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Deep Downhole Seismic Testing at the Waste Treatment Plant Site, Hanford, WA

Volume III
P-Wave Measurements in Borehole C4997 Seismic Records, Wave-Arrival Identifications and Interpreted P-Wave Velocity Profile

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June 2007

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Deep Downhole Seismic Testing at the Waste Treatment Plant Site, Hanford, WA

Volume III of VI

P-Wave Measurements in Borehole C4997
Seismic Records, Wave-Arrival Identifications and Interpreted P-Wave Velocity Profile

for

Pacific Northwest National Laboratory
Richland, WA

by

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June 28, 2007

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Volume III: P-Wave Measurements in Borehole C4997 Seismic Records, Wave-Arrival Identifications and Interpreted P-Wave Velocity Profile

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Volume III: P-Wave Measurements in Borehole C4997 Seismic Records, Wave-Arrival Identifications and Interpreted P-Wave Velocity Profile

Section 1: Introduction

The U.S. Department of Energy (DOE) and the Pacific Northwest National Laboratory (PNNL) installed three boreholes to a depth of approximately 1400 feet below ground surface (bgs) in 2006 at the Waste Treatment and Immobilization Plant (WTP) construction site on the Hanford Site in southeastern Washington State. The purpose of the new boreholes was to obtain direct shear (S) and compressional (P) wave velocity measurements in the subsurface for use in reducing the uncertainty in the seismic response spectra and design basis for the WTP. The University of Texas at Austin (UTA) was contracted by PNNL to collect S- and P-wave measurements in each of the three new boreholes identified as C4993, C4996 and C4997 (Barnett et al. 2007; Gardner and Price 2007).

Velocity measurements in shallow sediments from the ground surface to approximately 370 to 400 feet bgs were collected by Redpath Geophysics using impulsive S- and P-wave seismic sources (Redpath 2007). Measurements below this depth within basalt and sedimentary interbeds were made by UTA between October and December 2006 using the T-Rex vibratory seismic source (Stokoe et al. 2004) in each of the three boreholes. Results of these measurements including seismic records, wave-arrival identifications and interpreted velocity profiles are presented in the following six volumes:

I. P-Wave Measurements in Borehole C4993,

II. P-Wave Measurements in Borehole C4996,

III. P-Wave Measurements in Borehole C4997,

IV. S-Wave Measurements in Borehole C4993,

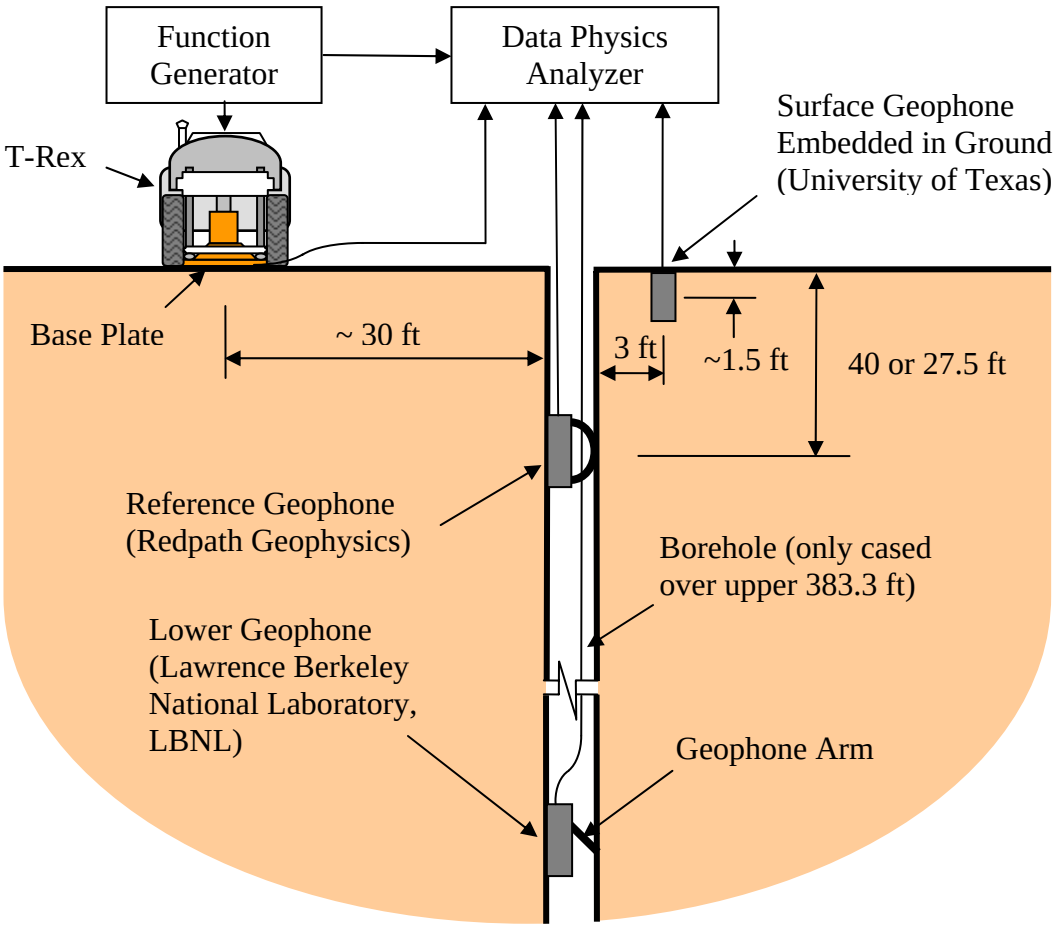
V. S-Wave Measurements in Borehole C4996, and

VI. S-Wave Measurements in Borehole C4997.

In this volume (III), all P-wave measurements are presented that were performed in Borehole C4997 at the WTP with T-Rex as the seismic source and the Lawrence Berkeley National Laboratory (LBNL) 3-D wireline geophone as the at-depth borehole receiver. P-wave measurements were performed over the depth range of 390 to 1220 ft, typically in 10-ft intervals.

However, in some interbeds, 5-ft depth intervals were used. The field setup is illustrated in Figure 1.1.

Figure 1.1 Field Setup for P- and S-Wave Measurement in Borehole C4997



Compression (P) waves were generated by moving the base plate of T-Rex for a given number of cycles at a fixed frequency as discussed in Section 2. This process was repeated so that signal averaging in the time domain was performed using 3 to about 15 averages, with 5 averages typically used.

In addition to the LBNL 3-D geophone, called the lower receiver herein, a 3-D geophone from Redpath Geophysics was fixed at a depth of 40 ft (later relocated to 27.5 ft due to visibility in borehole after rain) in Borehole C4997, and a 3-D geophone from the University of Texas was embedded near the borehole at about 1.5 ft below the ground surface.

This volume is organized into 13 sections as follows:

Section 1: Introduction,

Section 2: Explanation of Terminology,

Section 3: Vp Profile at Borehole C4997,

Sections 4 to 6: Unfiltered P-wave records of lower vertical receiver, reaction mass, and reference receiver, respectively,

Sections 7 to 9: Filtered P-wave signals of lower vertical receiver, reaction mass and reference receiver, respectively,

Section 10: Expanded and filtered P-wave signals of lower vertical receiver,

Sections 11 and 12: Waterfall plots of unfiltered and filtered lower vertical receiver signals, respectively, and

Section 13: References.

Section 2: Explanation of Terminology

1. Record or Signal

The recorded and sampled time series of analog voltage from a geophone or an accelerometer is called a record. A signal can generally be a raw record, a processed record or any designed or generated (as by function generator) time series.

The magnitude of any signals related to this test is by default in voltage. All signal amplitudes (y-axis for time series, both axes for hodograph) in figures of this report, if not otherwise explicitly labeled, have a unit of volt.

All figures for time series have the y axis scaled independently for legibility for each trace (gain-normalized). This makes them legible when the amplitude varies from trace to trace (large close to the surface, small at depth).

2. Input Signal or Drive Signal

At each measurement depth, an independent fixed sine wave with a frequency of either 50 Hz or 20 Hz was sent from a function generator to T-Rex. This signal is called the Input Signal to T-Rex, or the T-Rex Drive Signal. The input signal was a perfect sine wave, with 5 or 10 cycles of 50 Hz, or 4 cycles of 20 Hz. Input signals of all measurements were aligned so that they all began at the same instant, which is called time zero, and was marked as time zero (at $t = 0$) on all recorded signals.

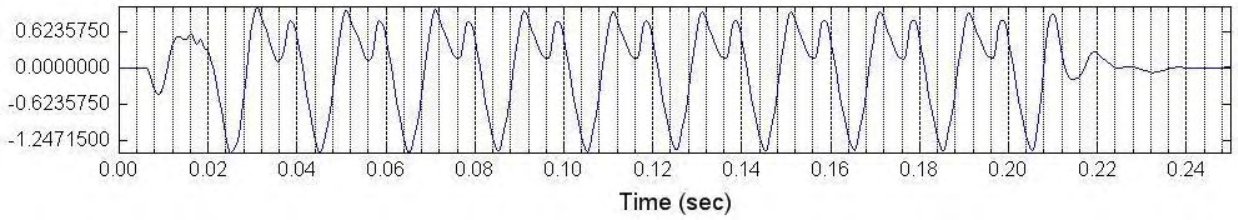
In addition, the given input signal was sent to T-Rex anywhere from 3 to about 15 times to allow signal averaging of the P-wave to be performed in the time domain.

3. Reaction Mass Acceleration or T-Rex Output Signal

The vertical output force of T-Rex was transmitted to the ground surface by a square base plate located on the bottom of T-Rex. The base plate directly contacted the ground surface. The acceleration of the reaction mass that loads the base plate, also called T-Rex Output Signal, was recorded by a vertical accelerometer on the reaction mass. An example of the reaction mass output signal is presented in Figure 2.1.

Figure 2.1 Unfiltered Vertical Acceleration of the Reaction Mass

Input Signal: 10 Cycles of 50-Hz Sine Wave

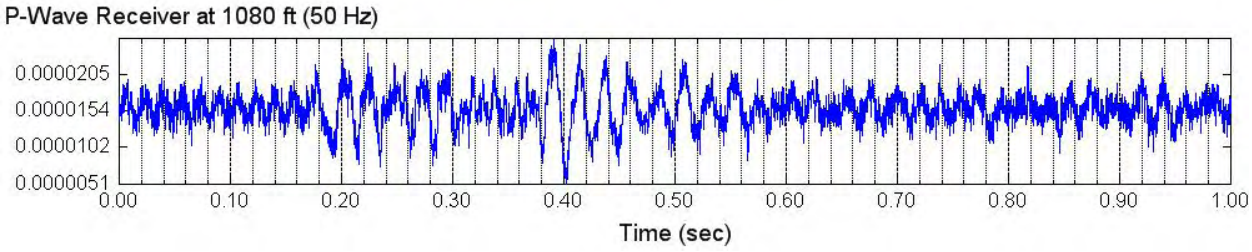


4. Unfiltered Signals

Unfiltered signals are the original time series directly recorded with the Data Physics Analyzer[1]. They are the outputs of the reaction mass accelerometer or the receiver geophones due to the 50-Hz or 20-Hz input signal. The average amplitudes of these unfiltered signals may not be zero due to the non-zero initial voltage. Figure 2.2 shows that the average amplitude of the unfiltered signal of the lower receiver at a depth of 1080 ft is greater than zero. If an unfiltered signal is not stationary, its average value may have a trend or vary with time. Only the fluctuation of the waves is our concern. The trend of each signal was removed to get a zero average, so that in waterfall plots showing signal fluctuations versus scaled depth intervals, the center line (average) of each signal is located exactly at each depth location.

Figure 2.2 Unfiltered Lower Vertical Receiver (P-Wave) Signal

Input Signal: 10 Cycles of 50-Hz Sine Wave



5. Filters and Filtered Signals

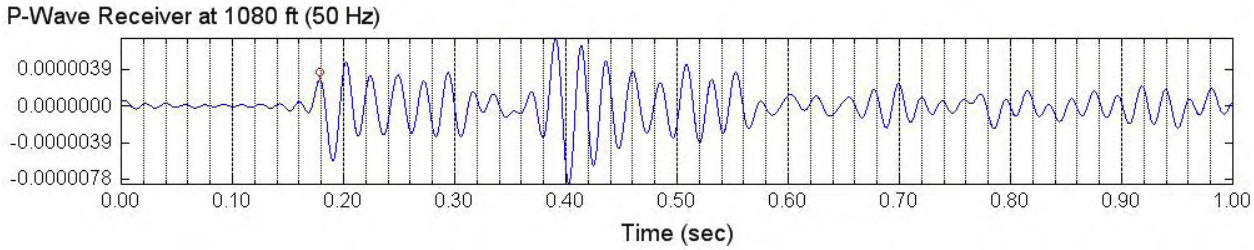
Filters were used in processing the unfiltered signals. A filter is a transfer function that can modify magnitudes and phases of the signal. A low-pass filter is a filter that attenuates or removes undesired high frequencies. The filtered signal is then smoother, and the input signal transmitted through the geologic column is easier to identify. Unfiltered signals in the time

[1] System No. 70270 Mobilyzer II – 16C2S – HS, Data Physics Corporation, San Jose, California

domain were transformed into the frequency domain using the discrete Fast Fourier Transform (FFT), where a low-pass filter was applied by multiplying filter coefficients with both the real and imaginary parts of the frequency magnitudes to get a modified frequency response. Then the inverse FFT was performed on the modified frequency response to obtain a filtered signal in the time domain. Figure 2.3 is the filtered version of the recorded signal in Figure 2.2.

Figure 2.3 Filtered Lower Vertical Receiver (P-Wave) Signal

Input Signal: 10 Cycles of 50-Hz Sine Wave; Filter Low Pass 57 Hz



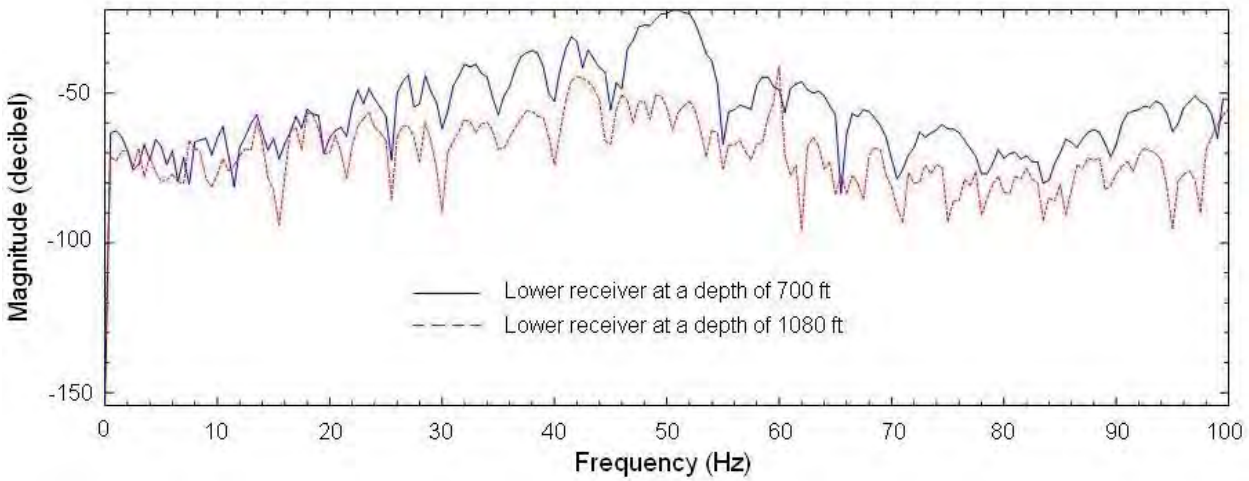
The exact same filtering was performed on all signals with a given fixed frequency. Therefore, any minor shifting in the time domain due to the filtering was the same for each fixed-frequency signal. As a result, the relative travel times determined herein are unaffected by this filtering. Also, the wave-arrival identification on the filtered waveform is denoted by a symbol added to the waveform (the small circle at t ~ 0.18 sec in Figure 2.3) as discussed below in item "Relative Travel Times".

6. Pass Band or Low Pass

By signal-processing convention, the "pass band" of a filter is the band of frequencies that lie within 3 decibels of the peak magnitude. The "stop band" or "reject band" is all other frequencies. The word "band" refers to a frequency range. The frequency corresponding to 3 decibels of the peak value is called the "cut-off" frequency. If a pass band of a filter is the frequency range between zero and the cut-off frequency, it is called a "low pass" filter.

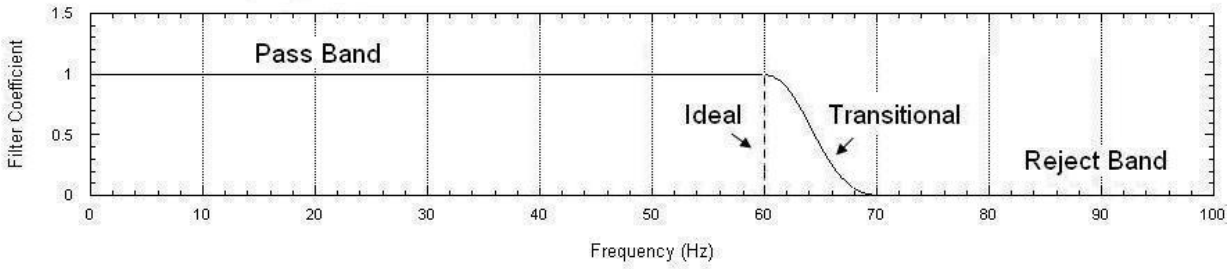
Unfiltered signals are all digital discrete time series, whose frequency domain is also discrete, as shown in Figure 2.4, where the input signal is a 50-Hz sine wave. As demonstrated in the figure, at a depth of 700 ft, 50-Hz signal has dominant energy, while at a depth of 1080 ft, the largest magnitude in the spectrum is 60-Hz noise. Because the 60-Hz noise has a dominant contribution in the unfiltered signal, it must be filtered or removed to retrieve and view the desired measurement of the 50-Hz input signal.

Figure 2.4 Power Spectrum of Unfiltered P-Wave Signals
Input Signal: 10 Cycles of 50-Hz Sine Wave; Expanded from 0 to 100 Hz



A discrete filter in the frequency domain, shown in Figure 2.5, is applicable to these discrete time series. The pass band is 0 to 60 Hz, the reject band is 70 Hz to the Nyquist frequency (not shown), and there is a transitional band between 60 Hz and 70 Hz, which is a cubic spline curve in this work.

Figure 2.5 Filter Pass Band and Stop Band Coefficient



A transitional band is preferred if the magnitude of the reject band is not negligible compared with the magnitude of the desired dominant frequency. For example, in Figure 2.4, if the pass band is 0 to 52 Hz, a transitional band of 52 to 70 Hz would make the filtered signal better. If the contribution of the reject band to the spectrum (or energy) is negligible, an ideal filter makes little difference compared to a transitional filter. For example, if the pass band of the signal at depth 1080 ft is 0 to 57 Hz, there is no significant difference between a transitional filter and an ideal filter. If there was a general trough (near 55 Hz) following the peak of the signal energy (near 50 Hz), a cut-off frequency (55 Hz) was chosen near the trough, and an ideal filter was used. Otherwise, a transitional filter was used.

7. Time Shift

The input signal to the ground, represented by the acceleration of the reaction mass, is not a perfect sine wave, as shown in Figure 2.6. It can be distorted when the initial state of the T-Rex mass is not consistently the same, or the soil below the reaction mass is loaded nonlinearly. Therefore, even if the drive signal is always aligned to zero time, the reaction mass initial response may be shifted from zero time, which is called a time shift. In Figure 2.6, the denoted first arrival is the best point for wave-arrival identification. However, it is not reliable because of the nonlinear initial response of the reaction mass, which may produce different first arrival times for reaction mass and receivers even if the drive signals are exactly aligned. This effect is demonstrated by the first cycle right after the first arrival that shows a transient amplitude and frequency.

Figure 2.6 P-Wave Initial Response of the Reaction Mass

Input Signal: 10 Cycles of 50-Hz Sine Wave

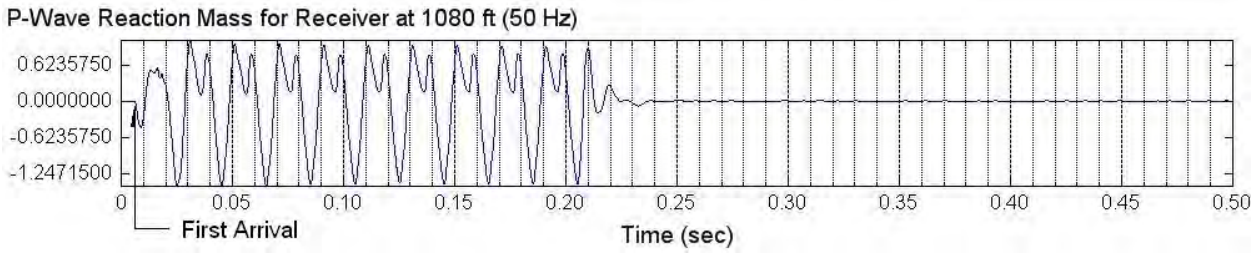
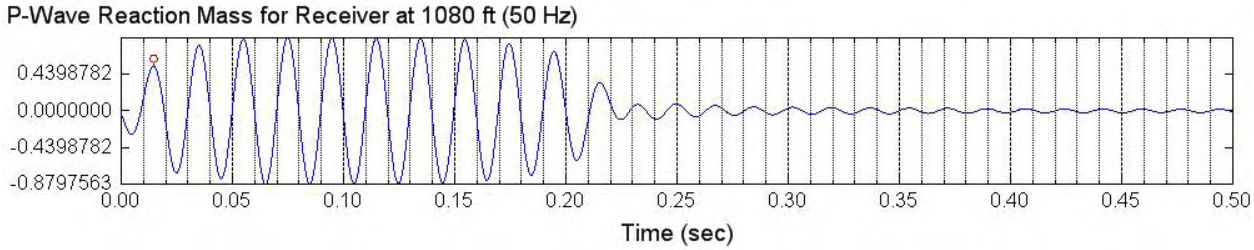


Figure 2.7 is used to further explain the unreliability of the first arrival (or first movement of the reaction mass) and the transient effect on both frequency and magnitude. The filter is a 60-Hz low pass (Figure 2.5) that removed all frequencies higher than 60 Hz. The first arrival point (or "first break") in Figure 2.6 no longer exists in Figure 2.7 because it contains transient frequencies that are higher than 60 Hz. On the other hand, the amplitude of the first peak denoted by a small circle is smaller than that of other peaks because the reaction mass is beginning to move at 50 Hz. The first peak is the correct point to use in evaluating the relative travel times of a 50-Hz P wave.

Further analysis confirmed that, different non-causal low pass filters for the 50-Hz signal in Figure 2.6 will shift the first arrival and first trough, but only slightly shift the first peak if the transient state extends to it, while other peaks and troughs that are in steady state stay unchanged and perfectly aligned. The shift of the first arrival is systematically backward (time is less) and stable because the desired 50-Hz signal remains dominant. Steady-state peaks of output signals

have no time shift if the input signals have no time shift. An FFT low-pass filter can do an excellent job in tracking the desired fixed frequencies.

