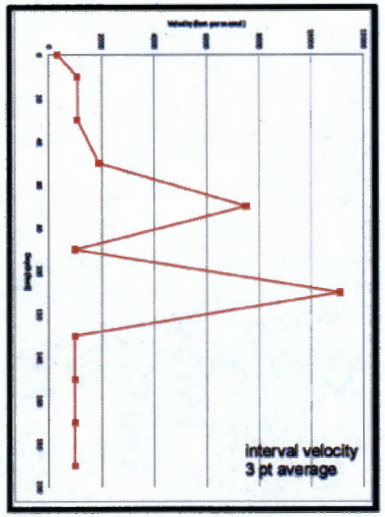


299-E26-11 S-WAVE



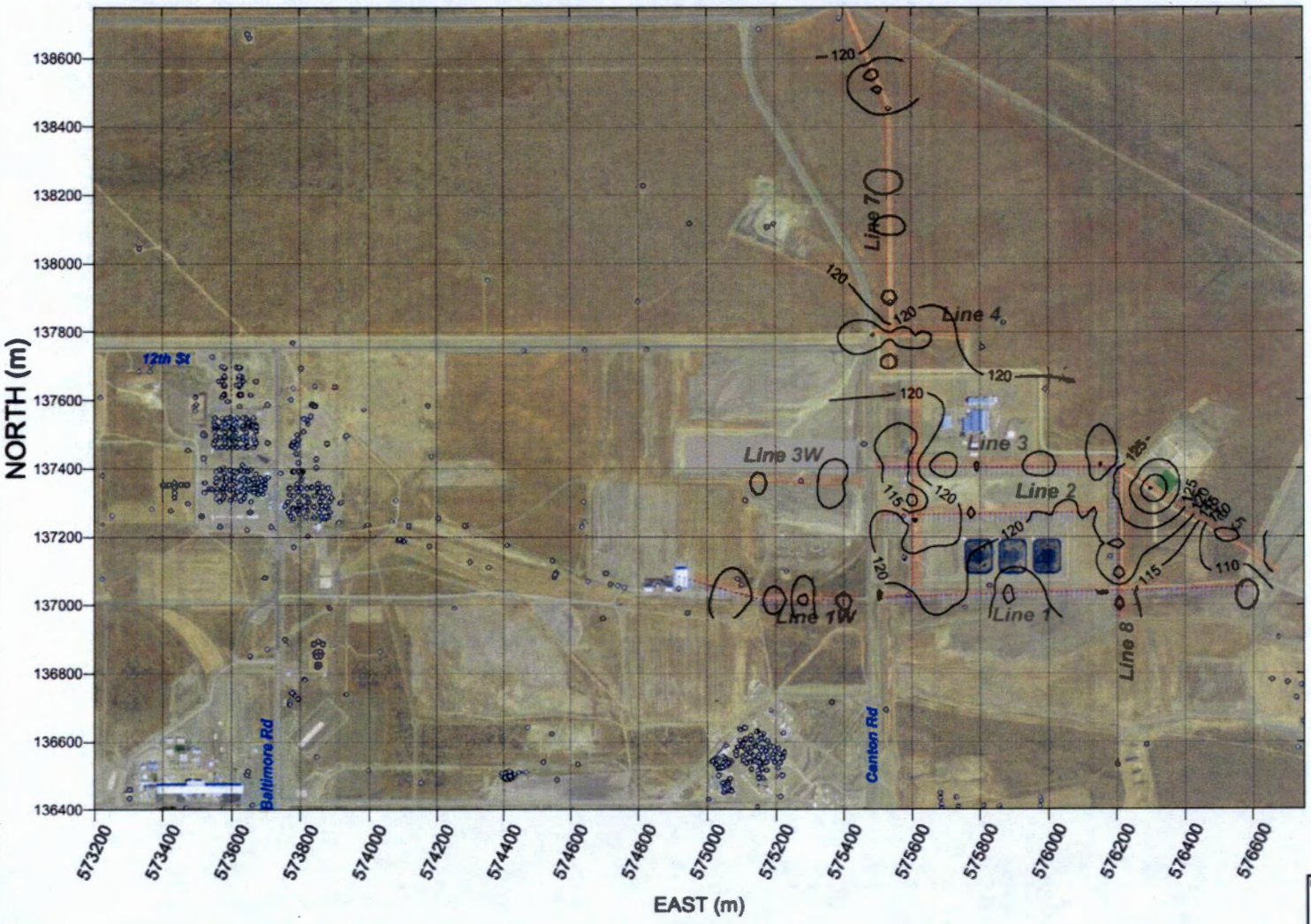
NOTES:
1. Check shot data collected in September 2011.
2. Seismic reflection data collected using Geode and BHG-3 geophone.
3. Survey objective is to help constrain velocity interpretation of reflection data.

PROJECT
CONTRACT 45109
LERF GEOPHYSICAL SURVEY
HANFORD 200 EAST AREA

TITLE
200 EAST - LERF GEOPHYSICAL SURVEY
CHECK SHOT RESULTS

Golder Associates

PROJECT No.	113-93040.200	FILE No.	—
DESIGN	MB	1/31/12	SCALE AS SHOWN REV.
CADD	MB	1/31/12	
CHECK	ML	1/31/12	FIGURE 9
REVIEW	ML	1/31/12	



LEGEND

- Seismic Reflection Line with CMP Location Label
- Seismic Refraction Line with Line Location Label
- Bedrock Elevation Contours

NOTES:

1. Seismic reflection and refraction data collected June -August 2011.
2. Seismic data collected using 72 channel Geometrics GEODE system.
3. Seismic data processed using SeisImager Pro and SPW software.
4. Base Map provided by CHPRC.
5. Horizontal datum is WA State Plane South meters, NAD83.
6. Survey objective is to map help map the top of basalt bedrock.

