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Downhole Measurements of Shear- and Compression-Wave Velocities in Boreholes C4993, C4996, C4997 and C4998 at the Waste Treatment Plant DOE Hanford Site

B. B. Redpath

April 2007

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by

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Contents

Figures

Tables

Downhole Measurements
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Introduction

This report describes the procedures and the results of a series of downhole measurements of shear- and compression-wave velocities performed as part of the Seismic Boreholes Project at the site of the Waste Treatment Plant (WTP). The measurements were made in several stages from October 2006 through early February 2007. Although some fieldwork was carried out in conjunction with the University of Texas at Austin (UT), all data acquired by UT personnel are reported separately by that organization.

The UT measurements were made using the university's large, electrohydraulic, triaxial vibrator ('T-Rex') as the energy source for both shear and compression waves. The measurements presented in this report were made using a sledgehammer or an accelerated-weight impact source (the 'Slingshot' source). The equipment and resulting data are described and discussed in this report. The scope of work is shown in chronological order in Table 1.

A full description of all procedures, equipment calibration, experimental setups, and seismograph files, together with some results, are contained in a separate Scientific Notebook that was compiled as the fieldwork progressed.

Table 1. Downhole Measurements Made in Seismic Boreholes

Borehole	Casing	Depth Range (ft)	Survey Mode	Source	Date
C4996	Uncased	355 to 650	Shear	Slingshot	18 Oct 06
C4993	Uncased	350 to 570	Shear	Slingshot	20 Oct 06
C4997	Uncased	390 to 610	Shear	Slingshot	13 Nov 06
C4998	PVC	3 to 370	Shear and Compression	Sledgehammer	10 Dec 06
C4996	PVC	3 to 530	Shear and Compression	Sledgehammer	29 Jan 07
C4993	Stainless	340 to 742	Shear	Slingshot	30 Jan 07
C4993	Stainless	3 to 400	Shear and Compression	Sledgehammer	9 Feb 07

Background

This work was part of a comprehensive measurement program intended to define the dynamic characteristics of the rocks and soils beneath the WTP site, which, in turn, were to be used in developing a reliable estimate of the site's earthquake response. Although the existence of soft interbeds between basalt flows was well known, there was virtually no information about the properties of these interbeds. The program was based on drilling three large-diameter holes and one core hole to a depth of approximately 1400 ft. The site is underlain by approximately 350 ft of alluvial deposits, below which is the sequence of basalts and interbeds.

Carbon-steel casing was installed to the top of the first basalt (Elephant Mountain) in the three large-diameter holes, and the presence of this casing precluded using a constant-azimuth geophone, with its internal electronic compass, to obtain meaningful velocity measurements in the alluvium. After Redpath Geophysics and UT had acquired measurements in the uncased portion of the holes below the alluvium, the carbon-steel casing was pulled and replaced with grouted-in-place PVC casing in one of the large holes (C4996) and in the corehole (C4998); UT made no measurements in the corehole. Nonmagnetic stainless steel casing was installed in a second large-diameter hole (C4993). Excellent downhole velocity data were eventually acquired in the alluvium in these three holes.

Earlier attempts had been made in June 2006 to collect velocity information in the interbeds by entering two existing steel-cased boreholes (DB4 and DB14) located several miles from the WTP site. These efforts were not successful, but they did provide extremely important information about the characteristics and operation of new, untested geophysical equipment. This information was crucial to the success of the downhole velocity measurements at the WTP site.

Procedures and Equipment

The standard procedure for a downhole velocity survey is to measure the travel times of signals from an impulsive source of energy at the surface to a sequence of measurement points in the borehole. The corresponding plot of travel time versus depth is then converted to velocity versus depth by computing slopes of the interpreted major straight-line segments of the plotted data.

We used two types of shear-wave sources. In every survey, the shear-wave sources were oriented magnetic north-south. This was done to simplify alignment of the fluxgate compass inside the downhole transducers. The first type of source was a 16-lb sledgehammer striking the ends of a 6-in. × 6-in. wood beam, 7 ft long, with steel ends caps and cleats on the bottom. The front wheels of a vehicle, typically a pickup truck, were driven up onto the beam to hold it in firm contact with the ground. The sledgehammer has an impact sensor attached to its handle near the head that generates a zero-time signal for the seismograph. This source was used for all surveys in the alluvial deposits and gave excellent signals to a depth of 530 ft in C4996.

The second source, called the Slingshot source, was simply a larger, heftier version of the sledgehammer-and-beam source. The larger beam consists of five 4-in. × 6-in. wood beams bolted together for a total width of 18 in. and a length of 7.5 ft. Both ends of the beam are capped by thick steel plates, and the underside of the beam has 12 evenly spaced cleats bolted to it. The total weight of the beam is about 350 lb.; the front wheels of a heavy vehicle were driven up on to the beam. Each end of the beam was impacted by an accelerated-weight mechanism obtained from GeoSurvey Systems (Houston, Texas). The weights are 3.5-in.-diameter, 36-in.-long, 100-lb steel rods that slide in a guide and are driven by pre-tensioned 0.5-in. × 3-in. elastic bands. The elastic bands are stretched, and the weight is ‘cocked,’ by a double-acting hydraulic cylinder with a stroke of 16 in. At the end of the stroke, the weight is released and is accelerated by the elastic band to impact the end of the beam. A Slingshot source is positioned at each end of the beam, and an impact sensor is attached at the center of the beam.

In tests conducted prior to the attempted surveys in the DB boreholes in June 2006, the velocity of the accelerated weight was measured at 20 ft/sec, so that the kinetic energy is approximately 20,000 ft-lb., which is about 6 times greater than that of a 16-lb sledgehammer swung with moderate force.

For the surveys in the alluvial deposits, compression waves were generated by vertical sledgehammer blows to a metal plate on the ground surface.

The downhole sensor was a Model BHG-3 geophone manufactured by Geostuff (Grass Valley, California). The sensor package contains an orthogonal array of three 10-Hz geophones, mounted on a gearhead-motor assembly, and a fluxgate compass. A servo circuit links the compass to the motor so that the horizontal geophones can be aligned to a constant, pre-determined azimuth at each measurement point. This allows one of the two horizontal geophone elements to stay aligned with the shear-wave source on the ground surface as the sensor package is raised or lowered in the borehole. This capability ensures that the detected shear-wave signal is always the optimum. Magnetometer/gyroscope surveys in the three large boreholes showed that the magnetic declination in the basalts did not vary by more than about 15º from that at the ground surface. Compression waves are detected by the vertical geophone element.

In the large-diameter (8-in. nominal) uncased holes, the BHG-3 was mechanically locked to the borehole wall with a rigid arm that was extended by an electric motor inside the BHG-3. The arm can be extended and retracted by operating the control box for the transducer. The motor current is monitored with an analog meter to determine whether the arm is encountering mechanical resistance. Operation of the arm in the uncased holes, especially in the soft interbeds that were frequently washed out to a larger diameter, was problematical, and on two occasions the arm was severely damaged for reasons that are not entirely clear.

When acquiring downhole signals in the smaller-diameter cased holes, the rigid arm on the BHG-3 is replaced with a bow-spring that runs along the length of the transducer; the bow-spring is extended and retracted by the same motor that actuates the rigid arm. The motor current is monitored to gauge the clamping force of the spring.

When working in shallow holes, generally 500 ft or less, the rubber-jacketed transducer cable can be raised and lowered by hand. Our normal procedure when working in shallow cased holes is to lower the BHG-3 to a depth of 400 ft, extend the spring until it will hold the transducer from sliding down the hole when the cable is slackened, and then work upward by simply dragging the BHG-3 to the desired measurement point. This expedites the flow of data collection and reduces wear and tear on the clamping mechanism. Because the weight of the manhandled transducer cable becomes a hindrance below 400 ft, we operate in a measure-release-lower-clamp-slackenmeasure sequence at depths greater than 400 ft. This system and procedure, which requires only a 12-V automobile battery for power, was used with success in all of the shallow cased holes in alluvium.

For the deeper surveys, and for all the surveys in the uncased holes, a Model WW1500 geophysical logging winch (Aries Industries, Fresno, California) was used to operate the BHG-3 transducer. The winch drum contains 1500 ft of 5/16-in., 7-conductor armored cable (Rochester Dataline™ 7-H-314A; The Rochester Corporation). The winch motor operates on 110 V AC, as does a dual DC-power system that provides 60 V DC for the clamping motor in the BHG-3 and 30 V DC to operate the fluxgate compass and its associated servo motor. Higher voltages are needed to operate the BHG-3 over the wireline cable because its electrical resistance is higher than that of the rubber-jacketed cable. A 2000-W Honda EU2000i portable generator furnished the overall system power.

At the request of UT, we fabricated a relay module that allowed us to operate two BHG-3 downhole sensors using only the 7 conductors in the winch cable and its armored sheath. Two BHG-3s could be suspended at the end of the winch cable at a fixed interval, say 50 ft, and their respective clamping motors and compasses could be operated independently. Simultaneous signals from two longitudinal geophones (i.e., the ones aligned with the shear-wave source) or from the two vertical geophones could be recorded. This dual-sensor system was used only in the early stages of the program, after which it was decided that it was not needed. All subsequent measurements using the winch were made using only a single BHG-3 geophone.

Careful attention is given to the polarity of the shear-wave signals when using the BHG-3 transducer. The system is configured so that at each measurement point, the first blow to the beam produces a shear wave for which the initial deflection (the first peak) of the seismograph trace is always upward (i.e., toward the top of the paper record). At each successive measurement point, the same end of the beam (the north end) is always struck first and the resulting signals recorded on an odd-numbered channel. The signals from blows to the other end of the beam (the south end) are then recorded on the adjacent even-numbered channel. Ideally, the signals from the north and south ends are nearly mirror images of one another and, when viewed as adjacent channels, help in identifying and tracking the shear wave with changing depth. When applicable, compression-wave signals from hammer blows to the steel plate are detected while at the same depth and recorded on an appropriate channel on the seismograph.

All signals were recorded with a Geometrics Model R24 Strataview™ digital seismograph (Geometrics, Inc., San Jose, California) configured to record as many as 24 channels of data. During the initial surveys in the uncased holes using the Slingshot source, each channel consisted of 2048 samples collected at a rate of 125 microseconds per sample with a 100-millisecond delay between the zero time and the start of recording. For the alluvium surveys, each channel consisted of 1024 samples collected at a rate of 250 microseconds with no delay. The R24 has the capability of 'stacking' or adding the signals from multiple hammer blows to increase the signal-to-noise ratio of the downhole recordings. In the worst case, as many as eight hammer blows of the Slingshot source would be stacked, but more typically only two to four were required.

A switchbox was used that allowed the geophone signals from an impact to one end of the shear-wave beam to be routed to odd-numbered channels, and signals generated by blows to the other end to be routed to the adjacent even-numbered channels. For the surveys in the alluvium, the shear waves were routed sequentially to channels 1 through 16, and the compression waves were routed to channels 17 through 24. In general, the data are collected channel-by-channel until all of the active channels have been recorded or until the survey is complete, at which time the signals are transferred to a hard disk drive and printed on the R24's internal printer for field examination. Signals are also displayed on the seismograph LCD screen as they are acquired.

Analysis

The raw, unfiltered signals acquired in a velocity survey are transferred directly to the hard disk drive on the seismograph; any filtering is applied only during playback. In general, filters are employed to suppress noise or interference that may be superimposed on a shear- or compression-wave signal. The sources of interference are not always apparent but may include mechanical noise from nearby traffic or structures, multiple travel paths of the downward traveling pulse, reverberations and reflections due to changes in acoustic impedance at the stratigraphic boundaries, and questionable coupling of the casing to the surrounding material. The frequency range of a typical shear wave is approximately 30 Hz to 70 Hz. As the pass band of a filter becomes more restrictive, it also diminishes the amplitude of the signal along with that of the interference. It is often a matter of judgment how much filtering to apply to the raw signals, and this judgment is guided by inspection of the raw recorded signals. As a general rule, the less filtering, the better.

Filtering was accomplished by using the digital filters built into the operating system of the R24 seismograph. A 100-Hz low-pass was used for the deeper surveys in the uncased holes and the stainless-cased lower part of C4993; a 200-Hz low-pass was applied to all of the shear-wave signals in the shallower, alluvium surveys; and a 400-Hz low-pass was used for all compression-wave surveys. The R24 filters are not zero-phase and introduce a small time shift in the signals but, as explained below, this shift is accounted for in the analysis.

Copies of complete sets of the filtered downhole signals are provided in the appendix to this report. Although both shear- and compression-wave signals are recorded on the same seismograph record, they have been played back and presented as separate paper records. They have been reduced in size and shown in a 'waterfall' format so that the signals can be visually followed down the hole. The horizontal offset of the source from the borehole collar and the frequency of the filter and its corresponding time delay are shown on each set of records. The values of travel times used for the velocity analyses were obtained from full-size copies of these records with expanded time scales.

The time of the onset or 'first break' of the shear wave was not used as the travel time. The onset of a shear-wave pulse may be reasonably clear at the shallowest depths but rapidly becomes vague and indistinct with increasing depth. For this reason, the time of either the first peak or of the maximum peak, and of the corresponding trough from the reverse-polarity signals, is chosen as the travel time of the shear wave. The selected shear-wave travel times are indicated on the records by small dots that represent the average time of the peak and of its companion trough from the reverse-polarity blow to the source. The times of the peaks of the compression waves were selected as the travel times. A transparent plastic scale is overlaid on the seismograph traces to determine the travel times, and times to within 0.5 millisecond were attempted.

Because the signal source is offset from the collar of the hole, it is necessary to correct travel times for this offset. The correction converts the actual travel time along the slant path from source to receiver to the equivalent time required to travel vertically from the ground surface down to the receiver. In essence, the correction amounts to multiplying the travel time by the cosine of the angle between the slant path and vertical. However, a simple cosine correction is valid only if the time of the onset of the signal is used. If this simple cosine correction is applied to a later portion of the waveform, such as the first peak or the maximum peak, then the times will be overcorrected and the computed near-surface velocities will be too low. The proper method of correcting for the source offset is as follows:

$$\mathbf{t_{vertical} = (t_{peak} - \Delta t_o - \Delta t_f) \times \cos\Theta}$$

where $\mathbf{t_{vertical}}$ is the time plotted against the depth to the measurement point; $\mathbf{t_{peak}}$ is the time of the selected peak; $\mathbf{\Delta t_o}$ is the time difference between the onset of the signal and the selected peak (and its corresponding trough) for signals recorded at shallow depth; $\mathbf{\Delta t_f}$ is the time shift (i.e., time delay) caused by filtering the signal; and $\mathbf{\Theta}$ is the angle between the slant path and vertical. The value of $\mathbf{\Delta t_f}$ is easily measured by comparing the times of common points on the waveforms of filtered and unfiltered records. In practice, the value of cos$\mathbf{\Theta}$ is computed from the source offset, **s**, and the depth to the transducer, **d**, so that the above equation becomes

$$\mathbf{t_{vertical} = (t_{peak} - \Delta t_o - \Delta t_f) \times [d/(d^2 + s^2)^{1/2}]}$$

The travel times are tabulated manually on forms designed for that purpose and then entered into a simple Excel™ program that calculates the vertical travel time using the above equation.

The times and their corresponding depths are plotted using Grapher™ 6 (Golden Software, Golden, Colorado).

Results

The results are presented graphically in Figures 1 through 15.

Figures 1 through 6 illustrate the results obtained in the upper 400 ft of boreholes C4993, C4996, and C4998, i.e., in the alluvium that overlies the basalt. Shear- and compression-wave plots are presented in sequence for each hole.

Figures 7, 8, and 9 combine the information from the shallow alluvial surveys with the data acquired during the deeper surveys in the same uncased or stainless-cased holes. Note that the downhole shear-wave times observed in C4998 have been plotted together with the relatively sparse set of times acquired in C4997; hole C4998 was located about 75 ft from C4997. Also note that Figure 8 includes the entire set of compression-wave times measured in C4996 because the times for depths greater than 400 ft could not be plotted in Figure 4.

The shallow downhole travel times observed in C4993, C4996, and C4998 for shear and compression waves have been overlaid in Figures 10 and 11, respectively. The travel times for C4998 are plotted as measured, whereas the times for the other holes were adjusted by the small amounts of time indicated on the figures. The times were adjusted so that the plotted times were nearly coincident at a depth of approximately 400 ft. Lines representing visual best fits through the aggregate plots have been drawn, and the corresponding velocities are shown on the figures. These plots are intended to give a large-scale overview of the velocity structure in the alluvium beneath the WTP site.

Figures 12 and 13 shows superimposed shear- and compression-wave velocities, respectively, as a function of depth in the upper 400 ft in boreholes C4993, C4996, and C4998.

Figures 14 and 15 present the same information as Figures 12 and 13 with the addition of average values of velocity and of the velocities in Figures 10 and 11 that are based on the superimposed plots of the travel times. The values of average velocity were simply calculated for each depth interval in each hole.

The downhole velocities measured in this program are presented in Table 2.

Discussion

It is clear from a cursory inspection of the travel-time versus depth plots that, in general, the data are characterized by some degree of scatter, with relatively more scatter associated with the compression-wave data. The scatter can be attributed to small-scale heterogeneities, variations in the coupling of the casing to the surrounding material, and reflected signals near stratigraphic interfaces. Nevertheless, the scatter is generally less than a few milliseconds for the shear signals and 5 milliseconds or less for the compression signals. The compression data may appear slightly more scattered, but some of this is due to the expanded time scale of these plots. In the upper 50 ft of borehole C4996 (see Figure 4), it appears that the compression wave propagated down the grout in the annulus around the casing.

It is often difficult to precisely define the depth of an interface, and judgment is frequently necessary when partitioning the subsurface into discrete velocity layers. This is especially so when there is scatter in the travel-time data, or if the velocity contrast between adjacent layers is not large.

It should be emphasized that all lines fitting the data points were drawn using considerable judgment and that the slopes of these lines on which the velocity values are based were determined graphically. No least-squares values of slopes and, therefore, of the corresponding velocities, were used for the final set of values, although least-squares were calculated as check values. The slopes were determined simply by measuring the intercepts of the visual best-fit lines on the axes of the graphs. For this reason, the values of velocity have generally been rounded to the nearest 10 ft/sec when warranted, and to even larger rounding limits at the higher values. To not do so would imply a false sense of accuracy. All available information, particularly the drilling logs, was evaluated when determining layer boundaries.

Table 2. Summary of Velocities
Measured in Downhole Surveys at the WTP Site

Borehole Number	Depth Range (ft)	Shear-Wave Velocity (ft/sec)	Compression-Wave Velocity (ft/sec)
C4993	0 – 15	780	1100
	15 – 30	780	1850
	30 – 100	1600	2900
	100 – 170	1760	2900
	170 – 236	2300	3900
	236 – 280	1950	3900
	280 – 300	1950	11,000
	300 – 358	7150	11,000
	358 – 400	8000	11,000
	400 – 474	8000	N/A
	474 – 532	2800	N/A
	532 – 725	8500	N/A
	725 – 742	3750	N/A
C4996	0 – 15	670	1050
	15 – 160	1620	2900
	160 – 175	2040	2900
	175 – 255	2040	3850
	255 – 275	2170	3850
	275 – 304	2170	13,000
	304 – 349	7300	13,000
	349 – 447	8500	13,000
	447 – 495	3300	7200
	495 – 520	5000	10,000
	520 – 650	8400	N/A
C4997	383 – 495	8000	N/A
	495 – 537	3150	N/A
	537 – 585	5000	N/A
	585 – 610	8000	N/A
C4998	0 – 18	1100	1700
	18 – 30	1100	2700
	30 – 70	1530	2700
	70 – 120	1880	2700
	120 – 190	1640	2700
	190 – 250	2650	5000
	250 – 322	2270	6700
	322 – 360	7000	10,000

Calculating the higher values of compression-wave velocities presented the most uncertainty. As a specific example, the compression-wave velocity from a depth of 280 ft to 400 ft in C4993 is reported as 11,000 ft/sec in Figure 2. The least-squares value over this same interval is 11,515 ft/sec. The bottom two points in Figure 2 were judged questionable; therefore, the value of velocity determined graphically is slightly less. Further, the total transit time of a compression-wave pulse over the 120 ft from 280 to 400 ft is less than 11 milliseconds at a velocity of 11,000 ft/sec. Consequently, a 1-millisecond uncertainty in the total travel time is equivalent to an uncertainty of about 10% in the velocity over this interval. In general, 'true' velocity values are believed to be within 5% of the reported values, although the uncertainty may be somewhat higher for some of the compression-wave values.

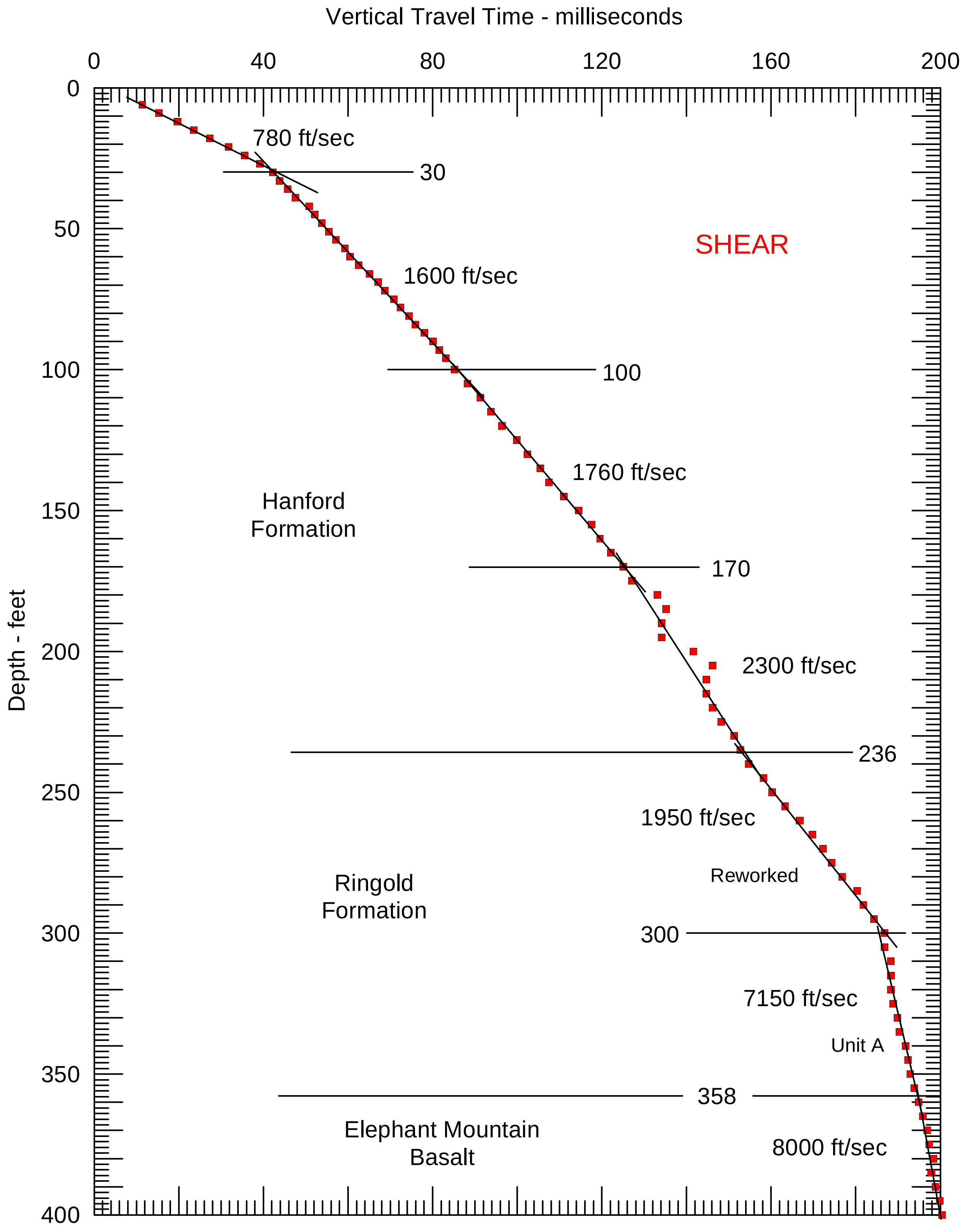


Fig. 1
Borehole C4993 - WTP Site at Hanford
Downhole Shear-Wave Travel Times in Alluvial Deposits
Sledgehammer Source - 9 February 2007
Showing Approximate Values of Velocities and Depths to Interfaces

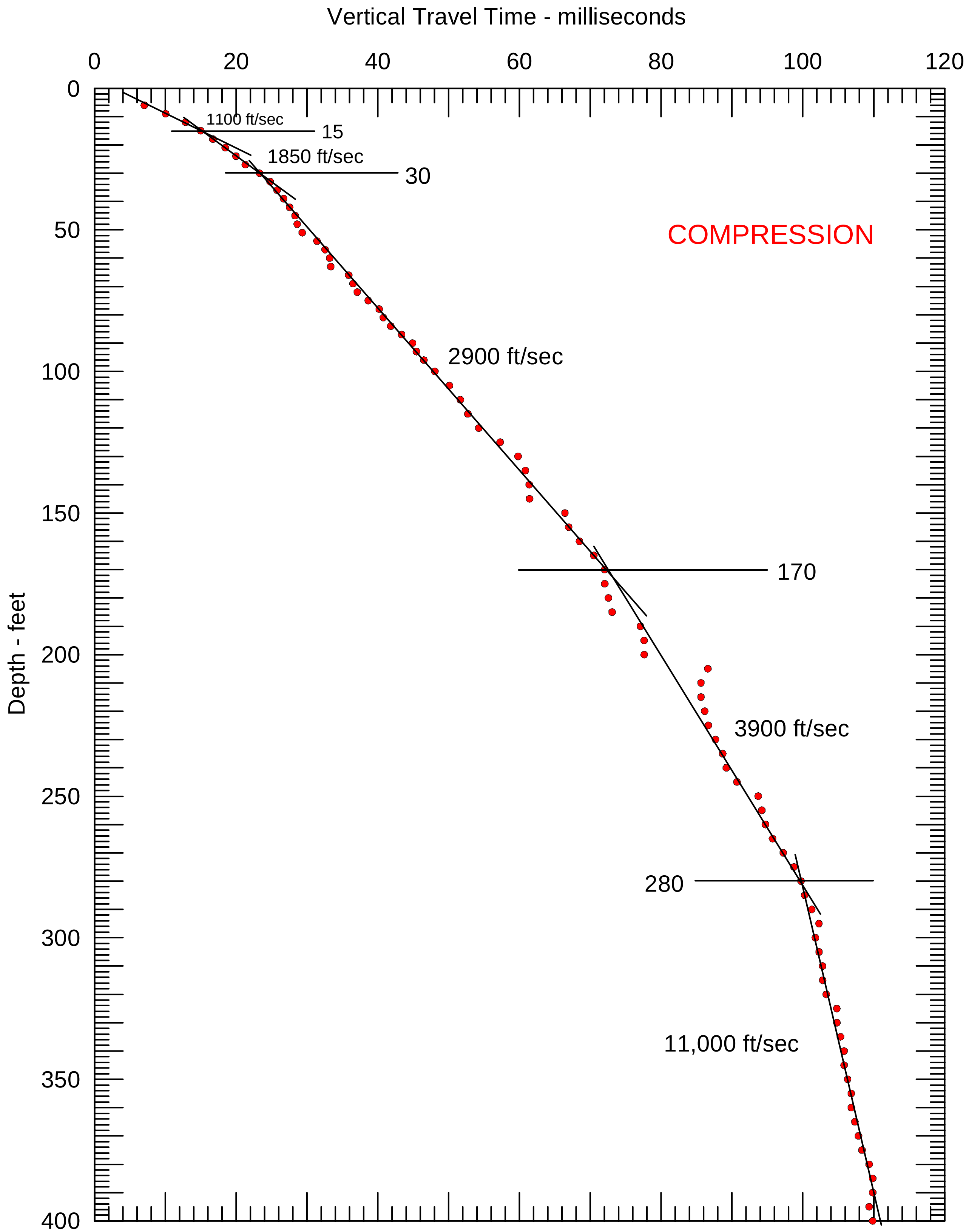


Fig. 2
Borehole C4993 - WTP Site at Hanford
Downhole Compression-Wave Travel Times in Alluvial Deposits
Sledgehammer Source - 9 February 2007
Showing Approximate Values of Velocities and Depths to Interfaces