Figure 2.7 First Peak of the Filtered Acceleration of the Reaction Mass
Input Signal: 10 Cycles of 50-Hz Sine Wave



Nevertheless, steady state peaks and troughs are not a perfect reference for wave-arrival identification because of reflection waves that come into the direct signal and distort the steady state peaks and troughs.

As a compromise and for convenience, the first-arrival wave identification method is replaced with the first peak or first trough of the waveform for the reaction mass acceleration and other receiver signals. There is little shifting from the steady state of the desired signal frequency (for example 50 Hz), and less interference from the reflections.

As an alternative for the non-causal filter, a Butterworth filter may secure the first arrival stationary, but it falls short if the frequency of the dominant noise (60-Hz noise in Figure 2.4 has greater magnitude than the desired signal at 50 Hz) is very close to that of the signal. If the noise can not be significantly attenuated or removed, it will shift not only the first arrival, but also the steady-state peaks and troughs, and the shift is irregular because it is controlled by the noise. While the FFT low-pass filter, which is non-causal, can remove undesired 60-Hz noise completely and track the desired frequency effectively. Therefore, the FFT low-pass filter was used herein.

8. Relative Travel Times

Relative travel times are the time intervals between the same points on the waveforms of the reaction mass and receivers (lower receiver or reference receiver). The time on each filtered waveform that is used to determine the relative travel time is denoted by a small symbol that has been added to all waveforms. Examples are shown in Figures 2.3 and 2.7 by the small circles. These points (representing times) are not the wave arrivals but are the same point on the

waveform from one measurement depth to the next. These points are called “wave-arrival identifications” herein.

9. Long Lever Arm and Short Lever Arm

The lower borehole geophone from Lawrence Berkeley National Laboratory (LBNL) was fixed to the borehole wall at a depth by rotating the pivoting lever arm that was attached to the geophone case. As the lever arm rotated outward, the geophone case was pushed into contact with the borehole wall. Two lengths of lever arms were compared in Borehole C4993, the longer one called a long lever arm and the shorter one called a short lever arm. Only the long lever arm was used for all depths in Borehole C4997.

10. Reference Receiver

The reference receiver is the vertical (geophone) receiver (see Figure 1.1) that was fixed at a depth of 40 ft in Borehole C4997 while the lower 3-D receiver of LBNL was moved downward along the borehole. Later the reference receiver was fixed at a depth of 27.5 ft due to poor visibility for alignment with the orientation of the base plate of T-Rex.

11. Lower Vertical Receiver

The lower vertical receiver is the vertical (geophone) component of the LBNL 3-D geophone (see Figure 1.1). It is positioned at the deeper depth or below the location of the reference receiver. It is one component in the only 3-D geophone that was moved during testing in the borehole.

Section 3: Vp Profile at Borehole C4997

Section 3 contains the geologic profile, interpreted Vp profile and relative P-wave travel times.

1. Figure 3.1 presents the geologic profile.
2. Figure 3.2 shows all relative P-wave travel times and the interpreted Vp profile at Borehole C4997.
3. Figures 3.3 to 3.5 are the expanded relative P-wave travel times and the interpreted Vp profile at Borehole C4997.
4. Tables 3.1 to 3.4 list the relative P-wave travel times at Borehole C4997, including the times of the wave-arrival identifications for the peaks or troughs of the reaction-mass acceleration, reference receiver and lower receiver signals.

Figure 3.1 General Stratigraphy of Borehole C4997

(Depths source: Barnett et al. 2007; Rohay and Brouns 2007)

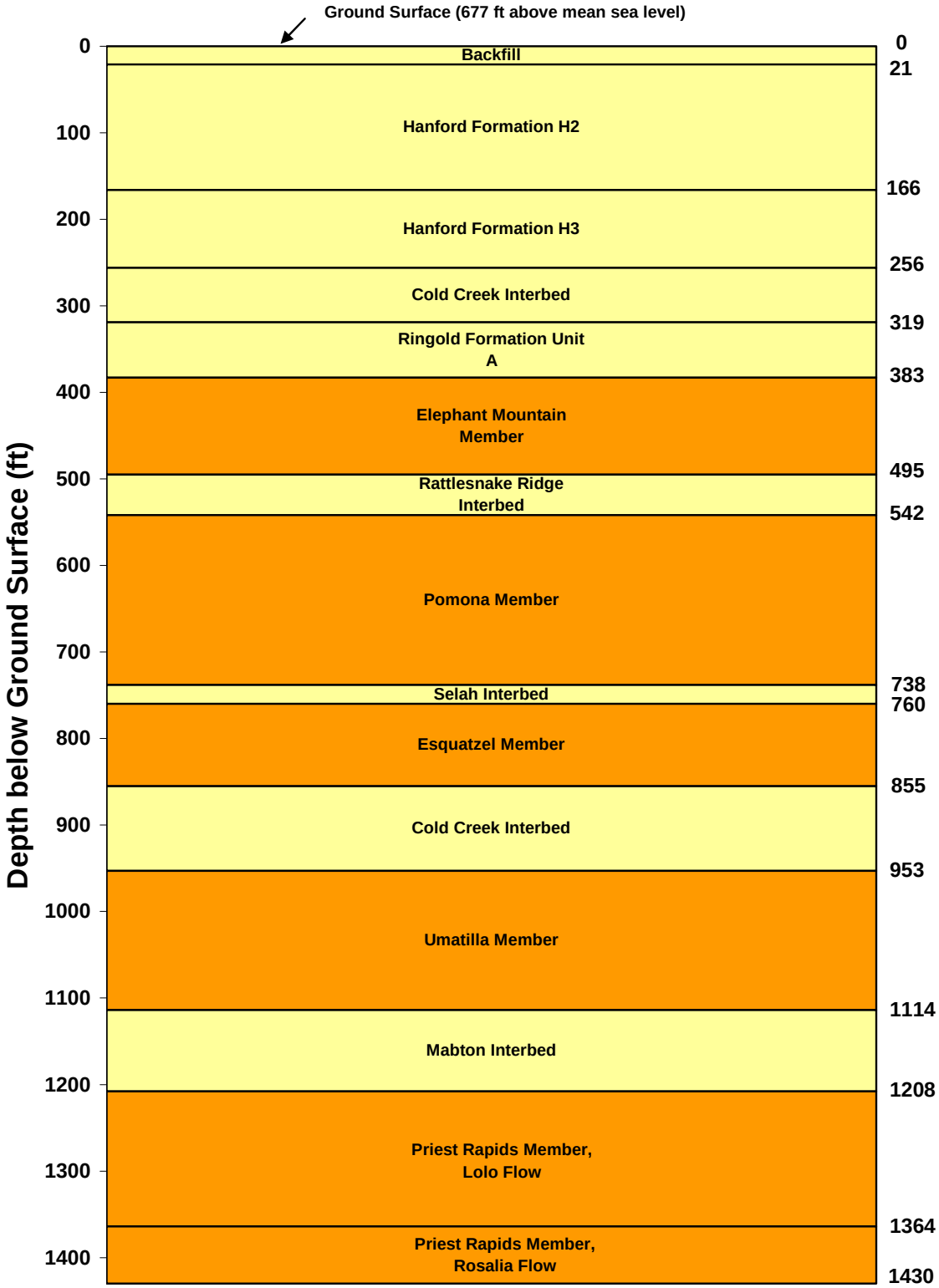


Figure 3.2 Relative P-Wave Travel Times and Interpreted Vp Profile at Borehole C4997

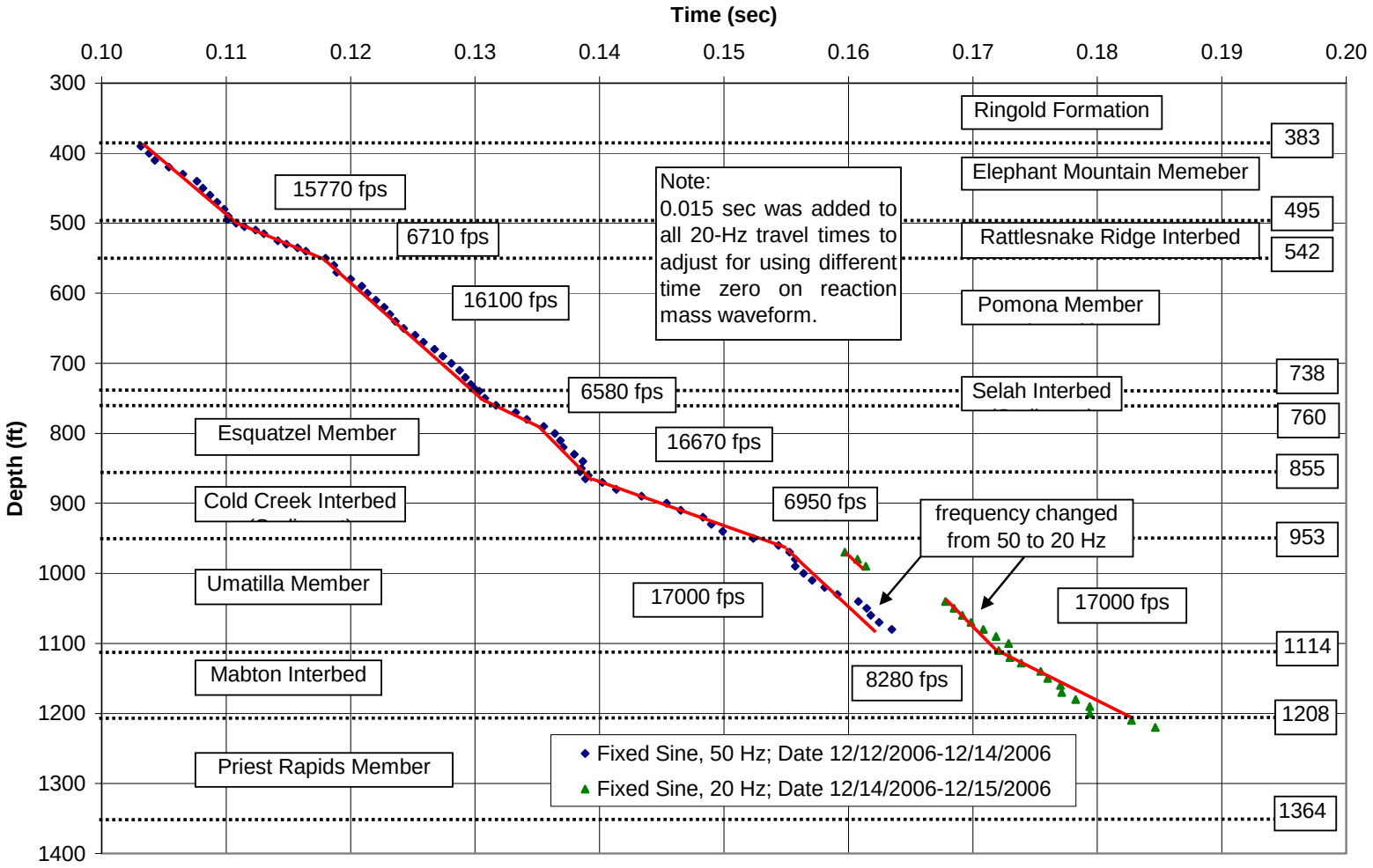


Figure 3.3 Expanded Relative P-Wave Travel Times and Interpreted Vp Profile at Borehole C4997, Depths 300 to 800 ft

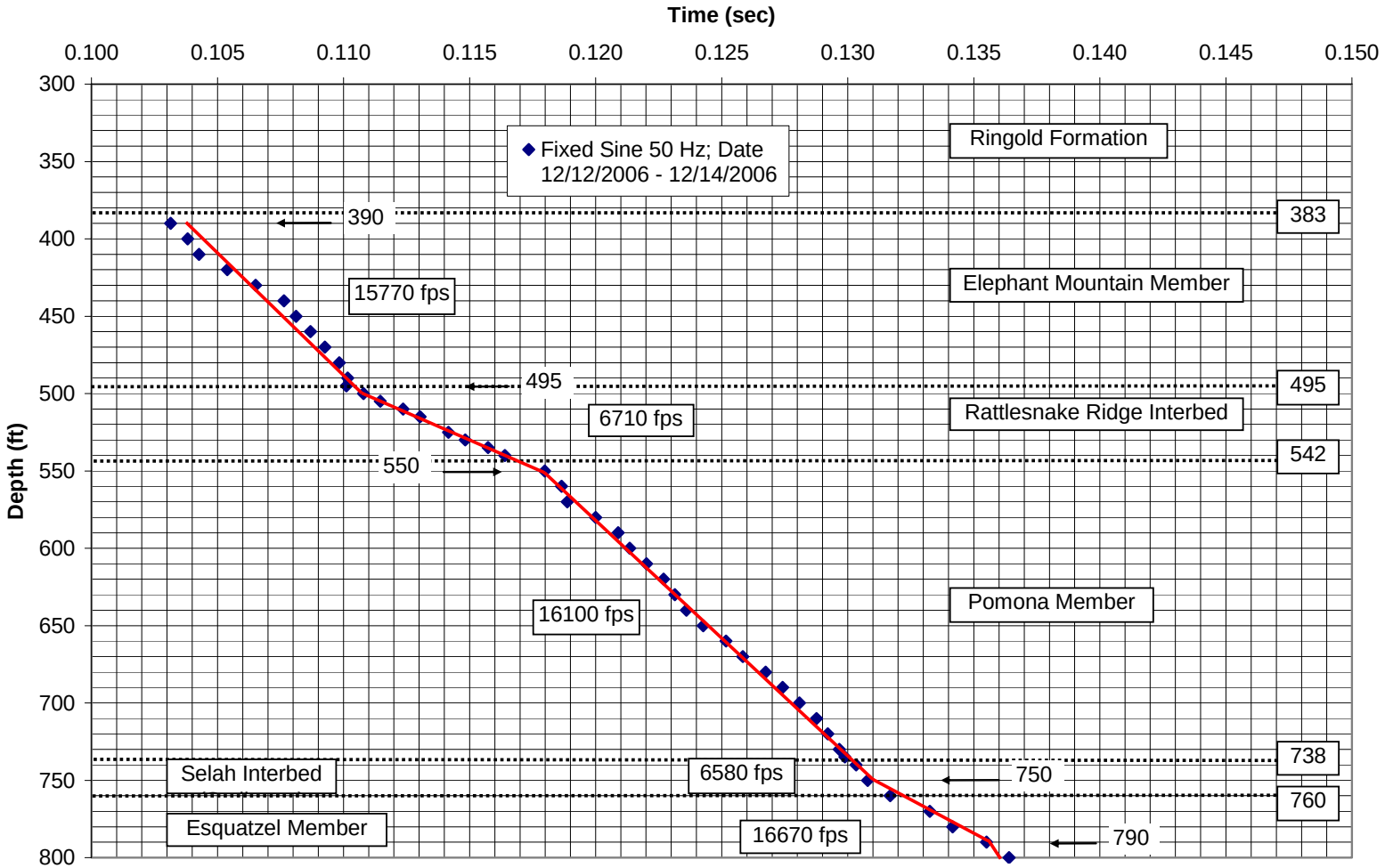


Figure 3.4 Expanded Relative P-Wave Travel Times and Interpreted Vp Profile at Borehole C4997, Depths 600 to 1100 ft

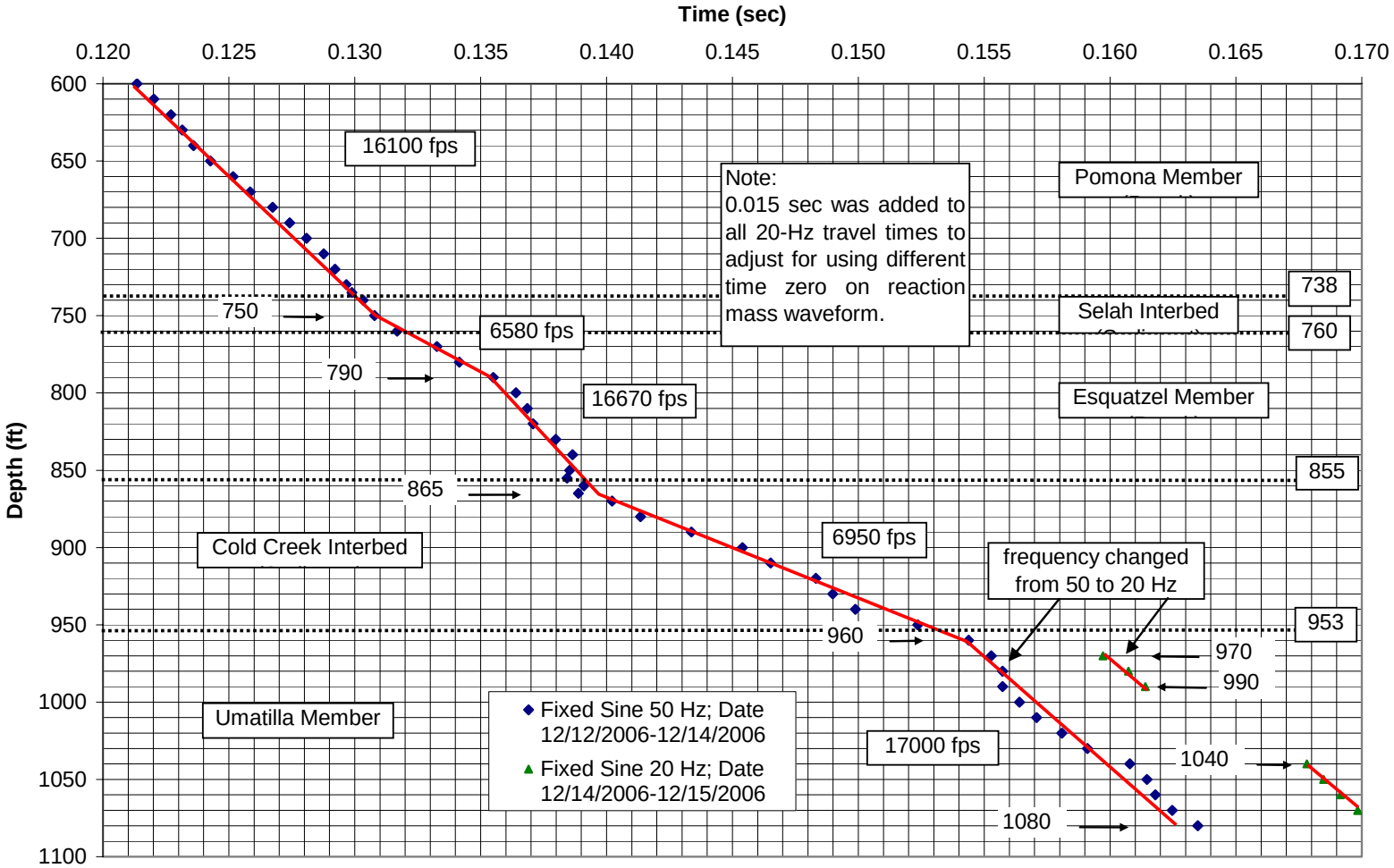


Figure 3.5 Expanded Relative P-Wave Travel Times and Interpreted Vp Profile at Borehole C4997, Depth 900 to 1400 ft

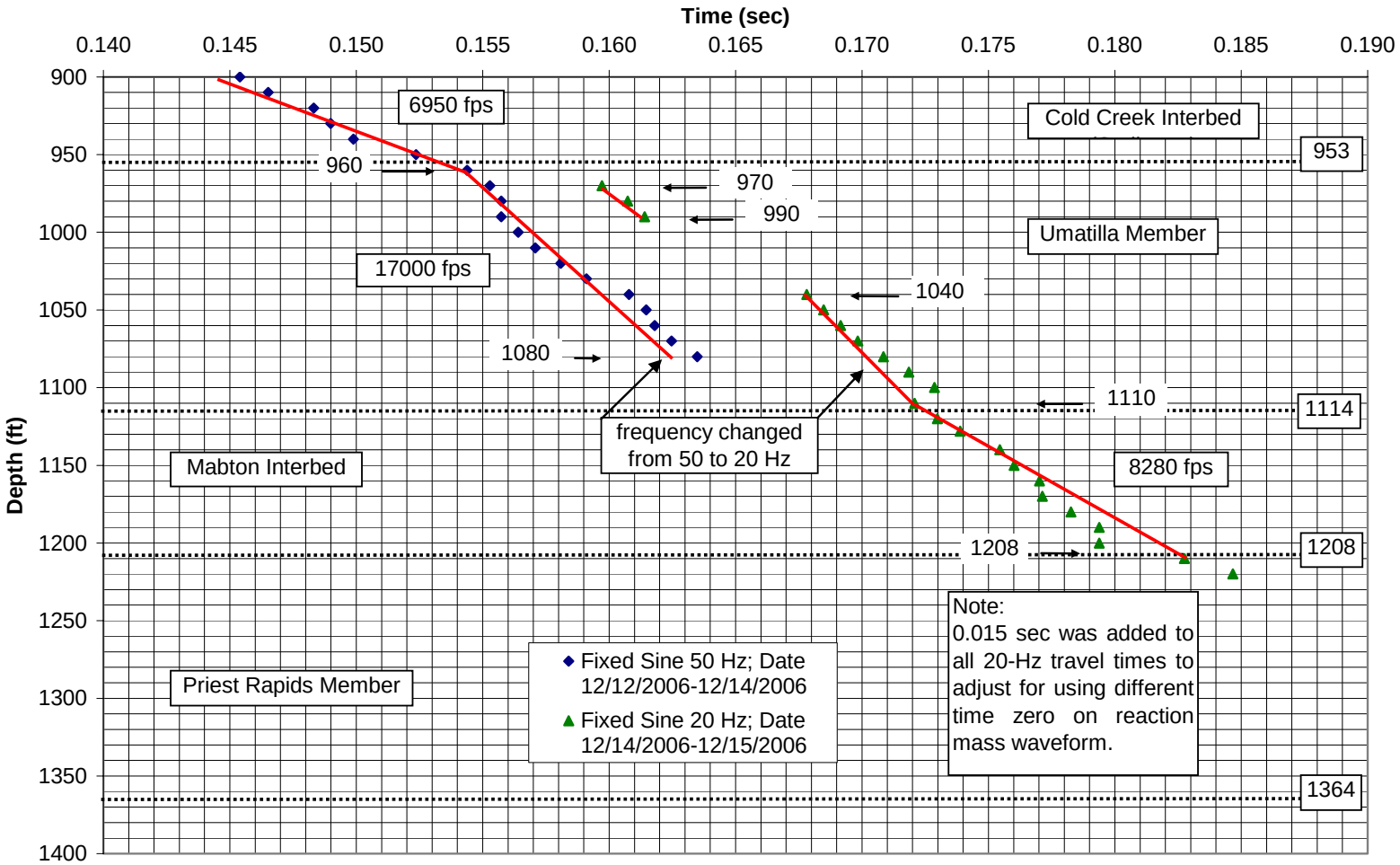


Table 3.1 Relative P-Wave Travel Times at Borehole C4997

Lower Receiver Depth (ft)	Reference Receiver Depth (ft)	T-Rex Drive Freq./ No. of Cycles (Hz/No.)	T-Rex Excitation Direction	Time: Peak or Trough at Reaction Mass (sec)	Time: Peak or Trough at Ref. Receiver (sec)	Time: Peak or Trough at Lower Receiver (sec)	Travel Time Relative to Ref. Receiver (sec)	Travel Time * Relative to Reaction Mass (sec)
390	40	50/5	Vertical	0.01506	0.04045	0.11820	0.07775	0.10315
400	40	50/5	Vertical	0.01506	0.04135	0.11888	0.07753	0.10382
410	40	50/5	Vertical	0.01506	0.04135	0.11933	0.07798	0.10427
420	40	50/5	Vertical	0.01506	0.04135	0.12045	0.07910	0.10539
430	40	50/5	Vertical	0.01506	0.04135	0.12157	0.08022	0.10652
440	40	50/5	Vertical	0.01506	0.04135	0.12270	0.08135	0.10764
450	40	50/5	Vertical	0.01506	0.04135	0.12318	0.08183	0.10812
460	40	50/5	Vertical	0.01506	0.04135	0.12375	0.08240	0.10869
470	40	50/5	Vertical	0.01506	0.04135	0.12432	0.08297	0.10927
480	40	50/5	Vertical	0.01506	0.04135	0.12489	0.08355	0.10984
490	40	50/5	Vertical	0.01506	0.04135	0.12523	0.08388	0.11017
495	27.5	50/10	Vertical	0.01506	0.04225	0.12517	0.08292	0.11011
500	27.5	50/10	Vertical	0.01506	0.04225	0.12584	0.08360	0.11079
505	27.5	50/10	Vertical	0.01506	0.04279	0.12652	0.08373	0.11146
510	27.5	50/10	Vertical	0.01506	0.04279	0.12742	0.08463	0.11236
515	27.5	50/10	Vertical	0.01506	0.04279	0.12809	0.08530	0.11303
525	27.5	50/10	Vertical	0.01506	0.04279	0.12921	0.08643	0.11416
530	27.5	50/10	Vertical	0.01506	0.04279	0.12989	0.08710	0.11483
535	27.5	50/10	Vertical	0.01506	0.04279	0.13079	0.08800	0.11573
540	27.5	50/10	Vertical	0.01506	0.04279	0.13146	0.08867	0.11640
550	27.5	50/10	Vertical	0.01506	0.04279	0.13303	0.09025	0.11798
560	27.5	50/10	Vertical	0.01506	0.04225	0.13371	0.09146	0.11865
570	27.5	50/10	Vertical	0.01506	0.04225	0.13393	0.09169	0.11888
580	27.5	50/10	Vertical	0.01506	0.04279	0.13506	0.09227	0.12000
590	40	50/10	Vertical	0.01506	0.04180	0.13596	0.09416	0.12090
600	40	50/10	Vertical	0.01506	0.04225	0.13640	0.09416	0.12135
610	40	50/10	Vertical	0.01506	0.04267	0.13708	0.09441	0.12202

* Use of the reaction mass as a reference for calculating relative travel times exhibited less scatter than using the reference receiver.