PROJECT

CONTRACT 45109
LERF GEOPHYSICAL SURVEY
HANFORD 200 EAST AREA

TITLE

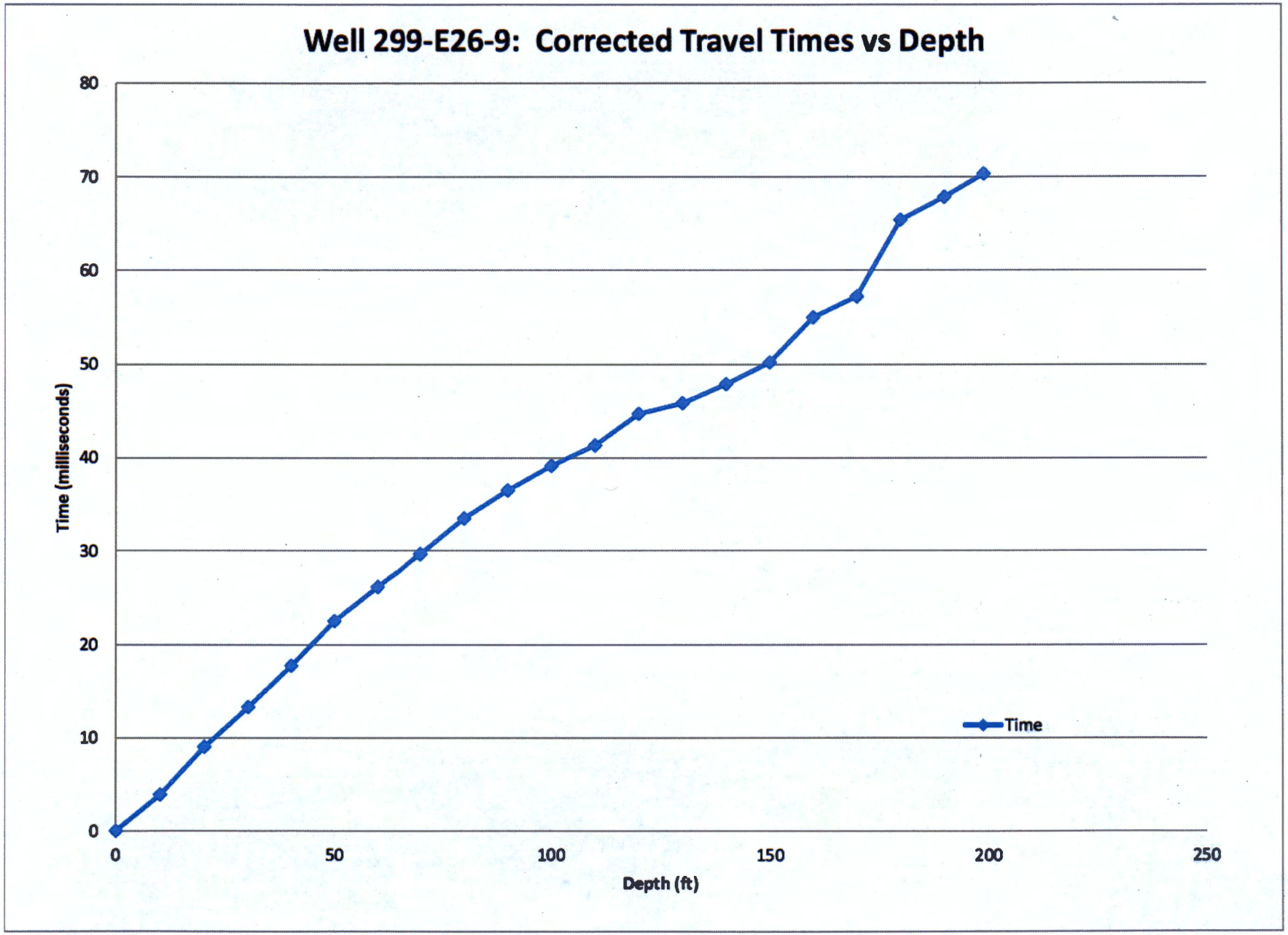
200 EAST - LERF GEOPHYSICAL SURVEY
BEDROCK ELEVATION CONTOURS

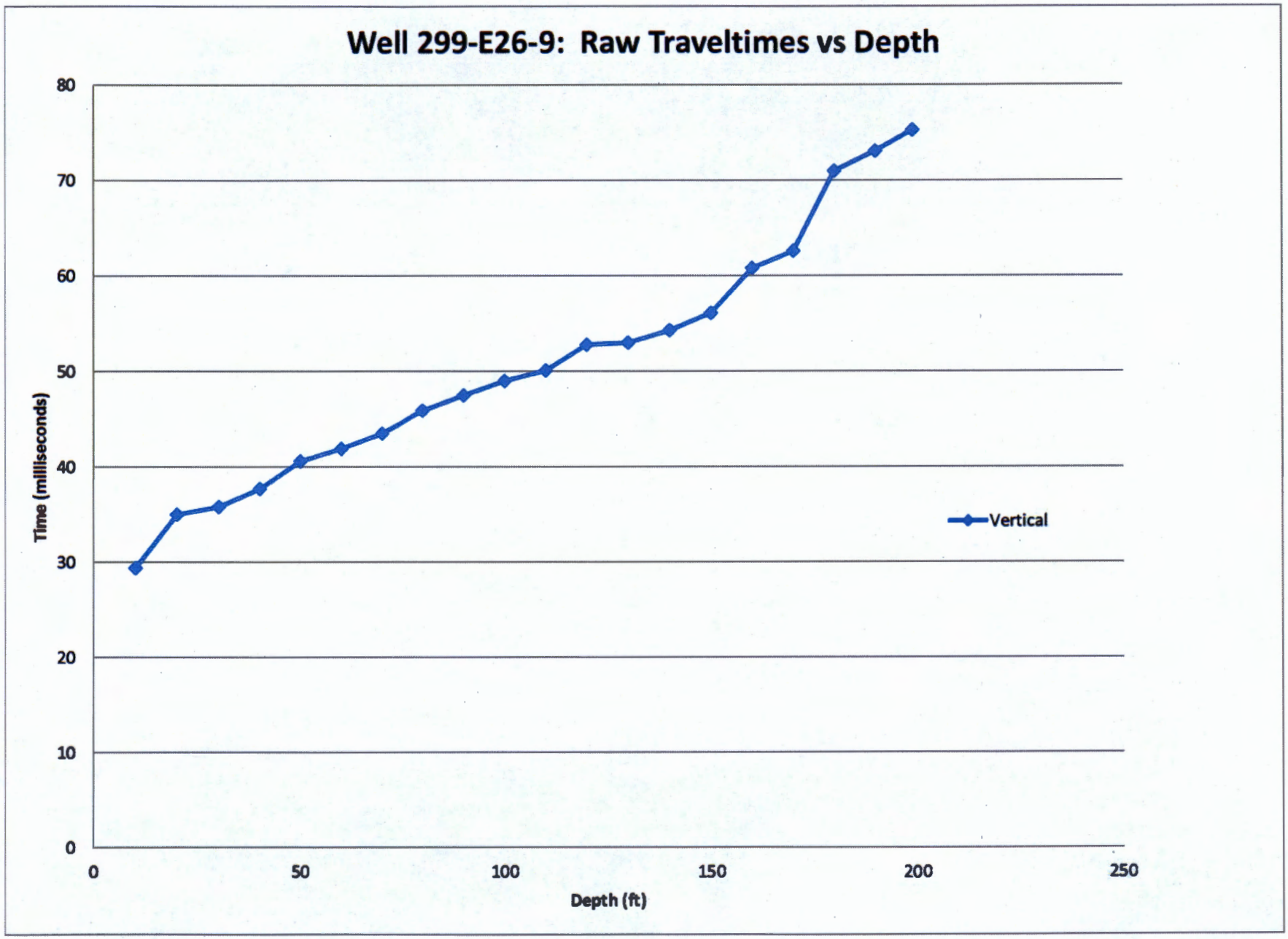