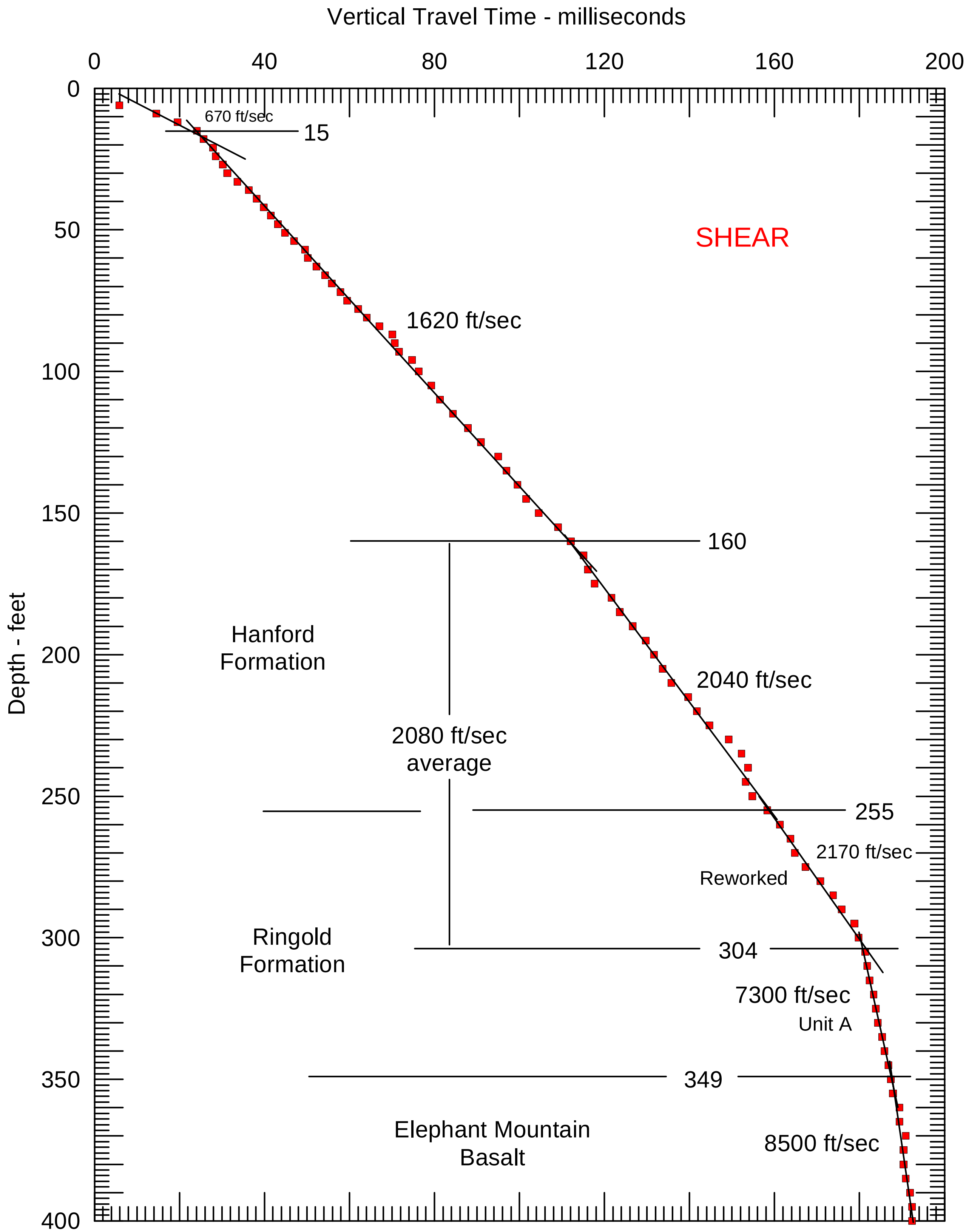


Fig. 3
Borehole C4996 - WTP Site at Hanford
Downhole Shear-Wave Travel Times in Alluvial Deposits
Sledgehammer Source - 29 January 2007
Showing Approximate Values of Velocities and Depths to Interfaces

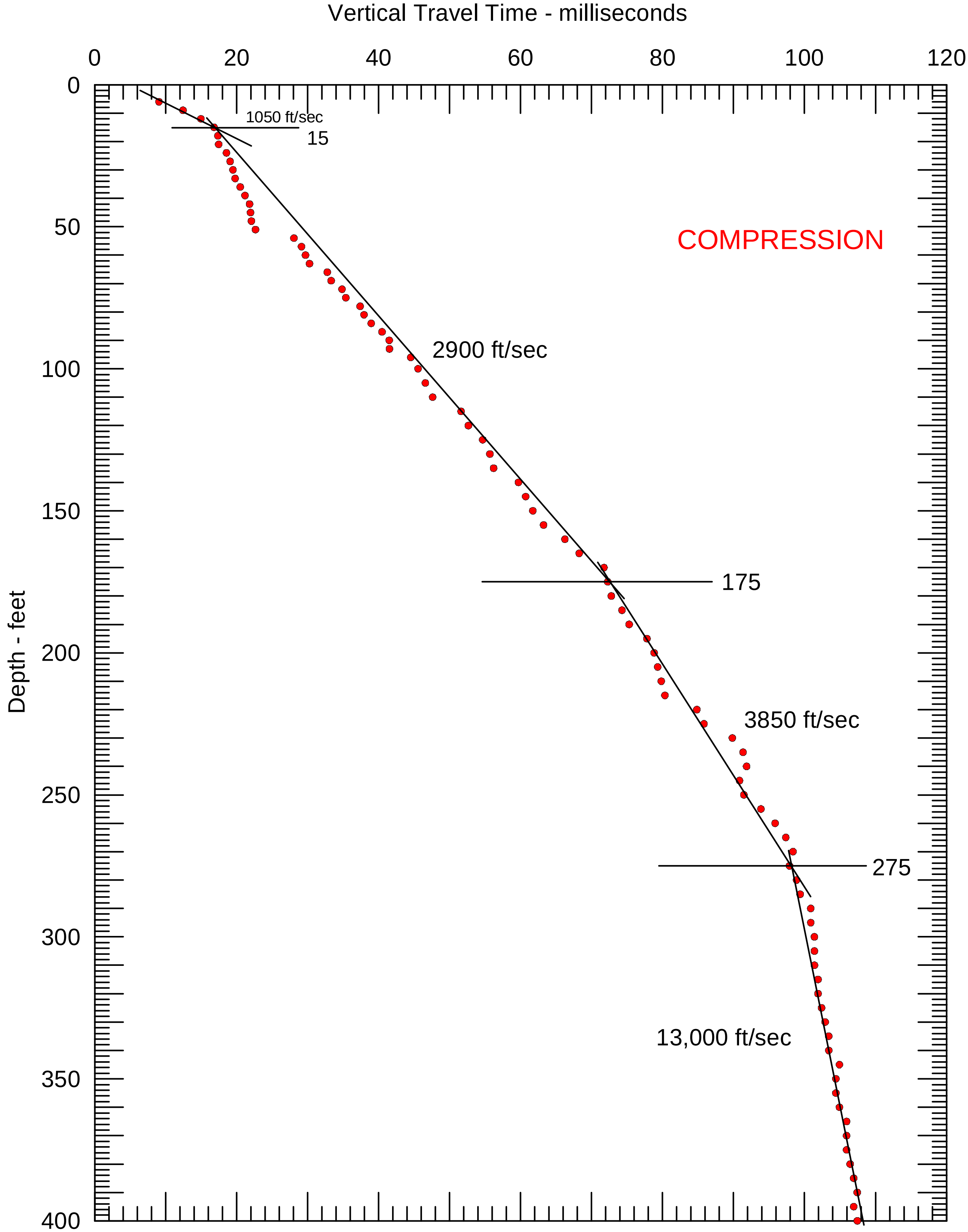


Fig. 4
Borehole C4996 - WTP Site at Hanford
Downhole Compression-Wave Travel Times in Alluvial Deposits
Sledgehammer Source - 29 January 2007
Showing Approximate Values of Velocities and Depths to Interfaces

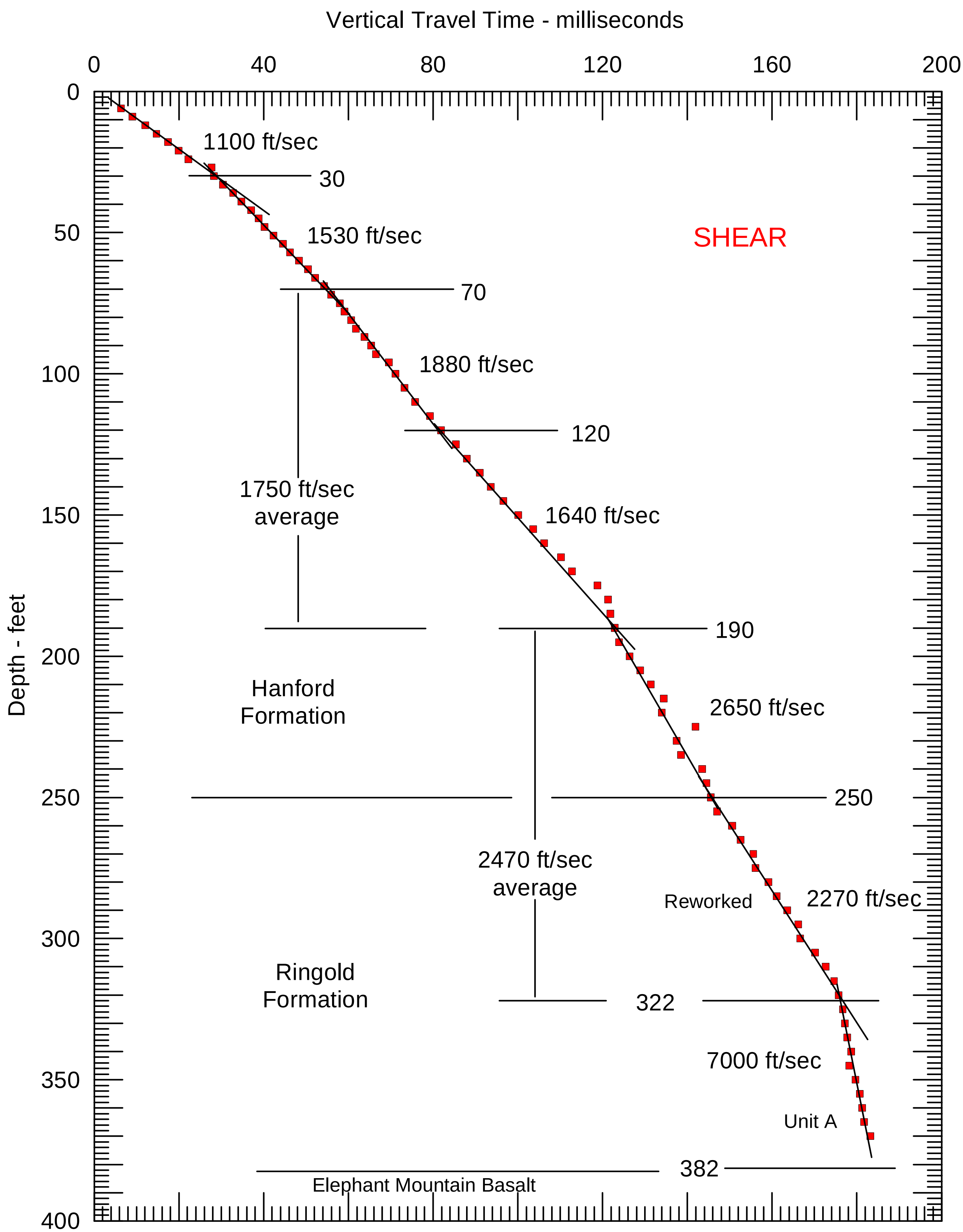


Fig. 5
Borehole C4998 - WTP Site at Hanford
Downhole Shear-Wave Travel Times in Alluvial Deposits
Sledgehammer Source - 10 December 2006
Showing Approximate Values of Velocities and Depths to Interfaces

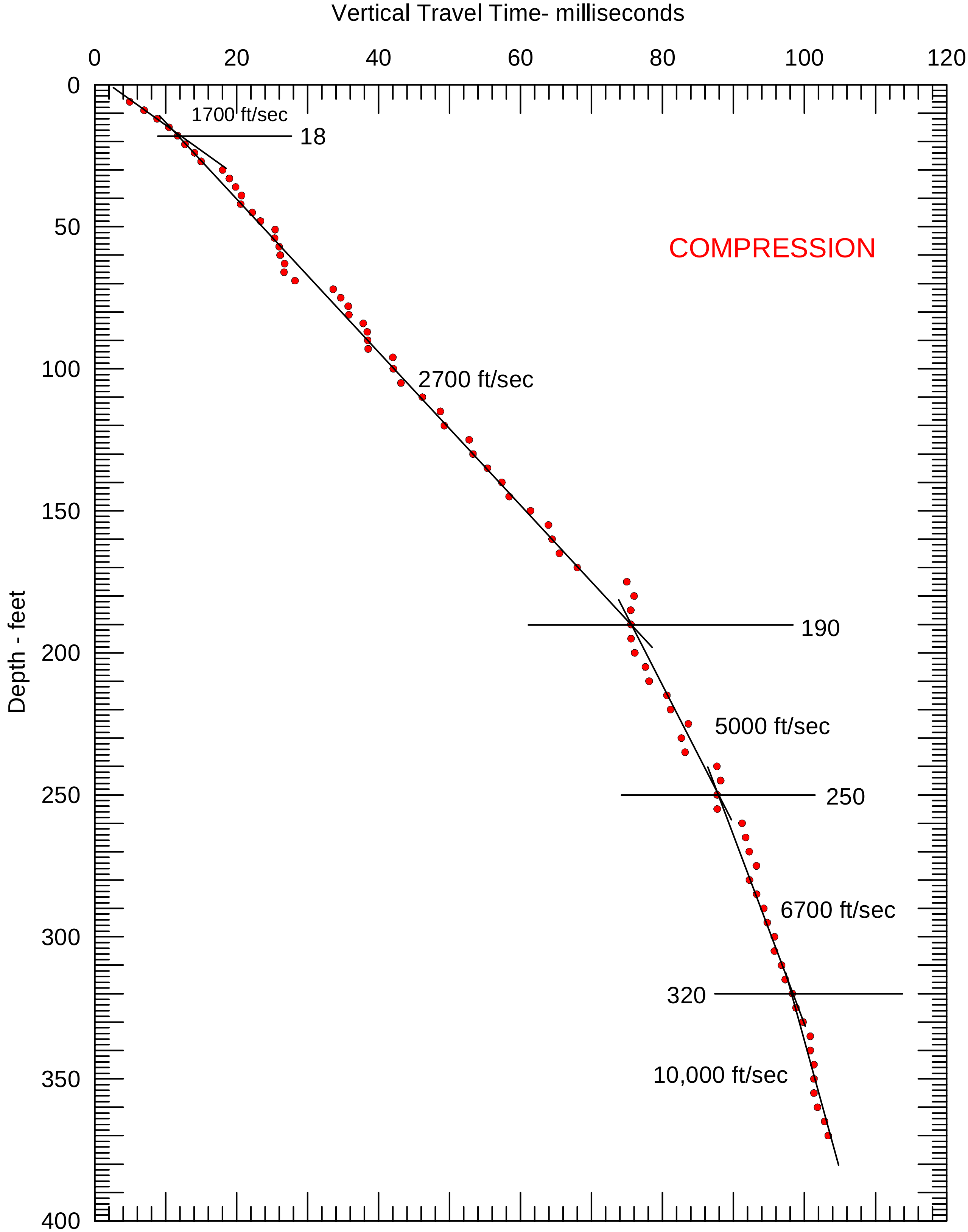


Fig. 6
Borehole C4998 - WTP Site at Hanford
Downhole Compression-Wave Travel Times in Alluvial Deposits
Sledgehammer Source - 10 December 2006
Showing Approximate Values of Velocities and Depths to Interfaces

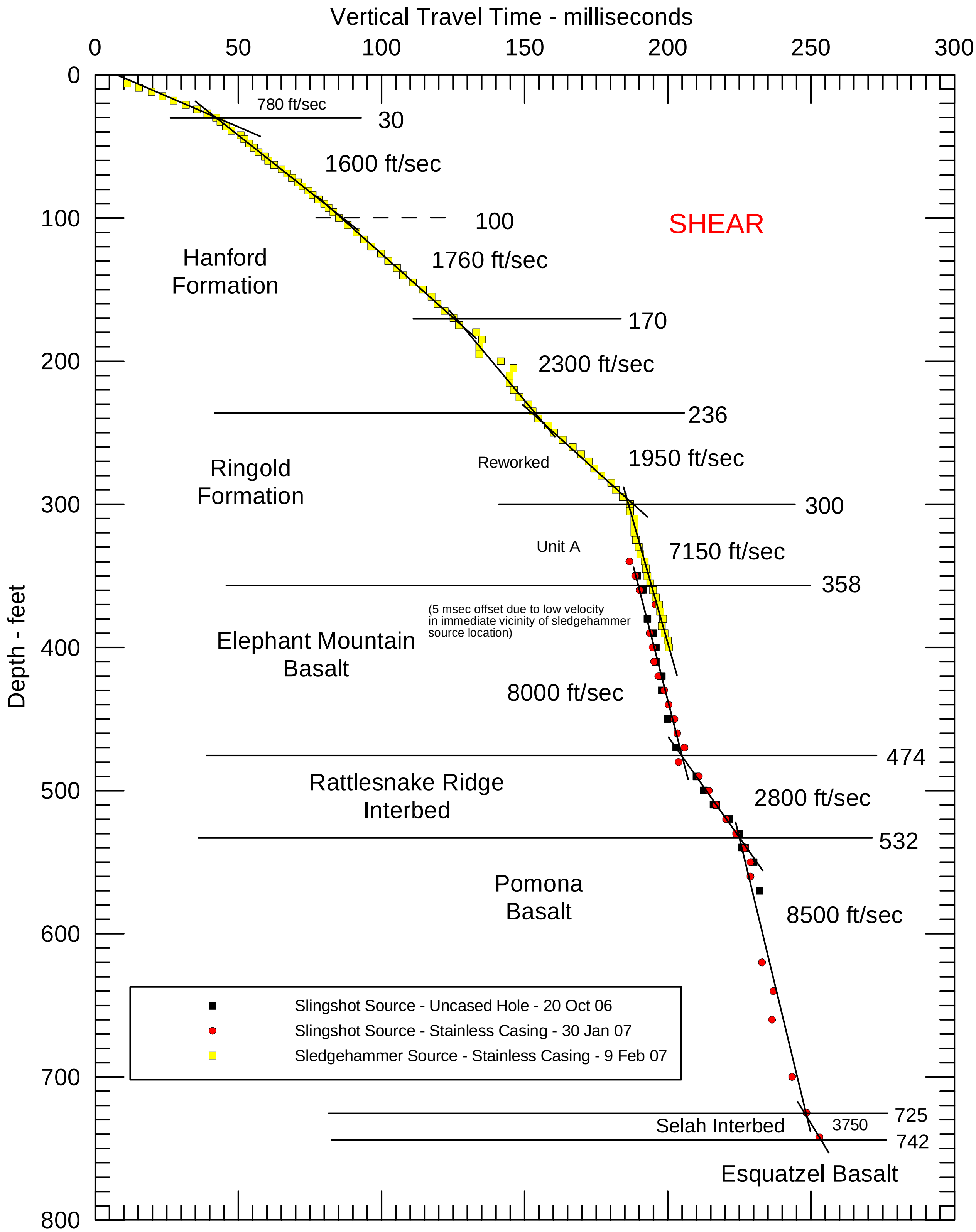


Fig. 7
Borehole C4993 - WTP Site at Hanford
Downhole Shear-Wave Travel Times
Slingshot Source (20 Oct 06 & 30 Jan 07) and Sledgehammer Source (9 Feb 07)
Showing Approximate Values of Velocity and Depths to Interfaces

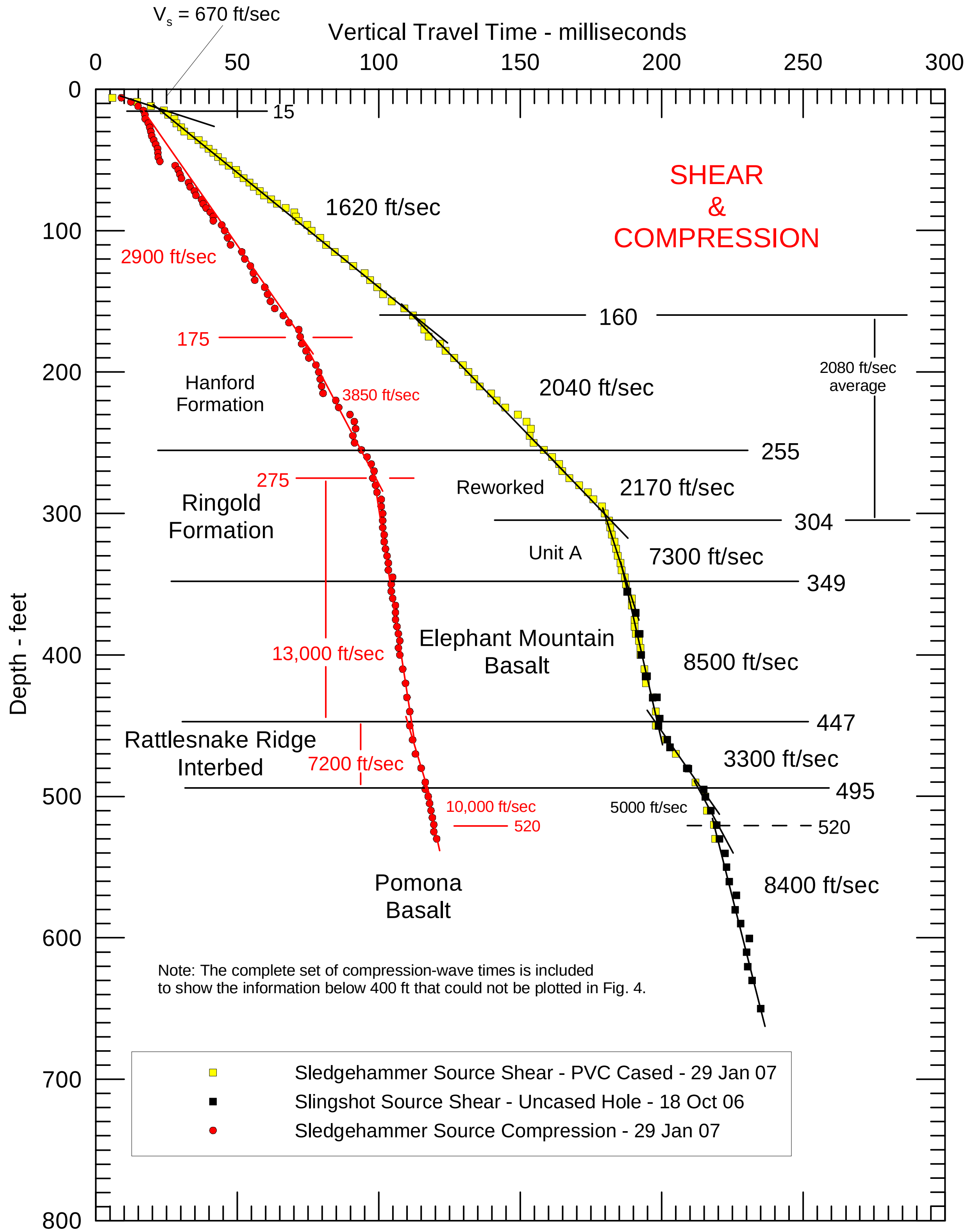


Fig. 8
Borehole C4996 - WTP Site at Hanford
Downhole Shear- and Compression-Wave Travel Times
Slingshot Source (18 Oct 06) and Sledgehammer Source (29 Jan 07)
Showing Approximate Values of Velocity and Depths to Interfaces