Table 3.2 Relative P-Wave Travel Times at Borehole C4997

Lower Receiver Depth (ft)	Reference Receiver Depth (ft)	T-Rex Drive Freq./ No. of Cycles (Hz/No.)	T-Rex Excitation Direction	Time: Peak or Trough at Reaction Mass (sec)	Time: Peak or Trough at Ref. Receiver (sec)	Time: Peak or Trough at Lower Receiver (sec)	Travel Time Relative to Ref. Receiver (sec)	Travel Time * Relative to Reaction Mass (sec)
620	40	50/10	Vertical	0.01506	0.04267	0.13775	0.09509	0.12270
630	40	50/10	Vertical	0.01506	0.04267	0.13820	0.09554	0.12315
640	40	50/10	Vertical	0.01506	0.04267	0.13865	0.09599	0.12360
650	40	50/10	Vertical	0.01506	0.04267	0.13933	0.09666	0.12427
660	40	50/10	Vertical	0.01506	0.04267	0.14022	0.09756	0.12517
670	40	50/10	Vertical	0.01506	0.04267	0.14090	0.09823	0.12584
680	40	50/10	Vertical	0.01506	0.04267	0.14180	0.09913	0.12674
690	40	50/10	Vertical	0.01506	0.04424	0.14247	0.09823	0.12742
700	40	50/10	Vertical	0.01506	0.04267	0.14315	0.10048	0.12809
710	40	50/10	Vertical	0.01506	0.04267	0.14382	0.10115	0.12876
720	40	50/10	Vertical	0.01506	0.04267	0.14427	0.10160	0.12921
730	27.5	50/10	Vertical	0.01506	0.04279	0.14472	0.10193	0.12966
735	27.5	50/10	Vertical	0.01506	0.04279	0.14494	0.10216	0.12989
740	27.5	50/10	Vertical	0.01506	0.04279	0.14539	0.10261	0.13034
750	27.5	50/10	Vertical	0.01506	0.04279	0.14584	0.10305	0.13079
760	27.5	50/10	Vertical	0.01506	0.04279	0.14674	0.10395	0.13169
770	27.5	50/10	Vertical	0.01506	0.04279	0.14831	0.10553	0.13326
780	40	50/10	Vertical	0.01506	0.04267	0.14921	0.10655	0.13416
790	40	50/10	Vertical	0.01506	0.04267	0.15056	0.10790	0.13551
800	40	50/10	Vertical	0.01506	0.04267	0.15146	0.10879	0.13640
810	40	50/10	Vertical	0.01506	0.04267	0.15191	0.10924	0.13685
820	40	50/10	Vertical	0.01506	0.04267	0.15213	0.10947	0.13708
830	40	50/10	Vertical	0.01506	0.04267	0.15303	0.11037	0.13798
840	40	50/10	Vertical	0.01506	0.04267	0.15371	0.11104	0.13865
850	40	50/10	Vertical	0.01506	0.04267	0.15360	0.11093	0.13854
855	27.5	50/10	Vertical	0.01506	0.04279	0.15348	0.11070	0.13843
860	27.5	50/10	Vertical	0.01506	0.04279	0.15416	0.11137	0.13910

* Use of the reaction mass as a reference for calculating relative travel times exhibited less scatter than using the reference receiver.

Table 3.3 Relative P-Wave Travel Times at Borehole C4997

Lower Receiver Depth (ft)	Reference Receiver Depth (ft)	T-Rex Drive Freq./ No. of Cycles (Hz/No.)	T-Rex Excitation Direction	Time: Peak or Trough at Reaction Mass (sec)	Time: Peak or Trough at Ref. Receiver (sec)	Time: Peak or Trough at Lower Receiver (sec)	Travel Time Relative to Ref. Receiver (sec)	Travel Time * Relative to Reaction Mass (sec)
865	27.5	50/10	Vertical	0.01506	0.04279	0.15393	0.11114	0.13888
870	27.5	50/10	Vertical	0.01506	0.04279	0.15528	0.11249	0.14022
880	27.5	50/10	Vertical	0.01506	0.04279	0.15640	0.11362	0.14135
890	27.5	50/10	Vertical	0.01506	0.04279	0.15843	0.11564	0.14337
900	27.5	50/10	Vertical	0.01506	0.04279	0.16045	0.11766	0.14539
910	27.5	50/10	Vertical	0.01506	0.04279	0.16157	0.11879	0.14652
920	27.5	50/10	Vertical	0.01506	0.04279	0.16337	0.12058	0.14831
930	27.5	50/10	Vertical	0.01506	0.04279	0.16404	0.12126	0.14899
940	27.5	50/10	Vertical	0.01506	0.04279	0.16494	0.12216	0.14989
950	27.5	50/10	Vertical	0.01506	0.04279	0.16742	0.12463	0.15236
960	40	50/10	Vertical	0.01506	0.04267	0.16944	0.12677	0.15438
970	40	50/10	Vertical	0.01506	0.04267	0.17034	0.12767	0.15528
980	40	50/10	Vertical	0.01506	0.04267	0.17079	0.12812	0.15573
990	40	50/10	Vertical	0.01506	0.04267	0.17079	0.12812	0.15573
1000	40	50/10	Vertical	0.01506	0.04267	0.17146	0.12879	0.15640
1010	40	50/10	Vertical	0.01506	0.04267	0.17213	0.12947	0.15708
1020	40	50/10	Vertical	0.01506	0.04267	0.17315	0.13048	0.15809
1030	40	50/10	Vertical	0.01506	0.04267	0.17416	0.13149	0.15910
1040	27.5	50/10	Vertical	0.01506	0.04279	0.17584	0.13305	0.16079
1050	27.5	50/10	Vertical	0.01506	0.04279	0.17652	0.13373	0.16146
1060	27.5	50/10	Vertical	0.01506	0.04279	0.17685	0.13407	0.16180
1070	27.5	50/10	Vertical	0.01506	0.04279	0.17753	0.13474	0.16247
1080	27.5	50/10	Vertical	0.01506	0.04279	0.17854	0.13575	0.16348
970	27.5	20/4	Vertical	0.01933	0.04479	0.16404	0.11926	0.14472
980	27.5	20/4	Vertical	0.01933	0.04479	0.16506	0.12027	0.14573
990	27.5	20/4	Vertical	0.01933	0.04479	0.16573	0.12094	0.14640

* Use of the reaction mass as a reference for calculating relative travel times exhibited less scatter than using the reference receiver.

Table 3.4 Relative P-Wave Travel Times at Borehole C4997

Lower Receiver Depth (ft)	Reference Receiver Depth (ft)	T-Rex Drive Freq./ No. of Cycles (Hz/No.)	T-Rex Excitation Direction	Time: Peak or Trough at Reaction Mass (sec)	Time: Peak or Trough at Ref. Receiver (sec)	Time: Peak or Trough at Lower Receiver (sec)	Travel Time Relative to Ref. Receiver (sec)	Travel Time * Relative to Reaction Mass (sec)
1040	27.5	20/4	Vertical	0.01933	0.04479	0.17213	0.12735	0.15281
1050	27.5	20/4	Vertical	0.01933	0.04479	0.17281	0.12802	0.15348
1060	27.5	20/4	Vertical	0.01933	0.04479	0.17348	0.12870	0.15416
1070	27.5	20/4	Vertical	0.01933	0.04479	0.17416	0.12937	0.15483
1080	27.5	20/4	Vertical	0.01933	0.04479	0.17517	0.13038	0.15584
1090	27.5	20/4	Vertical	0.01933	0.04479	0.17618	0.13139	0.15685
1100	27.5	20/4	Vertical	0.01933	0.04479	0.17719	0.13240	0.15787
1110	27.5	20/4	Vertical	0.01933	0.04479	0.17640	0.13162	0.15708
1120	27.5	20/4	Vertical	0.01933	0.04479	0.17730	0.13252	0.15798
1128	27.5	20/4	Vertical	0.01933	0.04479	0.17820	0.13341	0.15888
1140	27.5	20/4	Vertical	0.01933	0.04479	0.17978	0.13499	0.16045
1150	27.5	20/4	Vertical	0.01933	0.04479	0.18034	0.13555	0.16101
1160	27.5	20/4	Vertical	0.01933	0.04479	0.18135	0.13656	0.16202
1170	27.5	20/4	Vertical	0.01933	0.04479	0.18146	0.13667	0.16213
1180	27.5	20/4	Vertical	0.01933	0.04479	0.18258	0.13780	0.16326
1190	27.5	20/4	Vertical	0.01933	0.04479	0.18371	0.13892	0.16438
1200	27.5	20/4	Vertical	0.01933	0.04479	0.18371	0.13892	0.16438
1210	27.5	20/4	Vertical	0.01933	0.04479	0.18708	0.14229	0.16775
1220	27.5	20/4	Vertical	0.01933	0.04479	0.18899	0.14420	0.16966

* Use of the reaction mass as a reference for calculating relative travel times exhibited less scatter than using the reference receiver.

Section 4: Unfiltered P-Wave Records at Lower Receiver

Section 4 includes all unfiltered P-wave records at the lower vertical receiver.

1. Figure 4.1 presents unfiltered lower vertical receiver (P-wave) signals in Borehole C4997, depths 390 to 490 ft; input signal: 5 cycles of 50-Hz sine wave.
2. Figures 4.2 through 4.7 present unfiltered lower vertical receiver (P-wave) signals in Borehole C4997, depths 495 to 1080 ft; input signal: 10 cycles of 50-Hz sine wave.
3. Figures 4.8 through 4.9 present unfiltered lower vertical receiver (P-wave) signals in Borehole C4997, depths 970 to 1220 ft; input signal: 4 cycles of 20-Hz sine wave.

Figure 4.1 Unfiltered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 390 to 490 ft; Input Signal: 5 Cycles of 50-Hz Sine Wave

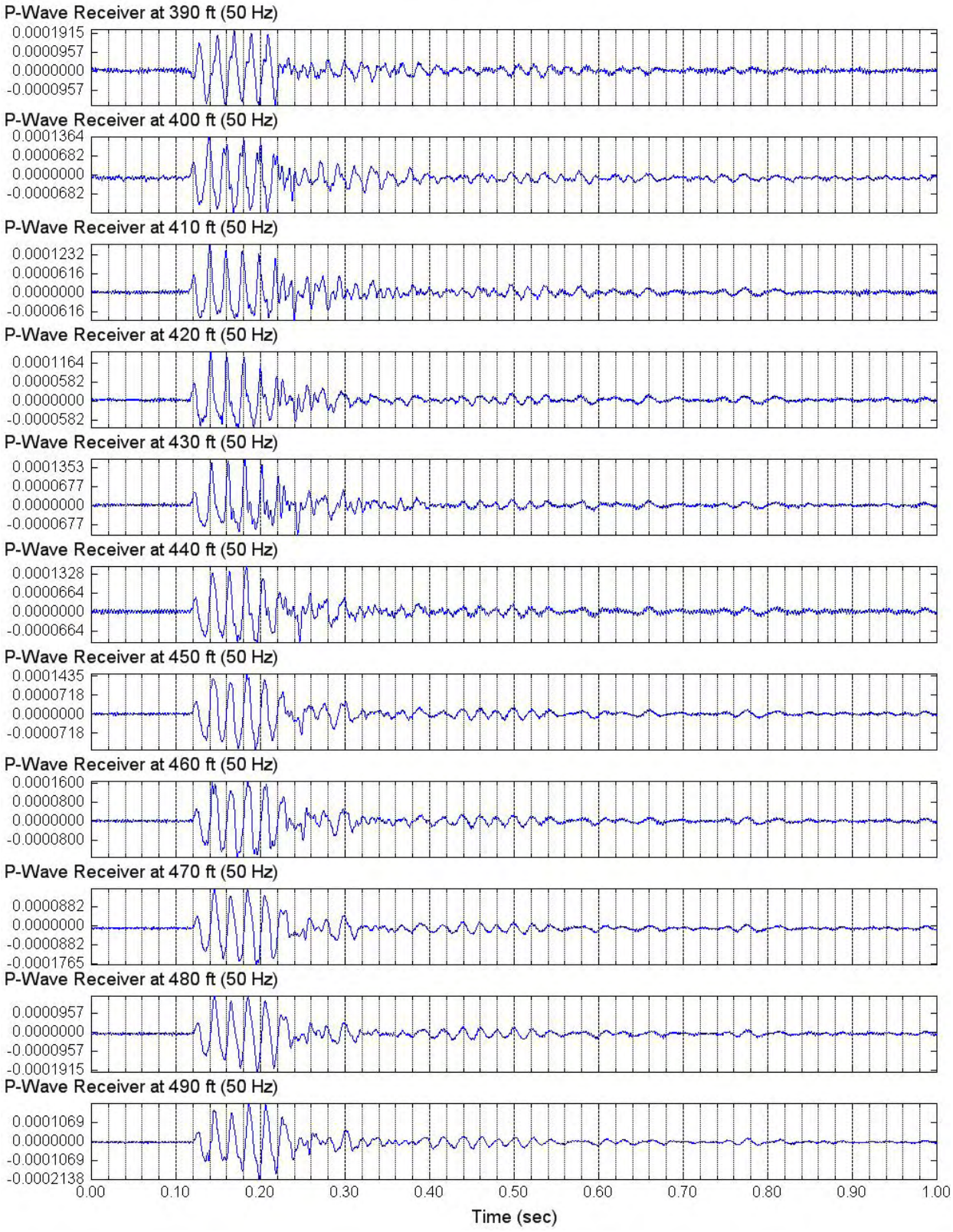


Figure 4.2 Unfiltered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 495 to 560 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave

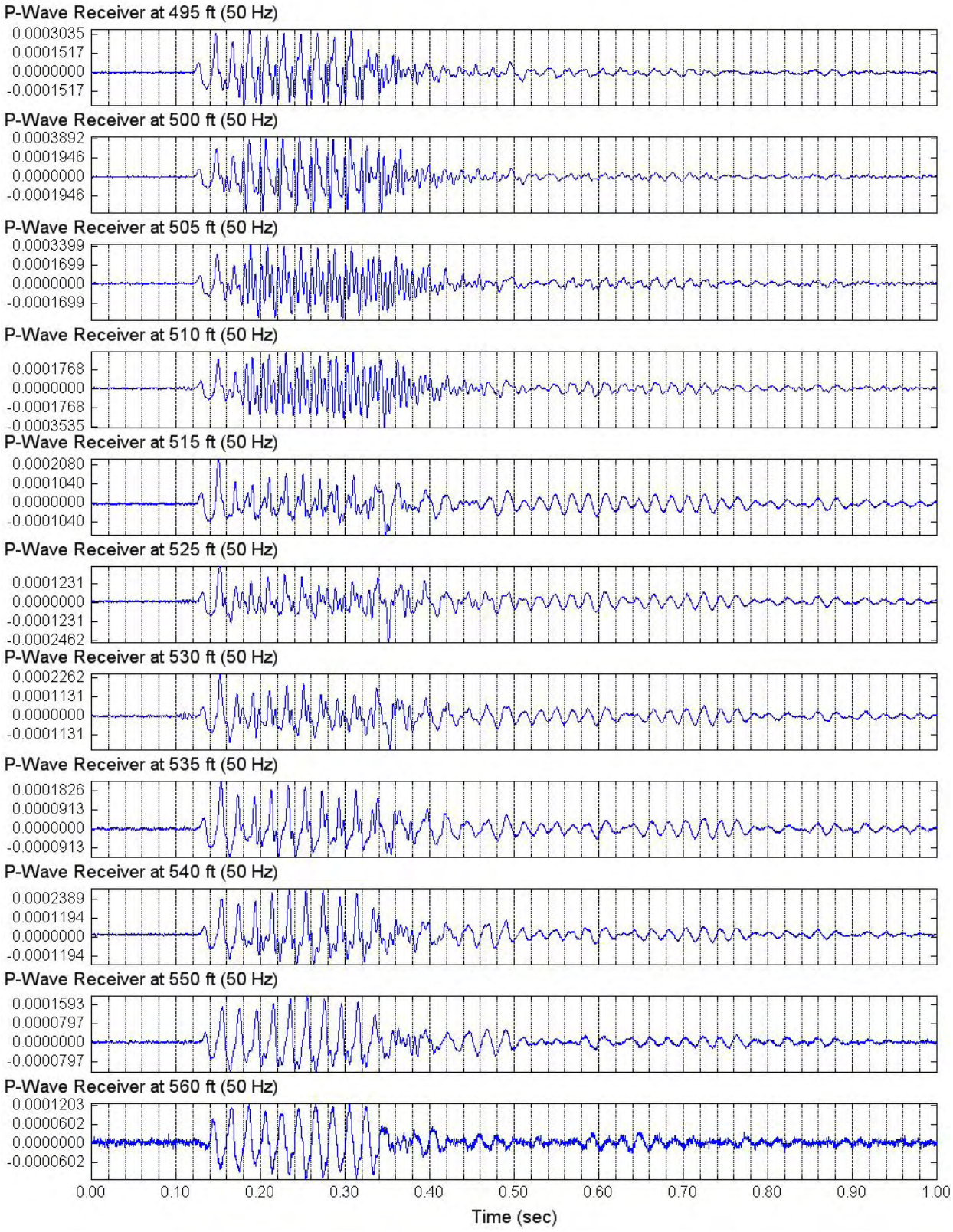


Figure 4.3 Unfiltered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 570 to 670 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave

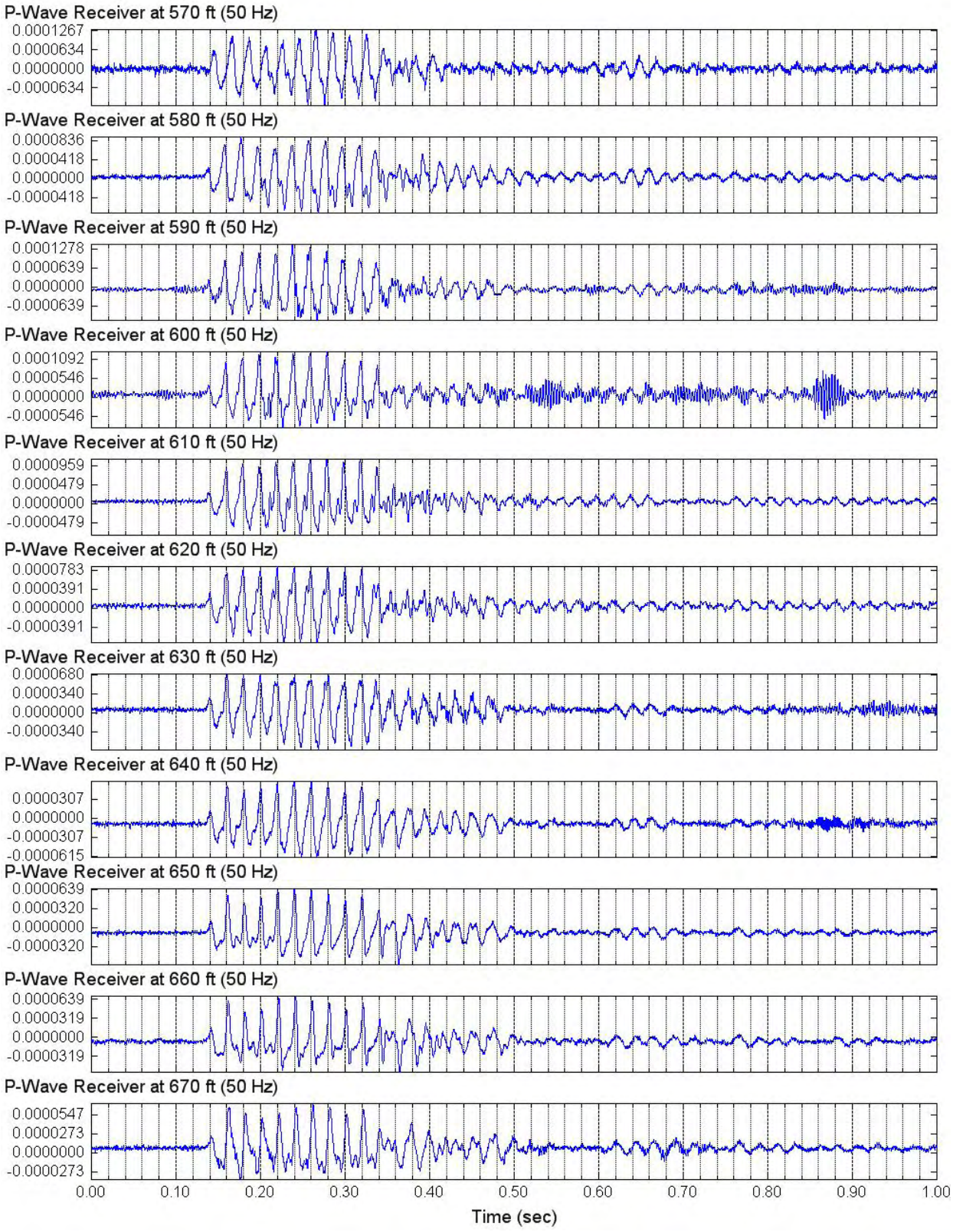


Figure 4.4 Unfiltered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 680 to 770 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave

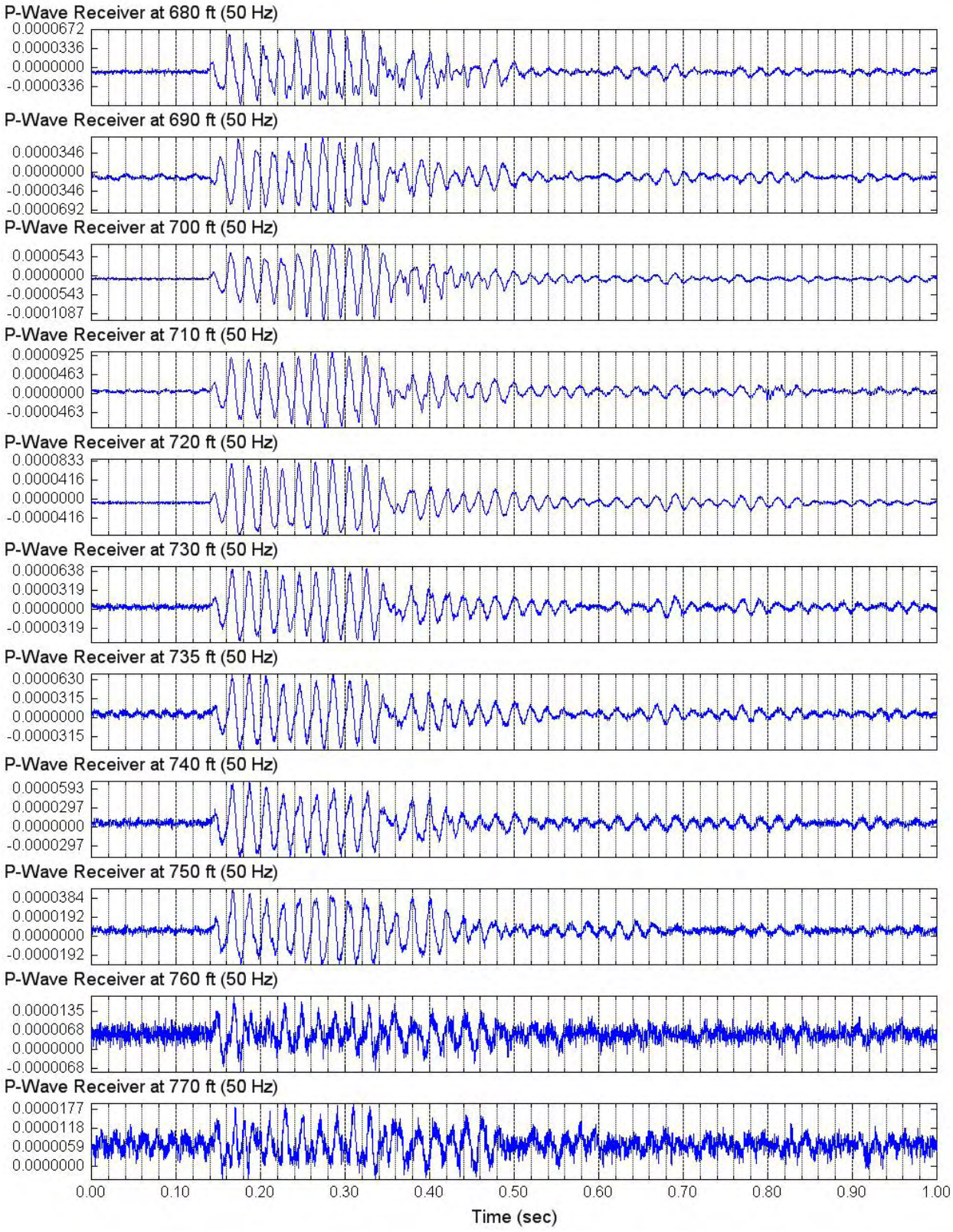


Figure 4.5 Unfiltered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 780 to 865 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave

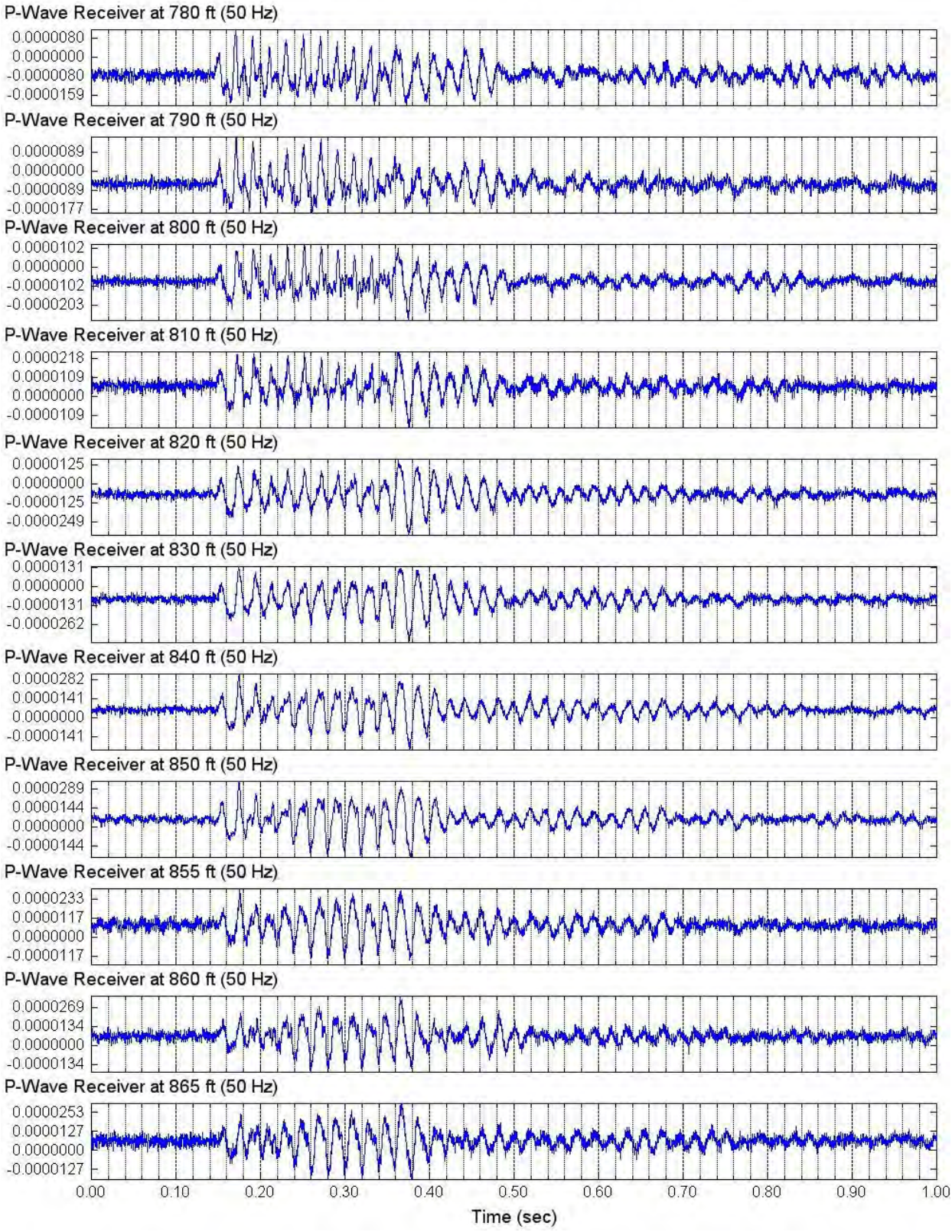


Figure 4.6 Unfiltered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 870 to 970 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave

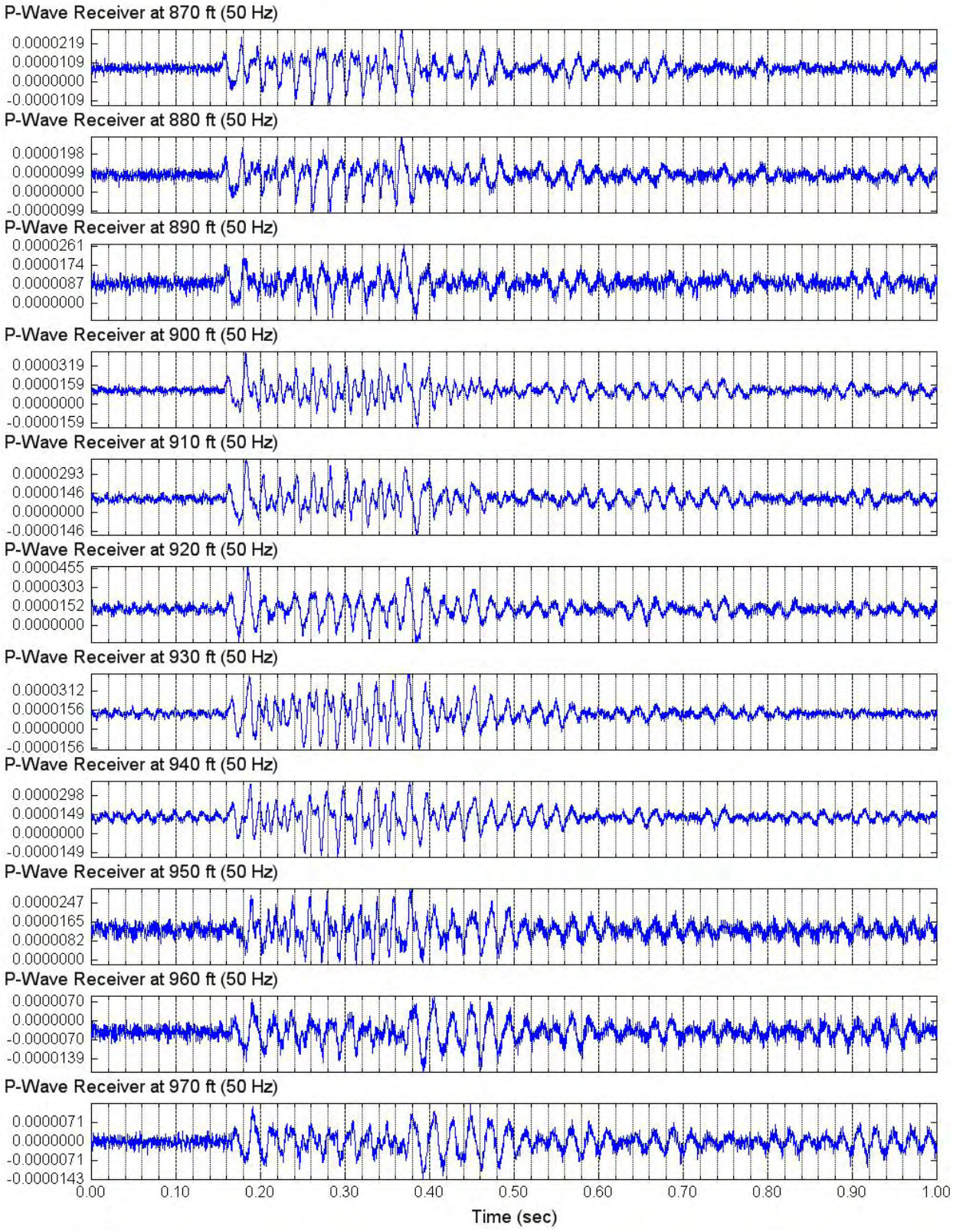


Figure 4.7 Unfiltered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 980 to 1080 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave

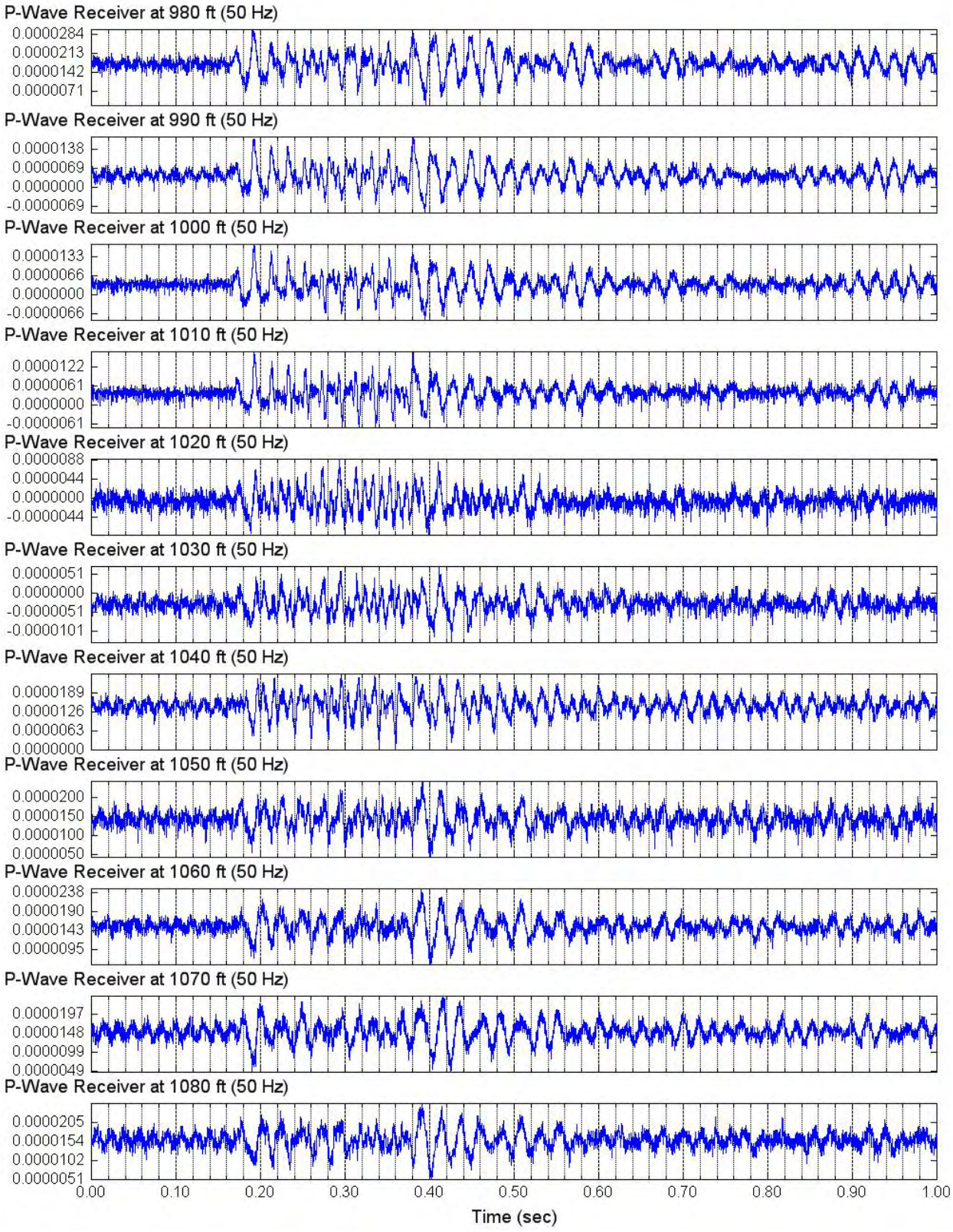


Figure 4.8 Unfiltered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 970 to 1110 ft; Input Signal: 4 Cycles of 20-Hz Sine Wave

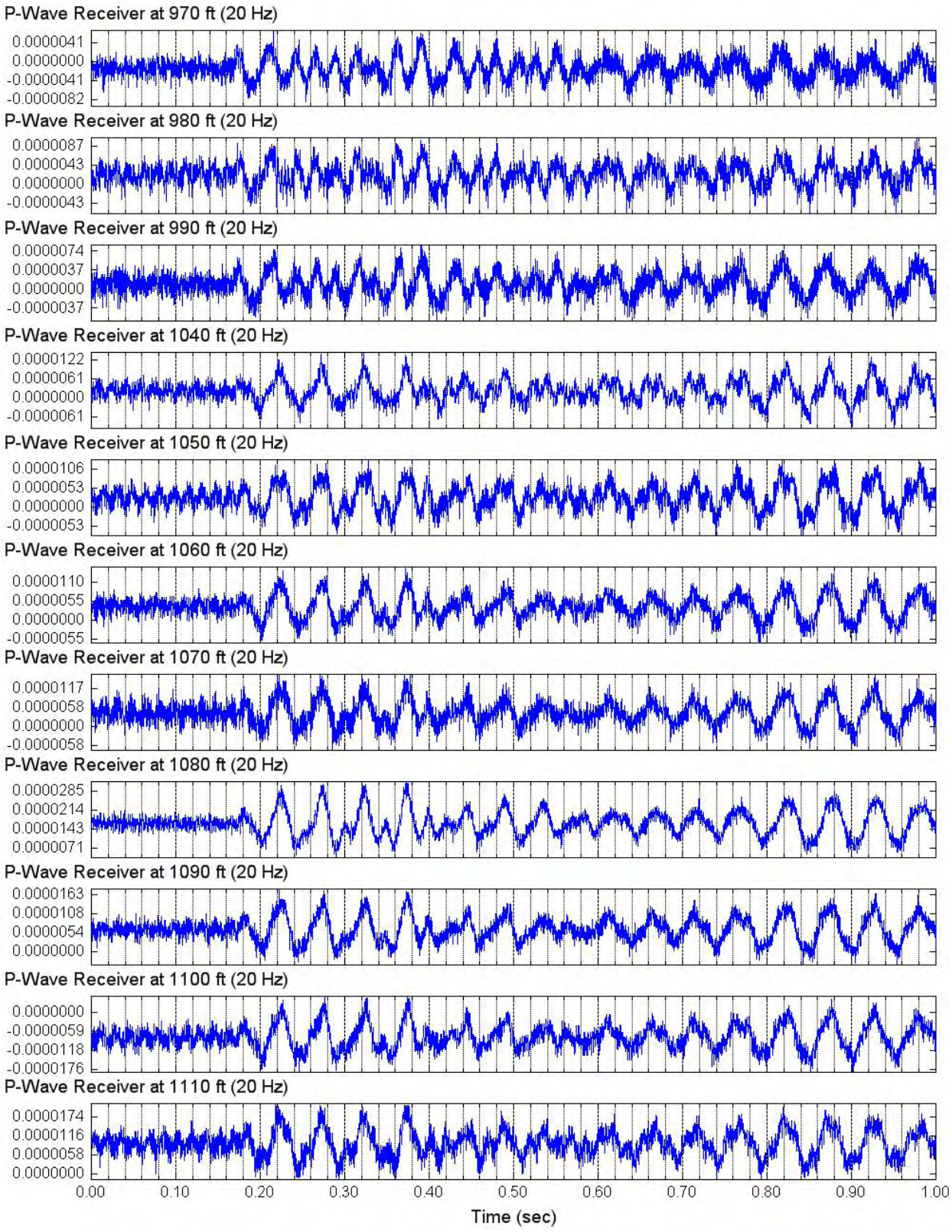
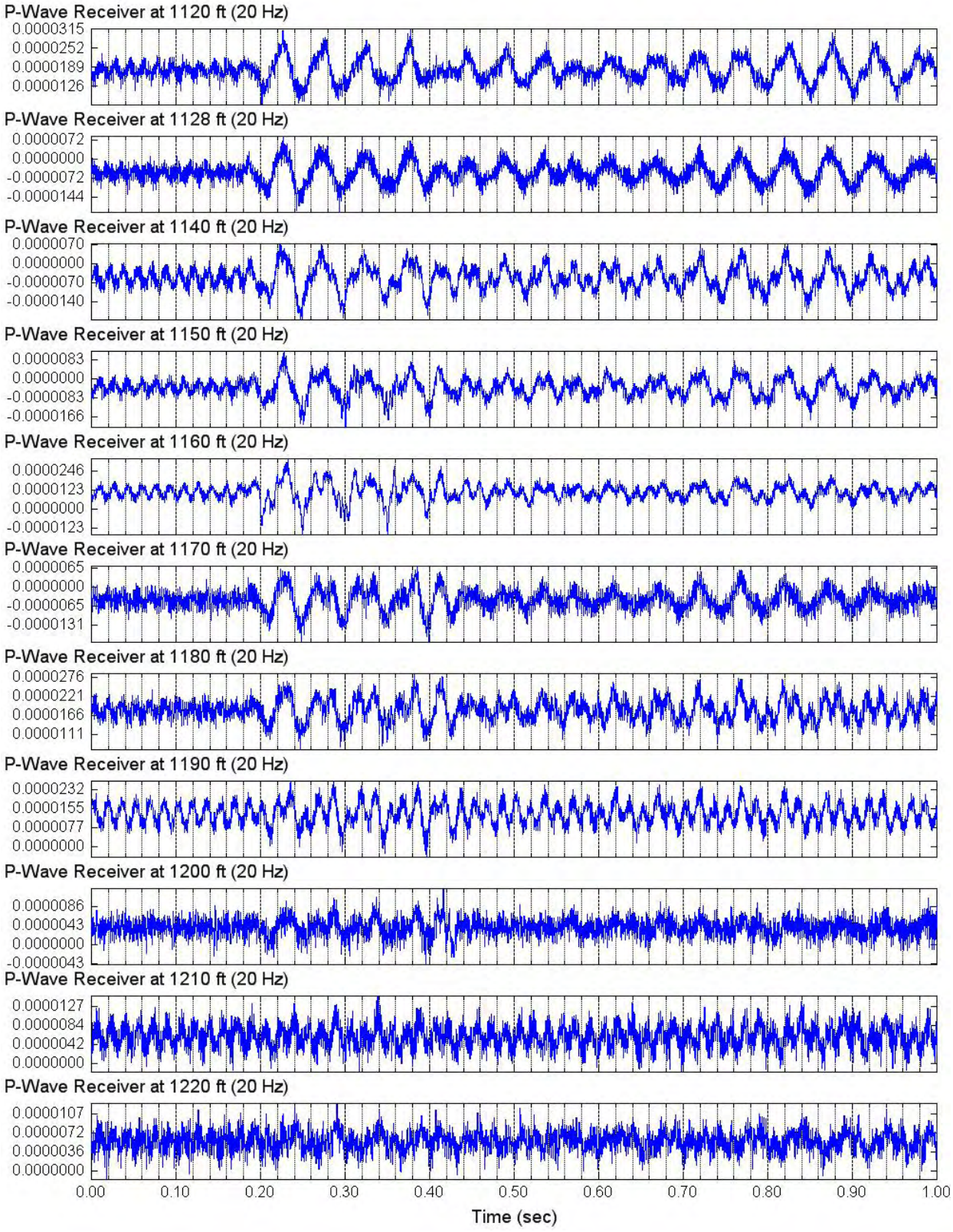


Figure 4.9 Unfiltered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 1120 to 1220 ft; Input Signal: 4 Cycles of 20-Hz Sine Wave



Section 5: Unfiltered P-Wave Records of Reaction Mass

Section 5 includes all unfiltered P-wave signals of the reaction mass accelerometer.