Golder Associates

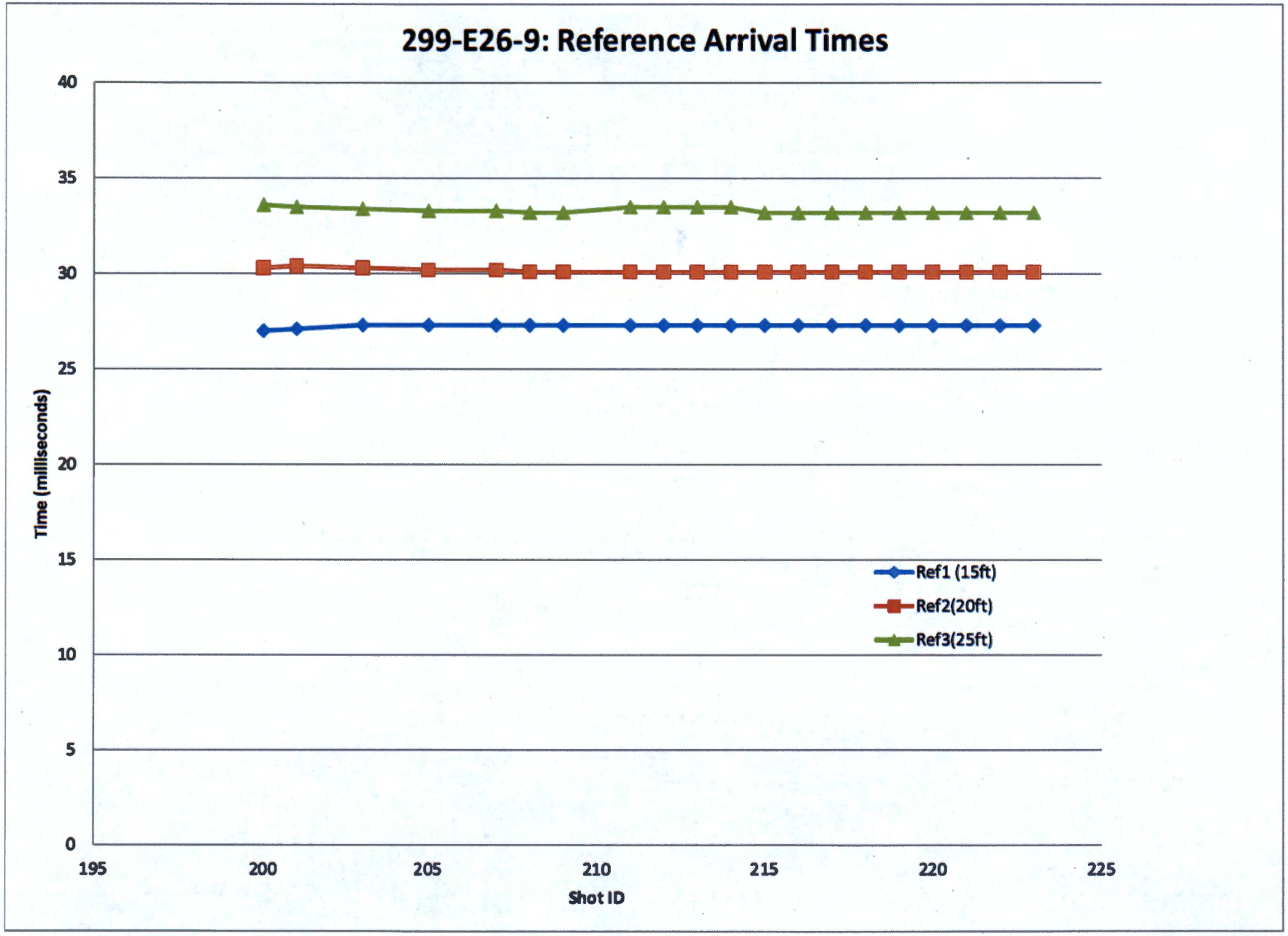
PROJECT No.	113-93040.200		FILE No.	—
DESIGN	MB	1/31/12	SCALE AS SHOWN	REV
CADD	MB	1/31/12		
CHECK	ML	1/31/12		
REVIEW	ML	1/31/12		