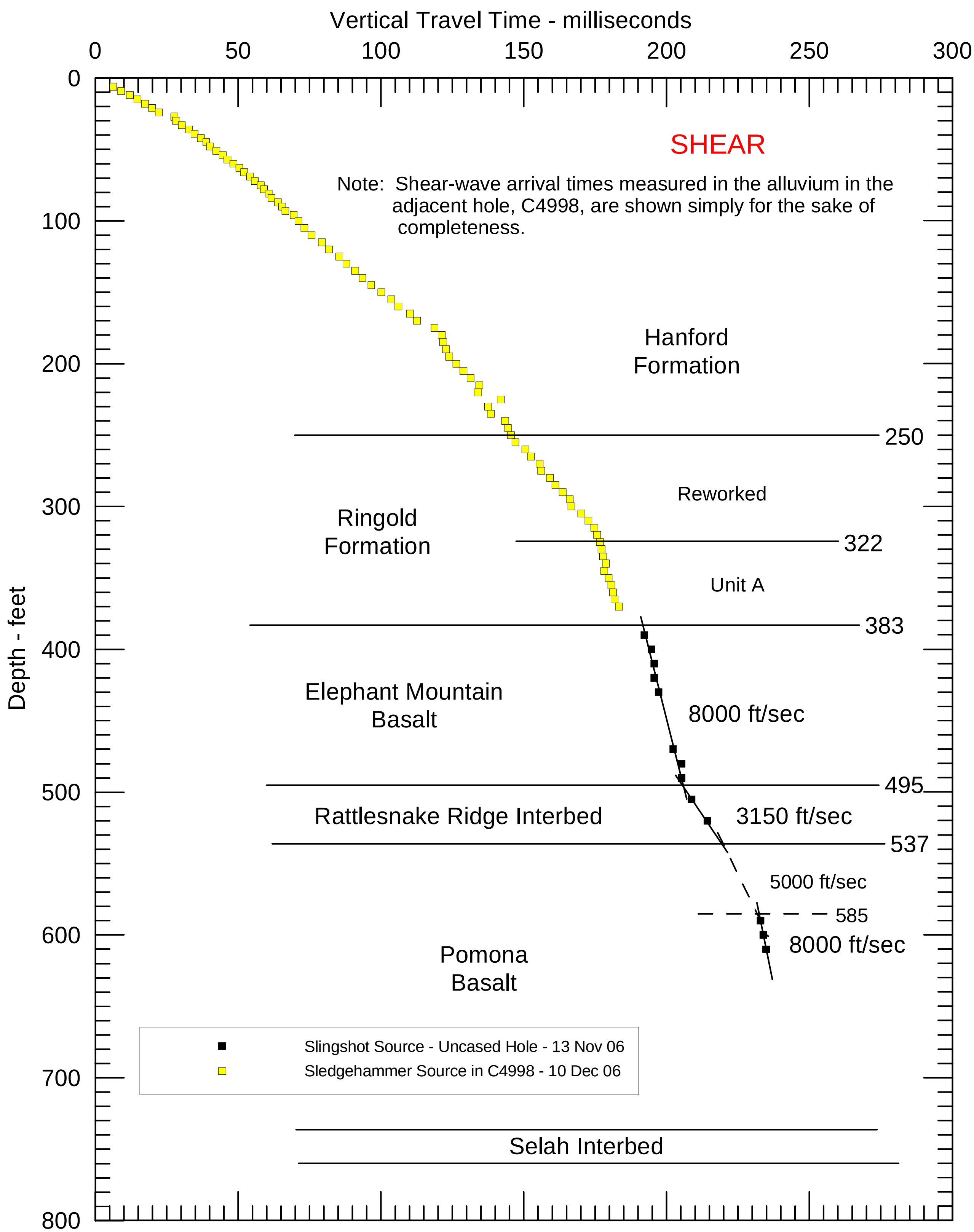


Fig. 9
Borehole C4997 - WTP Site at Hanford
Downhole Shear-Wave Times
Slingshot Source (13 Nov 06) and Sledgehammer Source in C4998 (10 Dec 06)
Showing Approximate Values of Velocity and Depths to Interfaces in C4997

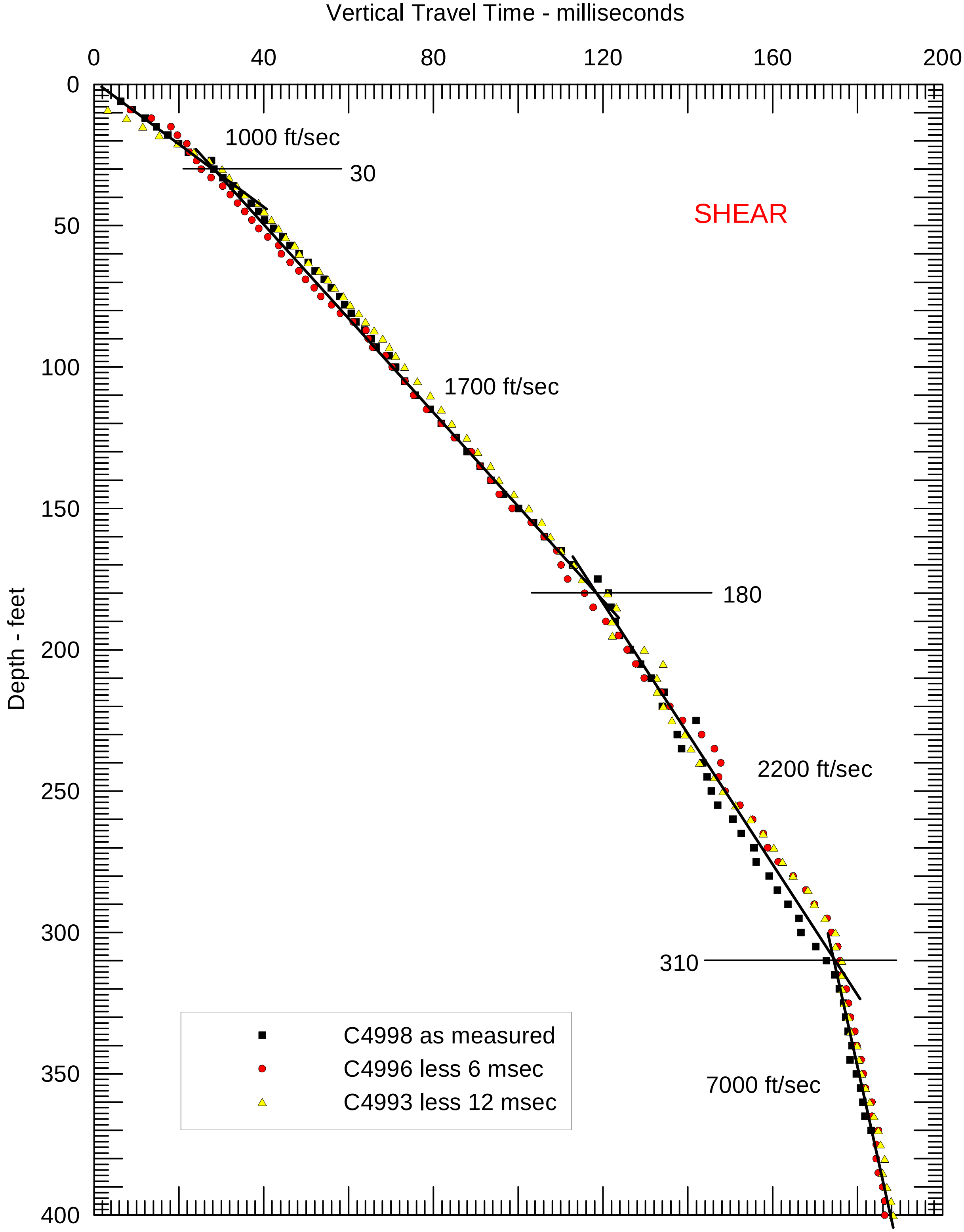


Fig. 10
Overlay of Shallow Shear-Wave Downhole Times in C4998, C4996 & C4993
C4998 Times Plotted as Measured
C4996 Times Reduced by 6 msec & C4993 Times Reduced by 12 msec
Showing Approximate Values of Velocities

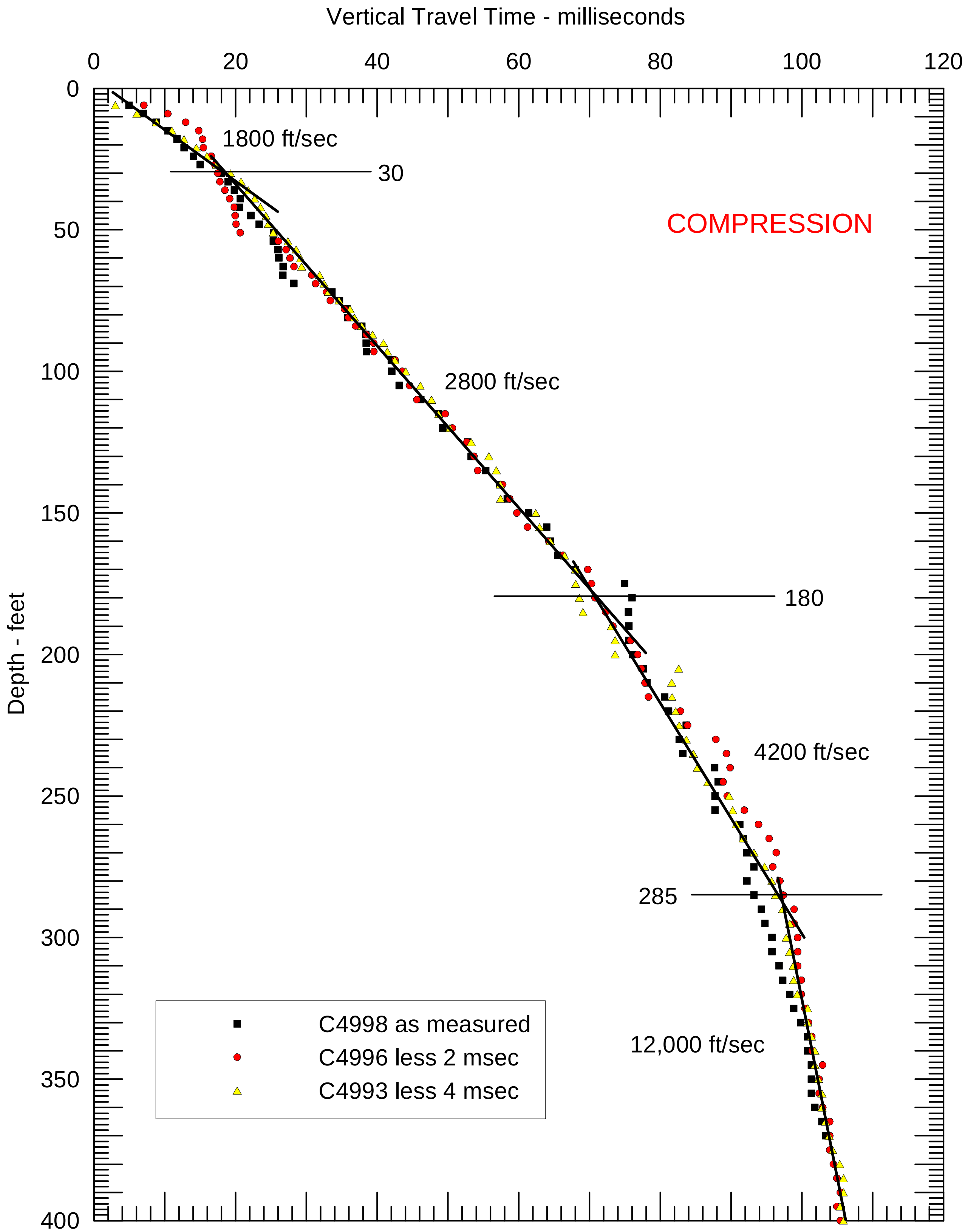


Fig. 11
Overlay of Shallow Compression-Wave Downhole Times in C4998, C4996 & C4993
C4998 Times Plotted as Measured
C4996 Times Reduced by 2 msec & C4993 Times Reduced by 4 msec
Showing Approximate Values of Velocities

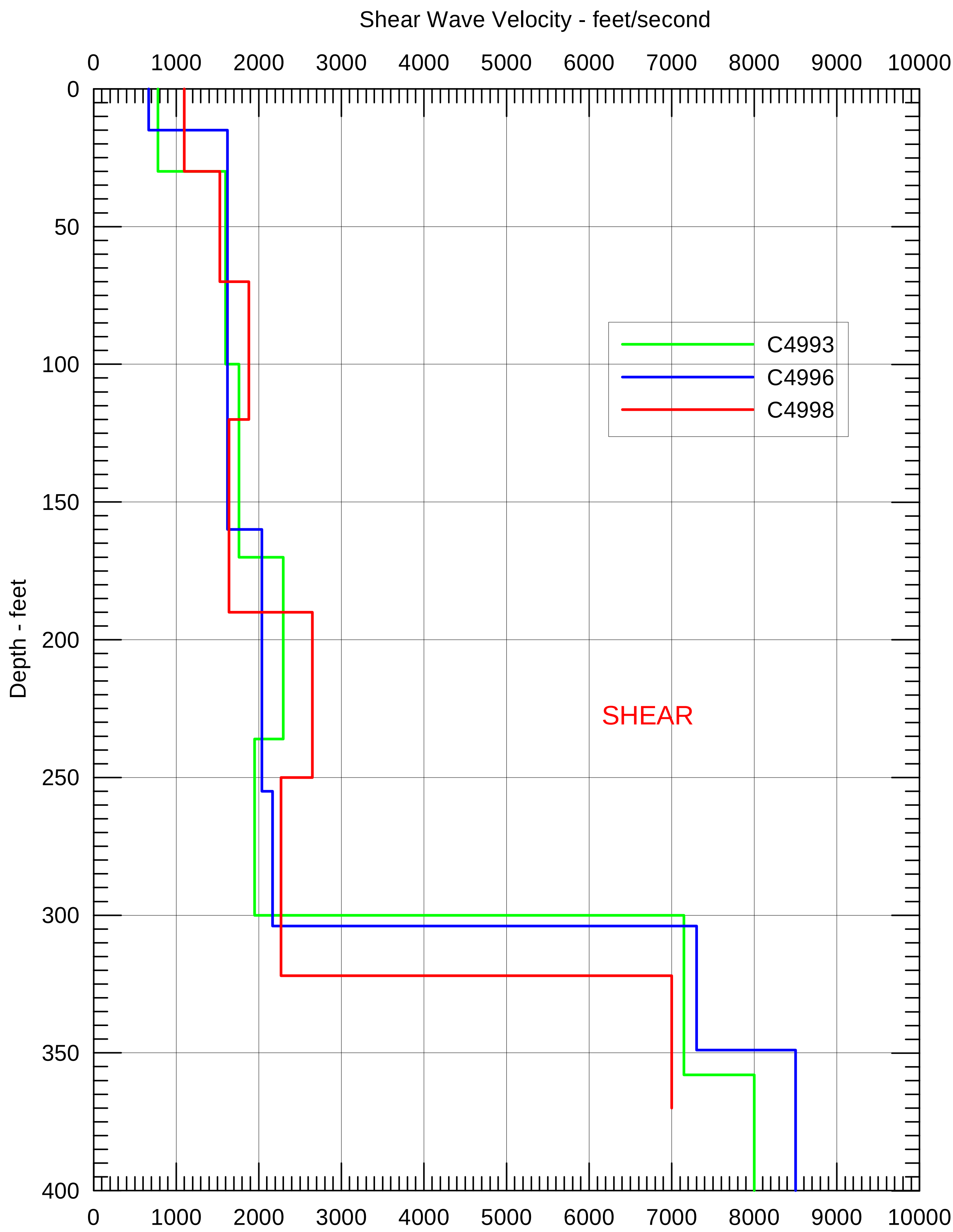


Fig. 12
Boreholes C4993, C4996 & C4998 - WTP Site at Hanford
Shallow Downhole Shear-Wave Velocities
Sledgehammer Source

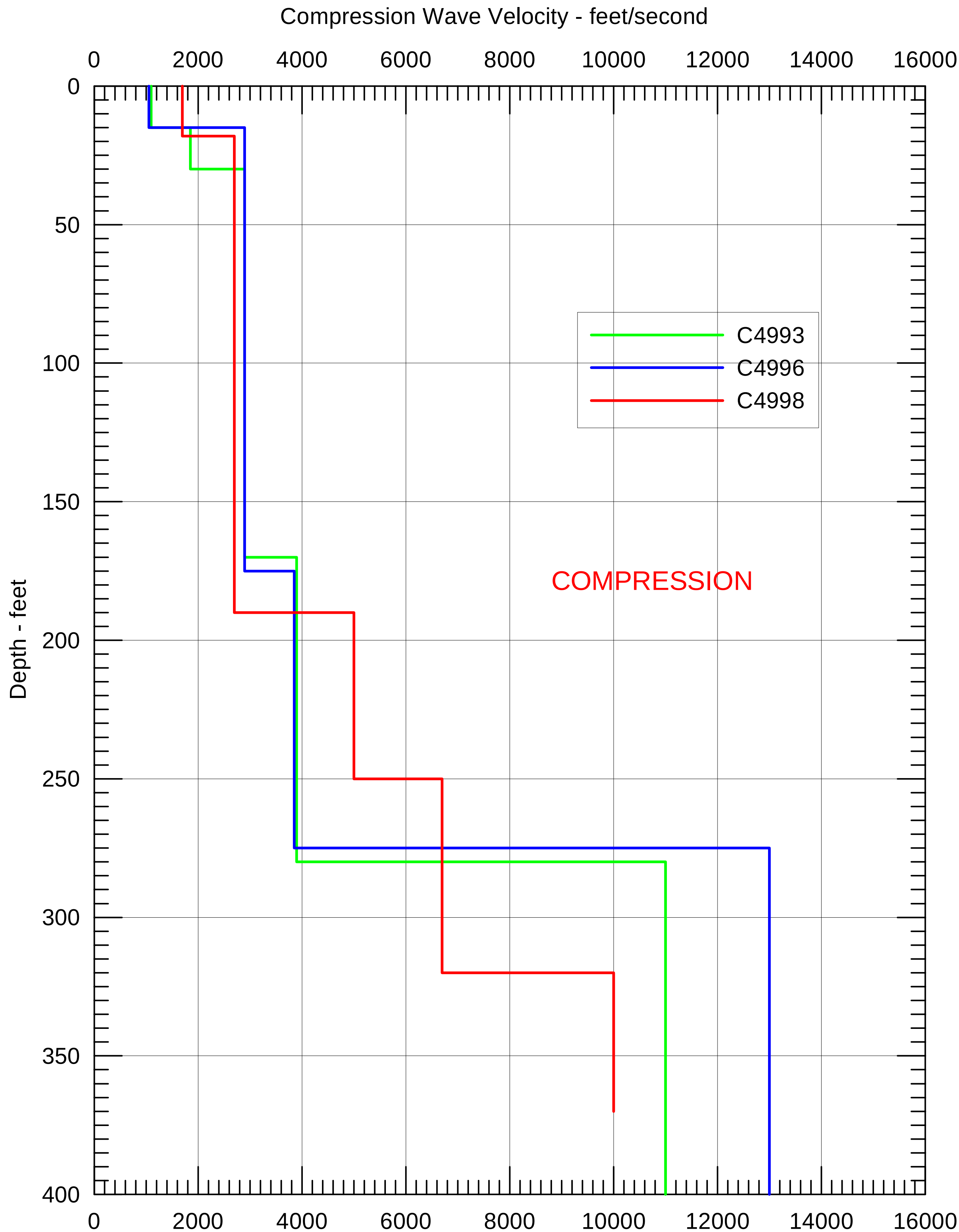


Fig. 13
Boreholes C4993, C4996 & C4998 - WTP Site at Hanford
Shallow Downhole Compression-Wave Velocities
Sledgehammer Source

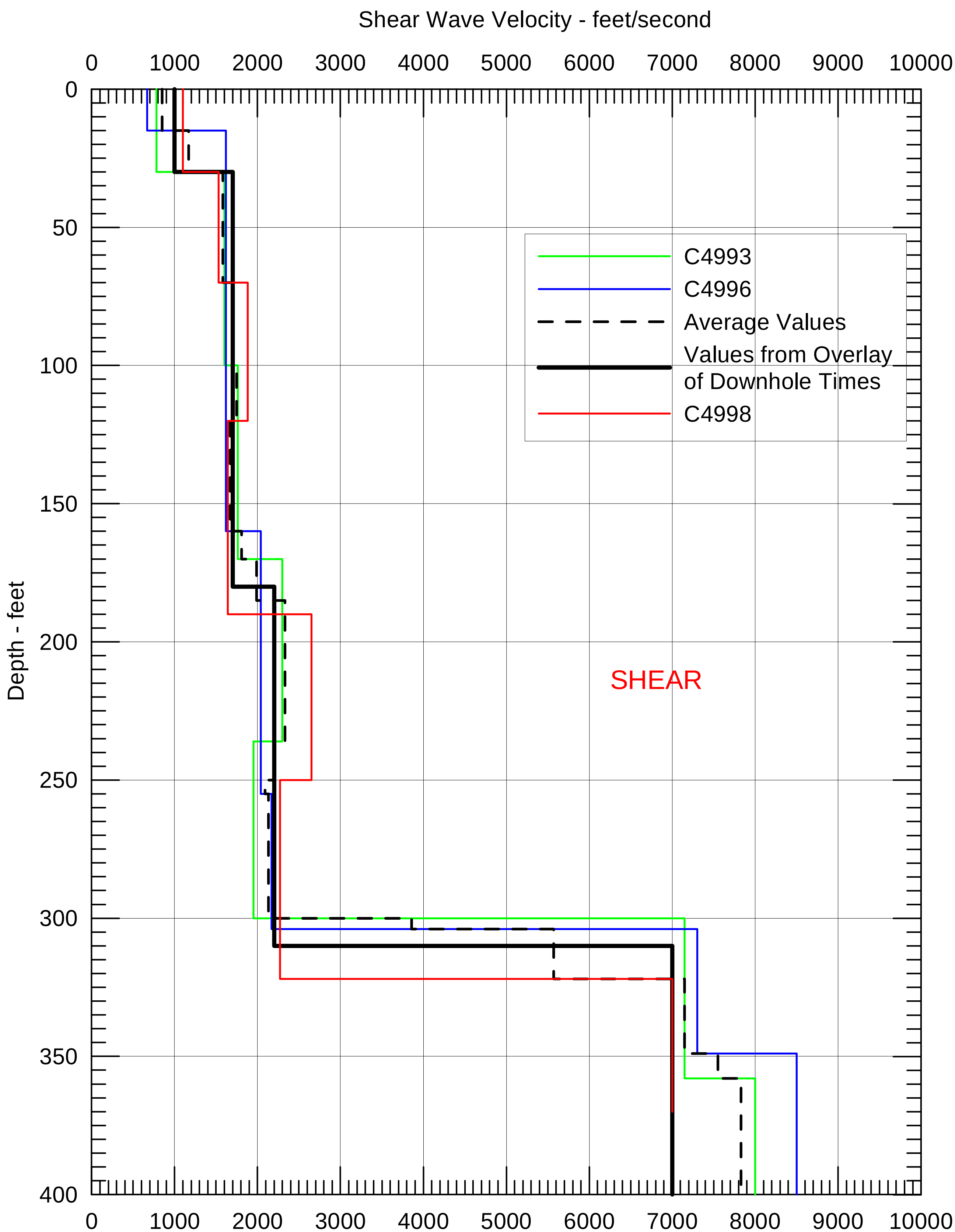


Fig. 14
Boreholes C4993, C4996 & C4998 - WTP Site at Hanford
Individual and Average Shallow Downhole Shear-Wave Velocities
Sledgehammer Source

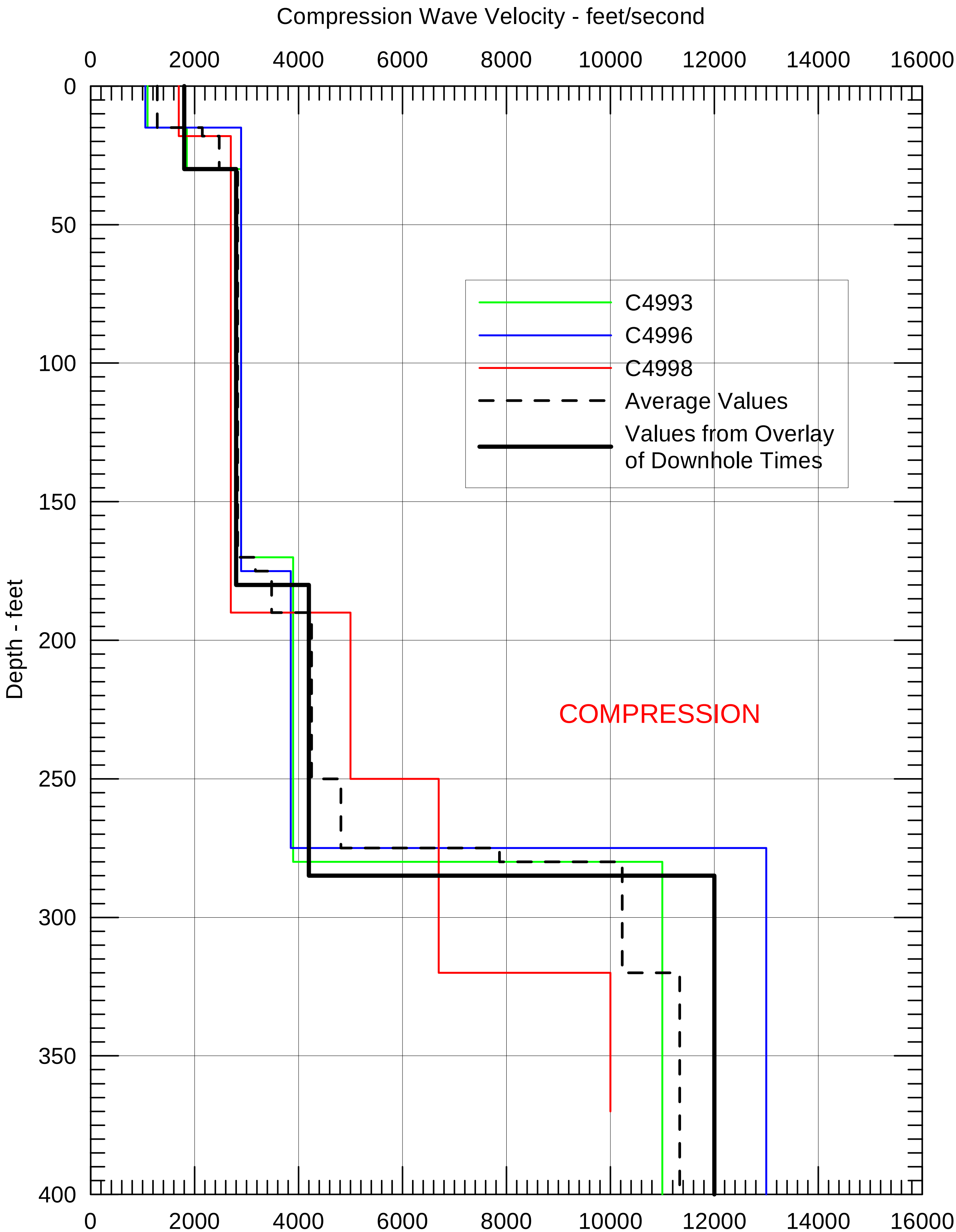


Fig. 15
Boreholes C4993, C4996 & C4998 - WTP Site at Hanford
Individual and Average Shallow Downhole Compression-Wave Velocities
Sledgehammer Source

Appendix

Seismograph Records
from Downhole Velocity Surveys

Appendix

Seismograph Records
from Downhole Velocity Surveys

Borehole C4996
Slingshot S-Wave Times
18 October 2006

Borehole No.	WTP-4996
Seismic Mode	Slingshot Shear
Source Offset (ft)	19
Onset-to-Peak (ms)	10
Filter Delay (ms)	5