1. Figure 5.1 presents unfiltered reaction mass vertical (P-wave) acceleration at Borehole C4997, depths 390 to 490 ft; input signal: 5 cycles of 50-Hz sine wave.
2. Figures 5.2 to 5.7 present unfiltered reaction mass vertical (P-wave) acceleration at Borehole C4997, depths 495 to 1080 ft; input signal: 10 cycles of 50-Hz sine wave.
3. Figures 5.8 to 5.9 present unfiltered reaction mass vertical (P-wave) acceleration at Borehole C4997, depths 970 to 1220 ft; input signal: 4 cycles of 20-Hz sine wave.

Figure 5.1 Unfiltered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 390 to 490 ft; Input Signal: 5 Cycles of 50-Hz Sine Wave

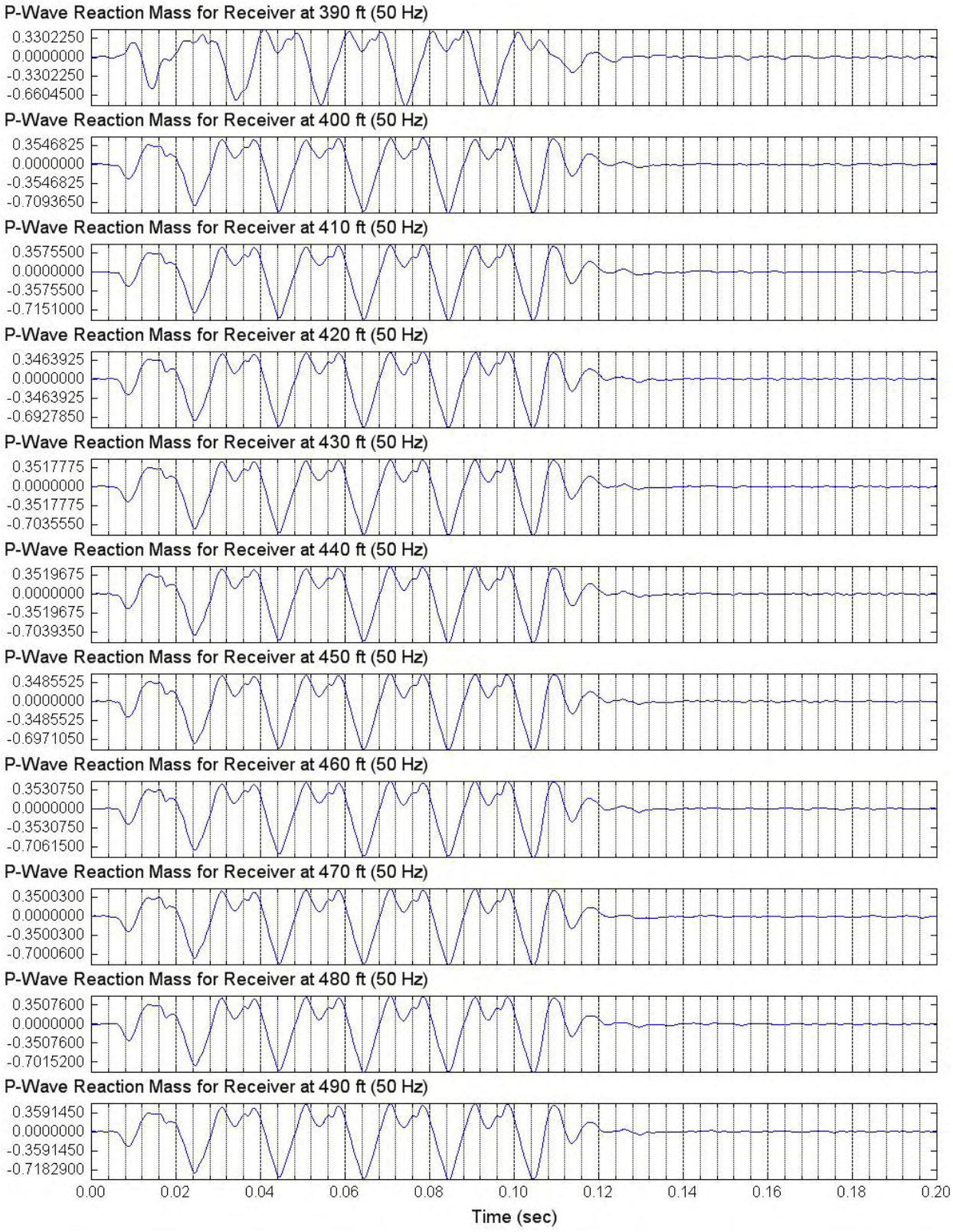


Figure 5.2 Unfiltered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 495 to 560 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave

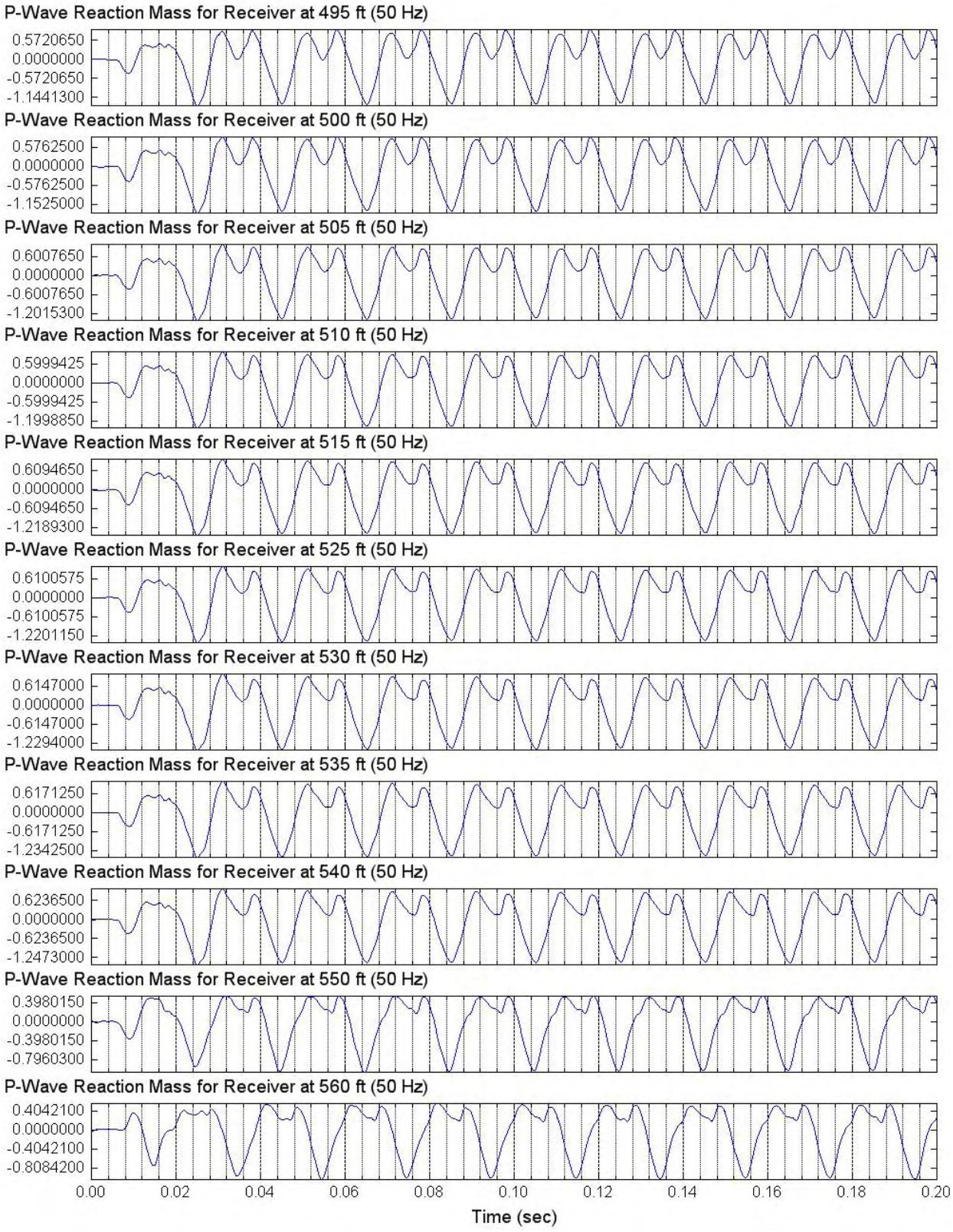


Figure 5.3 Unfiltered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 570 to 670 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave

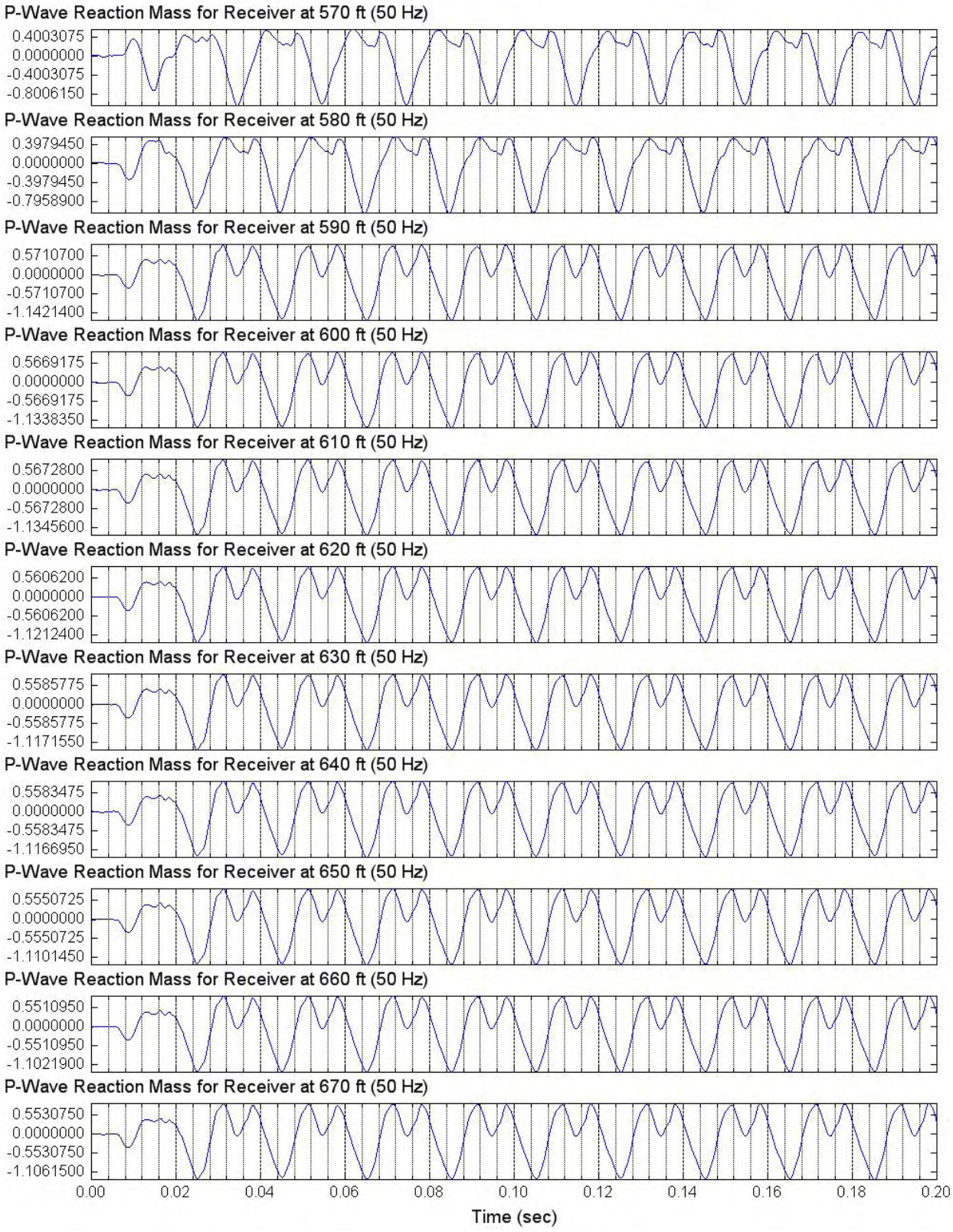


Figure 5.4 Unfiltered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 680 to 770 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave

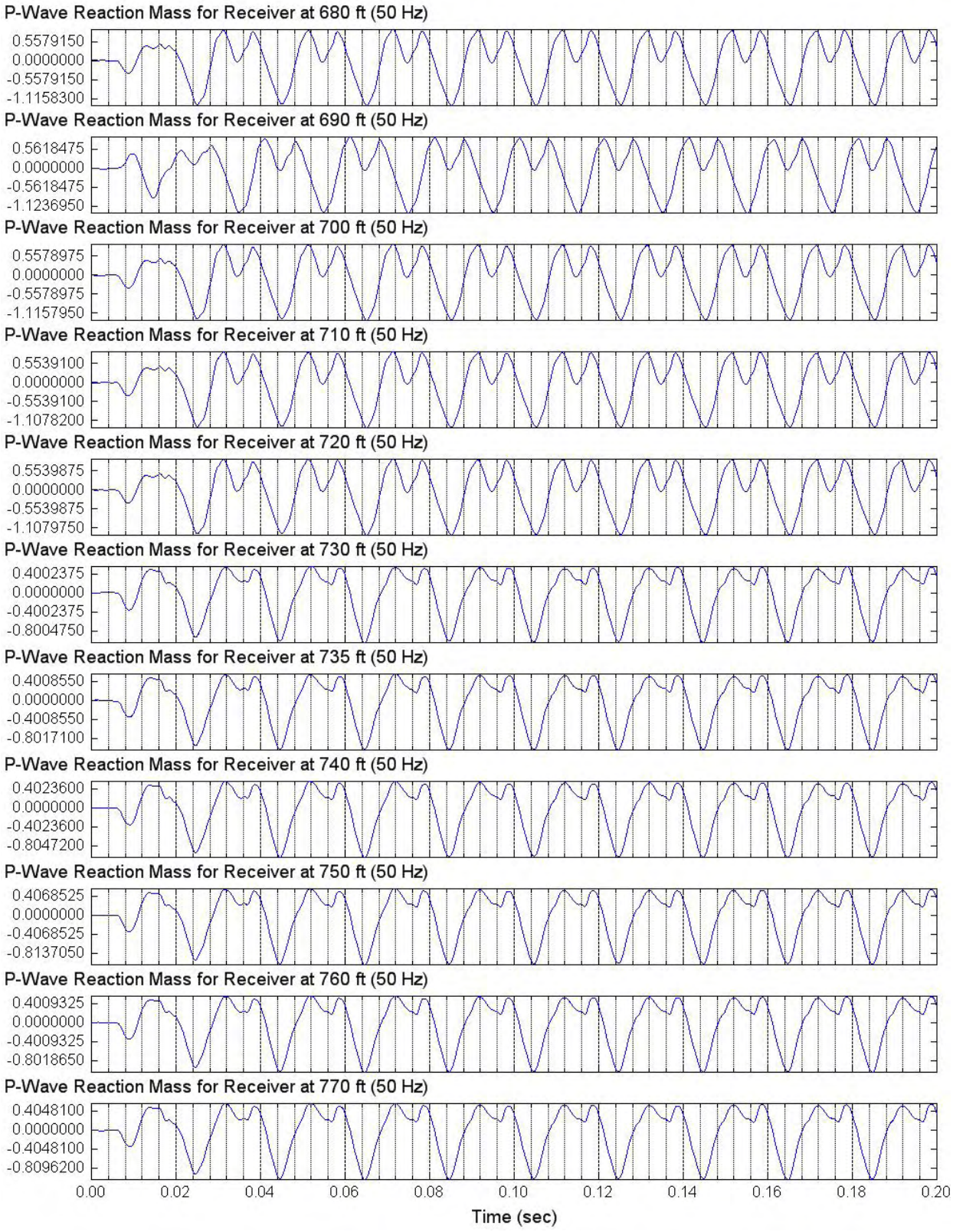


Figure 5.5 Unfiltered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 780 to 865 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave

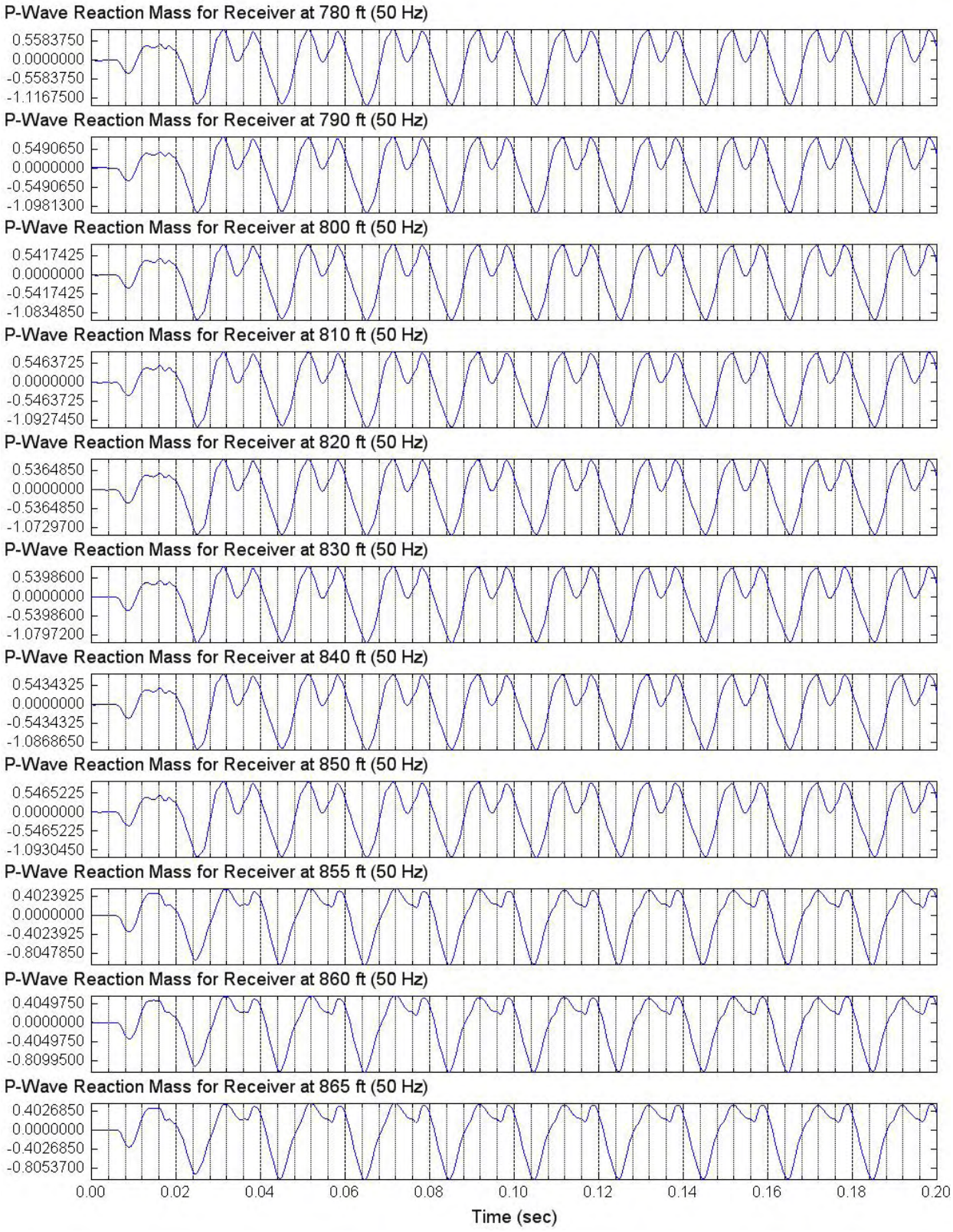


Figure 5.6 Unfiltered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 870 to 970 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave

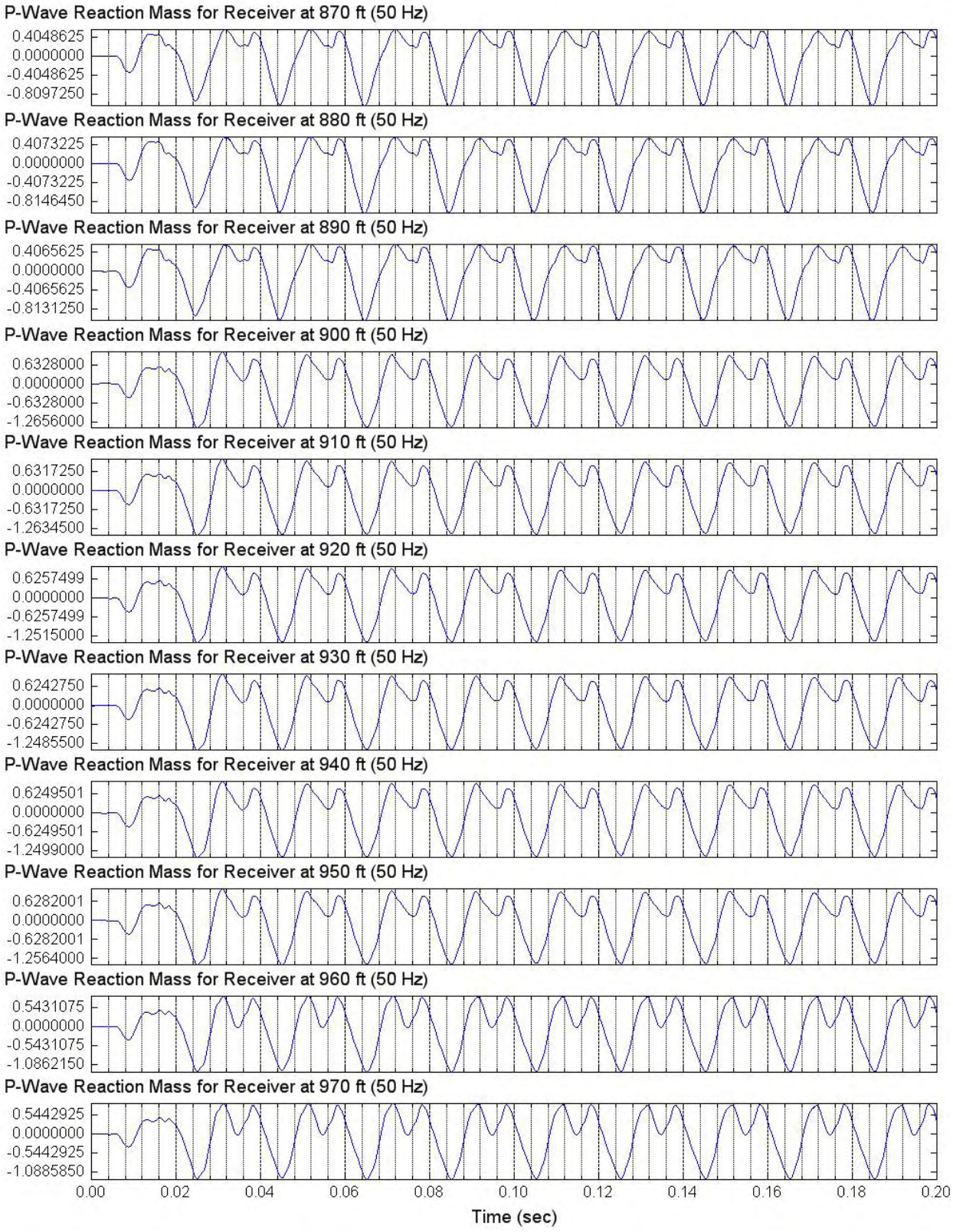


Figure 5.7 Unfiltered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 980 to 1080 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave