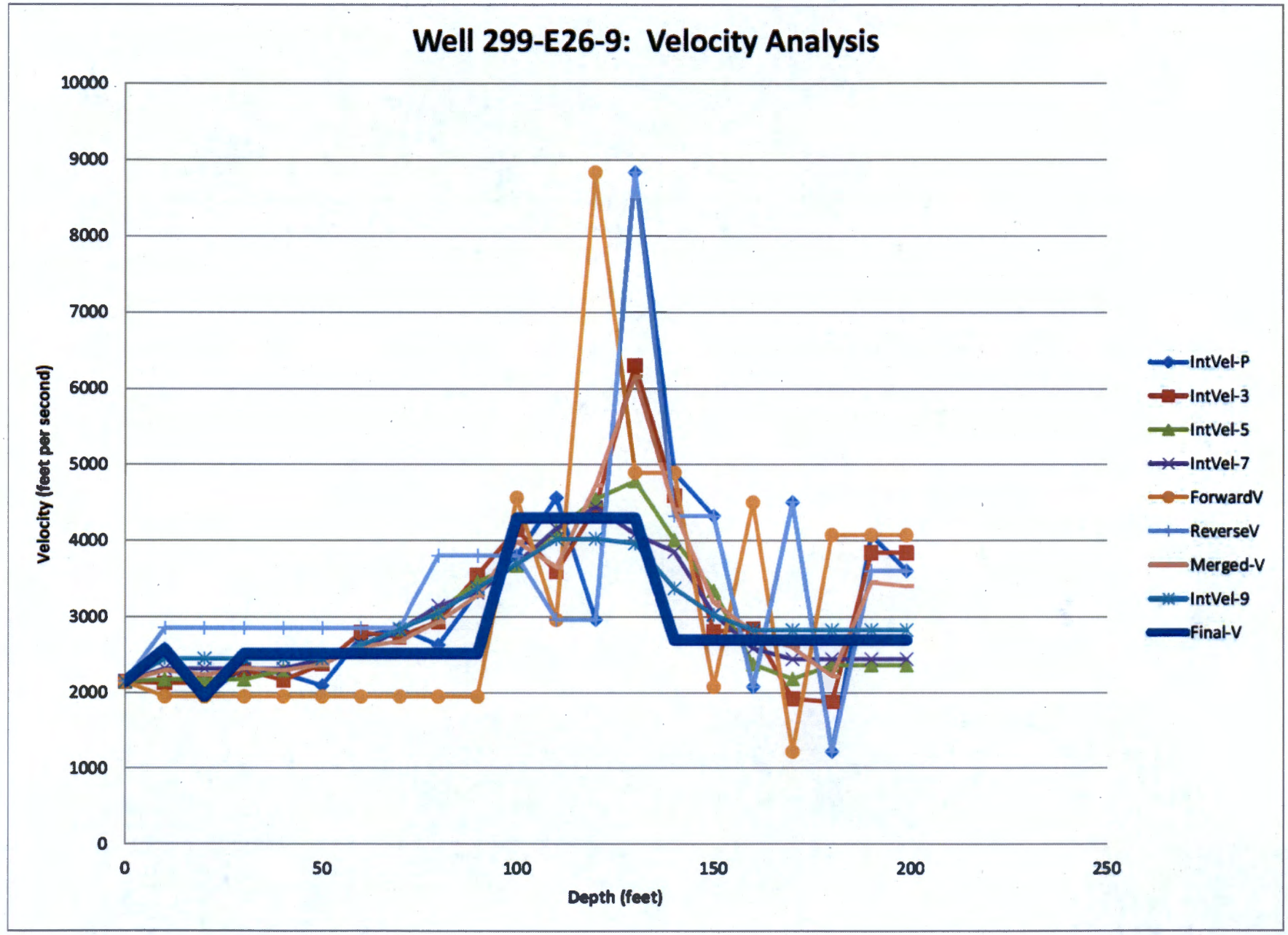
FIGURE 10

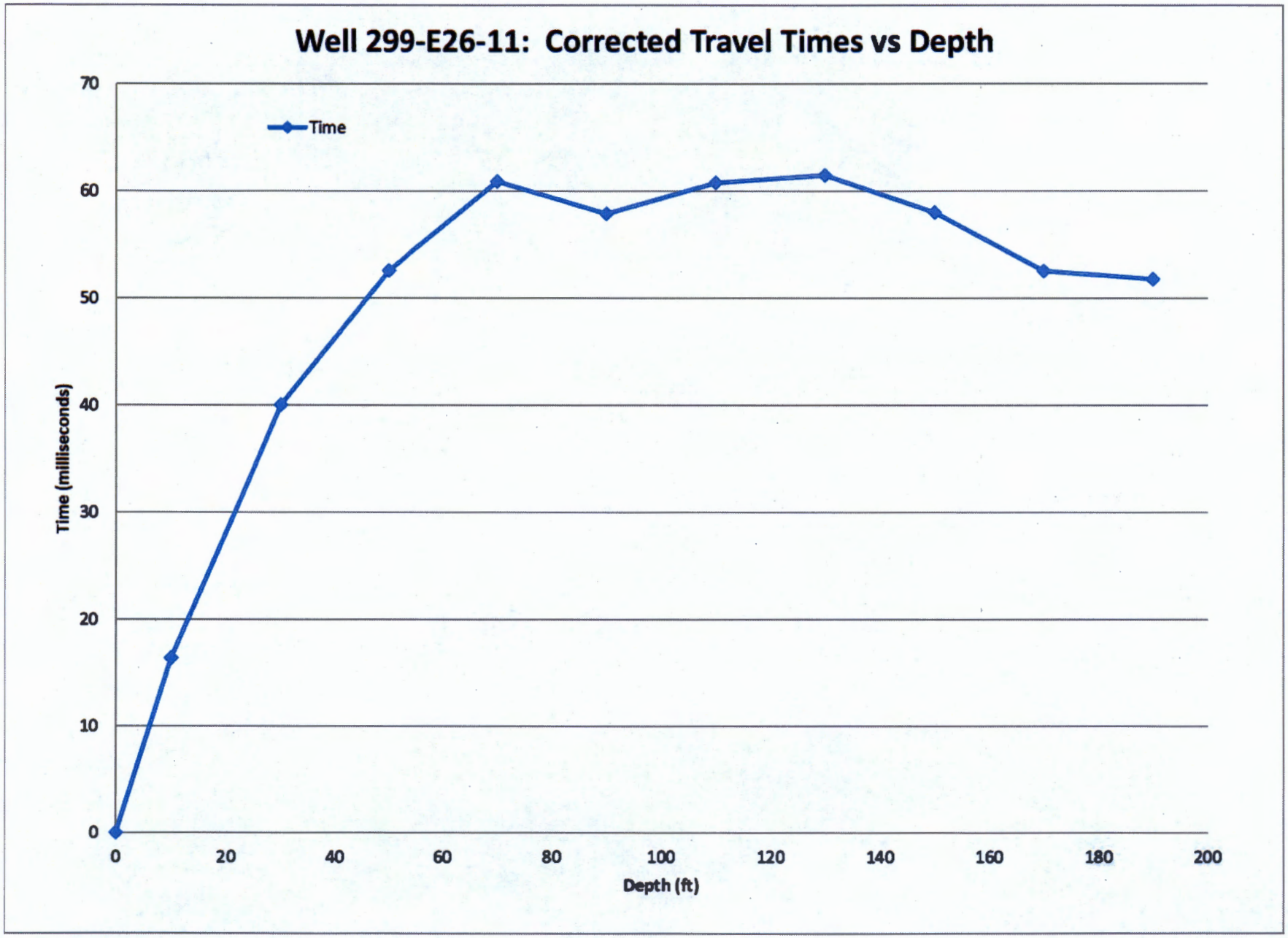
APPENDIX A
CHECK SHOT RESULTS

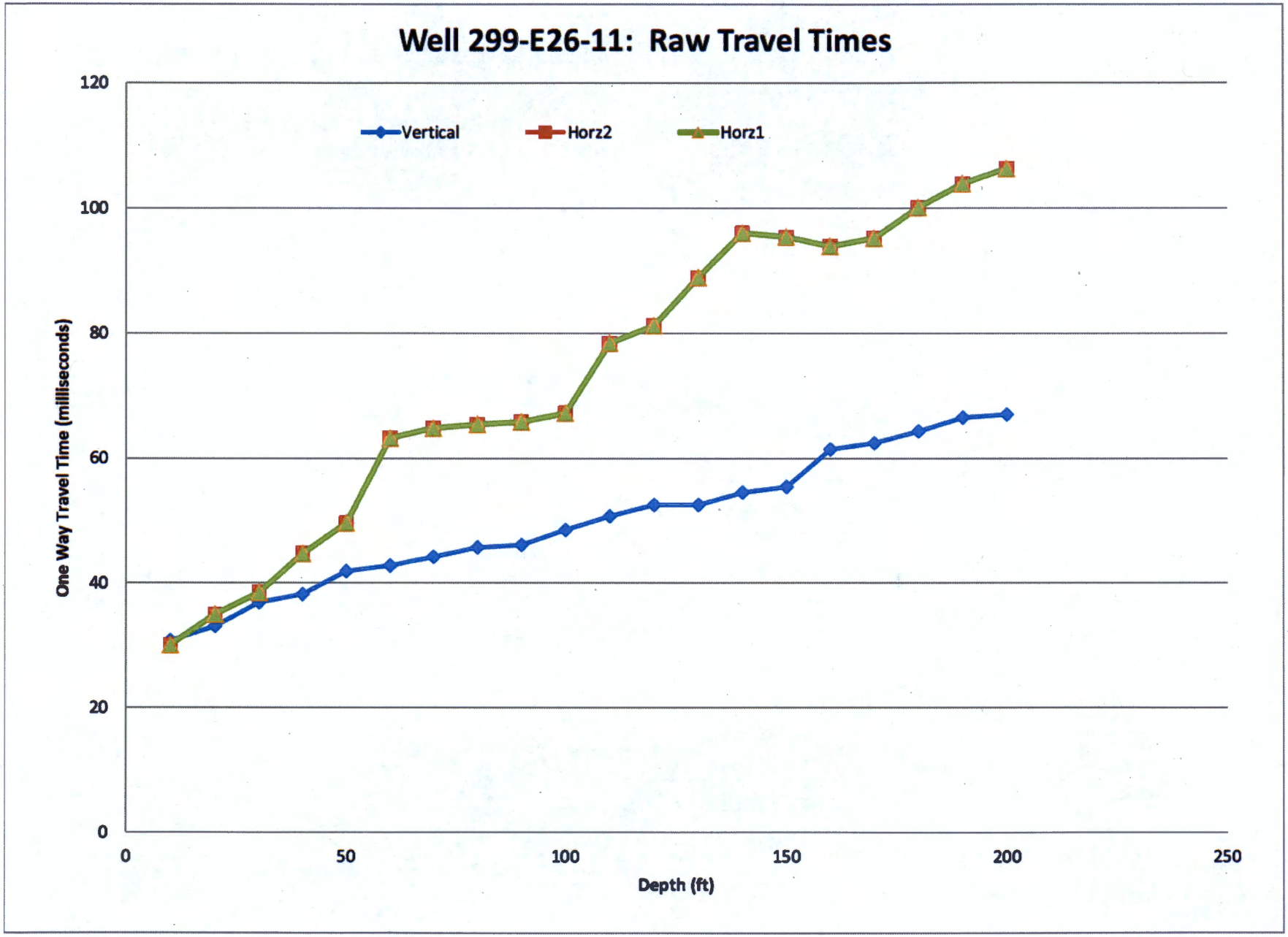

Well 299-E26-9: Corrected Travel Times vs Depth
Time (milliseconds)