Depth bgs (ft)	Slant TT (ms)	Slant TT - OP - FD	Cosine Factor	**Vertical Travel Time (ms)**
355.3	203.0	188.0	0.998573222	**187.7**
370.3	206.0	191.0	0.998686248	**190.7**
385	207.0	192.0	0.998784477	**191.8**
385	207.5	192.5	0.998784477	**192.3**
400	208.0	193.0	0.998873780	**192.8**
415	210.0	195.0	0.998953597	**194.8**
415.3	209.5	194.5	0.998955106	**194.3**
430	213.5	198.5	0.999025224	**198.3**
430.3	212.0	197.0	0.999026581	**196.8**
445	214.5	199.5	0.999089743	**199.3**
450.3	214.0	199.0	0.999111016	**198.8**
460	217.0	202.0	0.999148065	**201.8**
465.3	218.0	203.0	0.999167339	**202.8**
480	224.0	209.0	0.999217499	**208.8**
480.3	224.5	209.5	0.999218475	**209.3**
495	230.0	215.0	0.999264153	**214.8**
500.3	230.5	215.5	0.999279645	**215.3**
510	232.5	217.5	0.999306758	**217.3**
520.3	234.5	219.5	0.999333906	**219.4**
530	235.5	220.5	0.999358041	**220.4**
540.3	237.5	222.5	0.999382261	**222.4**
550	238.0	223.0	0.999403839	**222.9**
560.3	239.0	224.0	0.999425538	**223.9**
570	241.5	226.5	0.999444907	**226.4**
580.3	241.0	226.0	0.999464422	**225.9**
590	243.0	228.0	0.999481874	**227.9**
600.3	246.0	231.0	0.999499488	**230.9**
610	245.0	230.0	0.999515268	**229.9**
620.3	245.5	230.5	0.999531221	**230.4**
630	247.0	232.0	0.999545535	**231.9**
650	250.0	235.0	0.999573055	**234.9**

Downhole Velocity Records

SHEAR WAVES

Project WTP at HANFORD

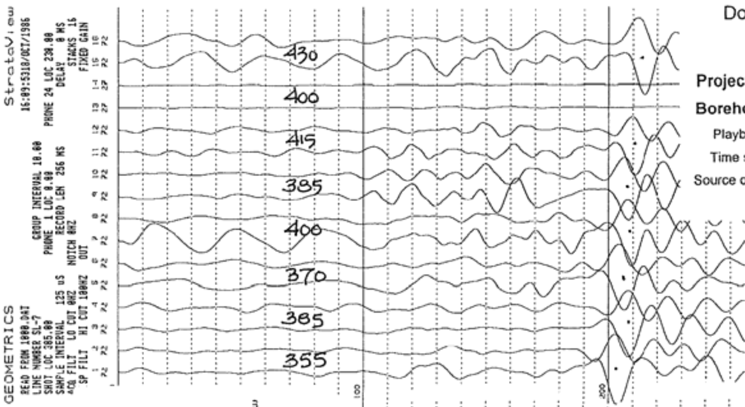
Borehole C4996 Date 18 OCT 06

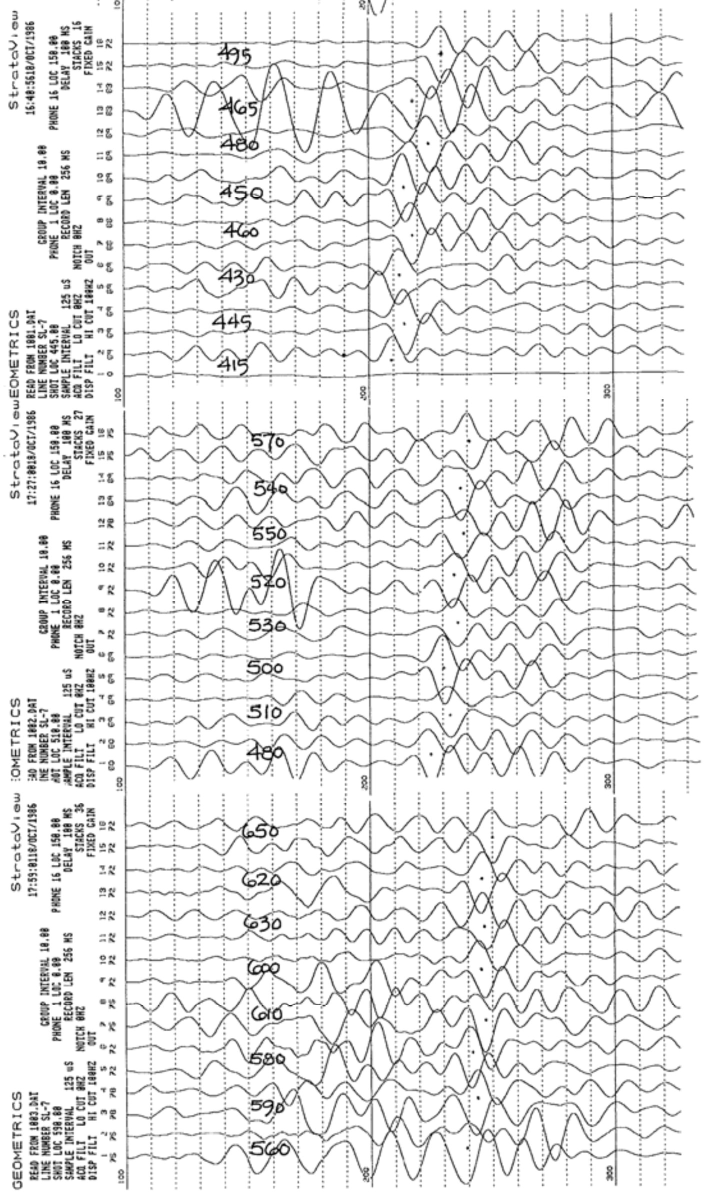
Playback filter 100 Hz low-pass

Time scale 10 milliseconds/line

Source offset 19 ft Filter delay 5 msec

[All depths in feet]





Borehole C4993
Slingshot S-Wave Times
20 October 2006

Borehole No.	WTP-4993
Seismic Mode	Slingshot Shear
Source Offset (ft)	16
Onset-to-Peak (ms)	10
Filter Delay (ms)	5

Depth bgs (ft)	Slant TT (ms)	Slant TT - OP - FD	Cosine Factor	**Vertical Travel Time (ms)**
349.8	204.5	189.5	0.998955545	**189.3**
359.8	206.0	191.0	0.999012711	**190.8**
359.8	206.5	191.5	0.999012711	**191.3**
380	208.0	193.0	0.999114750	**192.8**
390	210.0	195.0	0.999159509	**194.8**
400	211.0	196.0	0.999200959	**195.8**
410	211.0	196.0	0.999239417	**195.9**
420	213.0	198.0	0.999275165	**197.9**
430	213.0	198.0	0.999308452	**197.9**
450	215.0	200.0	0.999368500	**199.9**
470	218.0	203.0	0.999421055	**202.9**
490	225.0	210.0	0.999467315	**209.9**
499.8	227.5	212.5	0.999487984	**212.4**
509.8	231.0	216.0	0.999507859	**215.9**
519.8	236.5	221.5	0.999508245	**221.4**
510	232.0	217.0	0.999544633	**216.9**
530	240.0	225.0	0.999561006	**224.9**
539.8	241.0	226.0	0.999561331	**225.9**
540	242.0	227.0	0.999577128	**226.9**
550	245.0	230.0	0.999606265	**229.9**
570	247.0	232.0	0.999999900	**232.0**

Downhole Velocity Records

SHEAR WAVES

Project WTP at HANFORD

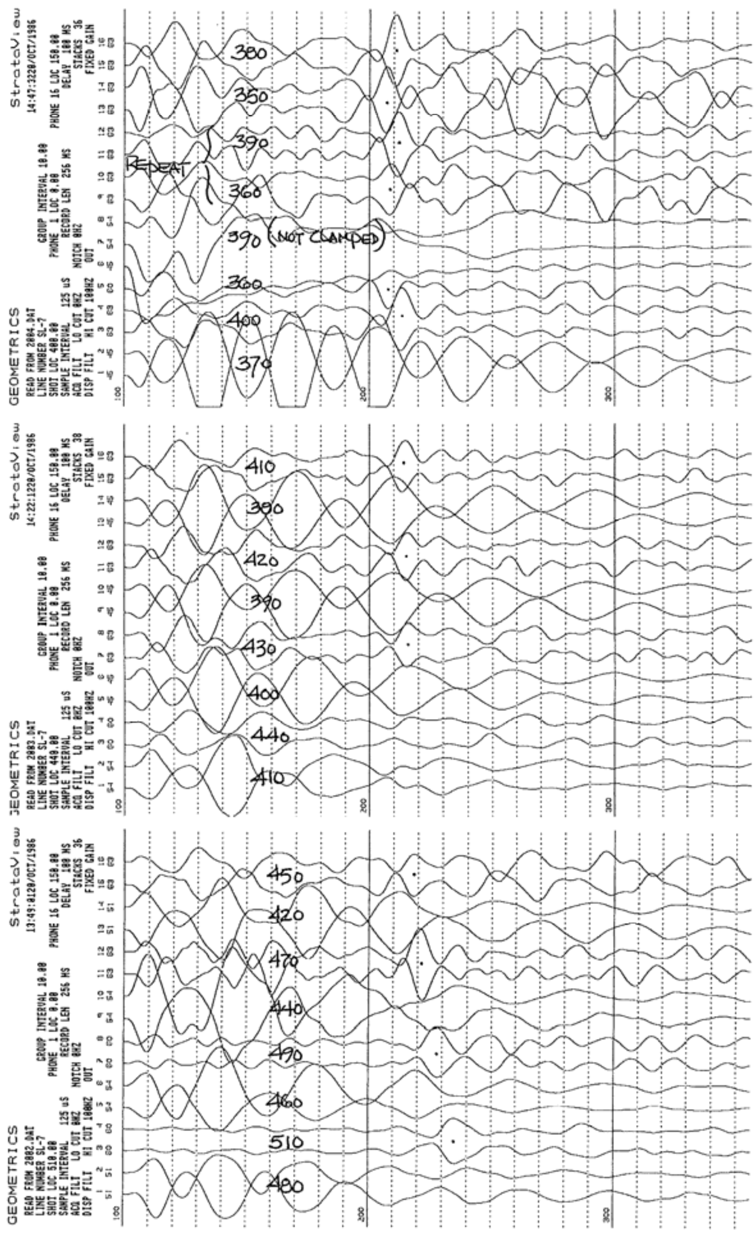
Borehole C4993 Date 20 OCT 06

Playback filter 100 Hz low-pass

Time scale 10 milliseconds/line

Source offset 16 ft Filter delay 5 msec

[All depths in feet]



Downhole Velocity Records

SHEAR WAVES

Project WTP at HANFORD

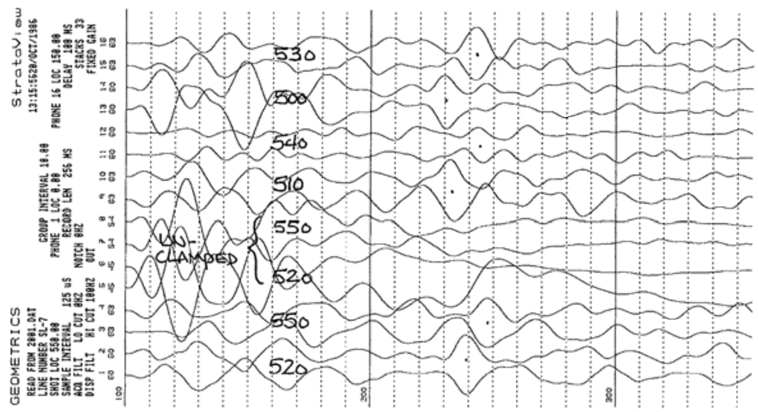
Borehole C4993 Date 20 OCT 06

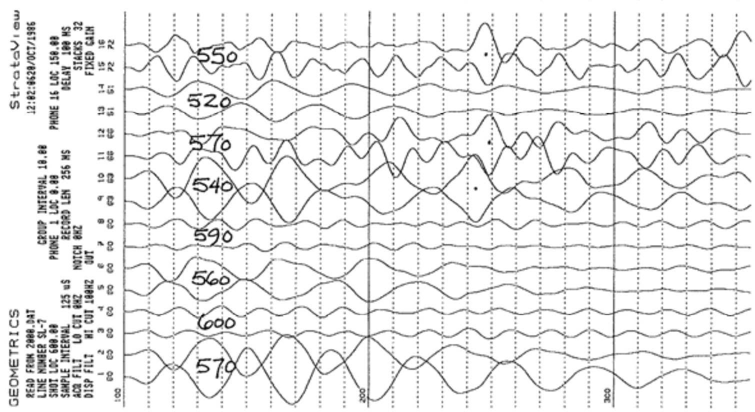
Playback filter 100 Hz low-pass

Time scale 10 milliseconds/line

Source offset 16 ft Filter delay 5 msec

[All depths in feet]





Borehole C4997
Slingshot S-WaveTimes
13 November 2006

Borehole No.	WTP-4997
Seismic Mode	Slingshot Shear
Source Offset (ft)	24.2
Onset-to-Peak (ms)	12
Filter Delay (ms)	4

Depth bgs (ft)	Slant TT (ms)	Slant TT - OP - FD	Cosine Factor	**Vertical Travel Time (ms)**
390	208.5	192.5	0.998080361	**192.1**
400	211.0	195.0	0.998174884	**194.6**
410	212.0	196.0	0.998262599	**195.7**
420	212.0	196.0	0.998344145	**195.7**
430	213.5	197.5	0.998420085	**197.2**
470	218.5	202.5	0.998677053	**202.2**
480	221.5	205.5	0.998731498	**205.2**
490	221.5	205.5	0.998782651	**205.2**
505	225.0	209.0	0.998853773	**208.8**
520	230.5	214.5	0.998918842	**214.3**
590	249.0	233.0	0.999159865	**232.8**
600	250.0	234.0	0.999187602	**233.8**
610	251.0	235.0	0.999213989	**234.8**

Downhole Velocity Records

SHEAR WAVES

Project WTP at HANFORD

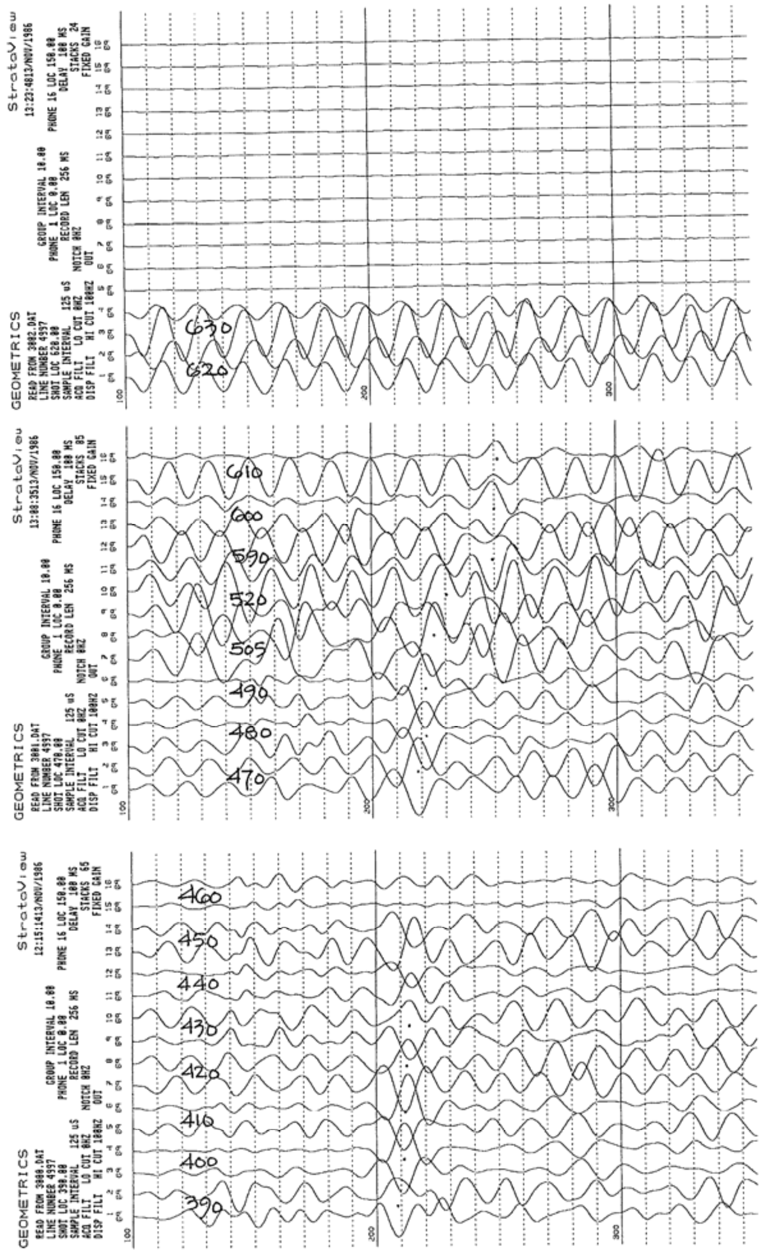
Borehole C4997 Date 13 Nov 06

Playback filter 100 Hz low-pass

Time scale 10 milliseconds/line

Source offset 24.2 ft Filter delay 4 msec

[All depths in feet]



Downhole Velocity Records

SHEAR WAVES

Project WTP at HANFORD

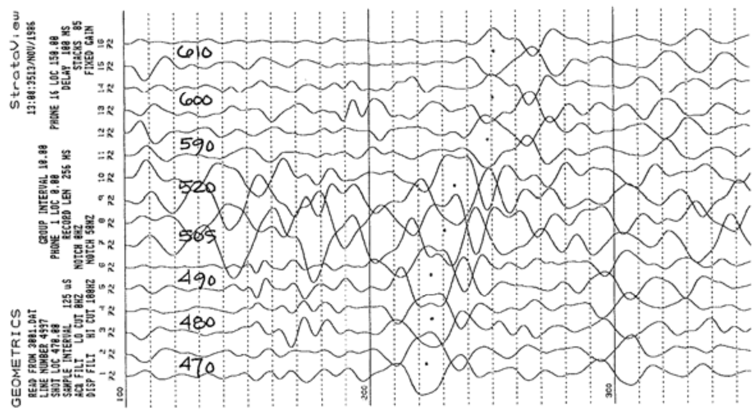
Borehole C4997 Date 13 Nov 06

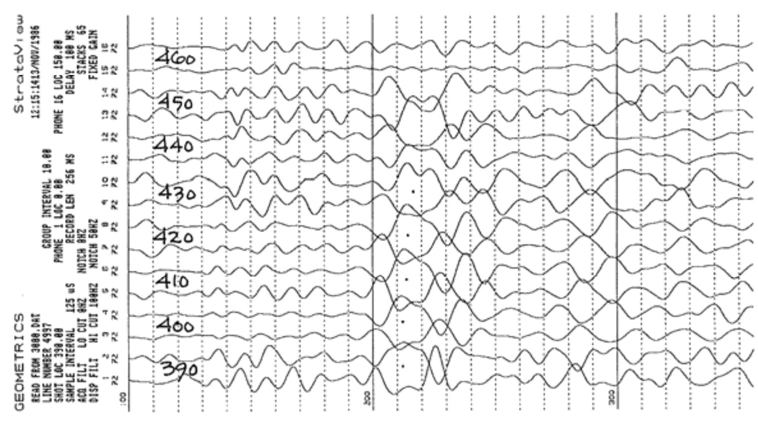
Playback filter 100 HZ-150 HZ NOTCH Hz low-pass

Time scale 10 milliseconds/line

Source offset 24.2 ft Filter delay 5½ msec

[All depths in feet]





Borehole C4998
Shallow S-Wave Times
10 December 2006

Borehole No.	4998
Seismic Mode	Shear Wave
Source Offset (ft)	20
Onset-to-Peak (ms)	5
Filter Delay (ms)	2

Depth bgs (ft)	Slant TT (ms)	Slant TT - OP - FD	Cosine Factor	**Vertical Travel Time (ms)**
6	29.0	22.0	0.287347886	**6.3**
9	29.0	22.0	0.410364677	**9.0**
12	30.5	23.5	0.514495755	**12.1**
15	31.5	24.5	0.600000000	**14.7**
18	33.0	26.0	0.668964732	**17.4**
21	34.5	27.5	0.724137931	**19.9**
24	36.0	29.0	0.768221280	**22.3**
27	41.5	34.5	0.803557193	**27.7**
30	41.0	34.0	0.832050294	**28.3**
33	42.5	35.5	0.855197832	**30.4**
36	44.5	37.5	0.874157276	**32.8**
39	46.0	39.0	0.889817463	**34.7**
42	48.0	41.0	0.902860519	**37.0**
45	49.5	42.5	0.913811549	**38.8**
48	50.5	43.5	0.923076923	**40.2**
51	52.5	45.5	0.930973198	**42.4**
54	54.5	47.5	0.937748761	**44.5**
57	56.0	49.0	0.943599982	**46.2**
60	58.0	51.0	0.948683298	**48.4**
63	60.0	53.0	0.953124267	**50.5**
66	61.5	54.5	0.957024404	**52.2**
69	63.5	56.5	0.960466366	**54.3**
72	65.0	58.0	0.963517910	**55.9**
75	67.0	60.0	0.966234940	**58.0**
78	68.0	61.0	0.968663866	**59.1**
81	69.5	62.5	0.970843444	**60.7**
84	70.5	63.5	0.972806215	**61.8**
87	72.5	65.5	0.974579651	**63.8**
90	74.0	67.0	0.976187060	**65.4**
93	75.0	68.0	0.977648311	**66.5**
96	78.0	71.0	0.978980420	**69.5**
100	79.5	72.5	0.980580676	**71.1**
105	81.5	74.5	0.982338566	**73.2**
110	84.0	77.0	0.983869910	**75.8**
115	87.5	80.5	0.985211755	**79.3**
120	90.0	83.0	0.986393924	**81.9**
125	93.5	86.5	0.987440632	**85.4**
130	96.0	89.0	0.988371698	**88.0**
135	99.0	92.0	0.989203462	**91.0**
140	101.5	94.5	0.989949494	**93.6**
145	104.5	97.5	0.990621129	**96.6**

Borehole C4998
Shallow S-Wave Times
10 December 2006

150	108.0	101.0	0.991227901	**100.1**
155	111.5	104.5	0.991777867	**103.6**
160	114.0	107.0	0.992277877	**106.2**
165	118.0	111.0	0.992733782	**110.2**
170	120.5	113.5	0.993150604	**112.7**
175	126.5	119.5	0.993532673	**118.7**
180	129.0	122.0	0.993883735	**121.3**
185	129.5	122.5	0.994207048	**121.8**
190	130.5	123.5	0.994505453	**122.8**
195	131.5	124.5	0.994781439	**123.9**
200	134.0	127.0	0.995037190	**126.4**
205	136.5	129.5	0.995274634	**128.9**
210	139.0	132.0	0.995495473	**131.4**
215	142.0	135.0	0.995701216	**134.4**
220	141.5	134.5	0.995893206	**133.9**
225	149.5	142.5	0.996072641	**141.9**
230	145.0	138.0	0.996240588	**137.5**
235	146.0	139.0	0.996398007	**138.5**
240	151.0	144.0	0.996545758	**143.5**
245	152.0	145.0	0.996684616	**144.5**
250	153.0	146.0	0.996815279	**145.5**
255	154.5	147.5	0.996938378	**147.0**
260	158.0	151.0	0.997054486	**150.6**
265	160.0	153.0	0.997164120	**152.6**
270	163.0	156.0	0.997267754	**155.6**
275	163.5	156.5	0.997365817	**156.1**
280	166.5	159.5	0.997458700	**159.1**
285	168.5	161.5	0.997546761	**161.1**
290	171.0	164.0	0.997630328	**163.6**
295	173.5	166.5	0.997709702	**166.1**
300	174.0	167.0	0.997785158	**166.6**
305	177.5	170.5	0.997856949	**170.1**
310	180.0	173.0	0.997925309	**172.6**
315	182.0	175.0	0.997990453	**174.6**
320	183.0	176.0	0.998052578	**175.7**
325	184.0	177.0	0.998111870	**176.7**
330	184.5	177.5	0.998168497	**177.2**
335	185.0	178.0	0.998222616	**177.7**
340	186.0	179.0	0.998274373	**178.7**
345	185.5	178.5	0.998323904	**178.2**
350	187.0	180.0	0.998371334	**179.7**
355	188.0	181.0	0.998416781	**180.7**
360	188.5	181.5	0.998460353	**181.2**
365	189.0	182.0	0.998502152	**181.7**
370	190.5	183.5	0.998542273	**183.2**