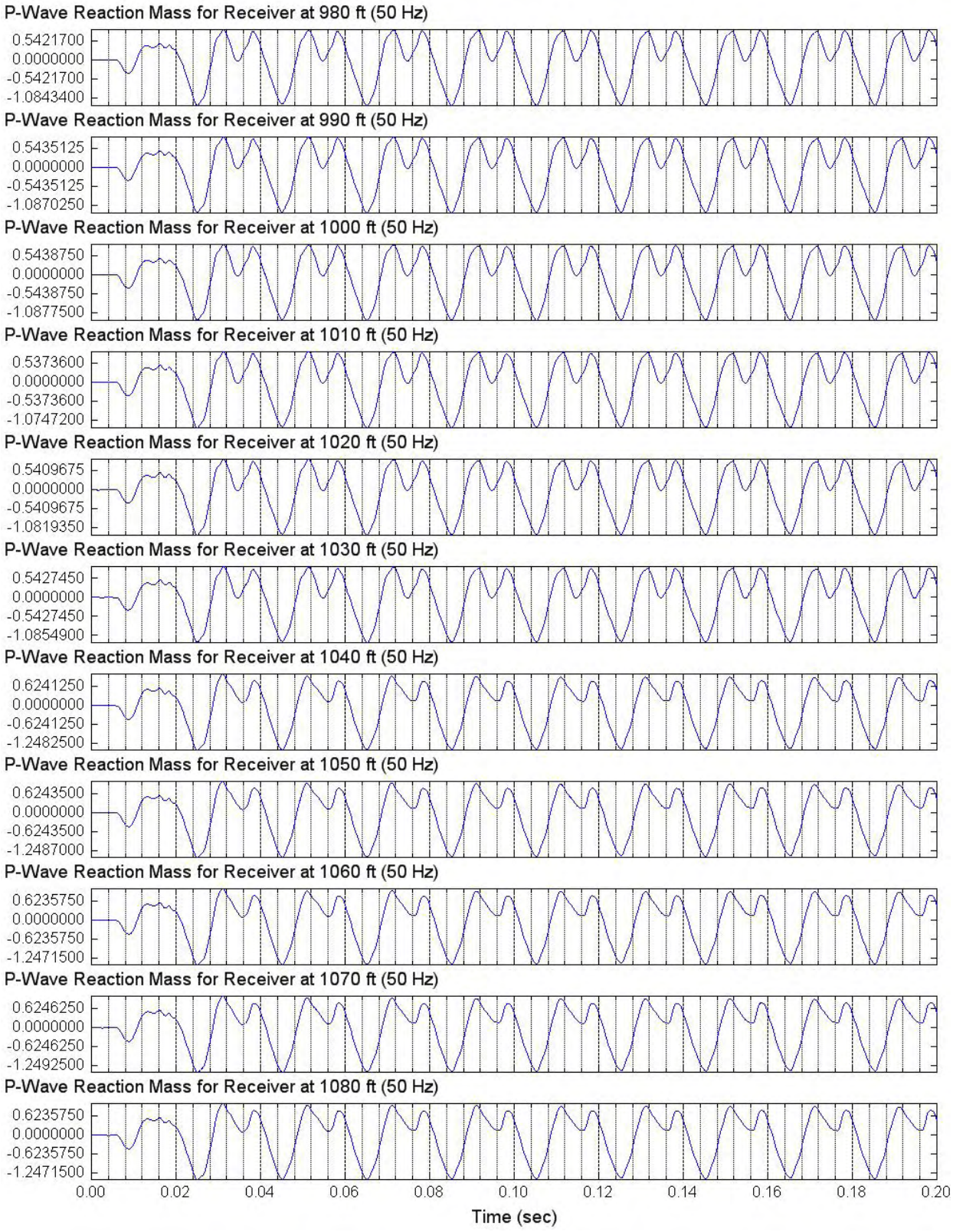


Figure 5.8 Unfiltered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 970 to 1110 ft; Input Signal: 4 Cycles of 20-Hz Sine Wave

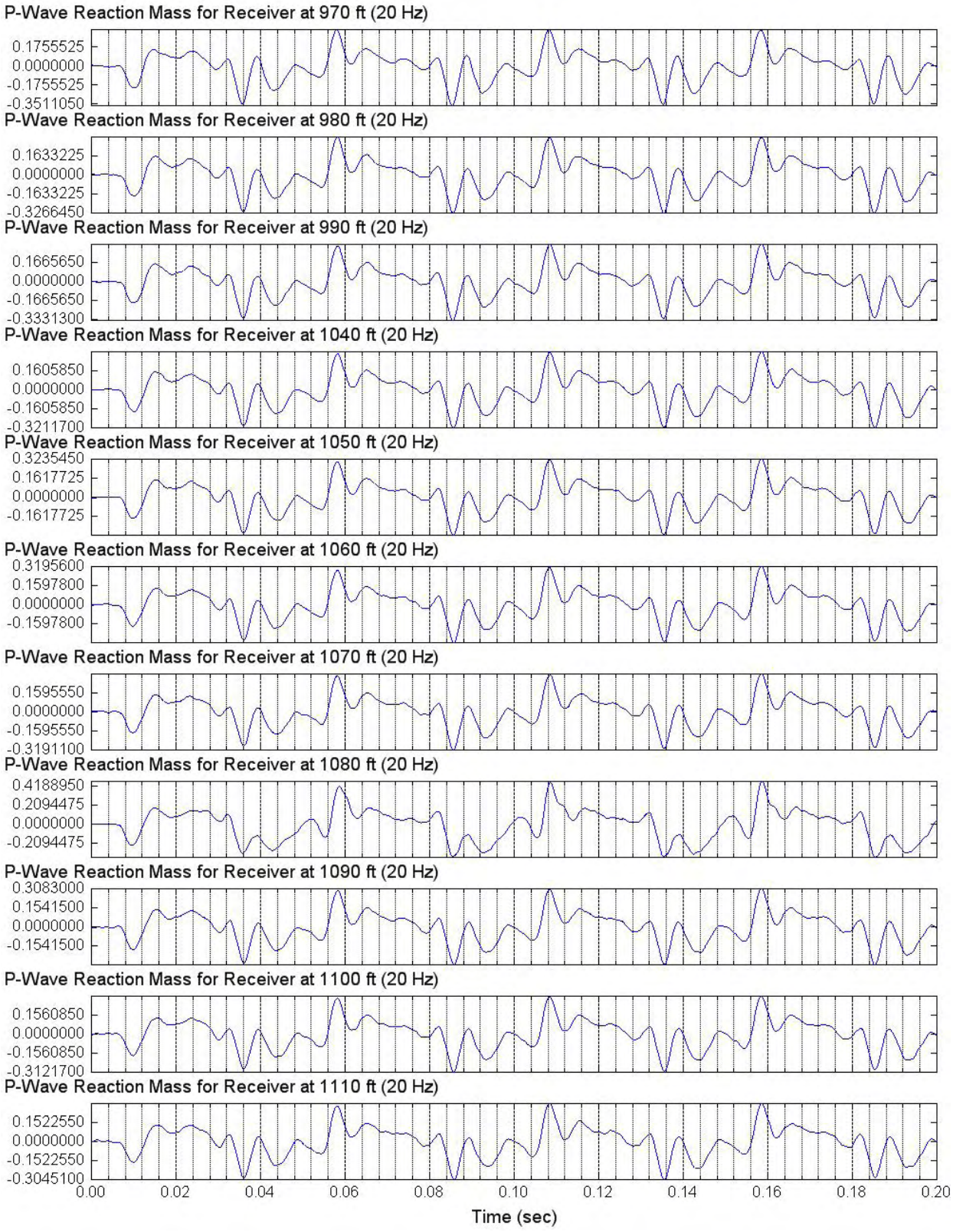
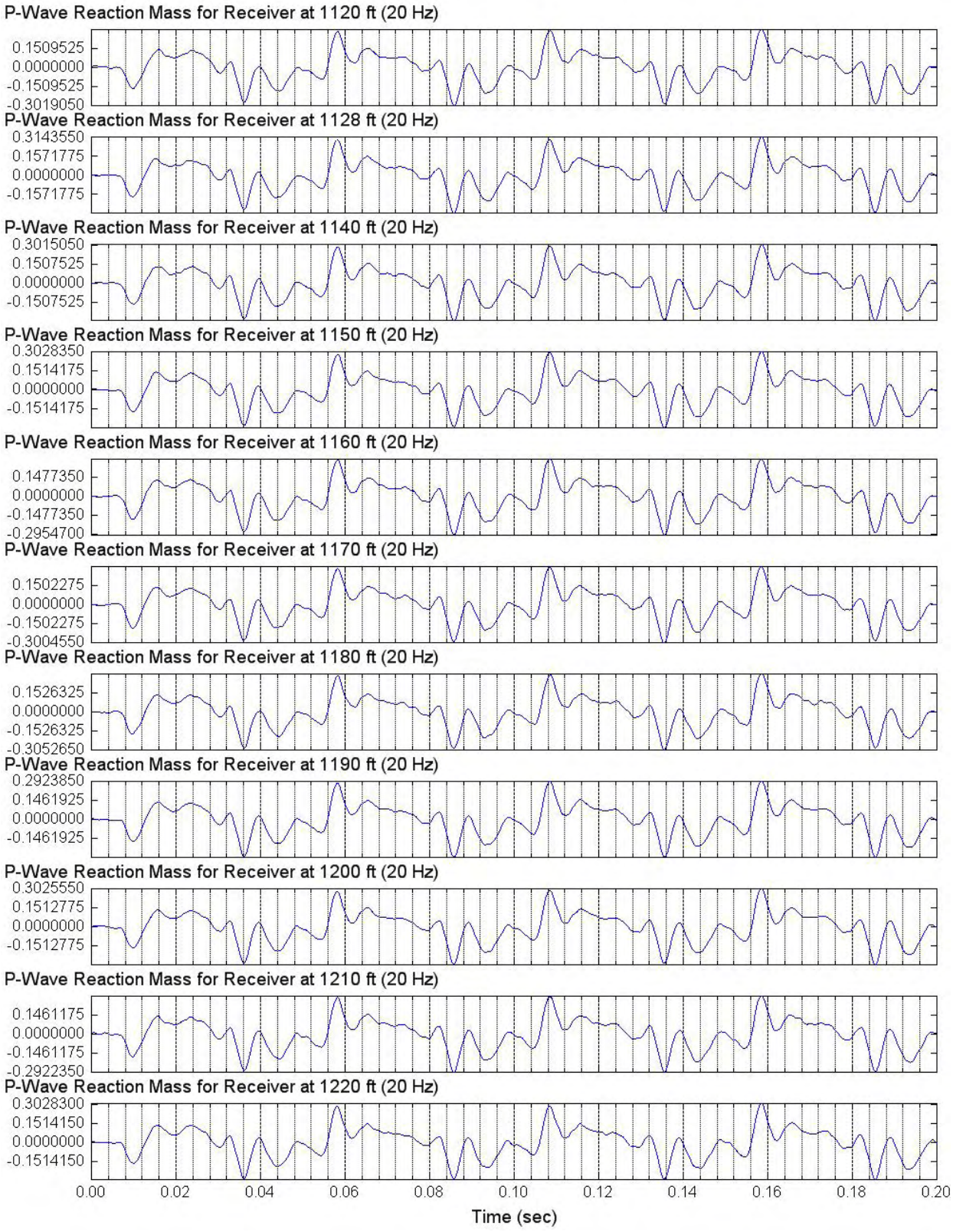


Figure 5.9 Unfiltered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 1120 to 1220 ft; Input Signal: 4 Cycles of 20-Hz Sine Wave



Section 6: Unfiltered P-Wave Records of Reference Receiver

Section 6 includes all unfiltered P-wave signals at the reference receiver.

1. Figure 6.1 presents unfiltered reference vertical receiver (P-wave) signals in Borehole C4997, depths 390 to 490 ft; input signal: 5 cycles of 50-Hz sine wave.
2. Figures 6.2 to 6.8 present unfiltered reference vertical receiver (P-wave) signals in Borehole C4997, depths 495 to 1080 ft; input signal: 10 cycles of 50-Hz sine wave.
3. Figures 6.9 to 6.10 present unfiltered reference vertical receiver (P-wave) signals in Borehole C4997, depths 970 to 1220 ft; input signal: 4 cycles of 20-Hz sine wave.

Figure 6.1 Unfiltered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

Lower Receiver Depths 390 to 490 ft; Reference Receiver Depth 40 ft;
Input Signal: 5 Cycles of 50-Hz Sine Wave

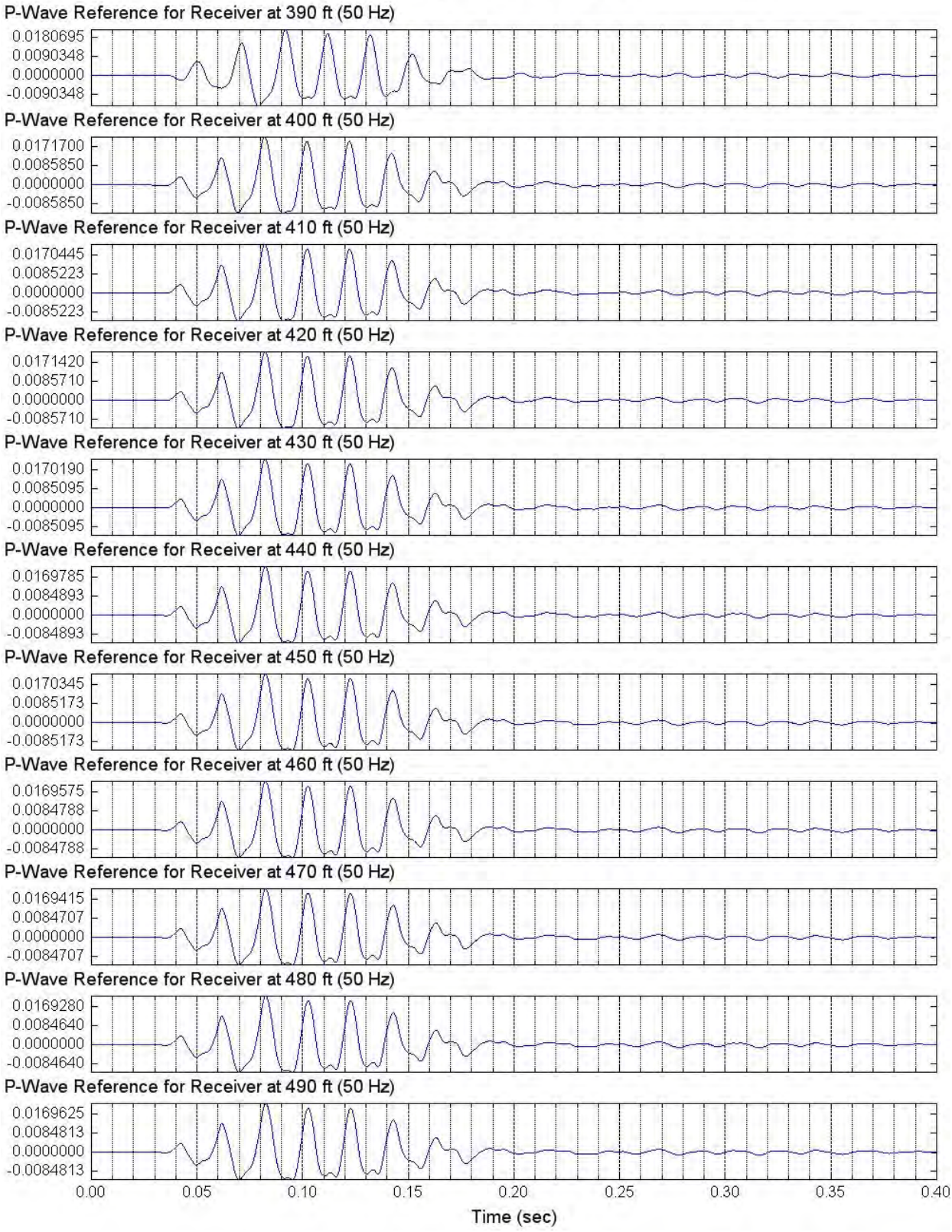


Figure 6.2 Unfiltered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

Lower Receiver Depths 495 to 580 ft; Reference Receiver Depth 27.5 ft;
Input Signal: 10 Cycles of 50-Hz Sine Wave