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
Depth (ft)
Time

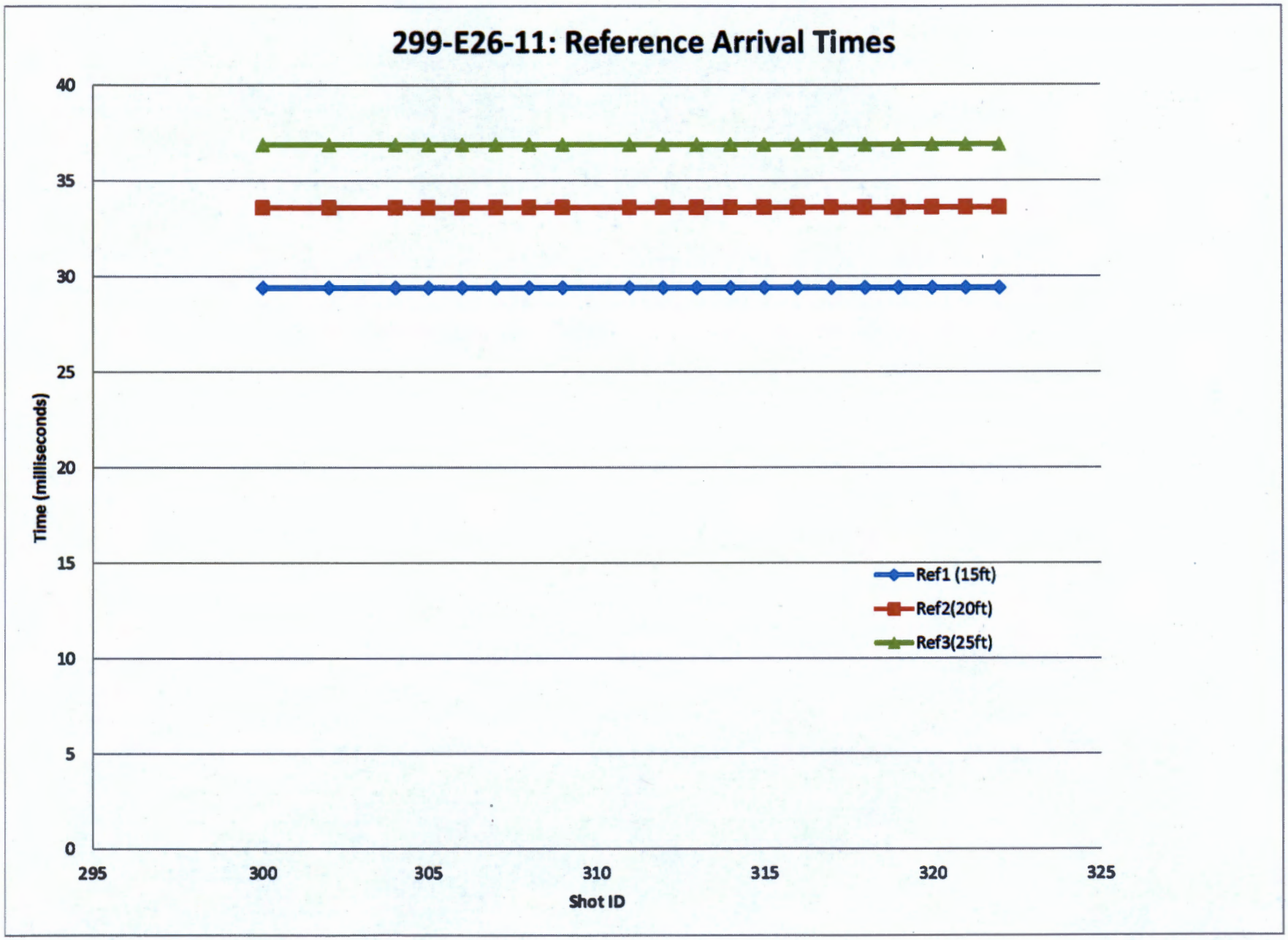

Well 299-E26-9: Raw Traveltimes vs Depth
Time (milliseconds)
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
Depth (ft)
Vertical