Downhole Velocity Records

SHEAR WAVES

Project WTP at HANFORD

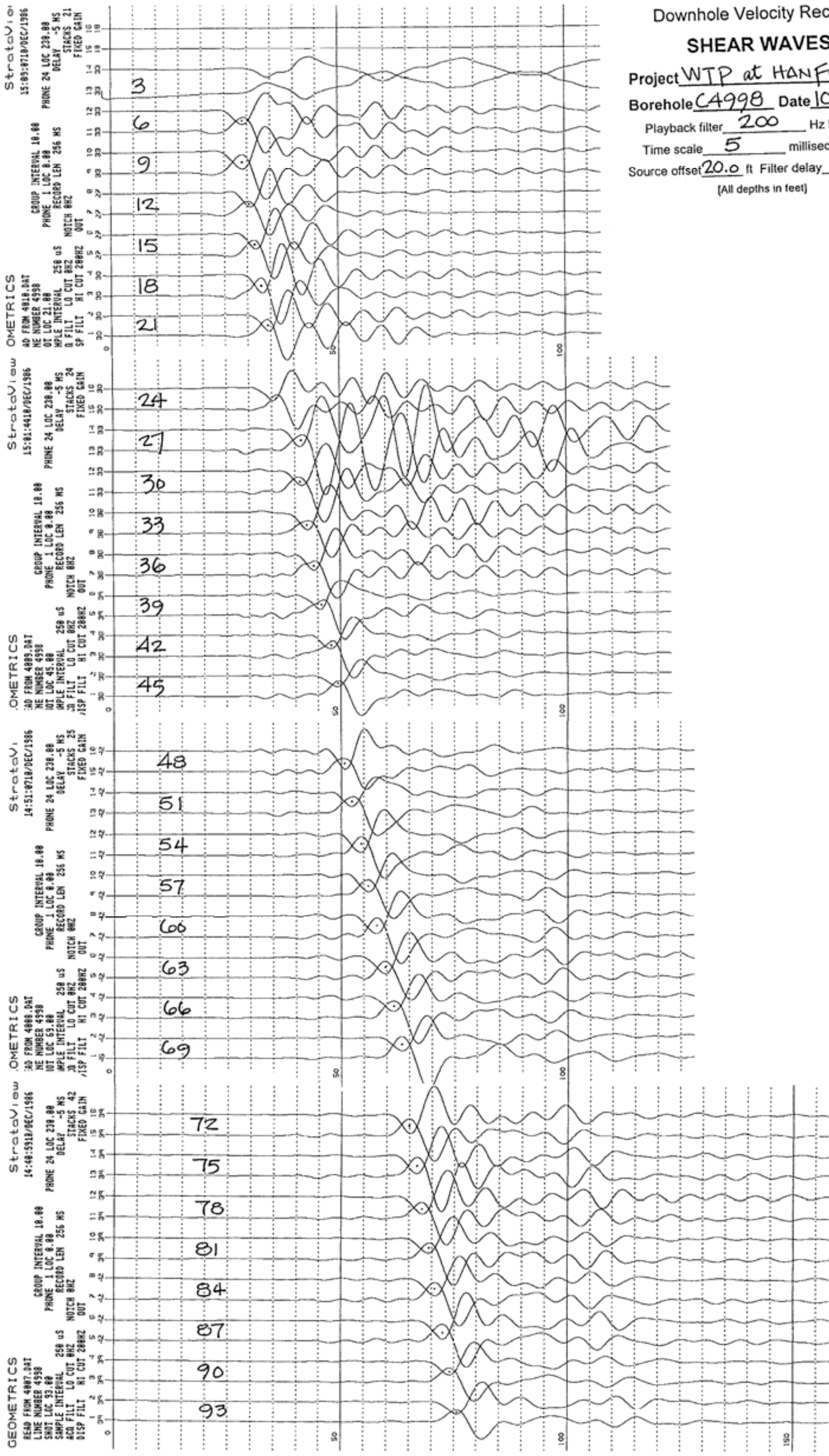
Borehole C4998 Date 10 DEC 06

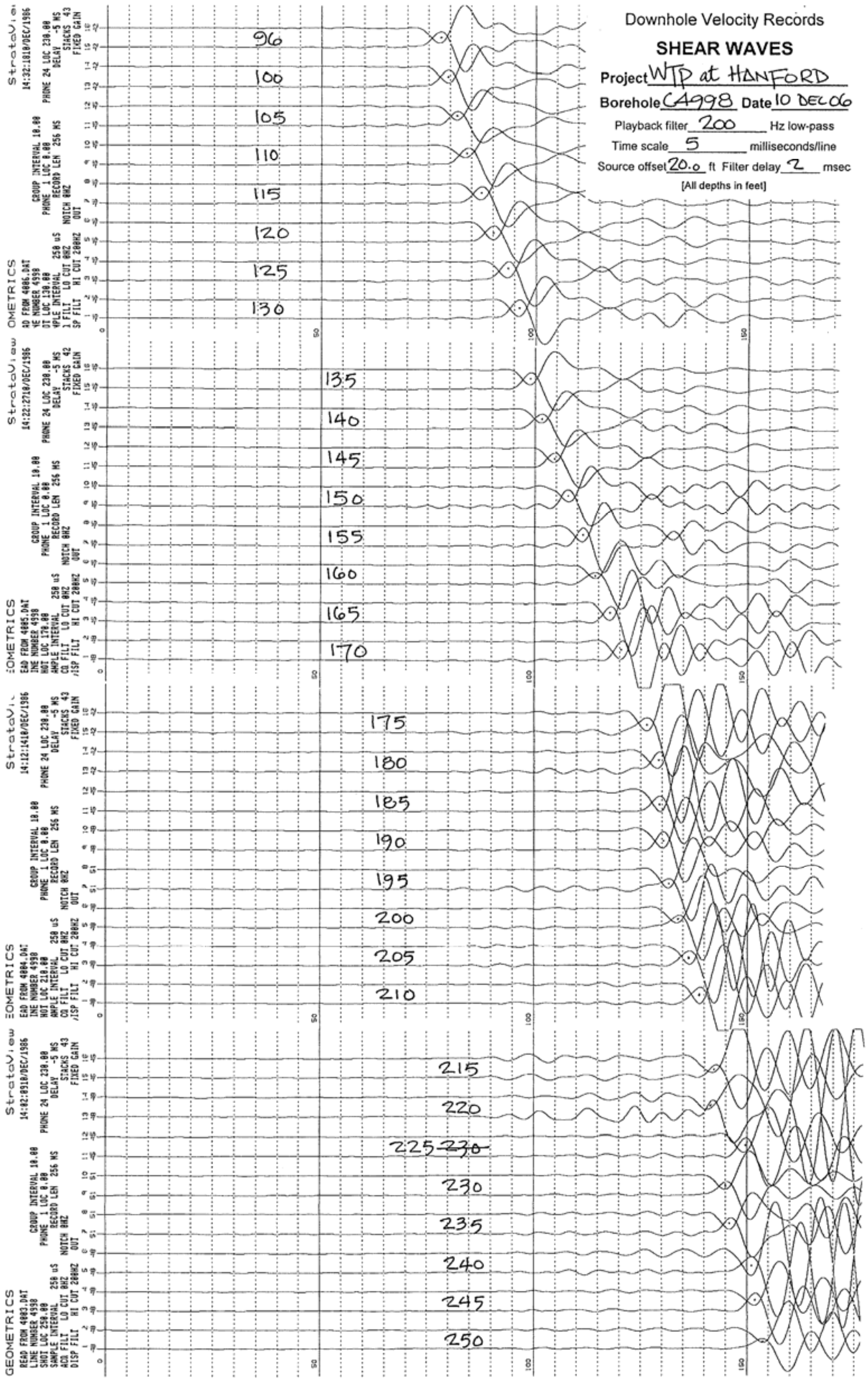
Playback filter 200 Hz low-pass

Time scale 5 milliseconds/line

Source offset 20.0 ft Filter delay 2 msec

[All depths in feet]




Downhole Velocity Records
SHEAR WAVES
Project WTP at HANFORD
Borehole C4998 Date 10 DEC 06
Playback filter 200 Hz low-pass
Time scale 5 milliseconds/line
Source offset 20.0 ft Filter delay 2 msec
[All depths in feet]
96
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
200
205
210
215
220
225
230
235
240
245
250

Downhole Velocity Records

SHEAR WAVES

Project WTP at HANFORD

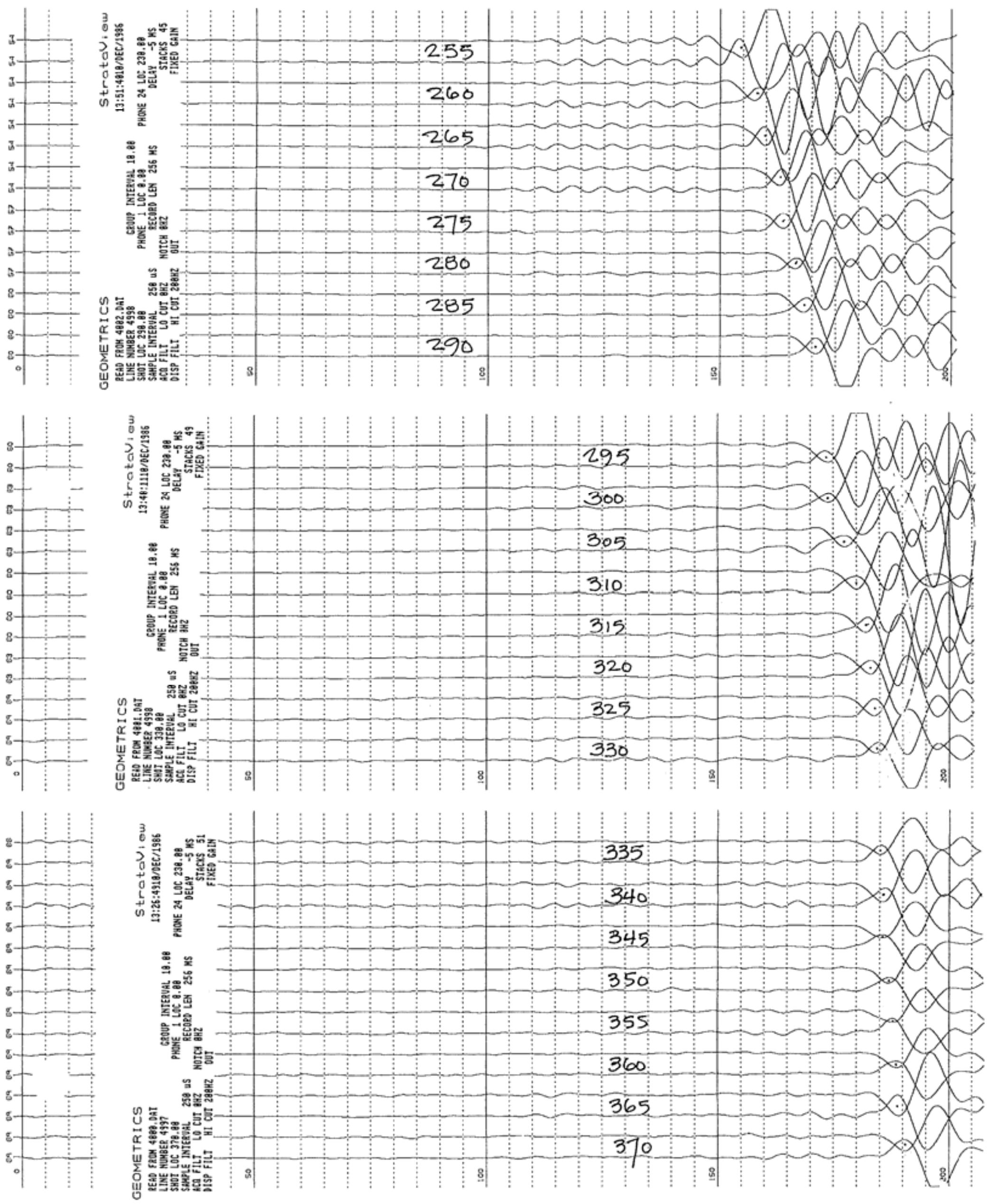
Borehole C4998 Date 10 DEC 06

Playback filter 200 Hz low-pass

Time scale 5 milliseconds/line

Source offset 20.0 ft Filter delay 2 msec

[All depths in feet]



Borehole 4998
Shallow P-Wave Times
10 December 2006

Borehole No.	4998
Seismic Mode	Compression Wave
Source Offset (ft)	21
Onset-to-Peak (ms)	3
Filter Delay (ms)	2

Depth bgs (ft)	Slant TT (ms)	Slant TT - OP - FD	Cosine Factor	**Vertical Travel Time (ms)**
6	23.0	18.0	0.274721128	**4.9**
9	22.7	17.7	0.393919299	**7.0**
12	22.7	17.7	0.496138938	**8.8**
15	23.0	18.0	0.581238194	**10.5**
18	23.0	18.0	0.650791373	**11.7**
21	23.0	18.0	0.707106781	**12.7**
24	23.7	18.7	0.752576695	**14.1**
27	24.0	19.0	0.789352217	**15.0**
30	27.0	22.0	0.819231921	**18.0**
33	27.5	22.5	0.843661488	**19.0**
36	28.0	23.0	0.863778901	**19.9**
39	28.5	23.5	0.880471100	**20.7**
42	28.0	23.0	0.894427191	**20.6**
45	29.5	24.5	0.906183140	**22.2**
48	30.5	25.5	0.916157335	**23.4**
51	32.5	27.5	0.924678098	**25.4**
54	32.2	27.2	0.932004672	**25.4**
57	32.7	27.7	0.938343117	**26.0**
60	32.7	27.7	0.943858356	**26.1**
63	33.2	28.2	0.948683298	**26.8**
66	33.0	28.0	0.952925780	**26.7**
69	34.5	29.5	0.956673880	**28.2**
72	40.0	35.0	0.960000000	**33.6**
75	41.0	36.0	0.962964020	**34.7**
78	42.0	37.0	0.965615759	**35.7**
81	42.0	37.0	0.967996898	**35.8**
84	44.0	39.0	0.970142500	**37.8**
87	44.5	39.5	0.972082209	**38.4**
90	44.5	39.5	0.973841210	**38.5**
93	44.5	39.5	0.975441002	**38.5**
96	48.0	43.0	0.976900017	**42.0**
100	48.0	43.0	0.978653497	**42.1**
105	49.0	44.0	0.980580676	**43.1**
110	52.0	47.0	0.982260322	**46.2**
115	54.5	49.5	0.983732755	**48.7**
120	55.0	50.0	0.985030467	**49.3**
125	58.5	53.5	0.986179866	**52.8**
130	59.0	54.0	0.987202583	**53.3**
135	61.0	56.0	0.988116469	**55.3**
140	63.0	58.0	0.988936353	**57.4**
145	64.0	59.0	0.989674635	**58.4**

Borehole 4998
Shallow P-Wave Times
10 December 2006

150	67.0	62.0	0.990341747	**61.4**
155	69.5	64.5	0.990946510	**63.9**
160	70.0	65.0	0.991496428	**64.4**
165	71.0	66.0	0.991997912	**65.5**
170	73.5	68.5	0.992456466	**68.0**
175	80.5	75.5	0.992876838	**75.0**
180	81.5	76.5	0.993263139	**76.0**
185	81.0	76.0	0.993618942	**75.5**
190	81.0	76.0	0.993947365	**75.5**
195	81.0	76.0	0.994251140	**75.6**
200	81.5	76.5	0.994532667	**76.1**
205	83.0	78.0	0.994794060	**77.6**
210	83.5	78.5	0.995037190	**78.1**
215	86.0	81.0	0.995263716	**80.6**
220	86.5	81.5	0.995475113	**81.1**
225	89.0	84.0	0.995672696	**83.6**
230	88.0	83.0	0.995857640	**82.7**
235	88.5	83.5	0.996030998	**83.2**
240	93.0	88.0	0.996193717	**87.7**
245	93.5	88.5	0.996346649	**88.2**
250	93.0	88.0	0.996490561	**87.7**
255	93.0	88.0	0.996626148	**87.7**
260	96.5	91.5	0.996754039	**91.2**
265	97.0	92.0	0.996874804	**91.7**
270	97.5	92.5	0.996988963	**92.2**
275	98.5	93.5	0.997096988	**93.2**
280	97.5	92.5	0.997199310	**92.2**
285	98.5	93.5	0.997296323	**93.2**
290	99.5	94.5	0.997388388	**94.3**
295	100.0	95.0	0.997475835	**94.8**
300	101.0	96.0	0.997558967	**95.8**
305	101.0	96.0	0.997638064	**95.8**
310	102.0	97.0	0.997713382	**96.8**
315	102.5	97.5	0.997785158	**97.3**
320	103.5	98.5	0.997853610	**98.3**
325	104.0	99.0	0.997918940	**98.8**
330	105.0	100.0	0.997981336	**99.8**
335	106.0	101.0	0.998040969	**100.8**
340	106.0	101.0	0.998098001	**100.8**
345	106.5	101.5	0.998152580	**101.3**
350	106.5	101.5	0.998204845	**101.3**
355	106.5	101.5	0.998254926	**101.3**
360	107.0	102.0	0.998302941	**101.8**
365	108.0	103.0	0.998349003	**102.8**
370	108.5	103.5	0.998393216	**103.3**

Downhole Velocity Records

COMPRESSION WAVES

Project WTP at HANFORD

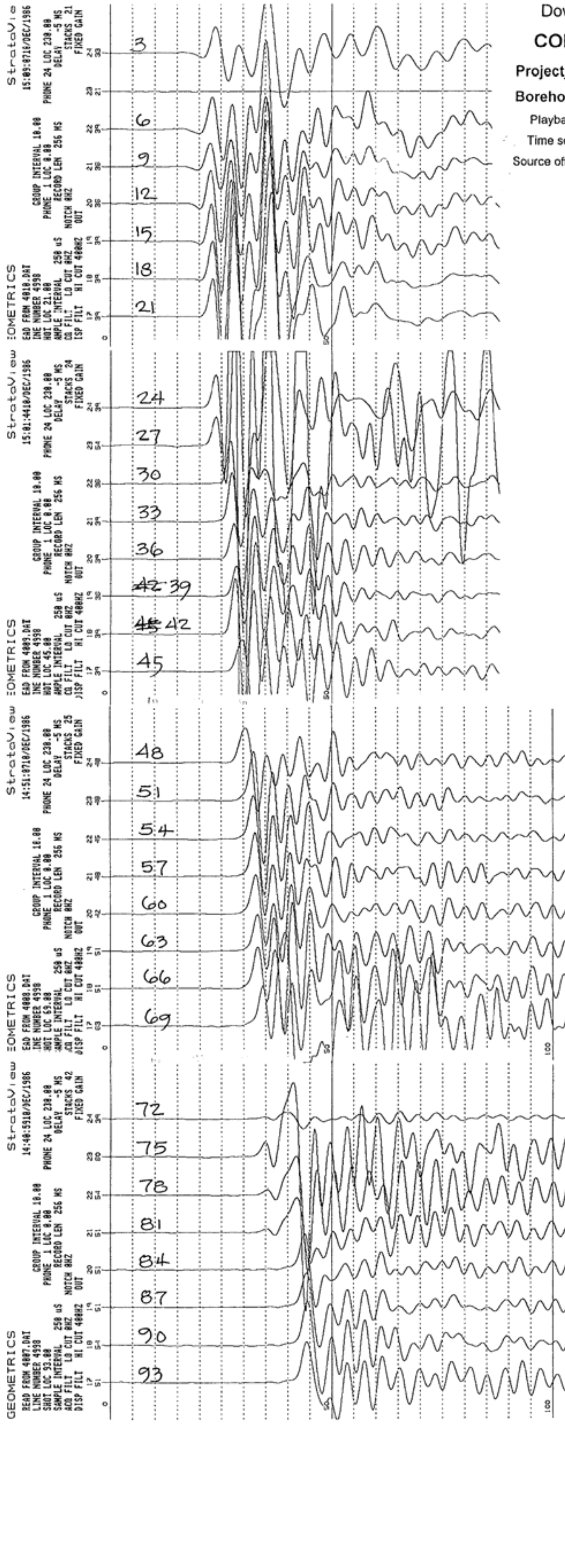
Borehole C4998 Date 10 DEC 06

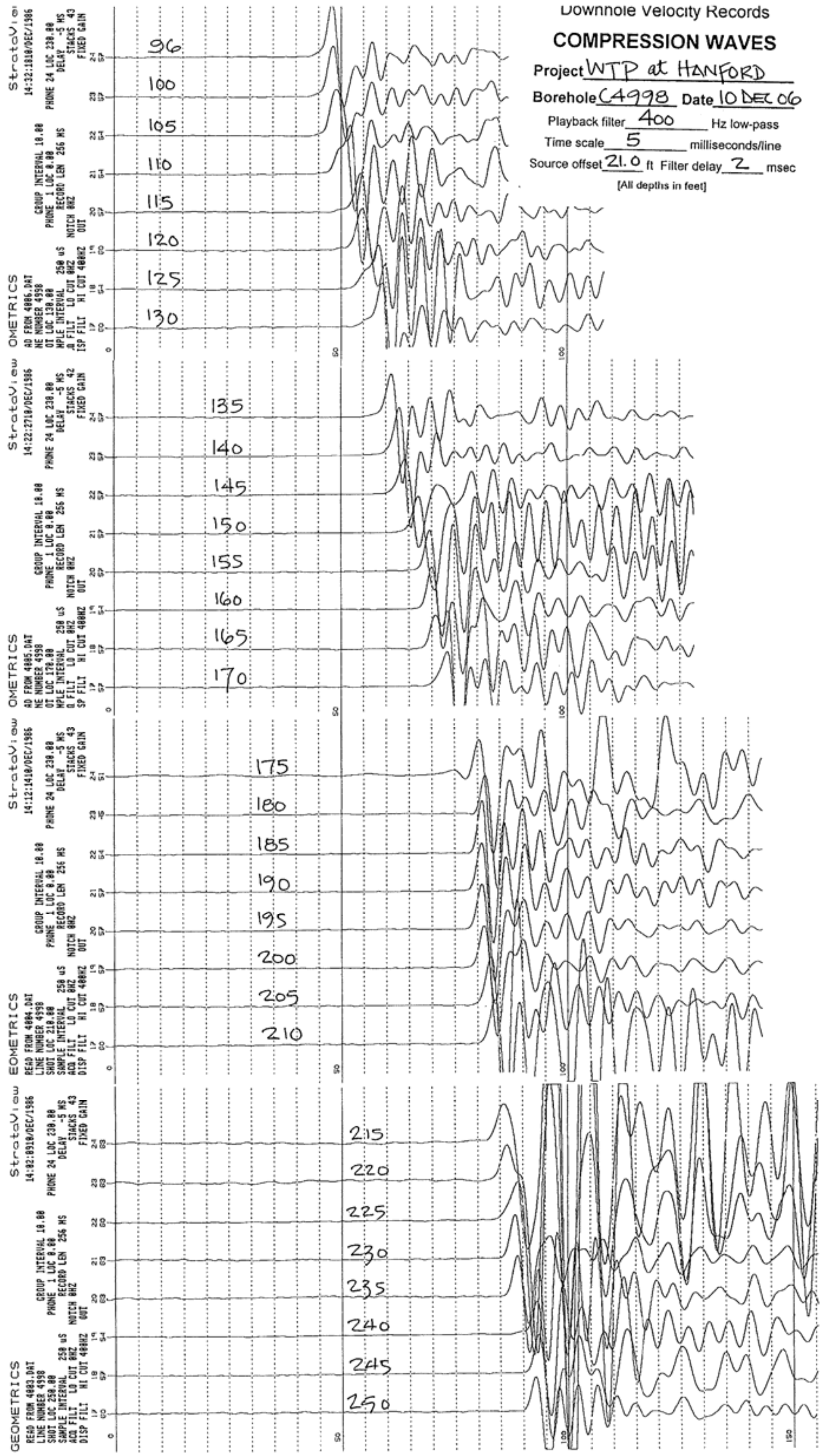
Playback filter 400 Hz low-pass

Time scale 5 milliseconds/line

Source offset 21.0 ft Filter delay 2 msec

[All depths in feet]




Downhole Velocity Records
COMPRESSION WAVES
Project WTP at HANFORD
Borehole C4998 Date 10 DEC 06
Playback filter 400 Hz low-pass
Time scale 5 milliseconds/line
Source offset 21.0 ft Filter delay 2 msec
[All depths in feet]
96
100
105
110
115
120
125
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225
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245
250

Borehole C4996
Shallow S-Wave Times
29 January 2007

Borehole No.	C4996 - Shallow
Seismic Mode	Shear Wave
Source Offset (ft)	14
Onset-to-Peak (ms)	8
Filter Delay (ms)	2

Depth bgs (ft)	Slant TT (ms)	Slant TT - OP - FD	Cosine Factor	**Vertical Travel Time (ms)**
6	25.0	15.0	0.393919299	**5.9**
9	37.0	27.0	0.540757591	**14.6**
12	40.0	30.0	0.650791373	**19.5**
15	43.0	33.0	0.731055268	**24.1**
18	42.5	32.5	0.789352217	**25.7**
21	43.5	33.5	0.832050294	**27.9**
24	43.0	33.0	0.863778901	**28.5**
27	44.0	34.0	0.887754531	**30.2**
30	44.5	34.5	0.906183140	**31.3**
33	46.5	36.5	0.920581782	**33.6**
36	49.0	39.0	0.932004672	**36.3**
39	50.5	40.5	0.941194671	**38.1**
42	52.0	42.0	0.948683298	**39.8**
45	53.5	43.5	0.954856776	**41.5**
48	55.0	45.0	0.960000000	**43.2**
51	56.5	46.5	0.964326148	**44.8**
54	58.5	48.5	0.967996898	**46.9**
57	61.0	51.0	0.971136422	**49.5**
60	61.5	51.5	0.973841210	**50.2**
63	63.5	53.5	0.976187060	**52.2**
66	65.5	55.5	0.978234125	**54.3**
69	67.0	57.0	0.980030589	**55.9**
72	69.0	59.0	0.981615390	**57.9**
75	70.5	60.5	0.983020249	**59.5**
78	73.0	63.0	0.984271207	**62.0**
81	75.0	65.0	0.985389793	**64.1**
84	78.0	68.0	0.986393924	**67.1**
87	81.0	71.0	0.987298603	**70.1**
90	81.5	71.5	0.988116469	**70.7**
93	82.5	72.5	0.988858224	**71.7**
96	85.5	75.5	0.989532981	**74.7**
100	87.0	77.0	0.990341747	**76.3**
105	90.0	80.0	0.991227901	**79.3**
110	92.0	82.0	0.991997912	**81.3**
115	95.0	85.0	0.992671155	**84.4**
120	98.5	88.5	0.993263139	**87.9**
125	101.5	91.5	0.993786397	**90.9**
130	105.5	95.5	0.994251140	**95.0**
135	107.5	97.5	0.994665758	**97.0**
140	110.0	100.0	0.995037190	**99.5**
145	112.0	102.0	0.995371220	**101.5**

Borehole C4996
Shallow S-Wave Times
29 January 2007

150	115.0	105.0	0.995672696	**104.5**
155	119.5	109.5	0.995945706	**109.1**
160	122.5	112.5	0.996193717	**112.1**
165	125.5	115.5	0.996419687	**115.1**
170	126.5	116.5	0.996626148	**116.1**
175	128.0	118.0	0.996815279	**117.6**
180	132.0	122.0	0.996988963	**121.6**
185	134.0	124.0	0.997148836	**123.6**
190	137.0	127.0	0.997296323	**126.7**
195	140.0	130.0	0.997432669	**129.7**
200	142.0	132.0	0.997558967	**131.7**
205	144.0	134.0	0.997676180	**133.7**
210	146.0	136.0	0.997785158	**135.7**
215	150.0	140.0	0.997886653	**139.7**
220	152.0	142.0	0.997981336	**141.7**
225	155.0	145.0	0.998069800	**144.7**
230	159.5	149.5	0.998152580	**149.2**
235	162.5	152.5	0.998230151	**152.2**
240	164.0	154.0	0.998302941	**153.7**
245	163.5	153.5	0.998371334	**153.2**
250	165.0	155.0	0.998435678	**154.8**
255	168.5	158.5	0.998496286	**158.3**
260	171.5	161.5	0.998553441	**161.3**
265	174.0	164.0	0.998607400	**163.8**
270	175.0	165.0	0.998658397	**164.8**
275	177.5	167.5	0.998706646	**167.3**
280	181.0	171.0	0.998752339	**170.8**
285	184.0	174.0	0.998795654	**173.8**
290	186.0	176.0	0.998836753	**175.8**
295	189.0	179.0	0.998875785	**178.8**
300	190.0	180.0	0.998912886	**179.8**
305	191.5	181.5	0.998948182	**181.3**
310	192.0	182.0	0.998981786	**181.8**
315	192.5	182.5	0.999013806	**182.3**
320	193.5	183.5	0.999044340	**183.3**
325	194.0	184.0	0.999073479	**183.8**
330	194.5	184.5	0.999101305	**184.3**
335	195.5	185.5	0.999127896	**185.3**
340	196.0	186.0	0.999153326	**185.8**
345	197.0	187.0	0.999177659	**186.8**
350	197.5	187.5	0.999200959	**187.4**
355	198.0	188.0	0.999223282	**187.9**
360	199.5	189.5	0.999244684	**189.4**
365	199.5	189.5	0.999265213	**189.4**
370	201.0	191.0	0.999284917	**190.9**
375	200.5	190.5	0.999303839	**190.4**
380	200.5	190.5	0.999322020	**190.4**
385	201.0	191.0	0.999339498	**190.9**
390	202.0	192.0	0.999356309	**191.9**