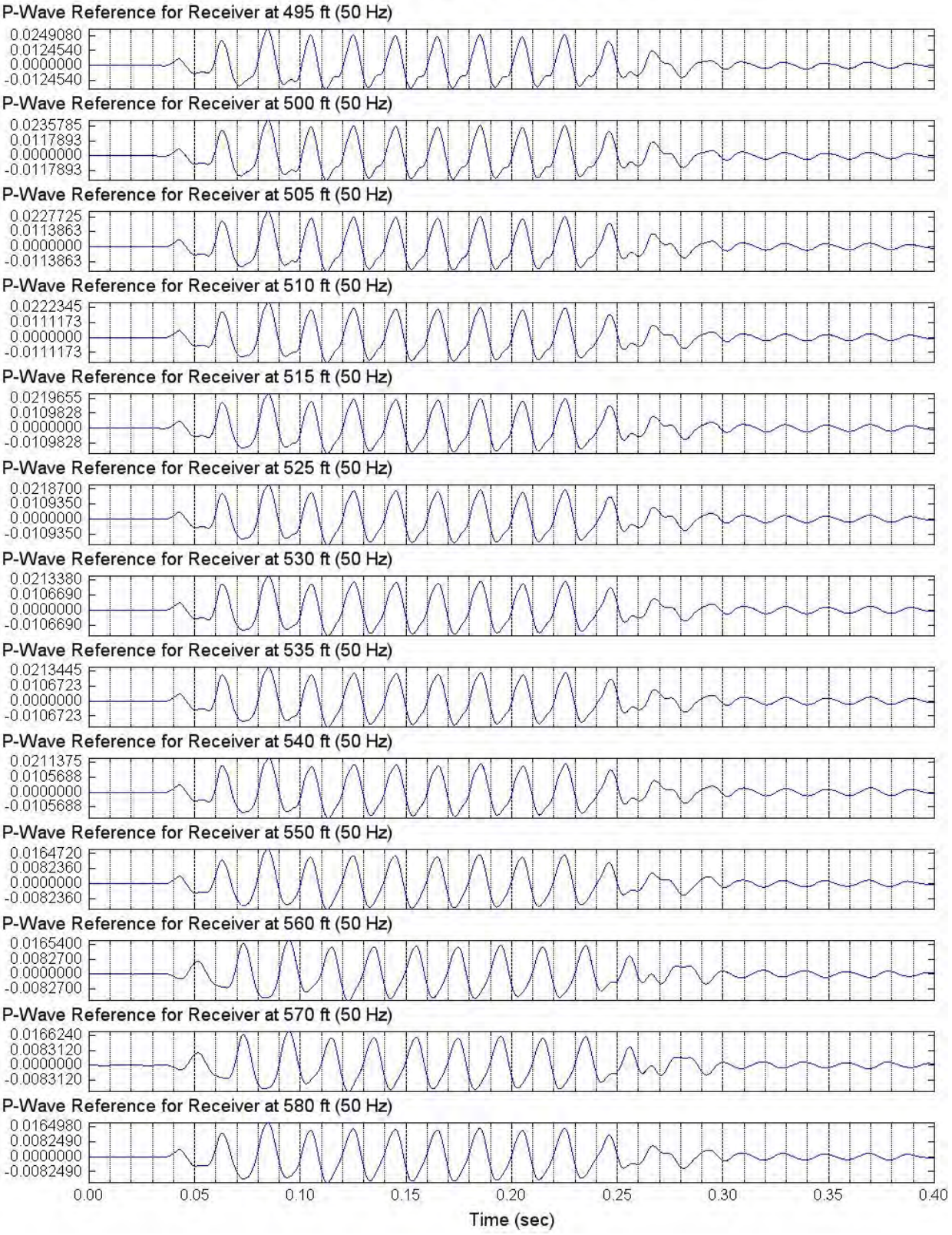


Figure 6.3 Unfiltered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

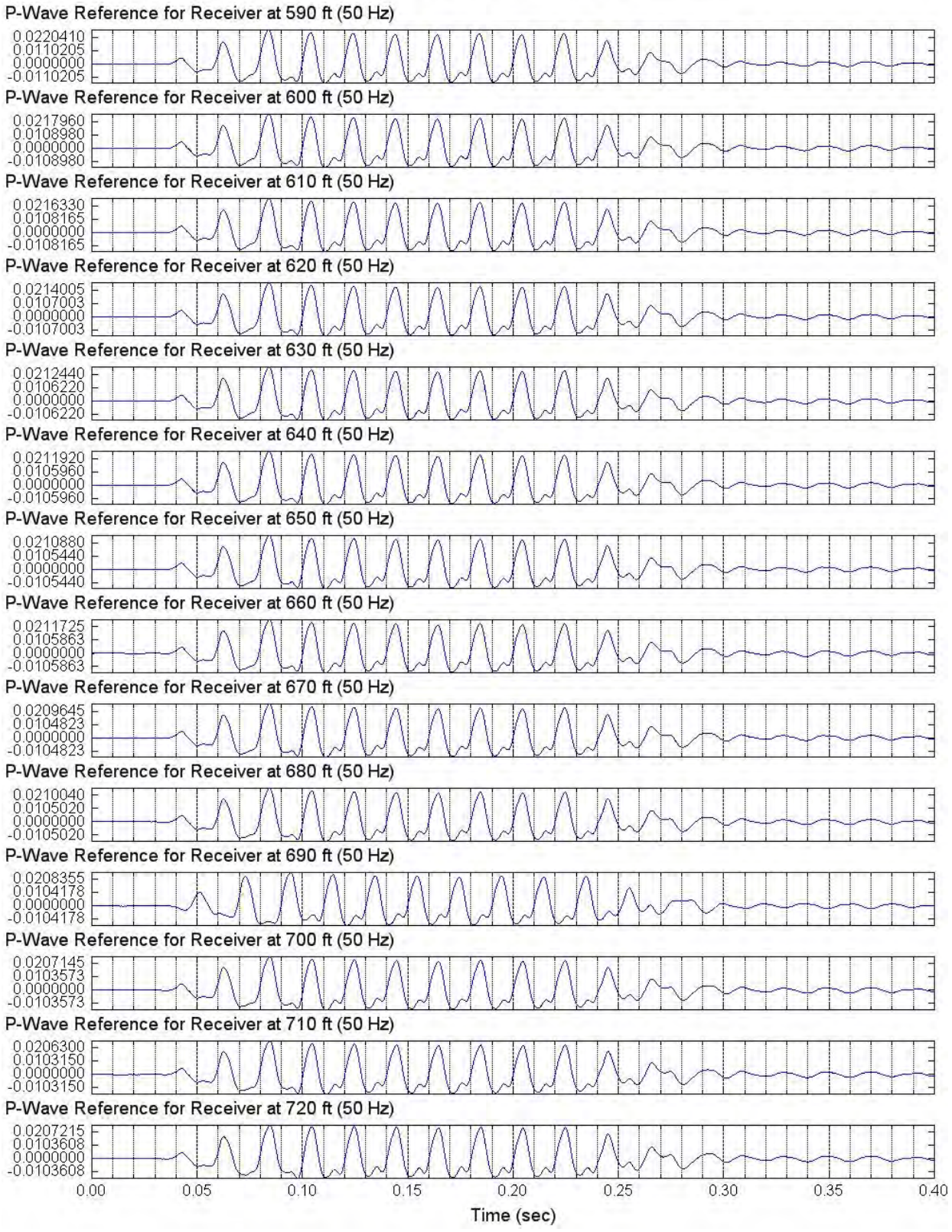


Figure 6.4 Unfiltered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

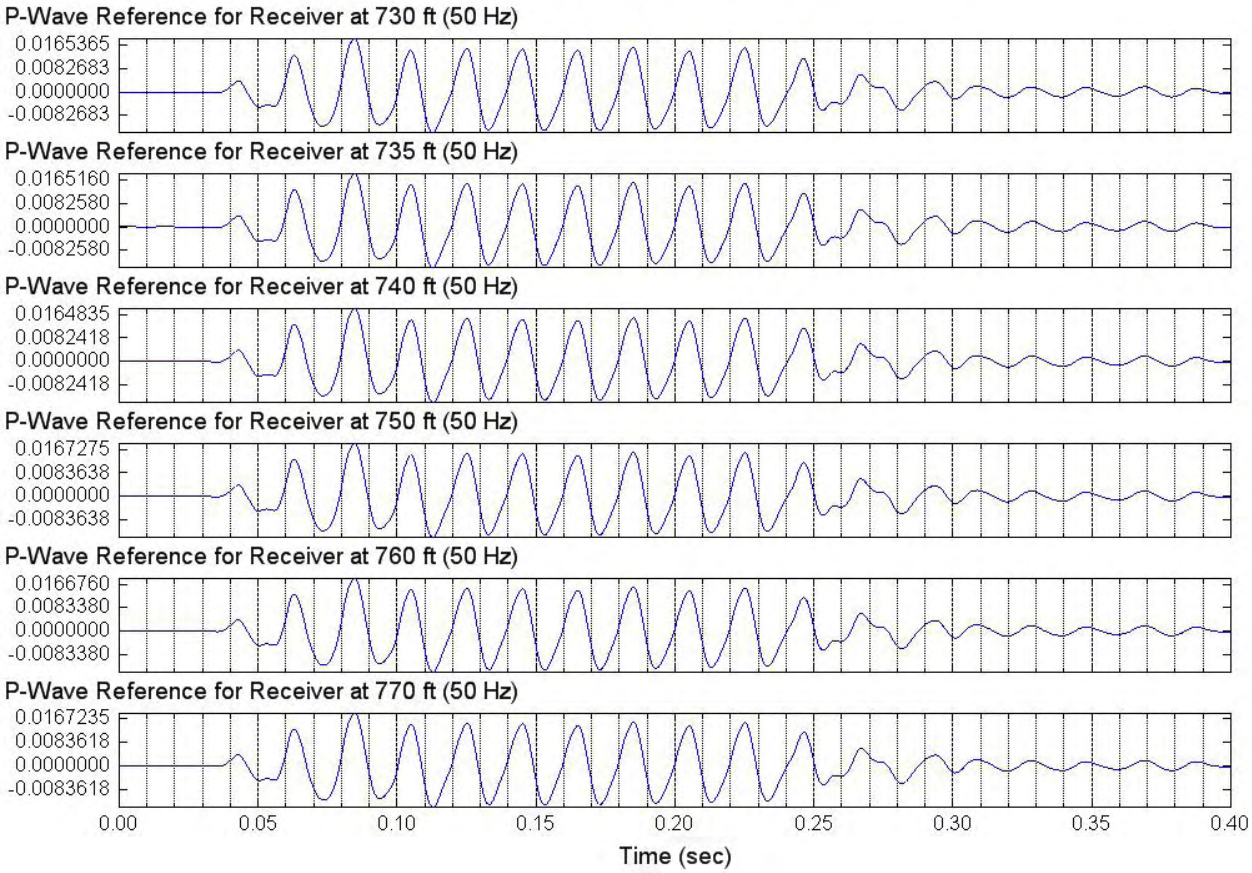


Figure 6.5 Unfiltered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

Lower Receiver Depths 780 to 850 ft; Reference Receiver Depth 40 ft;
Input Signal: 10 Cycles of 50-Hz Sine Wave

Figure 6.6 Unfiltered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

Lower Receiver Depths 855 to 950 ft; Reference Receiver Depth 27.5 ft;
Input Signal: 10 Cycles of 50-Hz Sine Wave

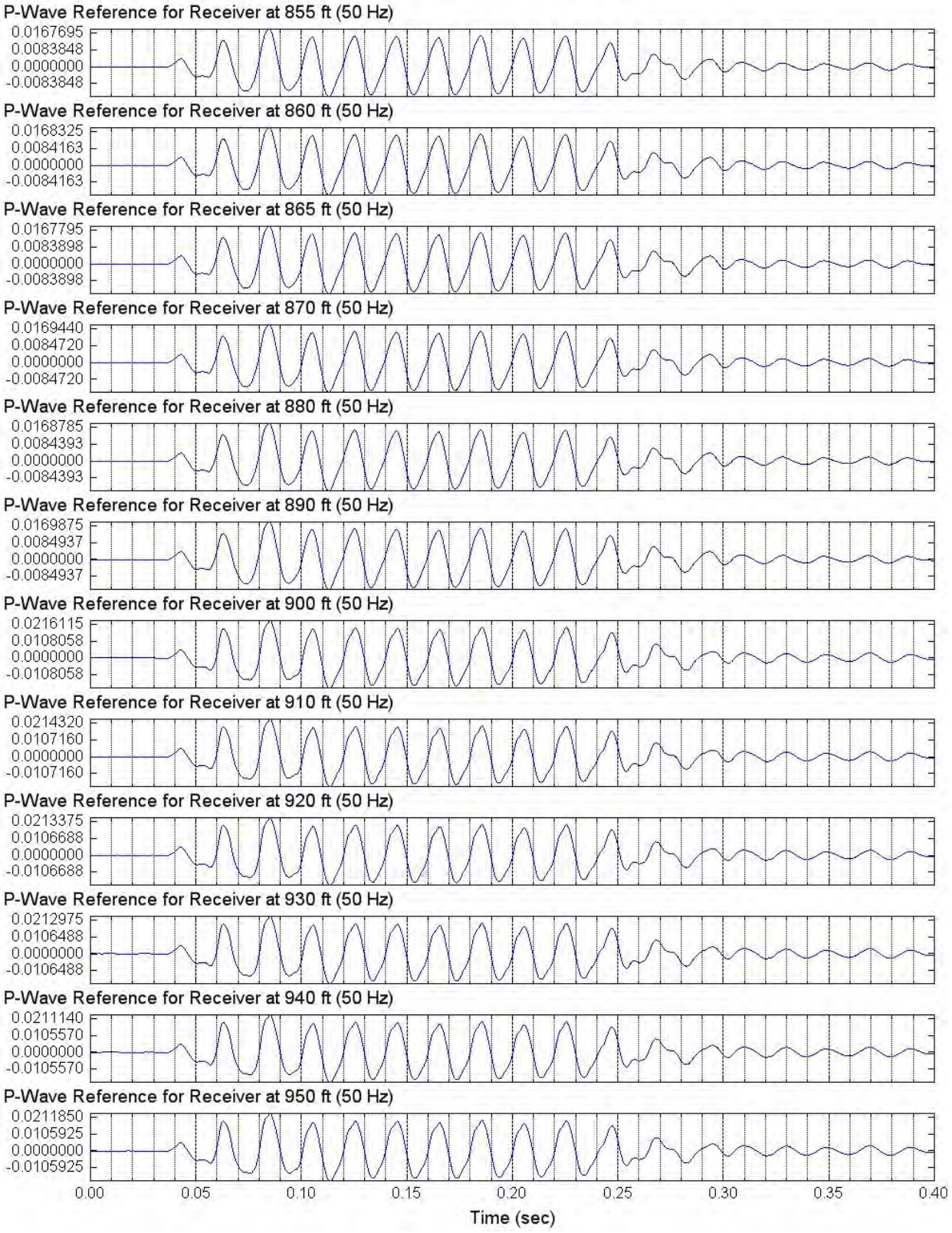


Figure 6.7 Unfiltered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

Lower Receiver Depths 960 to 1030 ft; Reference Receiver Depth 40 ft;
Input Signal: 10 Cycles of 50-Hz Sine Wave

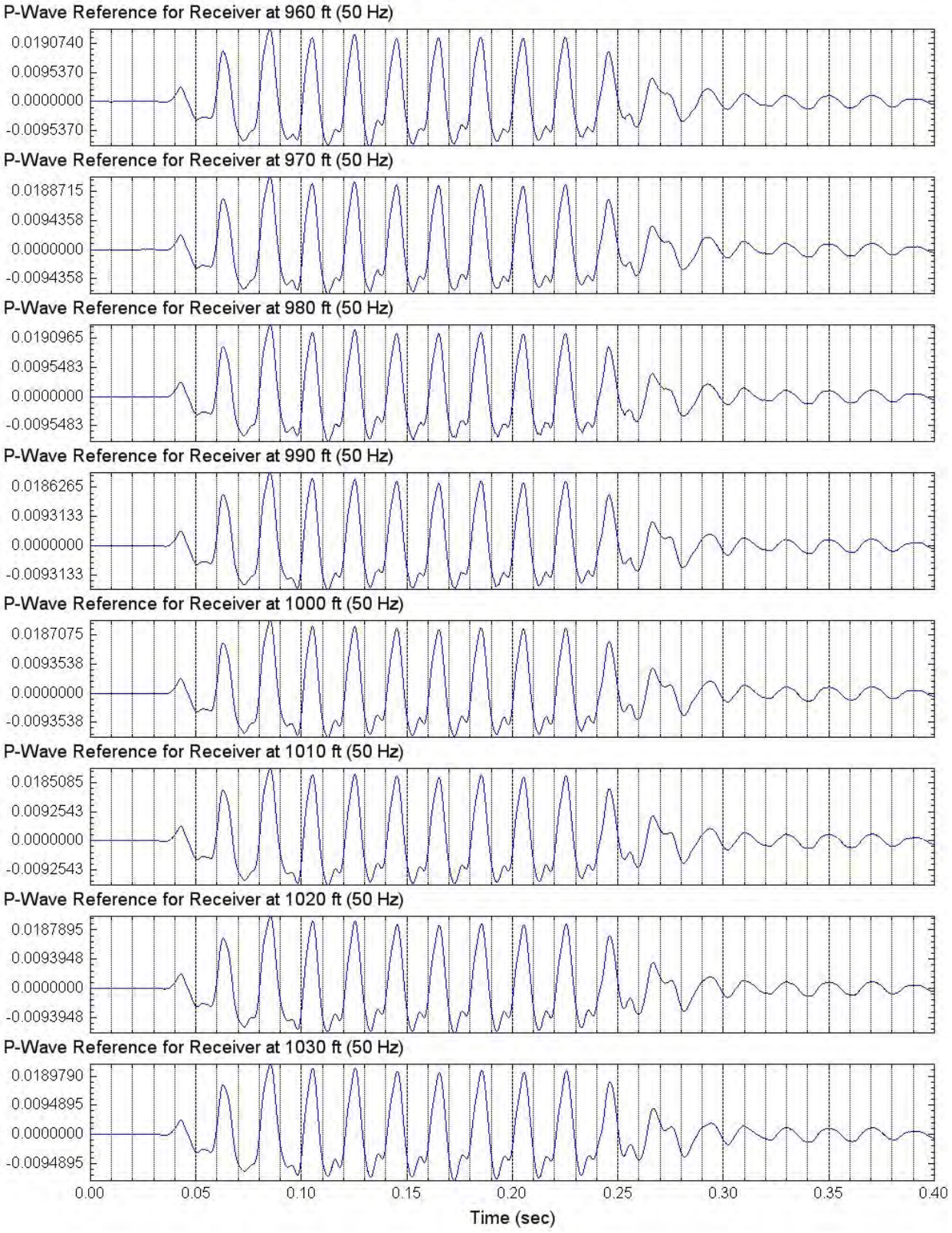


Figure 6.8 Unfiltered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

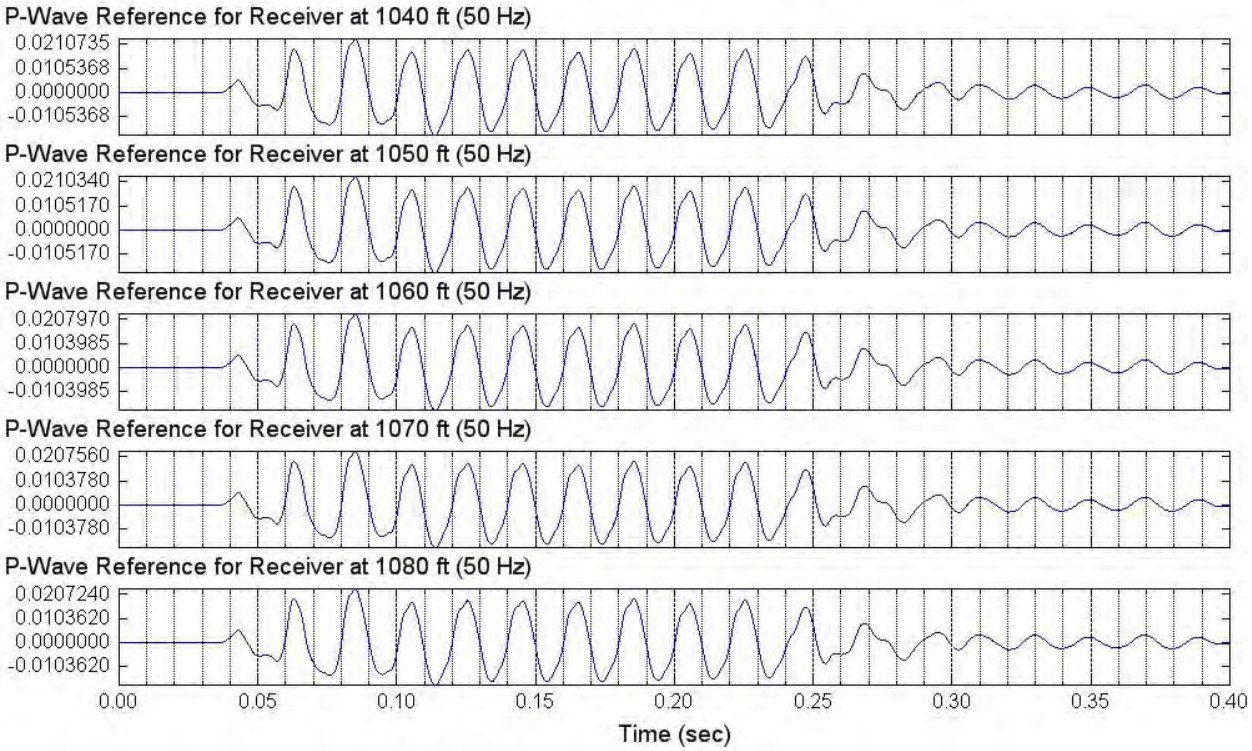


Figure 6.9 Unfiltered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

Lower Receiver Depths 970 to 1110 ft; Reference Receiver Depth 27.5 ft;
Input Signal: 4 Cycles of 20-Hz Sine Wave

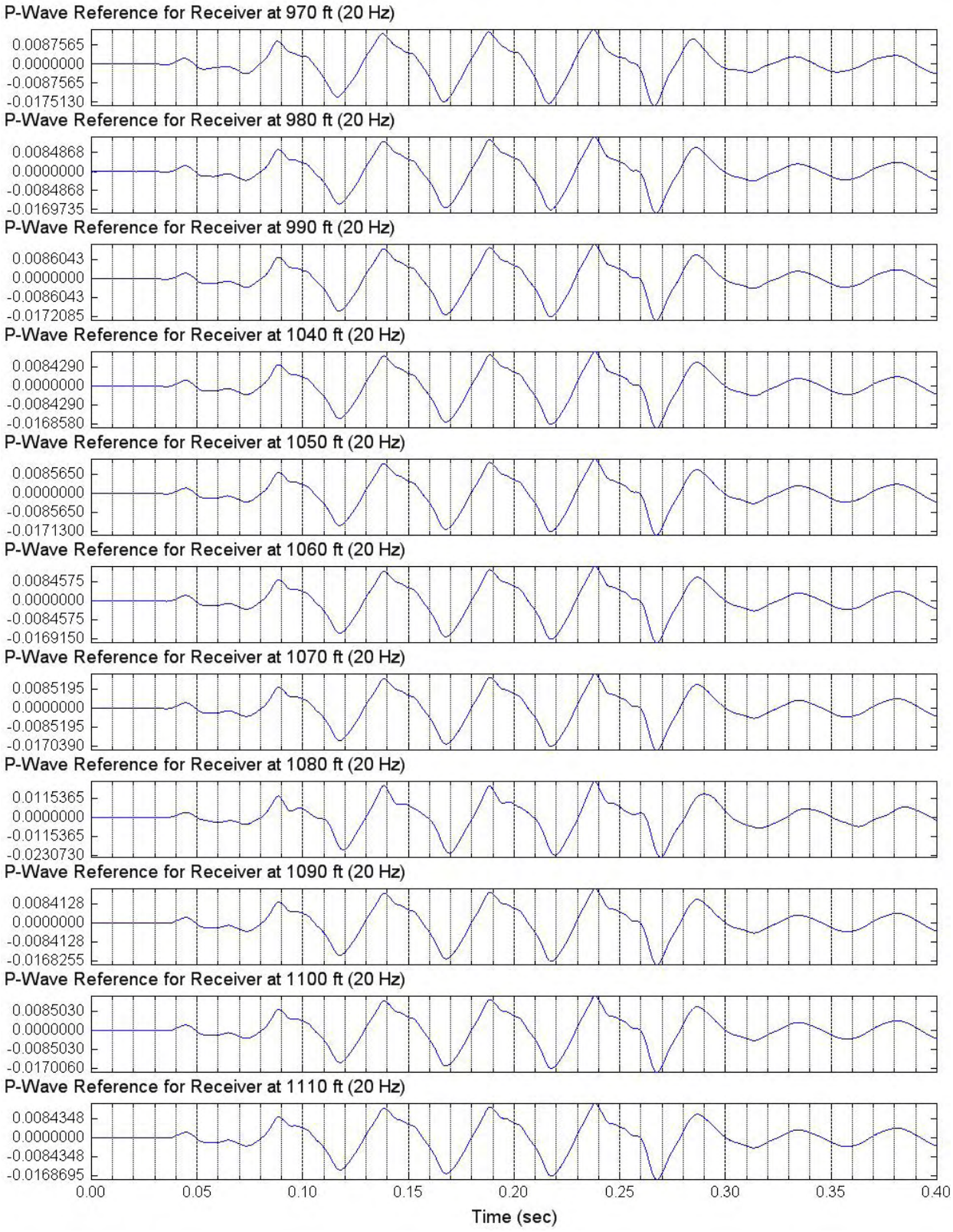
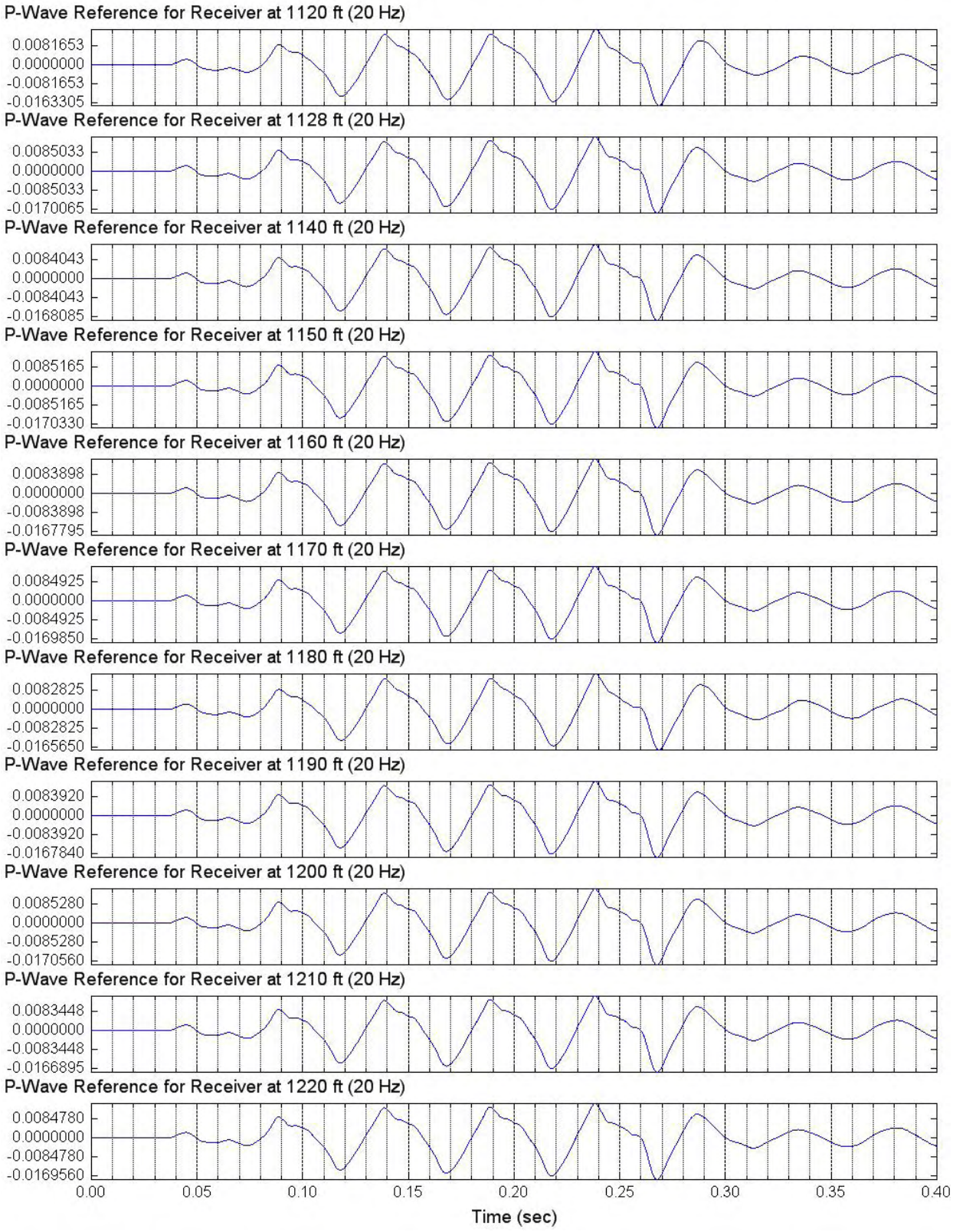


Figure 6.10 Unfiltered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

Lower Receiver Depths 1120 to 1220 ft; Reference Receiver Depth 27.5 ft;
Input Signal: 4 Cycles of 20-Hz Sine Wave



Section 7: Filtered P-Wave Signals of Lower Vertical Receiver

Section 7 includes all filtered P-wave signals at the lower vertical receiver.