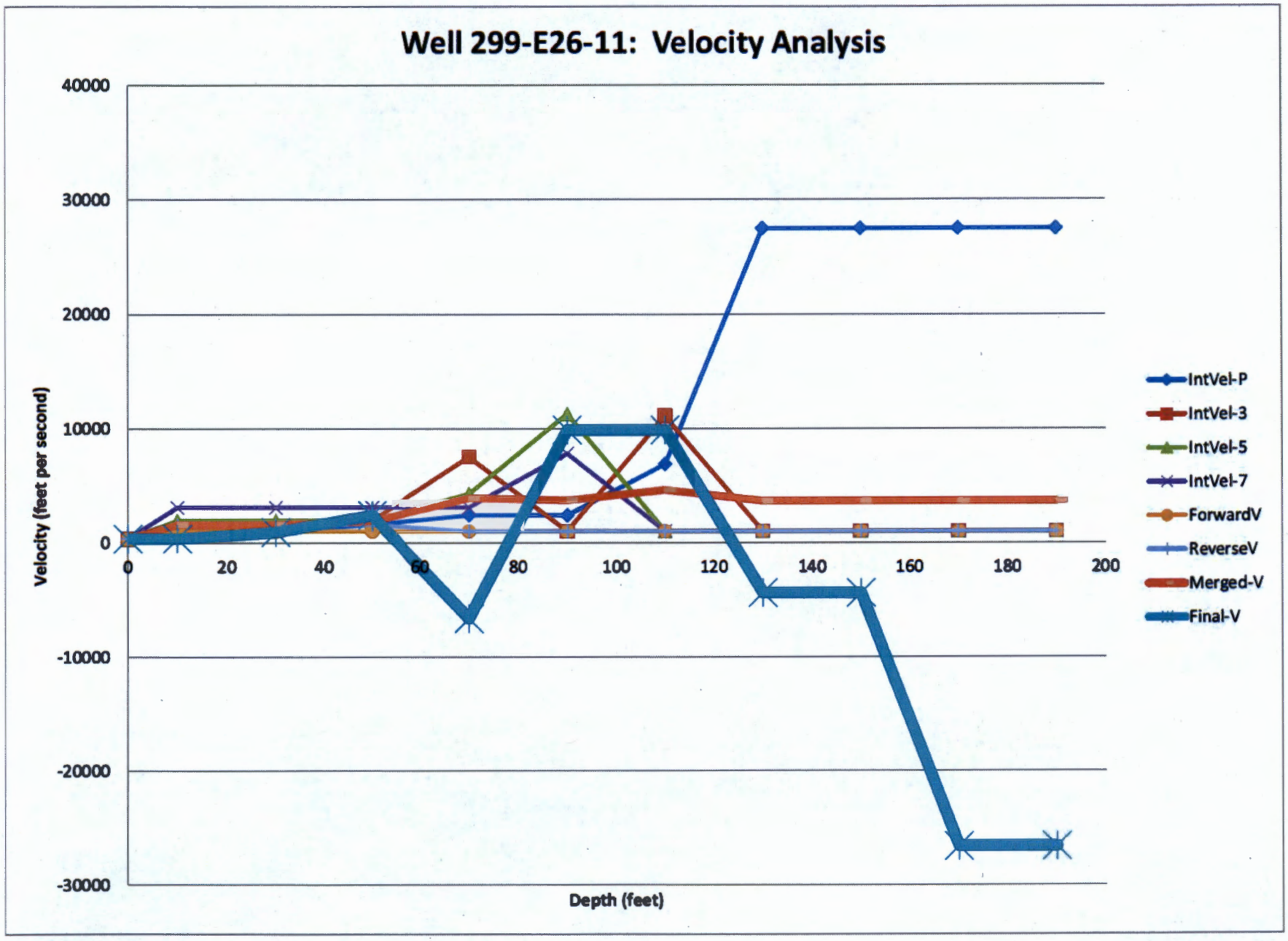

299-E26-9: Reference Arrival Times
Time (milliseconds)
40
35
30
25
20
15
10
5
0
195
200
205
210
215
220
225
Shot ID
Ref1 (15ft)
Ref2(20ft)
Ref3(25ft)

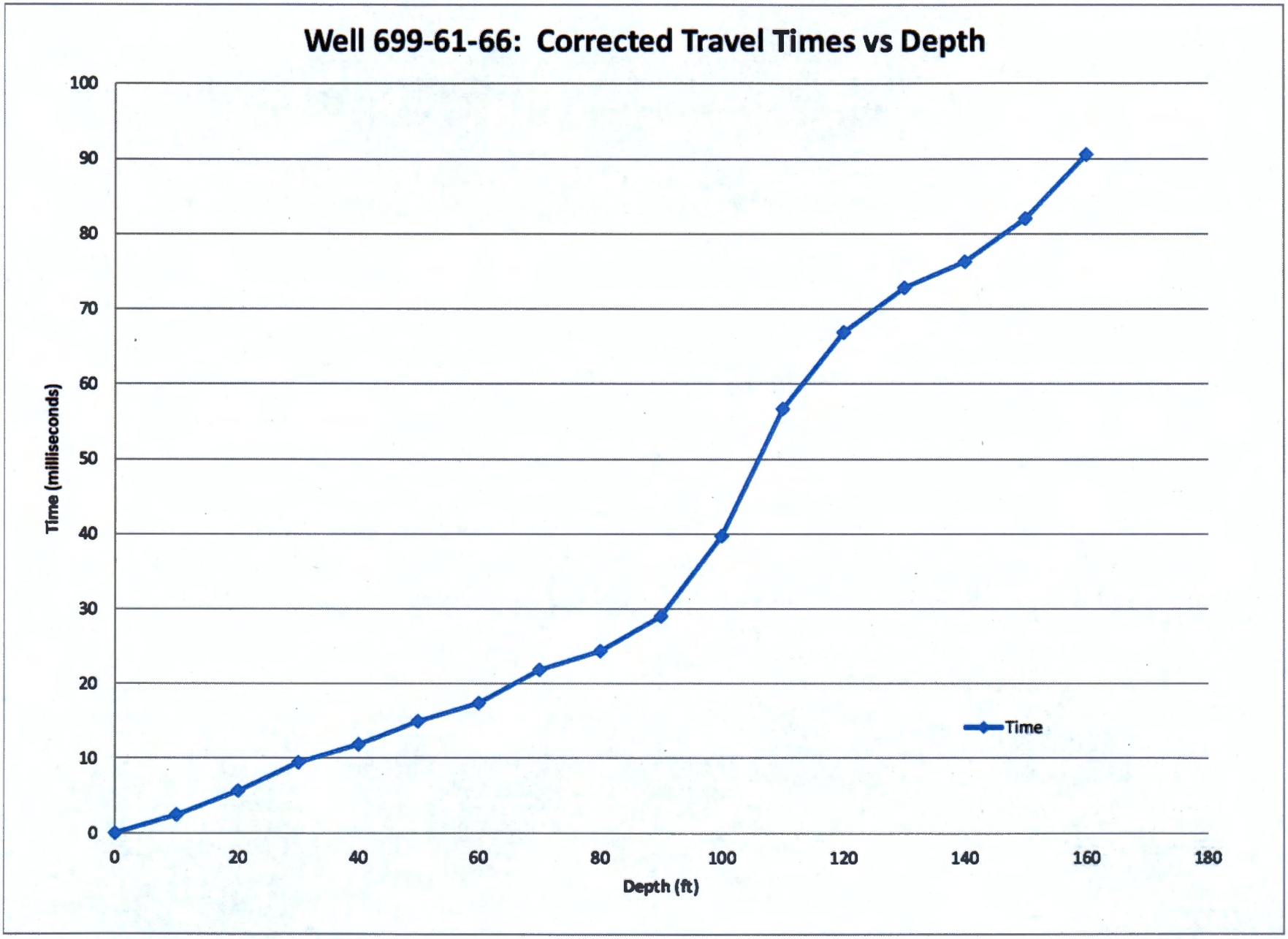

Well 299-E26-9: Velocity Analysis
Velocity (feet per second)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
50
100
150
200
250
Depth (feet)
IntVel-P
IntVel-3
IntVel-5
IntVel-7
ForwardV
ReverseV
Merged-V
IntVel-9
Final-V