Borehole C4996
Shallow S-Wave Times
29 January 2007

395	202.5	192.5	0.999372487	**192.4**
400	202.5	192.5	0.999388062	**192.4**
410	204.0	194.0	0.999417523	**193.9**
420	204.5	194.5	0.999444907	**194.4**
430	207.0	197.0	0.999470405	**196.9**
440	208.0	198.0	0.999494186	**197.9**
450	208.0	198.0	0.999516400	**197.9**
460	211.5	201.5	0.999537184	**201.4**
470	215.0	205.0	0.999556655	**204.9**
480	219.0	209.0	0.999574924	**208.9**
490	222.0	212.0	0.999592086	**211.9**
495	224.5	214.5	0.999600281	**214.4**
500	225.5	215.5	0.999608230	**215.4**
505	225.5	215.5	0.999615945	**215.4**
510	226.0	216.0	0.999623435	**215.9**
515	228.0	218.0	0.999630707	**217.9**
520	228.5	218.5	0.999637771	**218.4**
525	229.0	219.0	0.999644634	**218.9**
530	229.0	219.0	0.999651304	**218.9**

Downhole Velocity Records

SHEAR WAVES

Project WTP at HANFORD

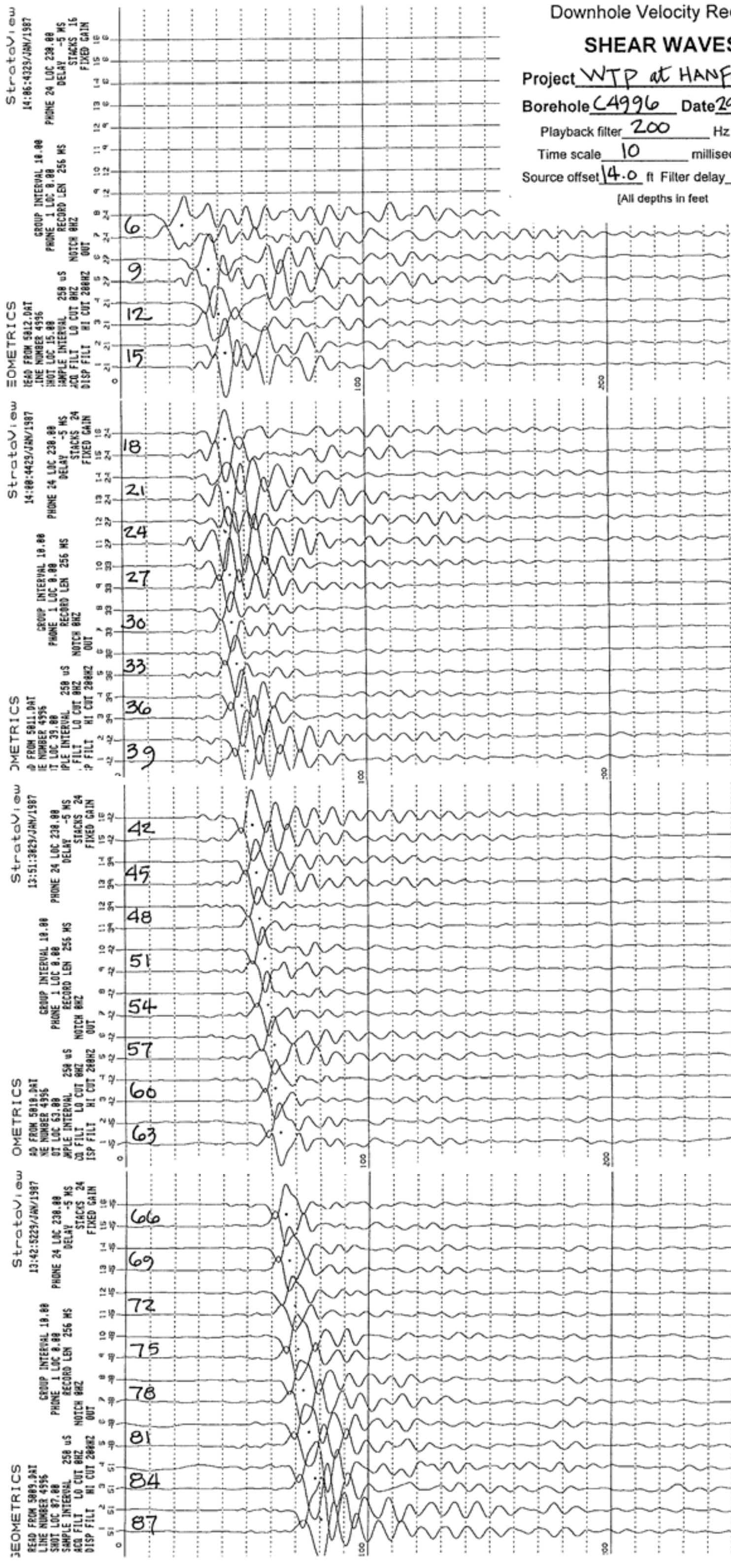
Borehole C4996 Date 29 JAN 07

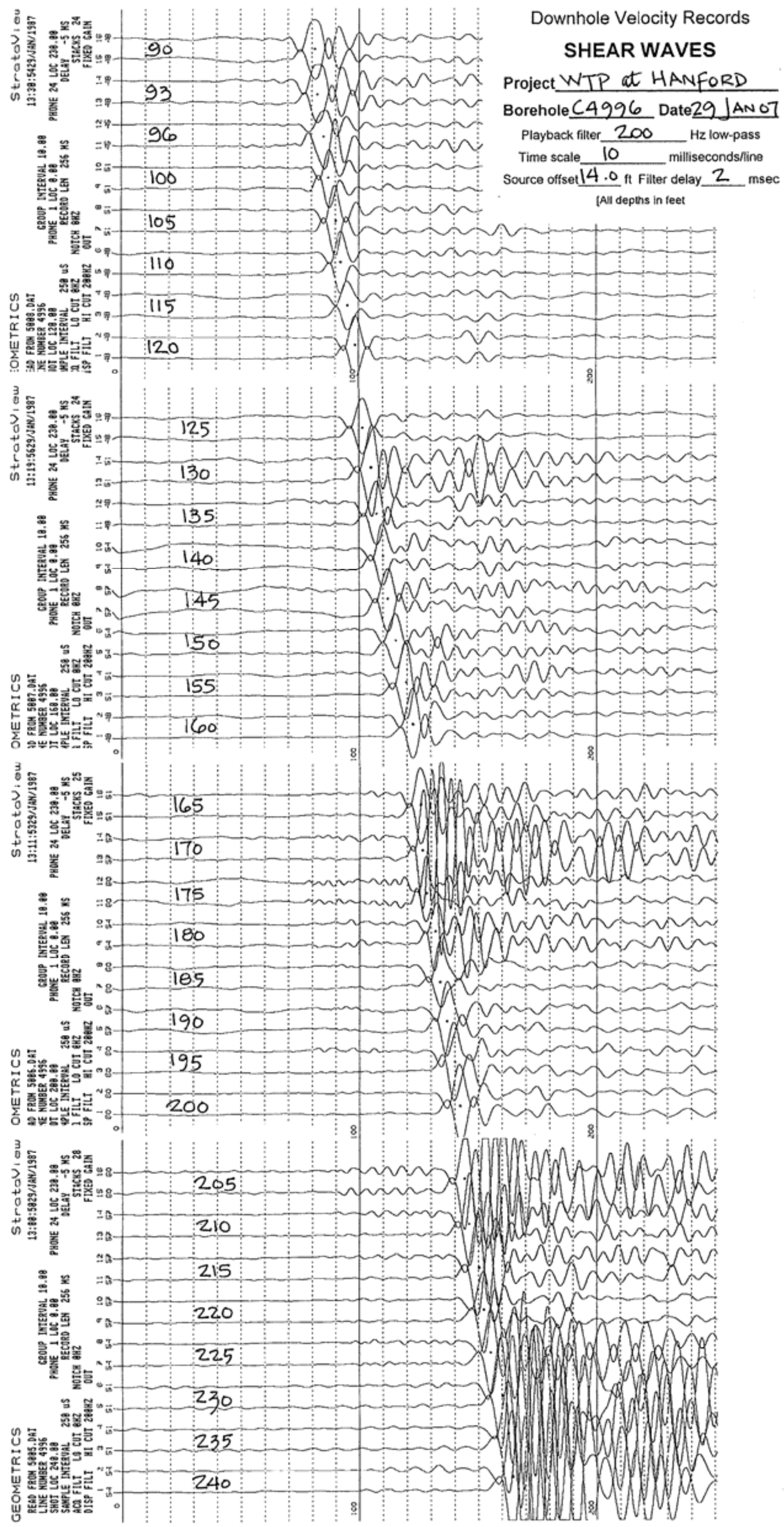
Playback filter 200 Hz low-pass

Time scale 10 milliseconds/line

Source offset 14.0 ft Filter delay 2 msec

[All depths in feet




Downhole Velocity Records
SHEAR WAVES
Project WTP at HANFORD
Borehole C4996 Date 29 JAN 07
Playback filter 200 Hz low-pass
Time scale 10 milliseconds/line
Source offset 14.0 ft Filter delay 2 msec
[All depths in feet
90
93
96
100
105
110
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120
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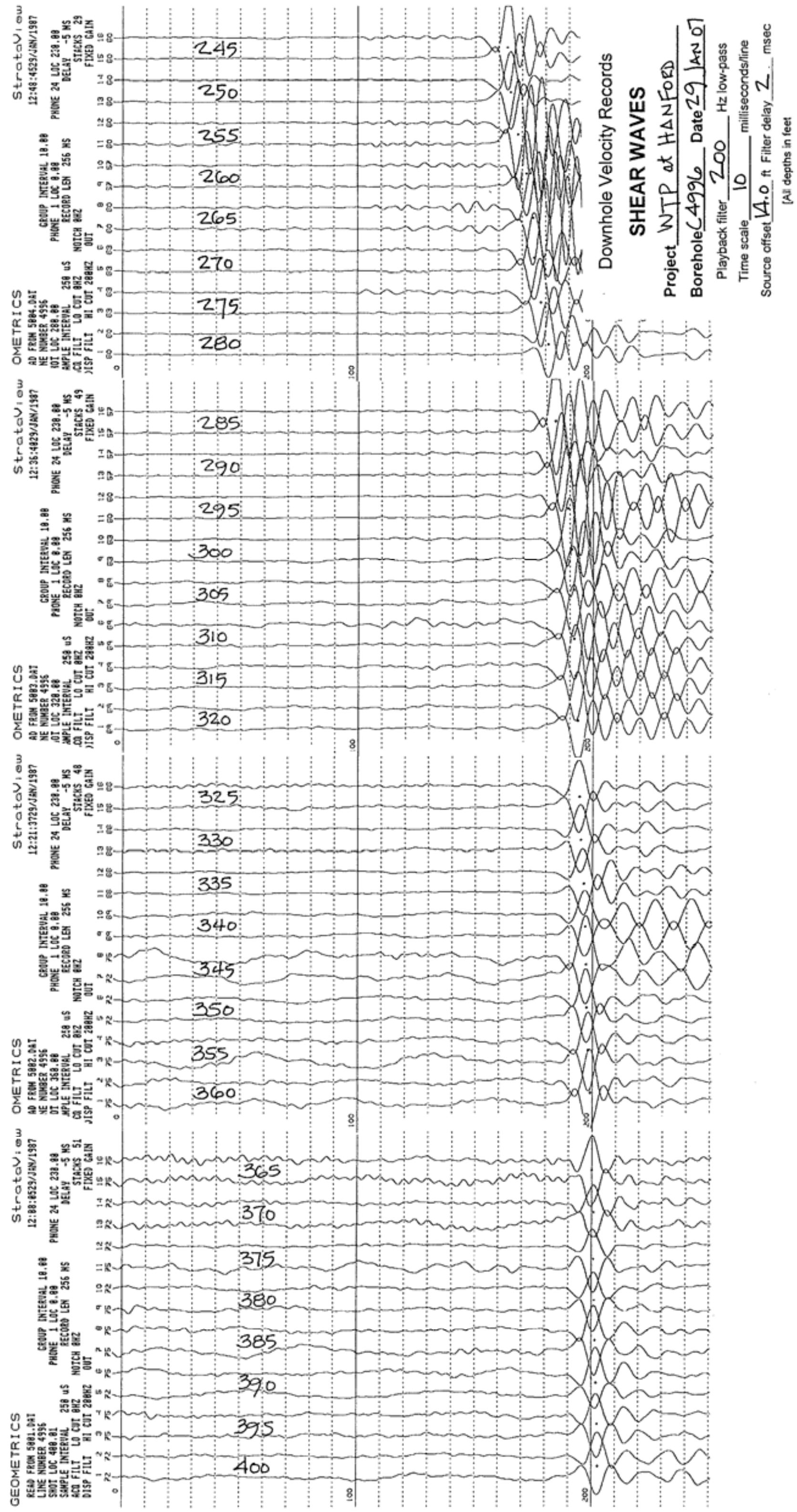

Downhole Velocity Records
SHEAR WAVES
Project WTP at HANFORD
Borehole C4996 Date 29 JAN 07
Playback filter 200 Hz low-pass
Time scale 10 milliseconds/line
Source offset 4.0 ft Filter delay 2 msec
[All depths in feet
245
250
255
260
265
270
275
280
285
290
295
300
305
310
315
320
325
330
335
340
345
350
355
360
365
370
375
380
385
390
395
400

Downhole Velocity Records

SHEAR WAVES

Project WTP at HANFORD

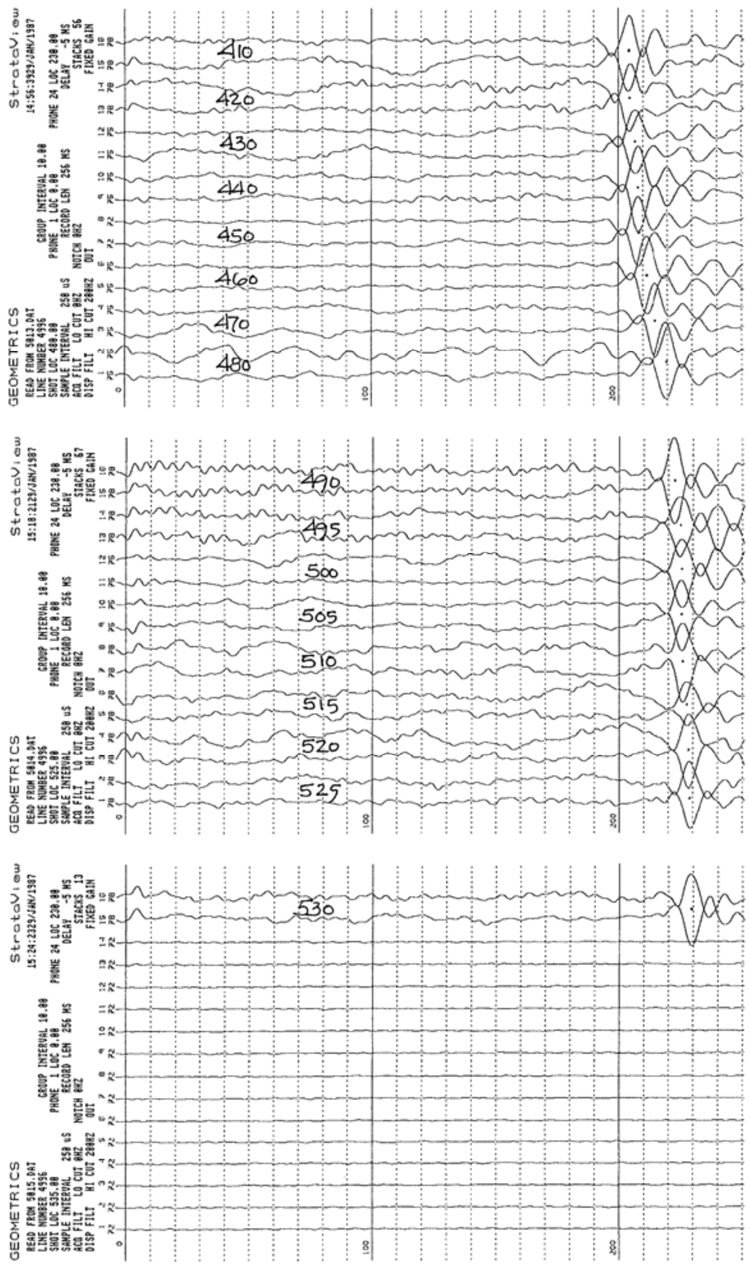
Borehole C4996 Date 29 JAN 07

Playback filter 200 Hz low-pass

Time scale 10 milliseconds/line

Source offset 14.0 ft Filter delay 2 msec

[All depths in feet



Borehole C4996
Shallow P-Wave Times
29 Jan 2007

Borehole No.	C4996 - Shallow
Seismic Mode	Compression Wave
Source Offset (ft)	14
Onset-to-Peak (ms)	3
Filter Delay (ms)	1

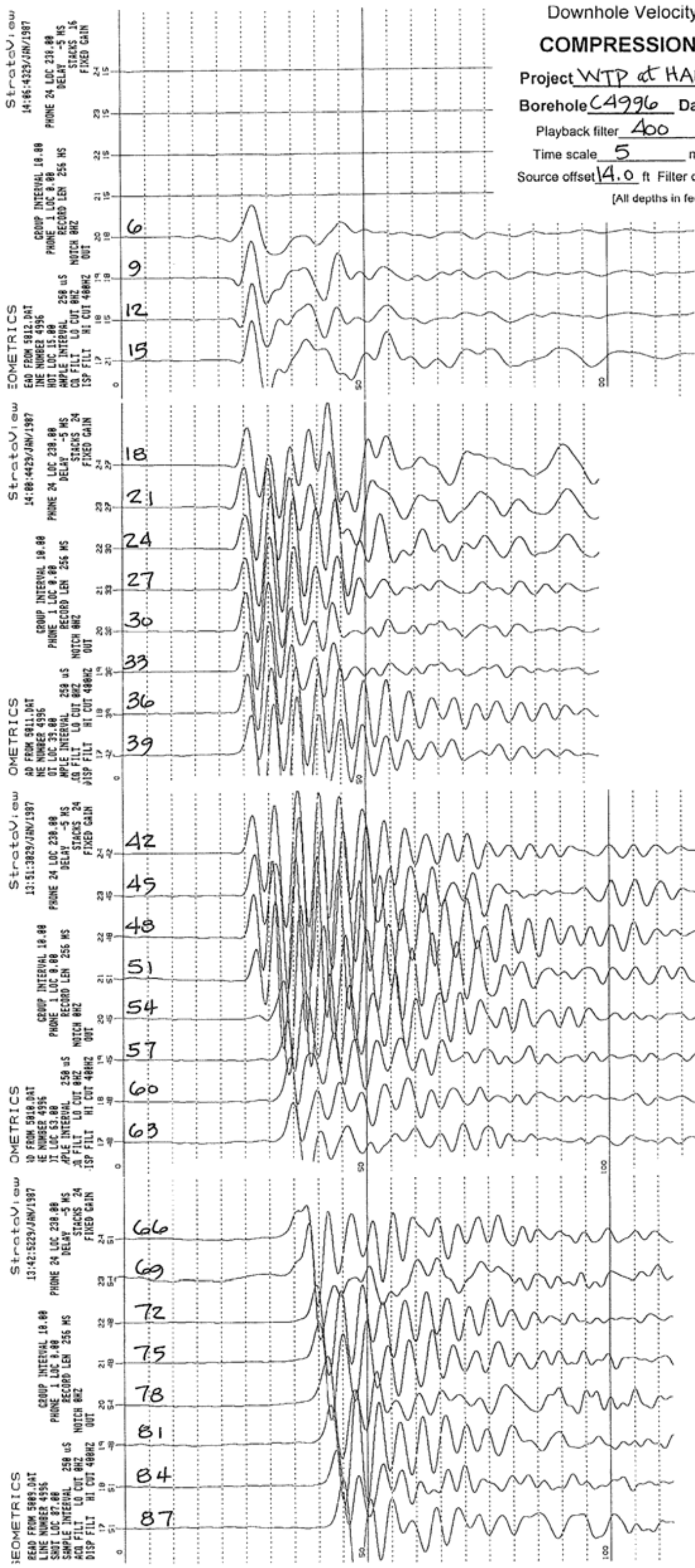
Depth bgs (ft)	Slant TT (ms)	Slant TT - OP - FD	Cosine Factor	**Vertical Travel Time (ms)**
6	27.0	23.0	0.393919299	**9.1**
9	27.0	23.0	0.540757591	**12.4**
12	27.0	23.0	0.650791373	**15.0**
15	27.0	23.0	0.731055268	**16.8**
18	26.0	22.0	0.789352217	**17.4**
21	25.0	21.0	0.832050294	**17.5**
24	25.5	21.5	0.863778901	**18.6**
27	25.5	21.5	0.887754531	**19.1**
30	25.5	21.5	0.906183140	**19.5**
33	25.5	21.5	0.920581782	**19.8**
36	26.0	22.0	0.932004672	**20.5**
39	26.5	22.5	0.941194671	**21.2**
42	27.0	23.0	0.948683298	**21.8**
45	27.0	23.0	0.954856776	**22.0**
48	27.0	23.0	0.960000000	**22.1**
51	27.5	23.5	0.964326148	**22.7**
54	33.0	29.0	0.967996898	**28.1**
57	34.0	30.0	0.971136422	**29.1**
60	34.5	30.5	0.973841210	**29.7**
63	35.0	31.0	0.976187060	**30.3**
66	37.5	33.5	0.978234125	**32.8**
69	38.0	34.0	0.980030589	**33.3**
72	39.5	35.5	0.981615390	**34.8**
75	40.0	36.0	0.983020249	**35.4**
78	42.0	38.0	0.984271207	**37.4**
81	42.5	38.5	0.985389793	**37.9**
84	43.5	39.5	0.986393924	**39.0**
87	45.0	41.0	0.987298603	**40.5**
90	46.0	42.0	0.988116469	**41.5**
93	46.0	42.0	0.988858224	**41.5**
96	49.0	45.0	0.989532981	**44.5**
100	50.0	46.0	0.990341747	**45.6**
105	51.0	47.0	0.991227901	**46.6**
110	52.0	48.0	0.991997912	**47.6**
115	56.0	52.0	0.992671155	**51.6**
120	57.0	53.0	0.993263139	**52.6**
125	59.0	55.0	0.993786397	**54.7**
130	60.0	56.0	0.994251140	**55.7**
135	60.5	56.5	0.994665758	**56.2**
140	64.0	60.0	0.995037190	**59.7**
145	65.0	61.0	0.995371220	**60.7**

Borehole C4996
Shallow P-Wave Times
29 Jan 2007

150	66.0	62.0	0.995672696	**61.7**
155	67.5	63.5	0.995945706	**63.2**
160	70.5	66.5	0.996193717	**66.2**
165	72.5	68.5	0.996419687	**68.3**
170	76.0	72.0	0.996626148	**71.8**
175	76.5	72.5	0.996815279	**72.3**
180	77.0	73.0	0.996988963	**72.8**
185	78.5	74.5	0.997148836	**74.3**
190	79.5	75.5	0.997296323	**75.3**
195	82.0	78.0	0.997432669	**77.8**
200	83.0	79.0	0.997558967	**78.8**
205	83.5	79.5	0.997676180	**79.3**
210	84.0	80.0	0.997785158	**79.8**
215	84.5	80.5	0.997886653	**80.3**
220	89.0	85.0	0.997981336	**84.8**
225	90.0	86.0	0.998069800	**85.8**
230	94.0	90.0	0.998152580	**89.8**
235	95.5	91.5	0.998230151	**91.3**
240	96.0	92.0	0.998302941	**91.8**
245	95.0	91.0	0.998371334	**90.9**
250	95.6	91.6	0.998435678	**91.5**
255	98.0	94.0	0.998496286	**93.9**
260	100.0	96.0	0.998553441	**95.9**
265	101.5	97.5	0.998607400	**97.4**
270	102.5	98.5	0.998658397	**98.4**
275	102.0	98.0	0.998706646	**97.9**
280	103.0	99.0	0.998752339	**98.9**
285	103.5	99.5	0.998795654	**99.4**
290	105.0	101.0	0.998836753	**100.9**
295	105.0	101.0	0.998875785	**100.9**
300	105.5	101.5	0.998912886	**101.4**
305	105.5	101.5	0.998948182	**101.4**
310	105.5	101.5	0.998981786	**101.4**
315	106.0	102.0	0.999013806	**101.9**
320	106.0	102.0	0.999044340	**101.9**
325	106.5	102.5	0.999073479	**102.4**
330	107.0	103.0	0.999101305	**102.9**
335	107.5	103.5	0.999127896	**103.4**
340	107.5	103.5	0.999153326	**103.4**
345	109.0	105.0	0.999177659	**104.9**
350	108.5	104.5	0.999200959	**104.4**
355	108.5	104.5	0.999223282	**104.4**
360	109.0	105.0	0.999244684	**104.9**
365	110.0	106.0	0.999265213	**105.9**
370	110.0	106.0	0.999284917	**105.9**
375	110.0	106.0	0.999303839	**105.9**
380	110.5	106.5	0.999322020	**106.4**
385	111.0	107.0	0.999339498	**106.9**
390	111.5	107.5	0.999356309	**107.4**

Borehole C4996
Shallow P-Wave Times
29 Jan 2007

395	111.0	107.0	0.999372487	**106.9**
400	111.5	107.5	0.999388062	**107.4**
410	112.5	108.5	0.999417523	**108.4**
420	113.5	109.5	0.999444907	**109.4**
430	114.0	110.0	0.999470405	**109.9**
440	115.0	111.0	0.999494186	**110.9**
450	115.0	111.0	0.999516400	**110.9**
460	116.0	112.0	0.999537184	**111.9**
470	117.0	113.0	0.999556655	**112.9**
480	119.0	115.0	0.999574924	**115.0**
490	120.5	116.5	0.999592086	**116.5**
495	120.5	116.5	0.999600281	**116.5**
500	121.5	117.5	0.999608230	**117.5**
505	122.0	118.0	0.999615945	**118.0**
510	122.5	118.5	0.999623435	**118.5**
515	123.0	119.0	0.999630707	**119.0**
520	123.5	119.5	0.999637771	**119.5**
525	123.5	119.5	0.999644634	**119.5**
530	124.5	120.5	0.999651304	**120.5**



Downhole Velocity Records

COMPRESSION WAVES

Project WTP at HANFORD

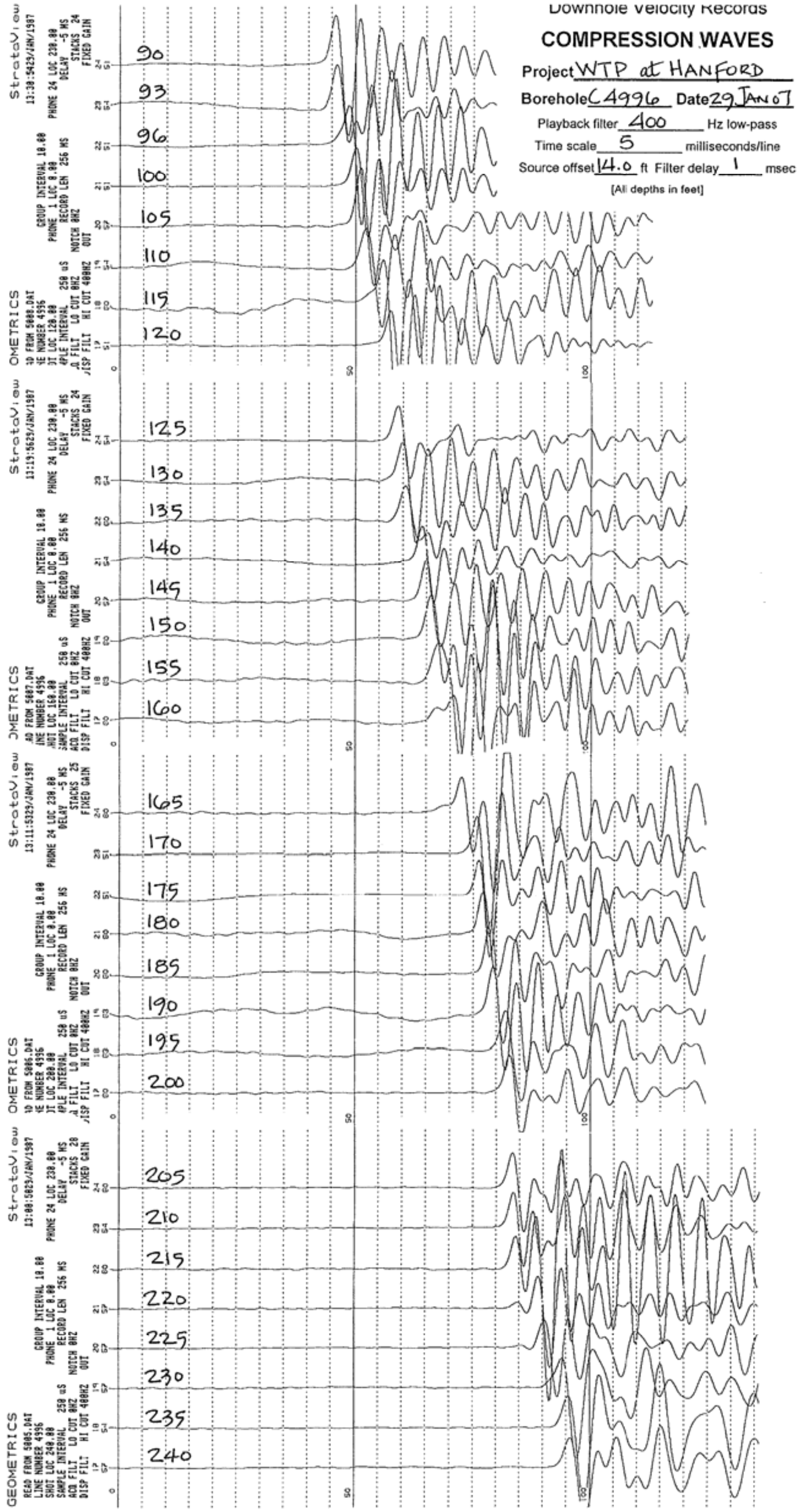
Borehole C4996 Date 29 JAN 07

Playback filter 400 Hz low-pass

Time scale 5 milliseconds/line

Source offset 14.0 ft Filter delay 1 msec

[All depths in feet]


Downhole Velocity Records
COMPRESSION WAVES
Project WTP at HANFORD
Borehole C4996 Date 29 JAN 07
Playback filter 400 Hz low-pass
Time scale 5 milliseconds/line
Source offset 14.0 ft Filter delay 1 msec
[All depths in feet]
90
93
96
100
105
110
115
120
125
130
135
140
145
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165
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175
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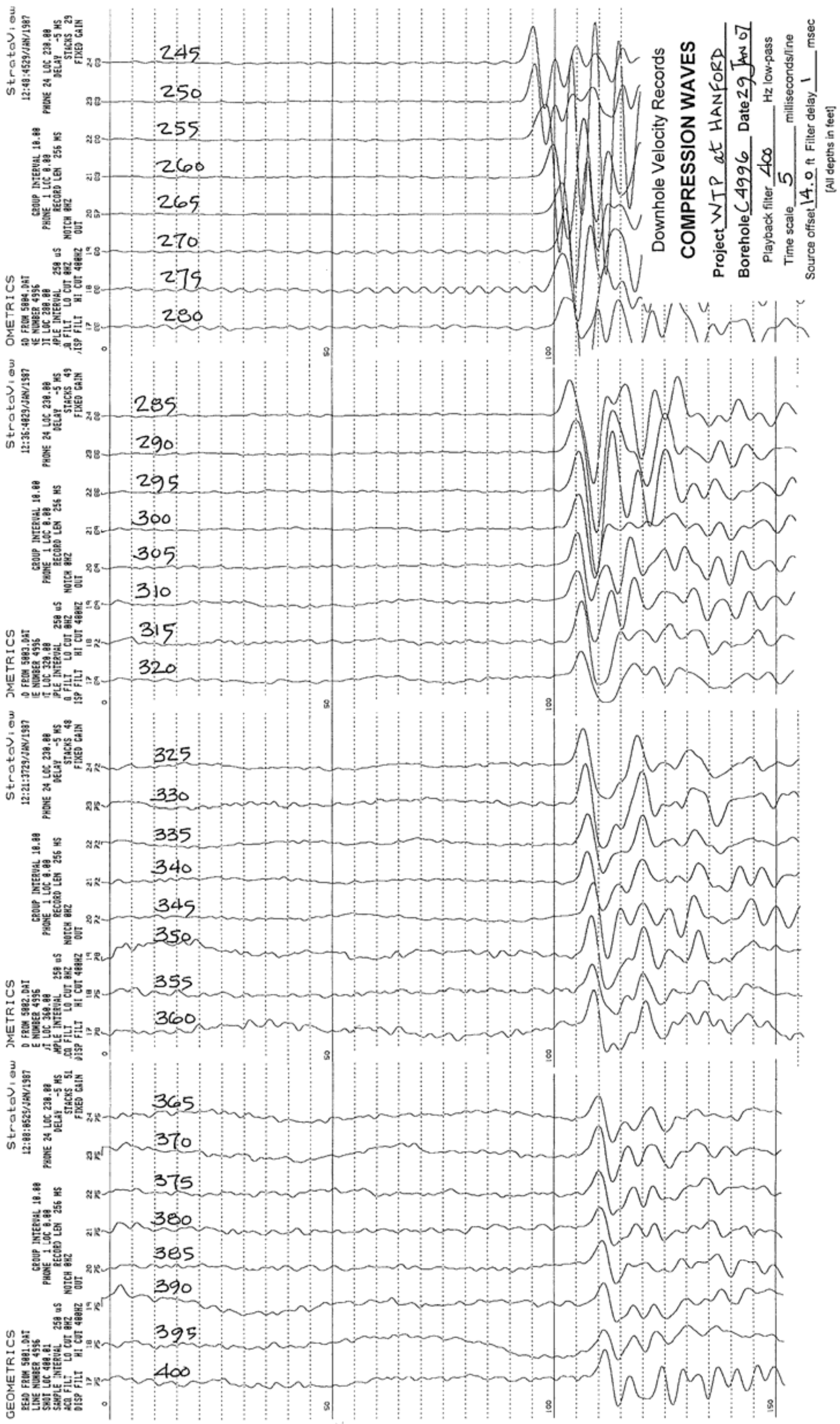
235
240


Downhole Velocity Records
COMPRESSION WAVES
Project WTP at HANFORD
Borehole C4996 Date 29 Jan 07
Playback filter 400 Hz low-pass
Time scale 5 milliseconds/line
Source offset 14.0 ft Filter delay 1 msec
[All depths in feet]
245
250
255
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265
270
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315
320
325
330
335
340
345
350
355
360
365
370
375
380
385
390
395
400
0
50
100
150

Downhole Velocity Records

COMPRESSION WAVES

Project WTP at HANFORD

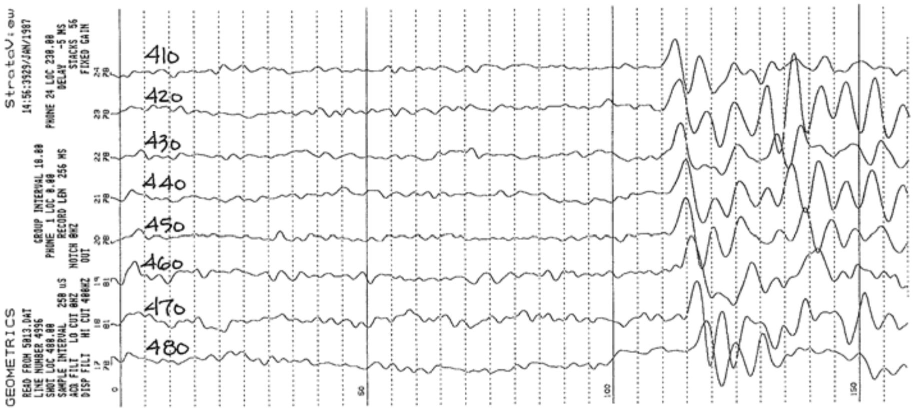
Borehole C4996 Date 29 JAN 07

Playback filter 400 Hz low-pass

Time scale 5 milliseconds/line

Source offset 14.0 ft Filter delay 1 msec

[All depths in feet



Borehole C4993-Stainless
Slingshot S-WaveTimes
30 January 2007

Borehole No.	C4993 - Stainless
Seismic Mode	Slingshot Shear
Source Offset (ft)	23
Onset-to-Peak (ms)	10
Filter Delay (ms)	5

Depth bgs (ft)	Slant TT (ms)	Slant TT - OP - FD	Cosine Factor	**Vertical Travel Time (ms)**
340	202.0	187.0	0.997719761	**186.6**
350	204.0	189.0	0.997847784	**188.6**
360	205.5	190.5	0.997965332	**190.1**
370	211.0	196.0	0.998073514	**195.6**
390	209.0	194.0	0.998265536	**193.7**
400	210.0	195.0	0.998350963	**194.7**
410	210.5	195.5	0.998430236	**195.2**
420	212.0	197.0	0.998503931	**196.7**
430	214.0	199.0	0.998572559	**198.7**
440	215.5	200.5	0.998636574	**200.2**
450	217.5	202.5	0.998696381	**202.2**
460	218.5	203.5	0.998752339	**203.2**
470	221.0	206.0	0.998804772	**205.8**
480	219.0	204.0	0.998853970	**203.8**
490	226.0	211.0	0.998900193	**210.8**
500	229.5	214.5	0.998943676	**214.3**
510	232.0	217.0	0.998984632	**216.8**
520	235.5	220.5	0.999023252	**220.3**
530	239.0	224.0	0.999059712	**223.8**
540	242.0	227.0	0.999094168	**226.8**
550	244.0	229.0	0.999126765	**228.8**
560	244.0	229.0	0.999157634	**228.8**
620	248.0	233.0	0.999312624	**232.8**
640	252.0	237.0	0.999354873	**236.8**
660	251.5	236.5	0.999393344	**236.4**
700	258.5	243.5	0.999460641	**243.4**
725	263.5	248.5	0.999497169	**248.4**
742	268.0	253.0	0.999519929	**252.9**

Downhole Velocity Records

SHEAR WAVES

Project WTP at HANFORD

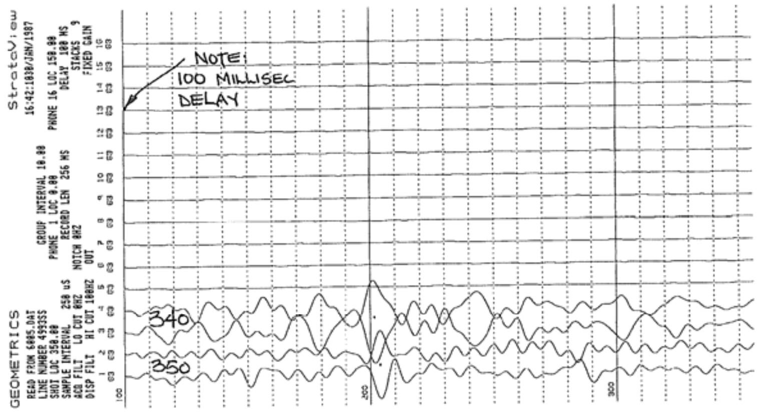
Borehole C4993 Date 30 JAN 07

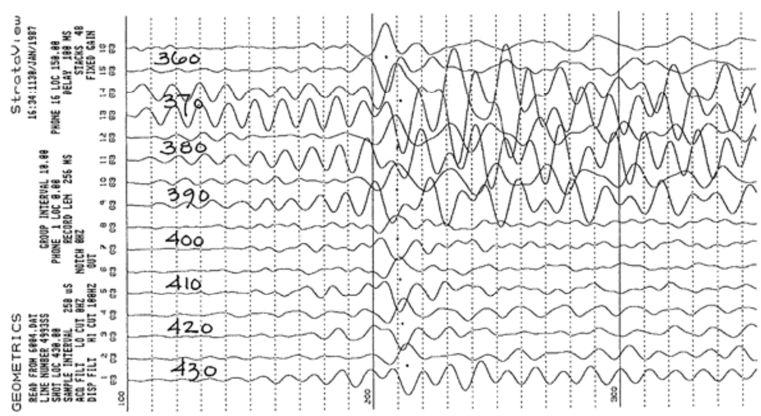
Playback filter 100 Hz low-pass

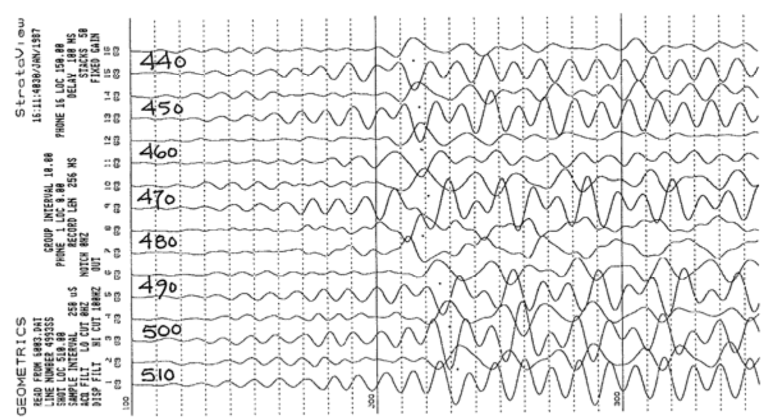
Time scale 10 milliseconds/line

Source offset 23.0 ft Filter delay 5 msec

[All depths in feet]







Downhole Velocity Records

SHEAR WAVES

Project WTP at HANFORD

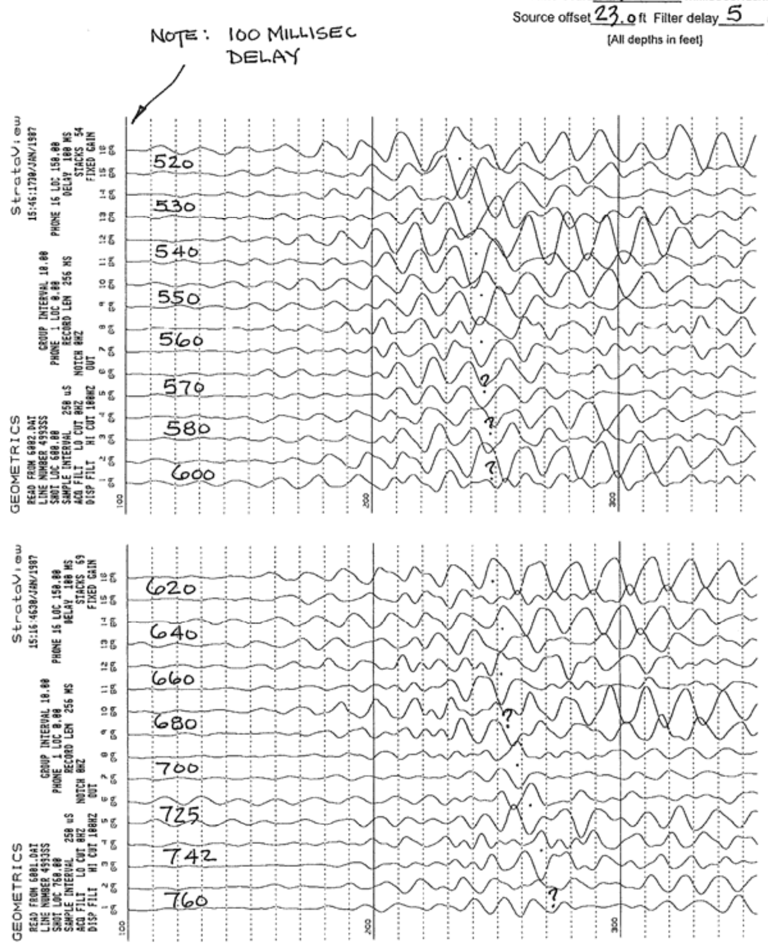
Borehole C4993 Date 30 JAN 07

Playback filter 100 Hz low-pass

Time scale 10 milliseconds/line

Source offset 23.0 ft Filter delay 5 msec

[All depths in feet]



Borehole C4993
Shallow S-Wave Times
9 February 2007

Borehole No.	C4993 - Shallow
Seismic Mode	Shear Wave
Source Offset (ft)	13.8
Onset-to-Peak (ms)	12
Filter Delay (ms)	2

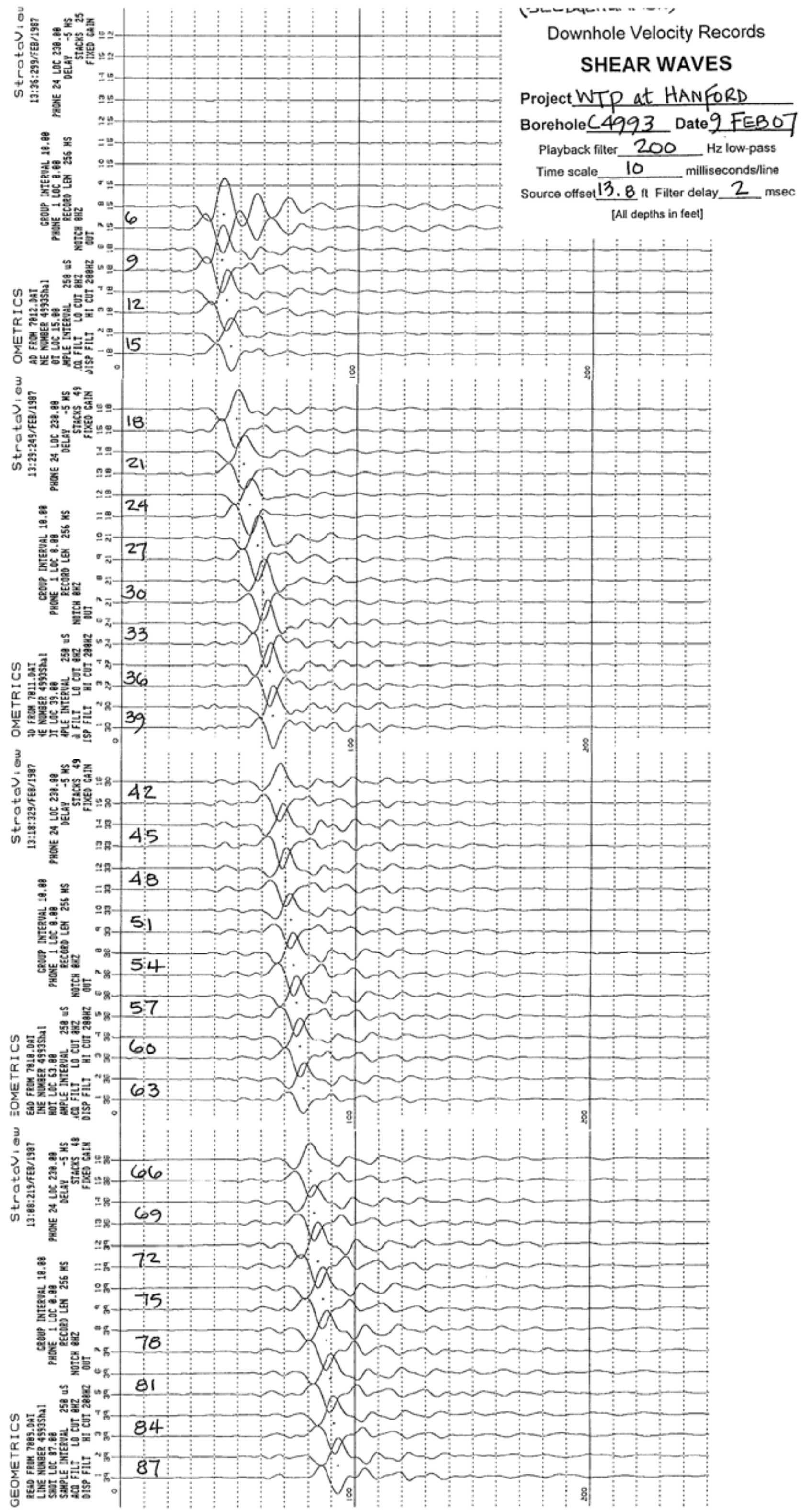
Depth bgs (ft)	Slant TT (ms)	Slant TT - OP - FD	Cosine Factor	Vertical Travel Time (ms)
6	42.5	28.5	0.398726111	**11.4**
9	42.0	28.0	0.546267781	**15.3**
12	44.0	30.0	0.656178715	**19.7**
15	46.0	32.0	0.735931012	**23.5**
18	48.5	34.5	0.793606361	**27.4**
21	52.0	38.0	0.835705480	**31.8**
24	55.0	41.0	0.866906303	**35.5**
27	58.0	44.0	0.890434682	**39.2**
30	60.5	46.5	0.908490453	**42.2**
33	61.5	47.5	0.922579877	**43.8**
36	63.0	49.0	0.933746117	**45.8**
39	64.5	50.5	0.942722273	**47.6**
42	67.5	53.5	0.950031749	**50.8**
45	68.5	54.5	0.956054208	**52.1**
48	70.0	56.0	0.961069304	**53.8**
51	71.5	57.5	0.965286044	**55.5**
54	73.0	59.0	0.968862786	**57.2**
57	75.0	61.0	0.971921047	**59.3**
60	76.0	62.0	0.974555187	**60.4**
63	78.0	64.0	0.976839286	**62.5**
66	80.5	66.5	0.978832101	**65.1**
69	82.5	68.5	0.980580676	**67.2**
72	84.0	70.0	0.982123012	**68.7**
75	86.0	72.0	0.983490057	**70.8**
78	87.5	73.5	0.984707209	**72.4**
81	89.5	75.5	0.985795458	**74.4**
84	91.0	77.0	0.986772268	**76.0**
87	93.0	79.0	0.987652263	**78.0**
90	95.0	81.0	0.988447755	**80.1**
93	96.5	82.5	0.989169171	**81.6**
96	98.0	84.0	0.989825387	**83.1**
100	100.0	86.0	0.990611880	**85.2**
105	103.0	89.0	0.991473568	**88.2**
110	106.0	92.0	0.992222268	**91.3**
115	108.5	94.5	0.992876838	**93.8**
120	111.0	97.0	0.993452373	**96.4**
125	114.5	100.5	0.993961067	**99.9**
130	117.0	103.0	0.994412856	**102.4**
135	120.0	106.0	0.994815901	**105.5**
140	122.0	108.0	0.995176955	**107.5**
145	125.5	111.5	0.995501642	**111.0**

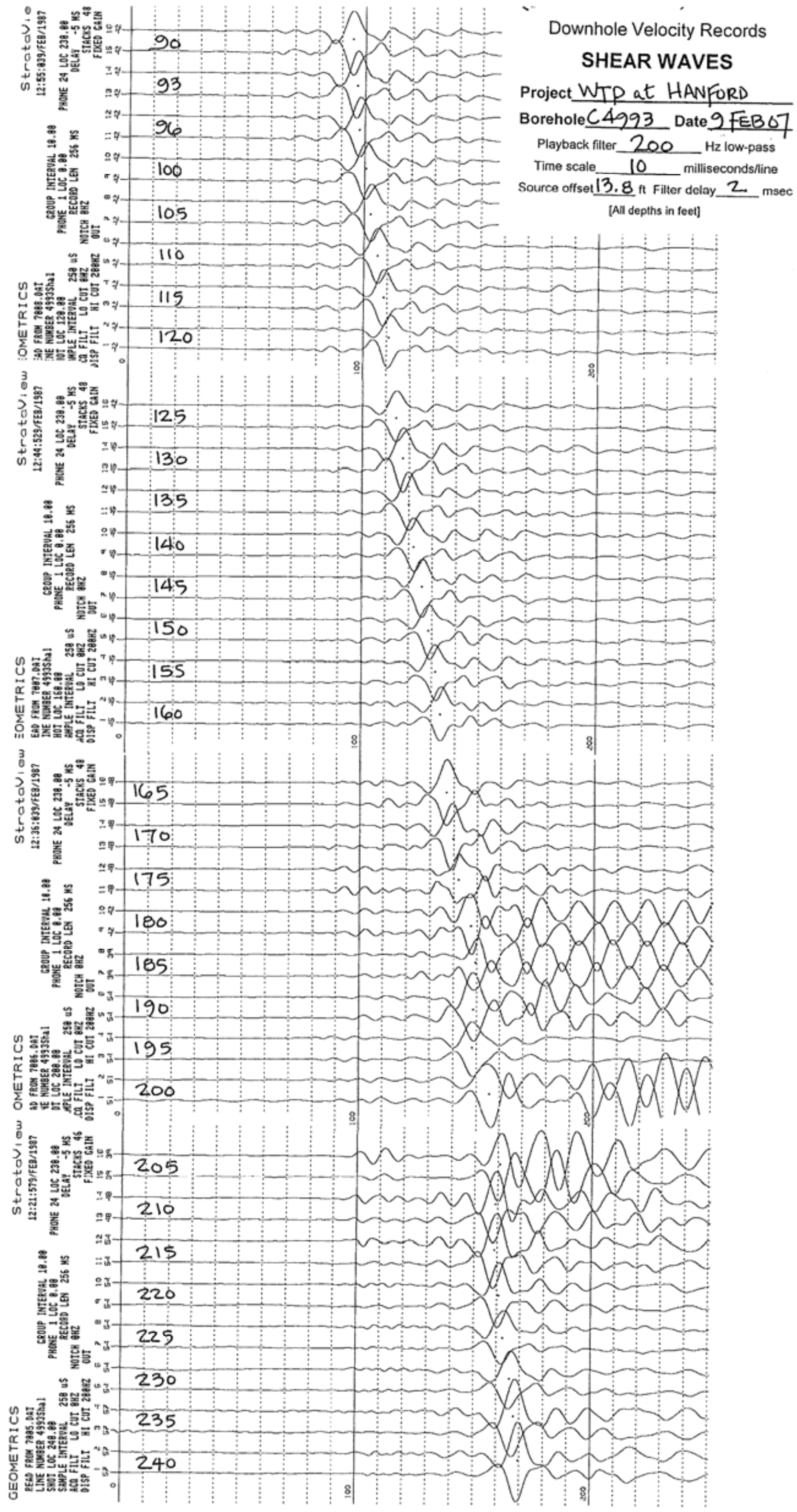
Borehole C4993
Shallow S-Wave Times
9 February 2007