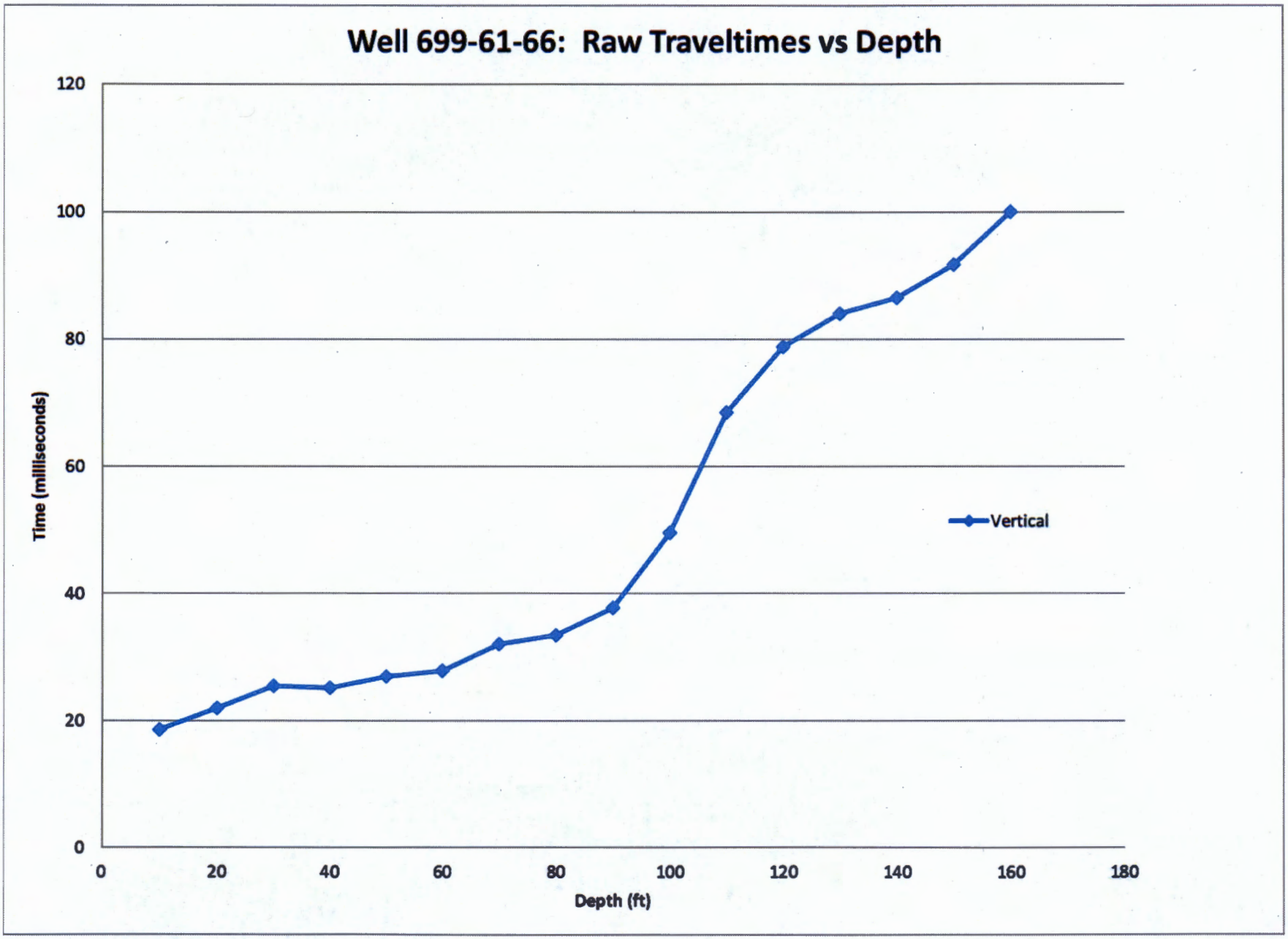

Well 299-E26-11: Corrected Travel Times vs Depth
Time
Time (milliseconds)
Depth (ft)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
140
160
180
200