150	129.0	115.0	0.995794677	**114.5**
155	132.0	118.0	0.996060036	**117.5**
160	134.0	120.0	0.996301093	**119.6**
165	136.5	122.5	0.996520722	**122.1**
170	139.5	125.5	0.996721385	**125.1**
175	141.5	127.5	0.996905202	**127.1**
180	147.5	133.5	0.997074004	**133.1**
185	149.5	135.5	0.997229380	**135.1**
190	148.5	134.5	0.997372717	**134.1**
195	148.5	134.5	0.997505225	**134.2**
200	156.0	142.0	0.997627967	**141.7**
205	160.5	146.5	0.997741878	**146.2**
210	159.0	145.0	0.997847784	**144.7**
215	159.0	145.0	0.997946419	**144.7**
220	160.5	146.5	0.998038431	**146.2**
225	162.5	148.5	0.998124401	**148.2**
230	165.5	151.5	0.998204845	**151.2**
235	167.0	153.0	0.998280228	**152.7**
240	169.0	155.0	0.998350963	**154.7**
245	172.5	158.5	0.998417426	**158.2**
250	174.5	160.5	0.998479953	**160.3**
255	177.5	163.5	0.998538849	**163.3**
260	181.0	167.0	0.998594389	**166.8**
265	184.0	170.0	0.998646824	**169.8**
270	186.5	172.5	0.998696381	**172.3**
275	188.5	174.5	0.998743266	**174.3**
280	191.0	177.0	0.998787667	**176.8**
285	194.5	180.5	0.998829758	**180.3**
290	196.0	182.0	0.998869696	**181.8**
295	198.5	184.5	0.998907624	**184.3**
300	201.0	187.0	0.998943676	**186.8**
305	201.0	187.0	0.998977973	**186.8**
310	202.5	188.5	0.999010627	**188.3**
315	202.5	188.5	0.999041742	**188.3**
320	202.5	188.5	0.999071412	**188.3**
325	203.0	189.0	0.999099726	**188.8**
330	204.0	190.0	0.999126765	**189.8**
335	204.5	190.5	0.999152604	**190.3**
340	206.0	192.0	0.999177314	**191.8**
345	206.5	192.5	0.999200959	**192.3**
350	207.0	193.0	0.999223599	**192.9**
355	208.0	194.0	0.999245291	**193.9**
360	209.0	195.0	0.999266087	**194.9**
365	210.0	196.0	0.999286035	**195.9**
370	211.0	197.0	0.999305181	**196.9**
375	211.5	197.5	0.999323567	**197.4**
380	212.5	198.5	0.999341233	**198.4**
385	212.0	198.0	0.999358217	**197.9**
390	213.0	199.0	0.999374552	**198.9**

Borehole C4993
Shallow S-Wave Times
9 February 2007

395	214.0	200.0	0.999390271	**199.9**
400	214.5	200.5	0.999405406	**200.4**


Downhole Velocity Records
SHEAR WAVES
Project WTP at HANFORD
Borehole C4993 Date 9 FEB 07
Playback filter 200 Hz low-pass
Time scale 10 milliseconds/line
Source offset 13.8 ft Filter delay 2 msec
[All depths in feet]


Downhole Velocity Records
SHEAR WAVES
Project WTP at HANFORD
Borehole C4993 Date 9 FEB 07
Playback filter 200 Hz low-pass
Time scale 10 milliseconds/line
Source offset 13.8 ft Filter delay 2 msec
[All depths in feet]
90
93
96
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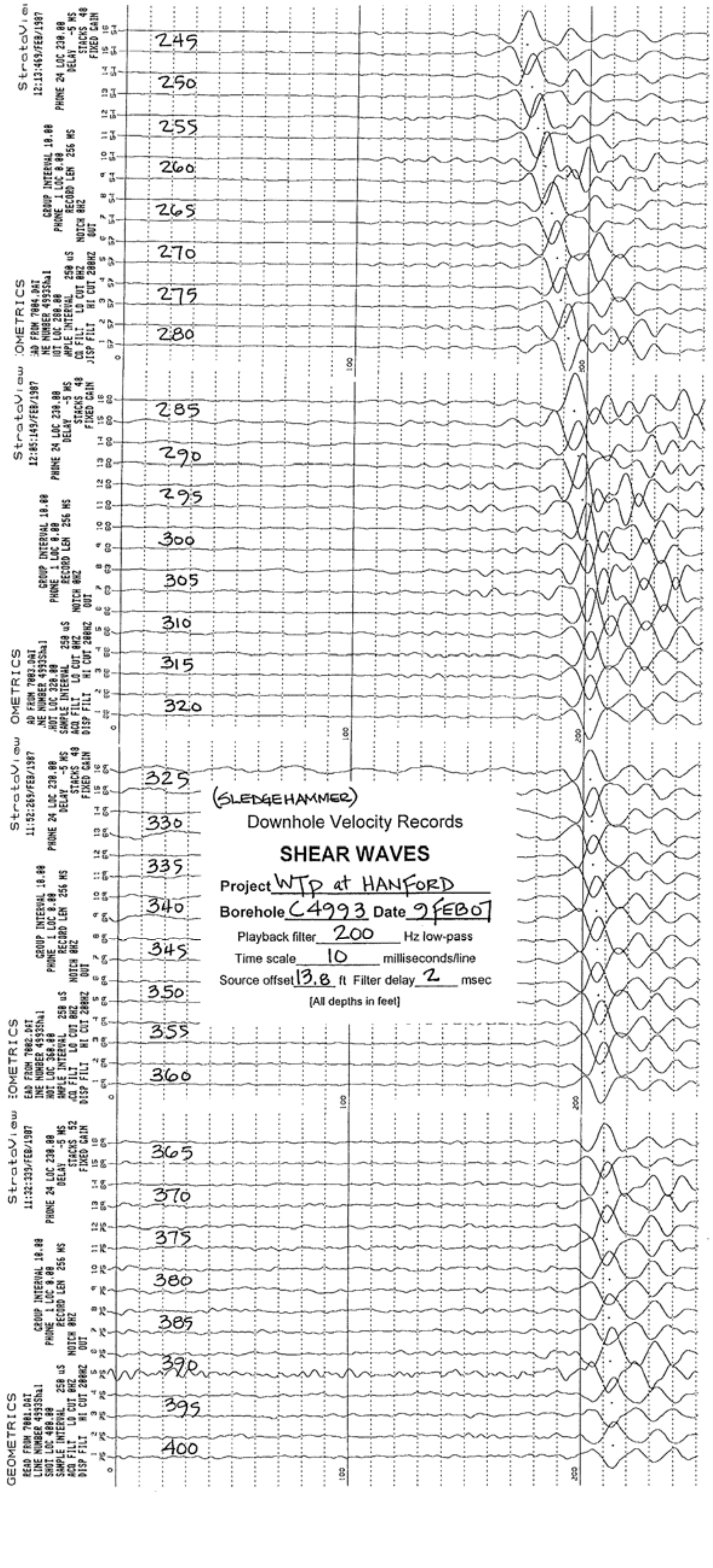
245
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360
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370
375
380
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395
400
(SLEDGEHAMMER)
Downhole Velocity Records
SHEAR WAVES
Project WTP at HANFORD
Borehole C4993 Date 9FEB07
Playback filter 200 Hz low-pass
Time scale 10 milliseconds/line
Source offset 13.8 ft Filter delay 2 msec
[All depths in feet]

Borehole C4993
Shallow P-Wave Times
9 February 2007

Borehole No.	C4993 - Shallow
Seismic Mode	Compression Wave
Source Offset (ft)	20
Onset-to-Peak (ms)	3
Filter Delay (ms)	1

Depth bgs (ft)	Slant TT (ms)	Slant TT - OP - FD	Cosine Factor	**Vertical Travel Time (ms)**
6	28.5	24.5	0.287347886	**7.0**
9	28.5	24.5	0.410364677	**10.1**
12	29.0	25.0	0.514495755	**12.9**
15	29.0	25.0	0.600000000	**15.0**
18	29.0	25.0	0.668964732	**16.7**
21	29.5	25.5	0.724137931	**18.5**
24	30.0	26.0	0.768221280	**20.0**
27	30.5	26.5	0.803557193	**21.3**
30	32.0	28.0	0.832050294	**23.3**
33	33.0	29.0	0.855197832	**24.8**
36	33.5	29.5	0.874157276	**25.8**
39	34.0	30.0	0.889817463	**26.7**
42	34.5	30.5	0.902860519	**27.5**
45	35.0	31.0	0.913811549	**28.3**
48	35.0	31.0	0.923076923	**28.6**
51	35.5	31.5	0.930973198	**29.3**
54	37.5	33.5	0.937748761	**31.4**
57	38.5	34.5	0.943599982	**32.6**
60	39.0	35.0	0.948683298	**33.2**
63	39.0	35.0	0.953124267	**33.4**
66	41.5	37.5	0.957024404	**35.9**
69	42.0	38.0	0.960466366	**36.5**
72	42.5	38.5	0.963517910	**37.1**
75	44.0	40.0	0.966234940	**38.6**
78	45.5	41.5	0.968663866	**40.2**
81	46.0	42.0	0.970843444	**40.8**
84	47.0	43.0	0.972806215	**41.8**
87	48.5	44.5	0.974579651	**43.4**
90	50.0	46.0	0.976187060	**44.9**
93	50.5	46.5	0.977648311	**45.5**
96	51.5	47.5	0.978980420	**46.5**
100	53.0	49.0	0.980580676	**48.0**
105	55.0	51.0	0.982338566	**50.1**
110	56.5	52.5	0.983869910	**51.7**
115	57.5	53.5	0.985211755	**52.7**
120	59.0	55.0	0.986393924	**54.3**
125	62.0	58.0	0.987440632	**57.3**
130	64.5	60.5	0.988371698	**59.8**
135	65.5	61.5	0.989203462	**60.8**
140	66.0	62.0	0.989949494	**61.4**
145	66.0	62.0	0.990621129	**61.4**

Borehole C4993
Shallow P-Wave Times
9 February 2007

150	71.0	67.0	0.991227901	**66.4**
155	71.5	67.5	0.991777867	**66.9**
160	73.0	69.0	0.992277877	**68.5**
165	75.0	71.0	0.992733782	**70.5**
170	76.5	72.5	0.993150604	**72.0**
175	76.5	72.5	0.993532673	**72.0**
180	77.0	73.0	0.993883735	**72.6**
185	77.5	73.5	0.994207048	**73.1**
190	81.5	77.5	0.994505453	**77.1**
195	82.0	78.0	0.994781439	**77.6**
200	82.0	78.0	0.995037190	**77.6**
205	91.0	87.0	0.995274634	**86.6**
210	90.0	86.0	0.995495473	**85.6**
215	90.0	86.0	0.995701216	**85.6**
220	90.5	86.5	0.995893206	**86.1**
225	91.0	87.0	0.996072641	**86.7**
230	92.0	88.0	0.996240588	**87.7**
235	93.0	89.0	0.996398007	**88.7**
240	93.5	89.5	0.996545758	**89.2**
245	95.0	91.0	0.996684616	**90.7**
250	98.0	94.0	0.996815279	**93.7**
255	98.5	94.5	0.996938378	**94.2**
260	99.0	95.0	0.997054486	**94.7**
265	100.0	96.0	0.997164120	**95.7**
270	101.5	97.5	0.997267754	**97.2**
275	103.0	99.0	0.997365817	**98.7**
280	104.0	100.0	0.997458700	**99.7**
285	104.5	100.5	0.997546761	**100.3**
290	105.5	101.5	0.997630328	**101.3**
295	106.5	102.5	0.997709702	**102.3**
300	106.0	102.0	0.997785158	**101.8**
305	106.5	102.5	0.997856949	**102.3**
310	107.0	103.0	0.997925309	**102.8**
315	107.0	103.0	0.997990453	**102.8**
320	107.5	103.5	0.998052578	**103.3**
325	109.0	105.0	0.998111870	**104.8**
330	109.0	105.0	0.998168497	**104.8**
335	109.5	105.5	0.998222616	**105.3**
340	110.0	106.0	0.998274373	**105.8**
345	110.0	106.0	0.998323904	**105.8**
350	110.5	106.5	0.998371334	**106.3**
355	111.0	107.0	0.998416781	**106.8**
360	111.0	107.0	0.998460353	**106.8**
365	111.5	107.5	0.998502152	**107.3**
370	112.0	108.0	0.998542273	**107.8**
375	112.5	108.5	0.998580805	**108.3**
380	113.5	109.5	0.998617829	**109.3**
385	114.0	110.0	0.998653425	**109.9**
390	114.0	110.0	0.998687663	**109.9**

Borehole C4993
Shallow P-Wave Times
9 February 2007

395	113.5	109.5	0.998720614	**109.4**
400	114.0	110.0	0.998752339	**109.9**

Downhole Velocity Records

COMPRESSION WAVES

Project WTP at HANFORD

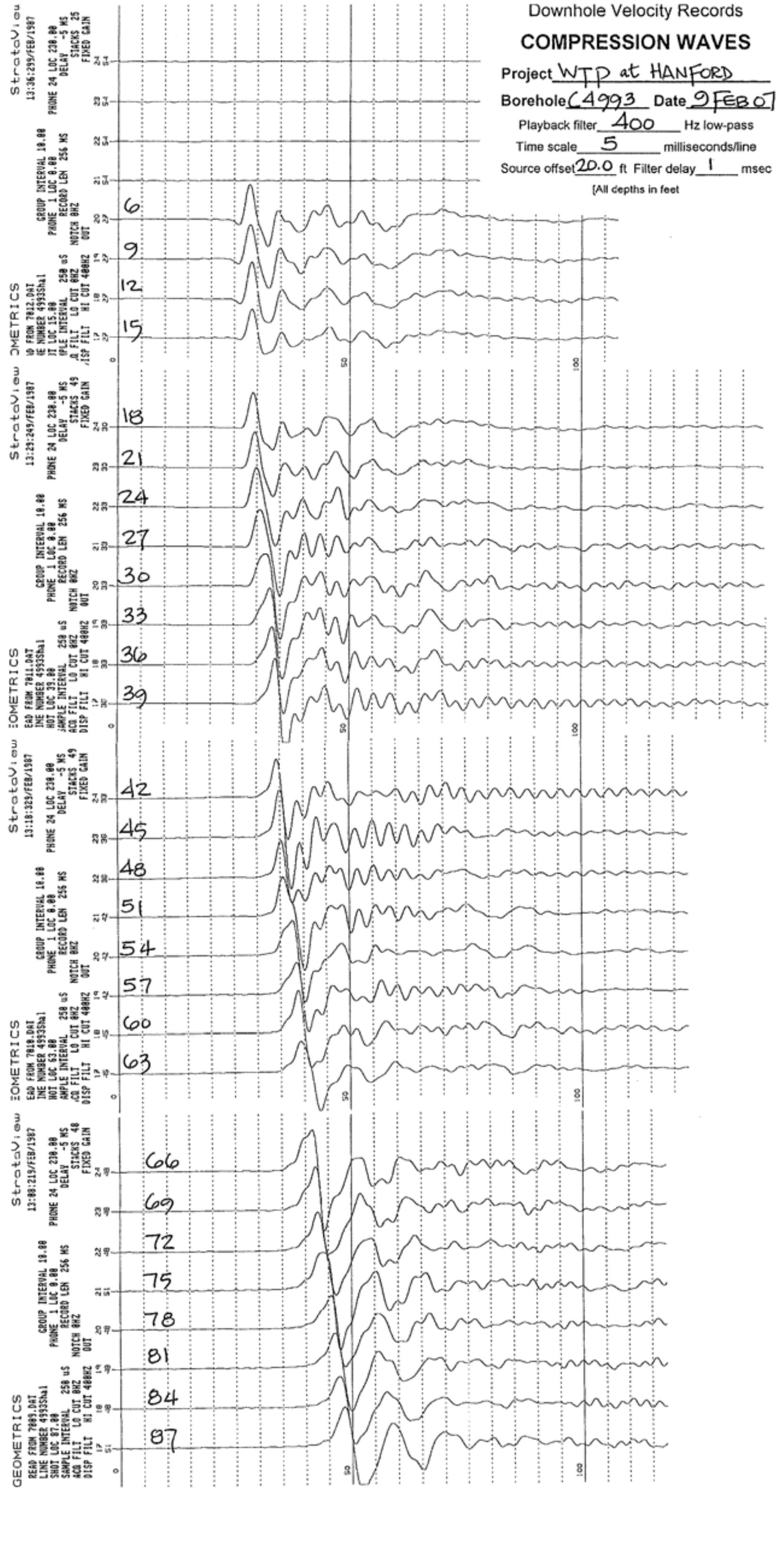
Borehole C4993 Date 9 FEB 07

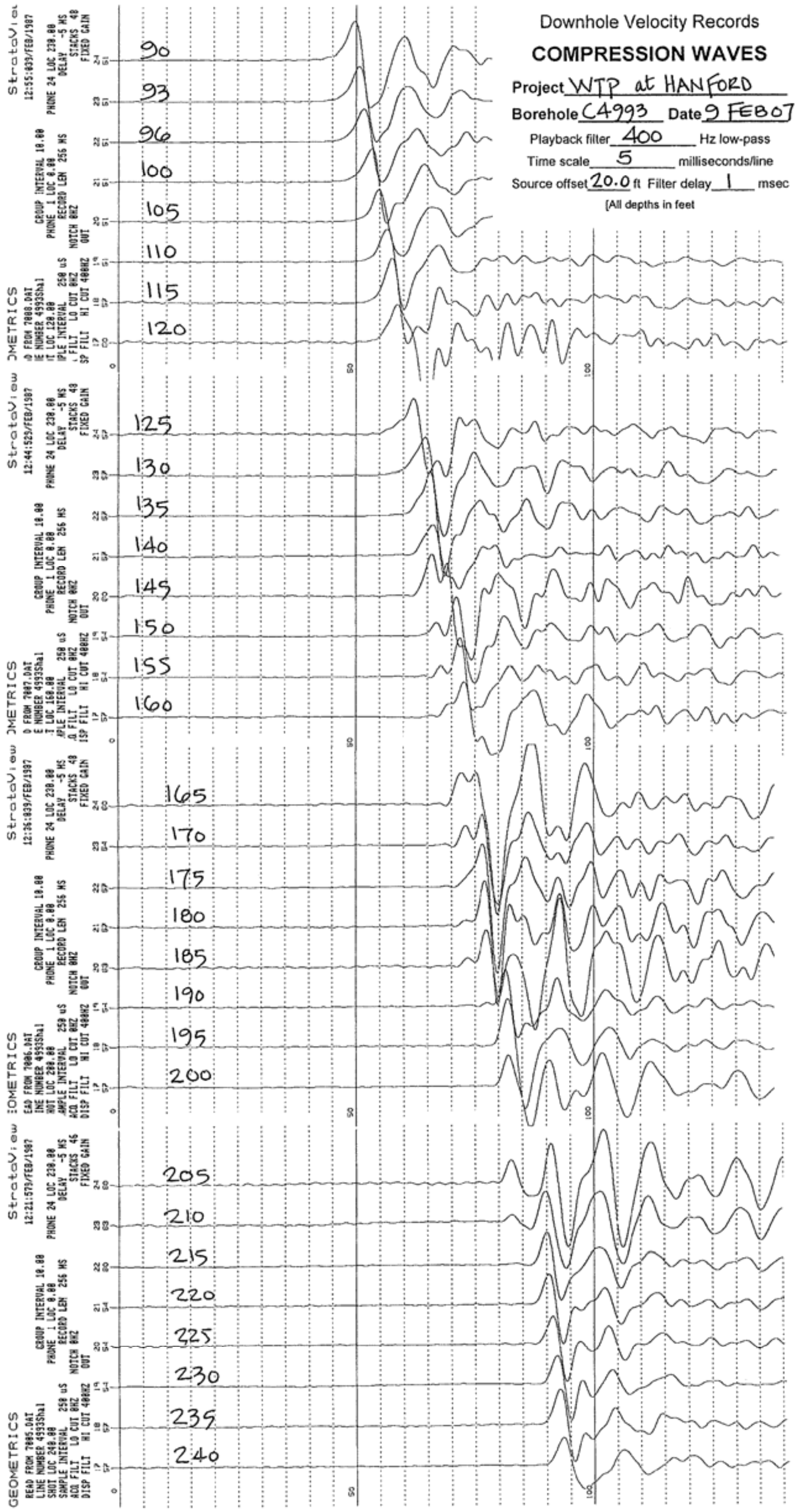
Playback filter 400 Hz low-pass

Time scale 5 milliseconds/line

Source offset 20.0 ft Filter delay 1 msec

[All depths in feet




Downhole Velocity Records
COMPRESSION WAVES
Project WTP at HANFORD
Borehole C4993 Date 9 FEB 07
Playback filter 400 Hz low-pass
Time scale 5 milliseconds/line
Source offset 20.0 ft Filter delay 1 msec
[All depths in feet
90
93
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145
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160
165
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175
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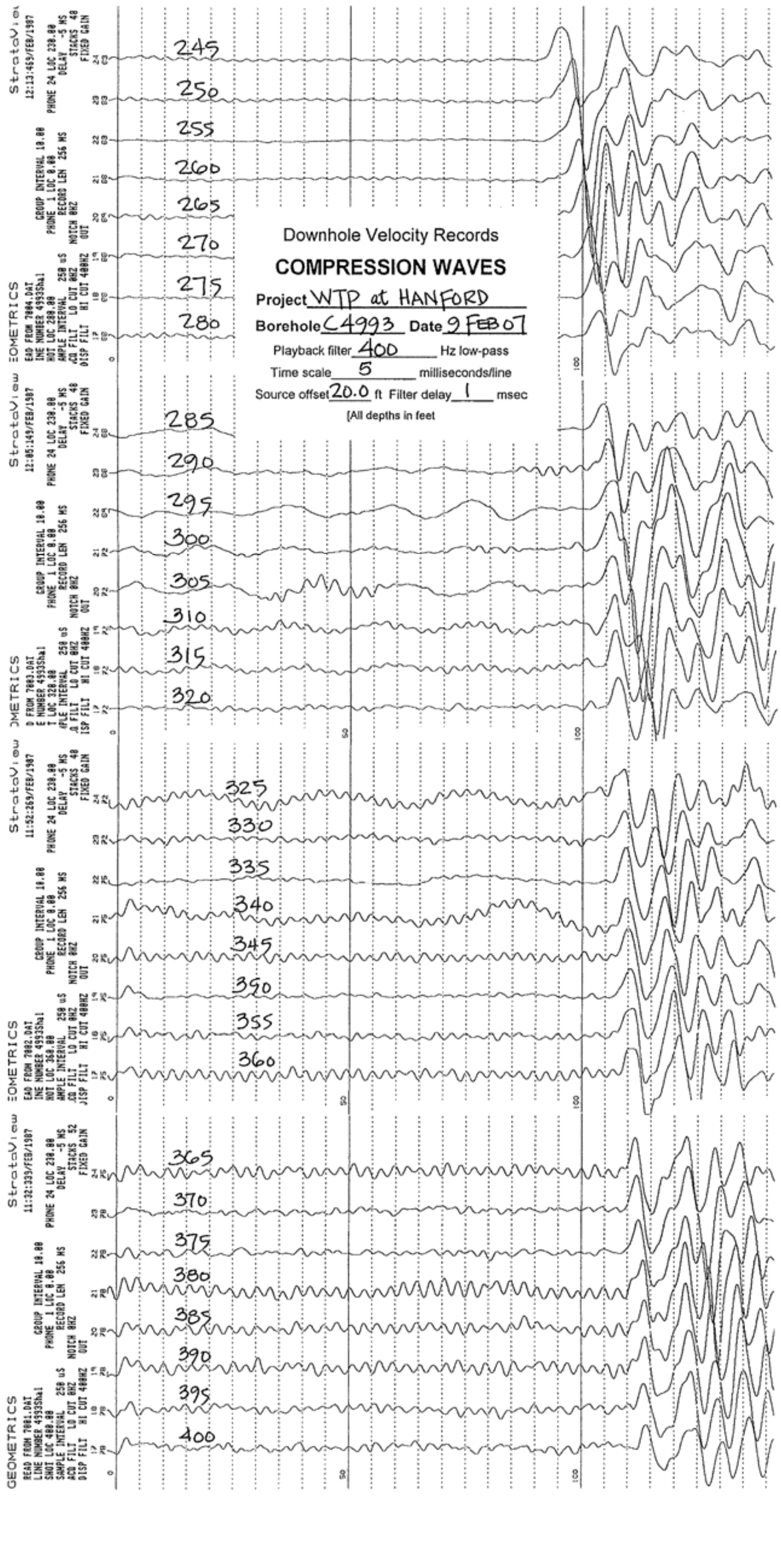
Downhole Velocity Records
COMPRESSION WAVES
Project WTP at HANFORD
Borehole C4993 Date 9 FEB 07
Playback filter 400 Hz low-pass
Time scale 5 milliseconds/line
Source offset 20.0 ft Filter delay 1 msec
[All depths in feet