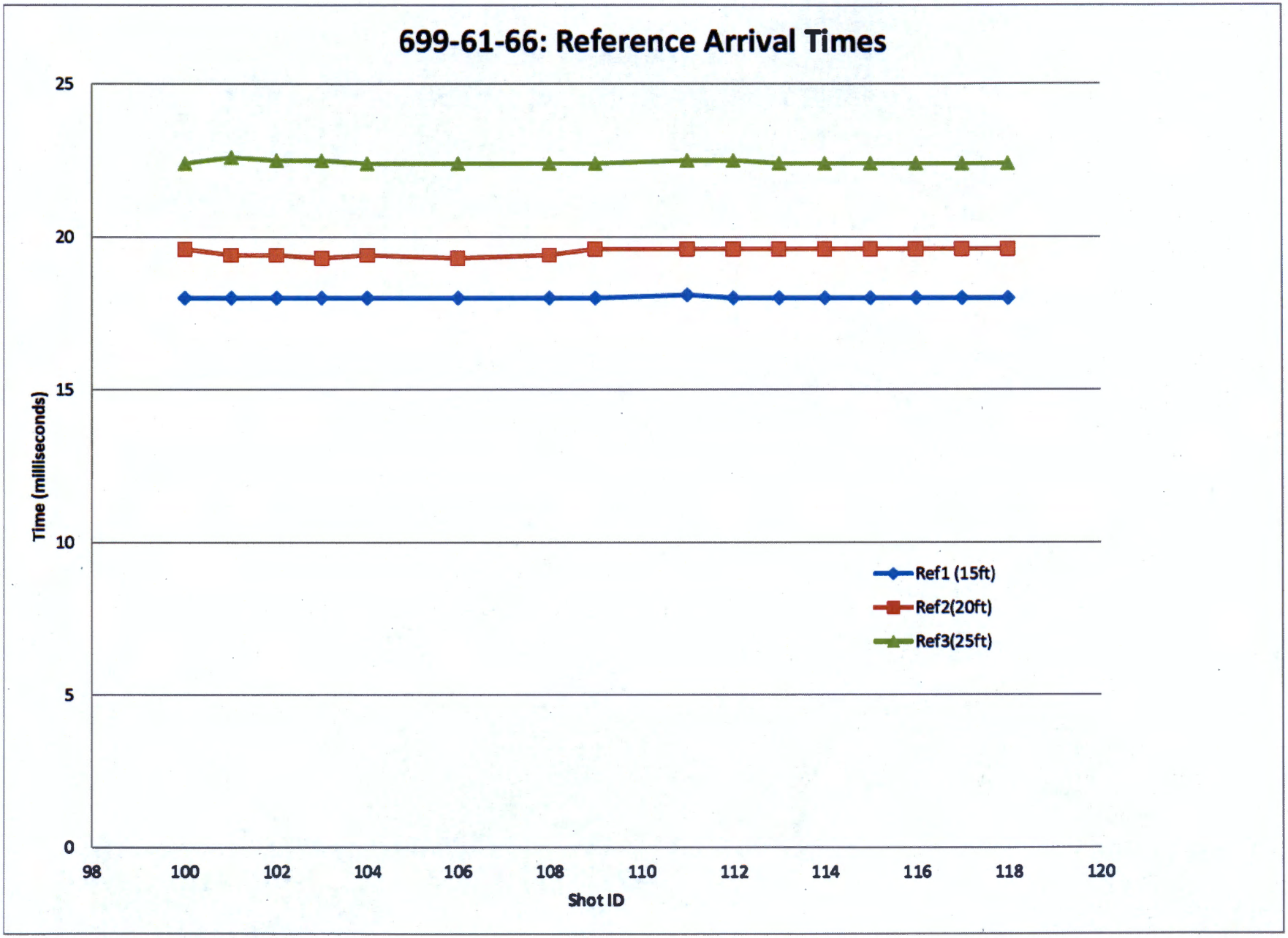

Well 299-E26-11: Raw Travel Times
Vertical
Horz2
Horz1
One Way Travel Time (milliseconds)
Depth (ft)
0
20
40
60
80
100
120
0
50
100
150
200
250

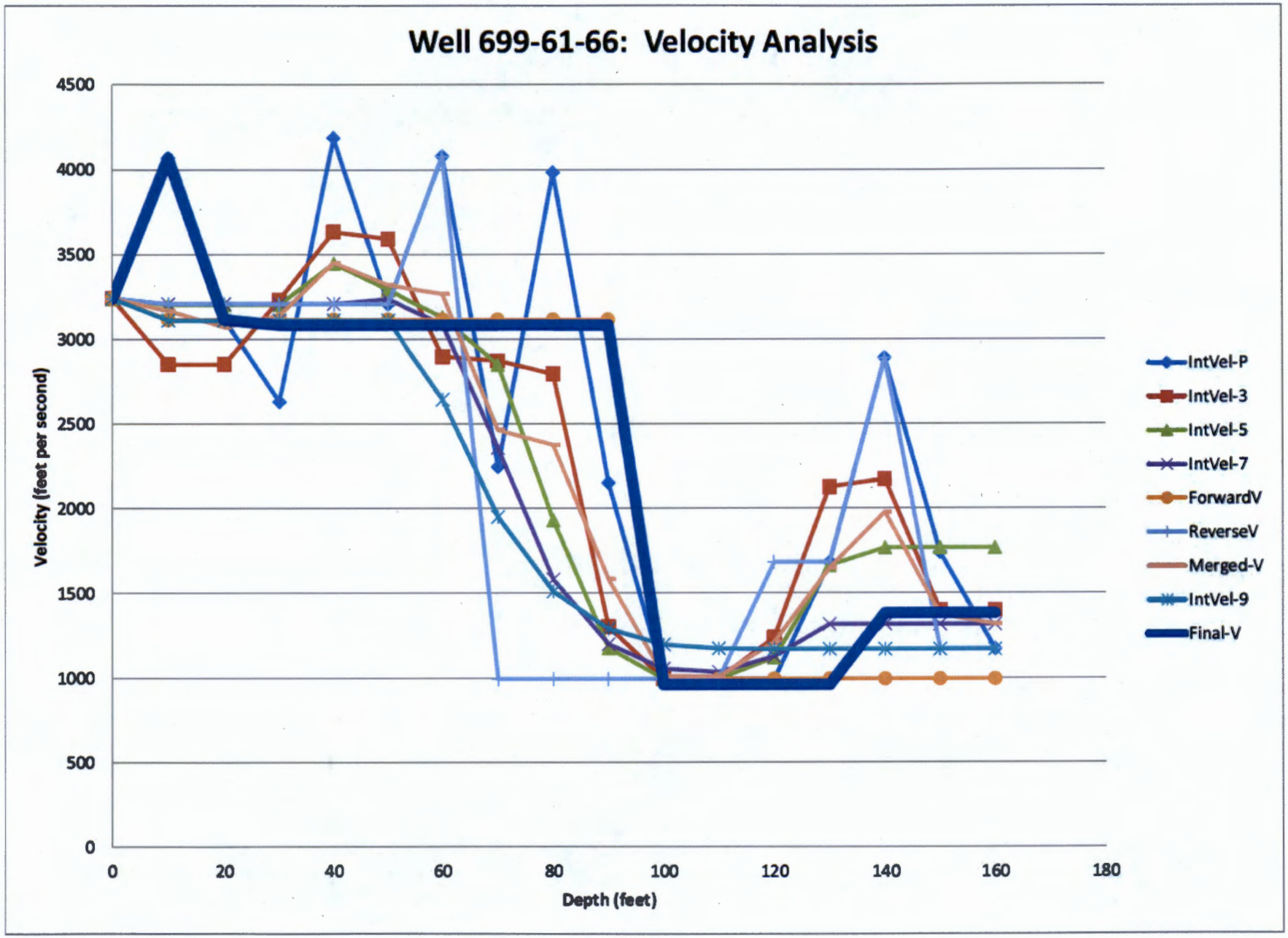

299-E26-11: Reference Arrival Times
Time (milliseconds)
40
35
30
25
20
15
10
5
0
295
300
305
310
315
320
325
Shot ID
Ref1 (15ft)
Ref2(20ft)
Ref3(25ft)


Well 299-E26-11: Velocity Analysis
40000
30000
20000
10000
0
-10000
-20000
-30000
Velocity (feet per second)
0
20
40
60
80
100
120
140
160
180
200
Depth (feet)
IntVel-P
IntVel-3
IntVel-5
IntVel-7
ForwardV
ReverseV
Merged-V
Final-V


Well 699-61-66: Corrected Travel Times vs Depth
Time (milliseconds)
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
Depth (ft)
Time


Well 699-61-66: Raw Traveltimes vs Depth
Time (milliseconds)
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
180
Depth (ft)
Vertical


699-61-66: Reference Arrival Times
Time (milliseconds)
25
20
15
10
5
0
98
100
102
104
106
108
110
112
114
116
118
120
Shot ID
Ref1 (15ft)
Ref2(20ft)
Ref3(25ft)


Well 699-61-66: Velocity Analysis
Velocity (feet per second)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
20
40
60
80
100
120
140
160
180
Depth (feet)
IntVel-P
IntVel-3
IntVel-5
IntVel-7
ForwardV
ReverseV
Merged-V
IntVel-9
Final-V

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