1. Figure 7.1 presents filtered lower vertical receiver (P-wave) signals in Borehole C4997, depths 390 to 490 ft; FFT low pass 57 Hz; input signal: 5 cycles of 50-Hz sine wave.
2. Figures 7.2 to 7.7 present filtered lower vertical receiver (P-wave) signals in Borehole C4997, depths 495 to 1080 ft; FFT low pass 57 Hz; input signal: 10 cycles of 50-Hz sine wave.
3. Figures 7.8 to 7.9 present filtered lower vertical receiver (P-wave) signals in Borehole C4997, depths 990 to 1400 ft; FFT low pass 25 Hz; input signal: 4 cycles of 20-Hz sine wave.

Figure 7.1 Filtered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 390 to 490 ft; Input Signal: 5 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

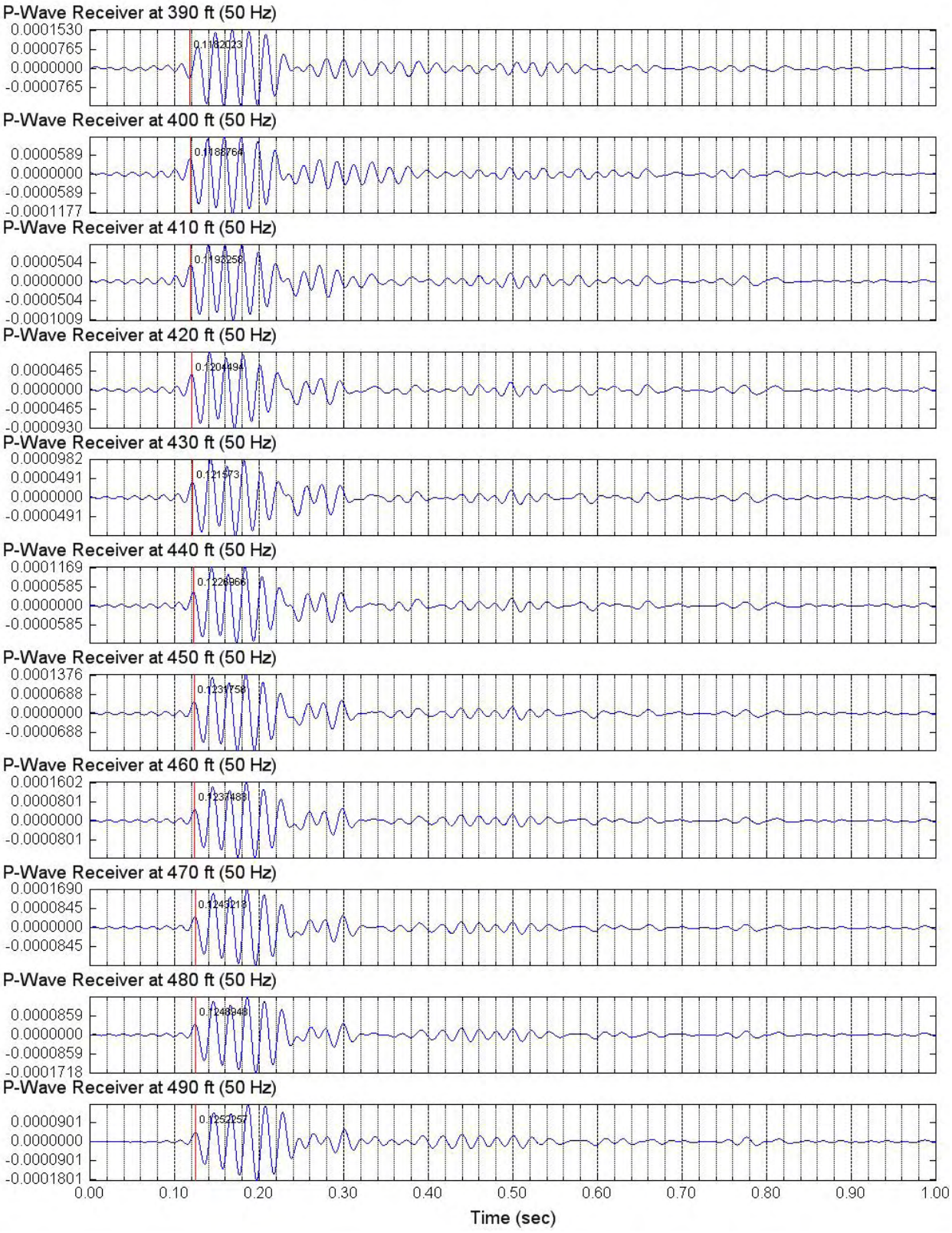


Figure 7.2 Filtered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 495 to 560 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

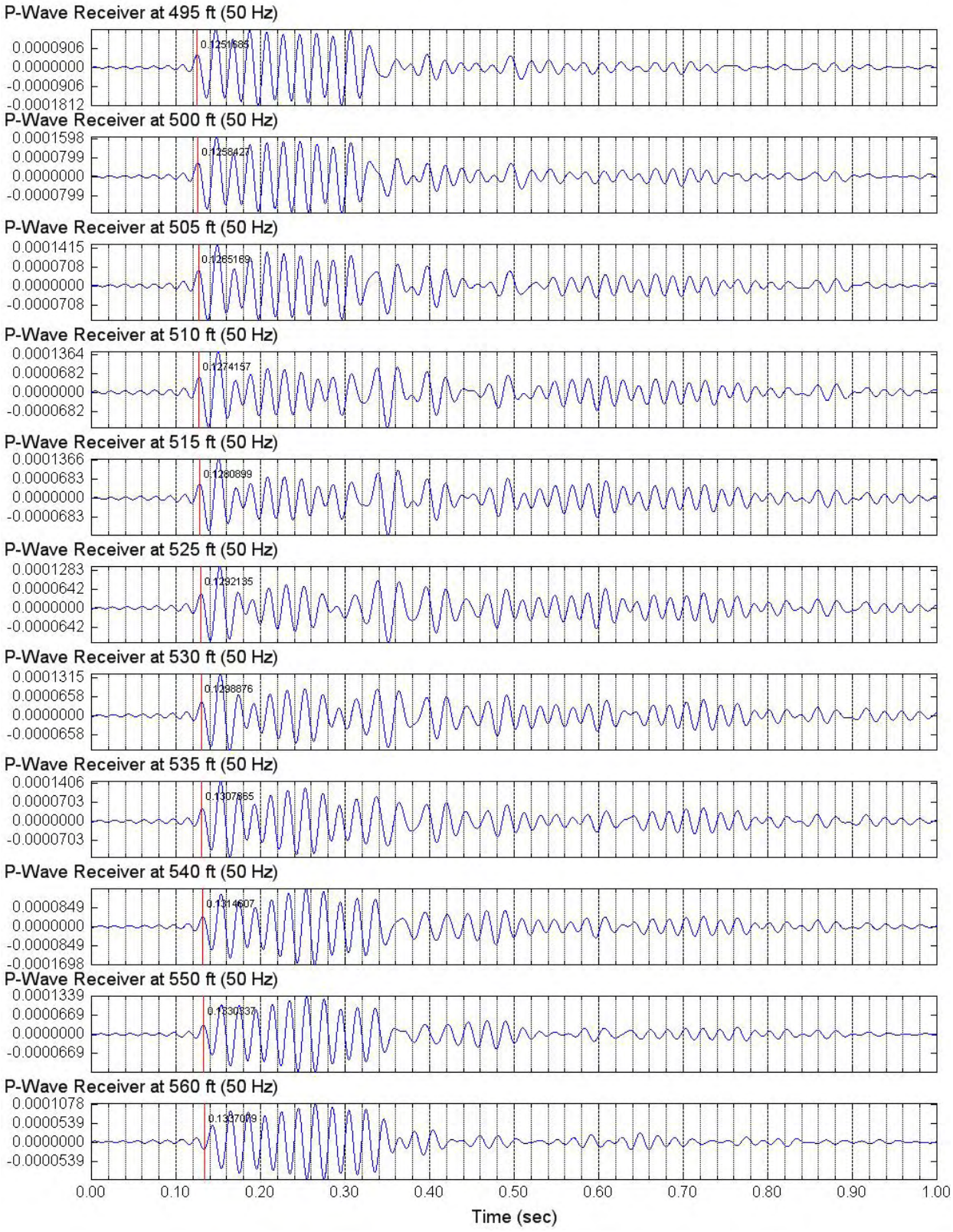


Figure 7.3 Filtered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 570 to 670 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

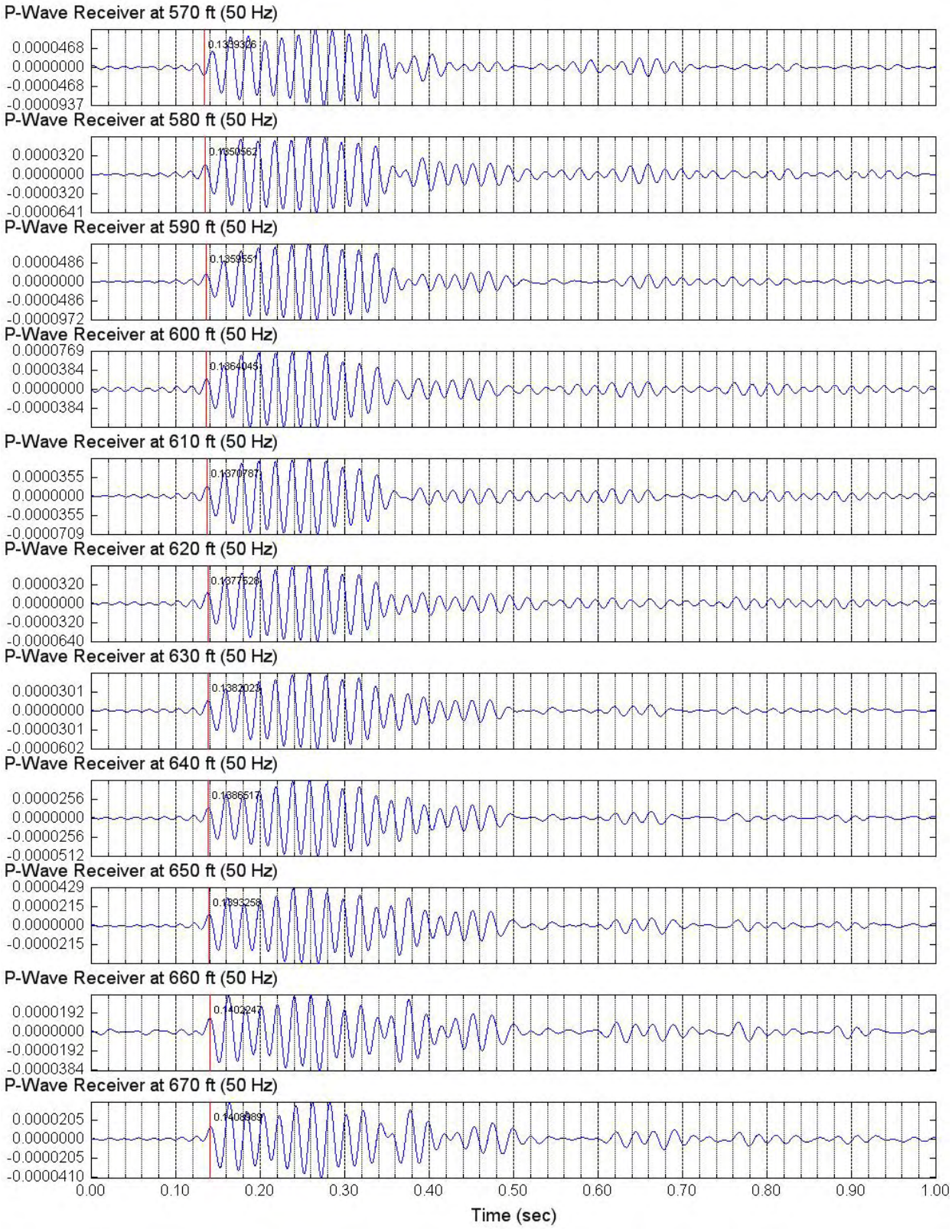


Figure 7.4 Filtered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 680 to 770 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

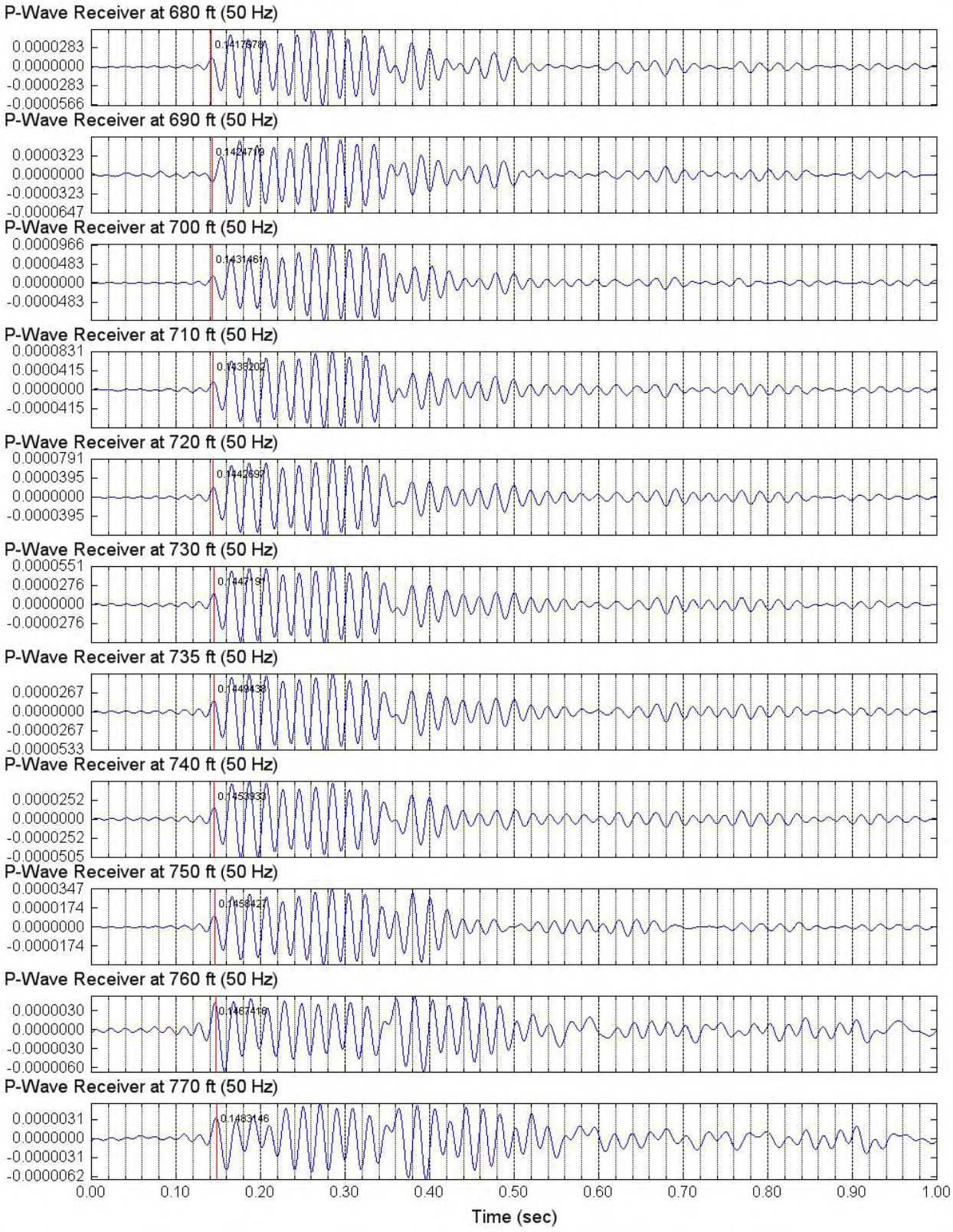


Figure 7.5 Filtered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 780 to 865 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

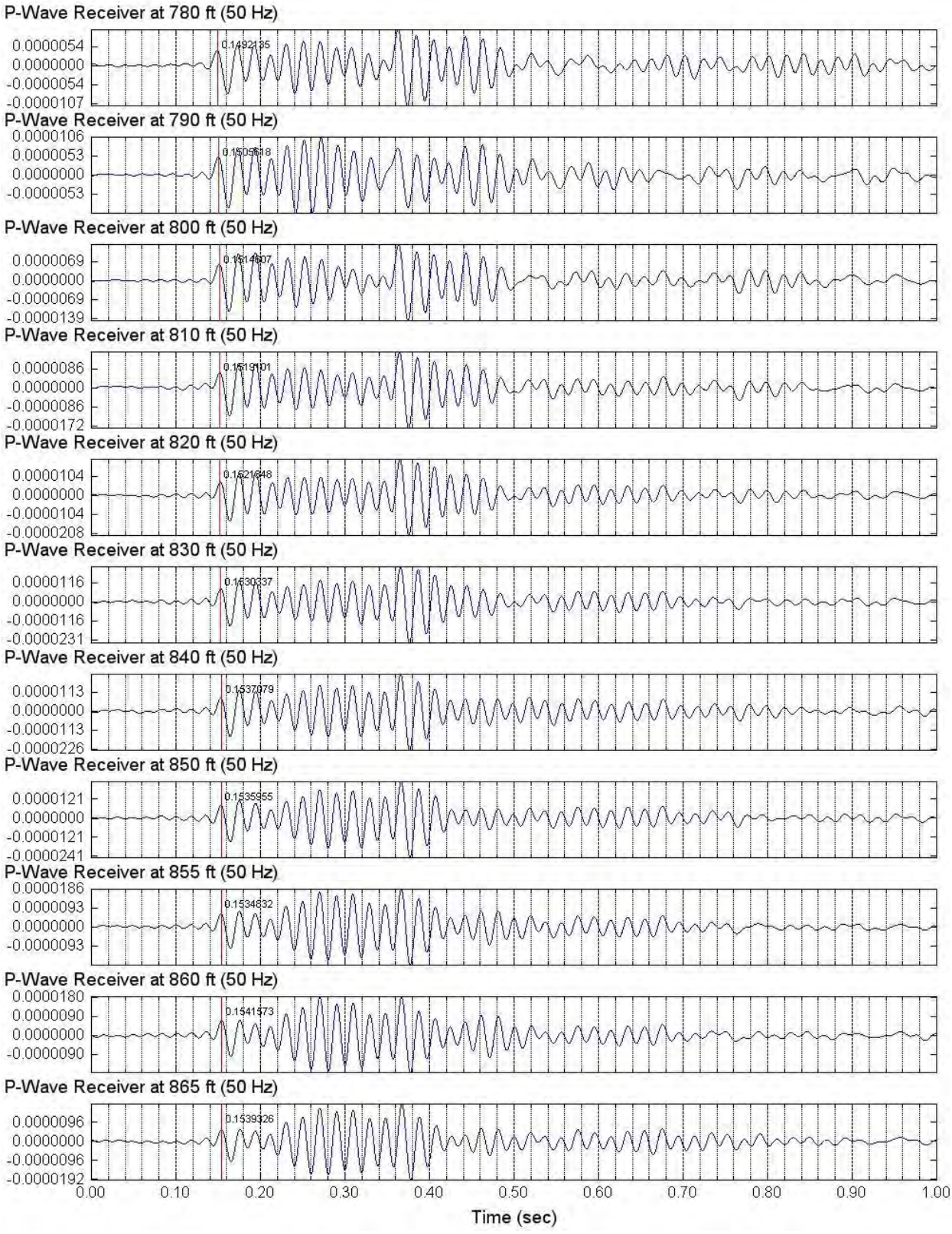


Figure 7.6 Filtered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 870 to 970 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

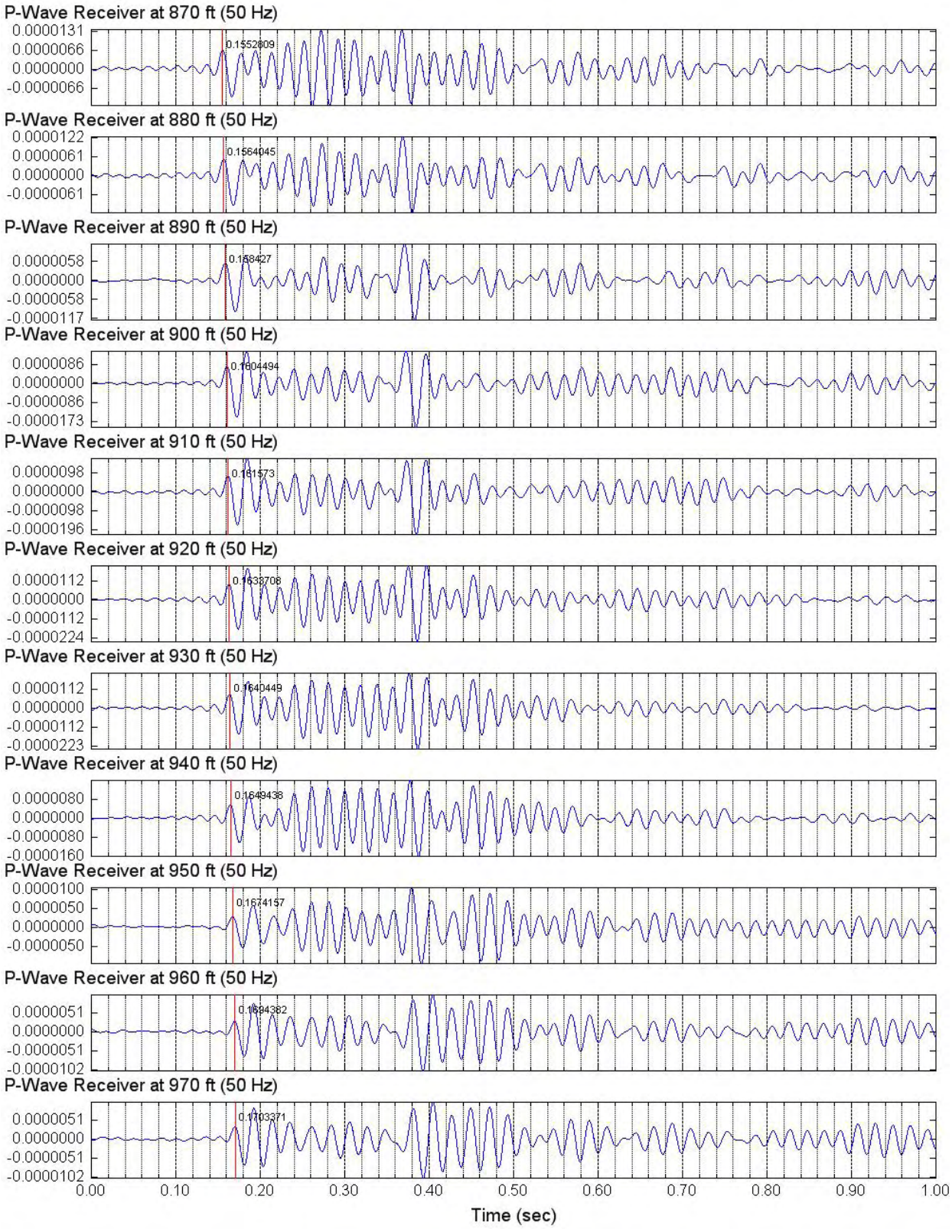


Figure 7.7 Filtered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 980 to 1080 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

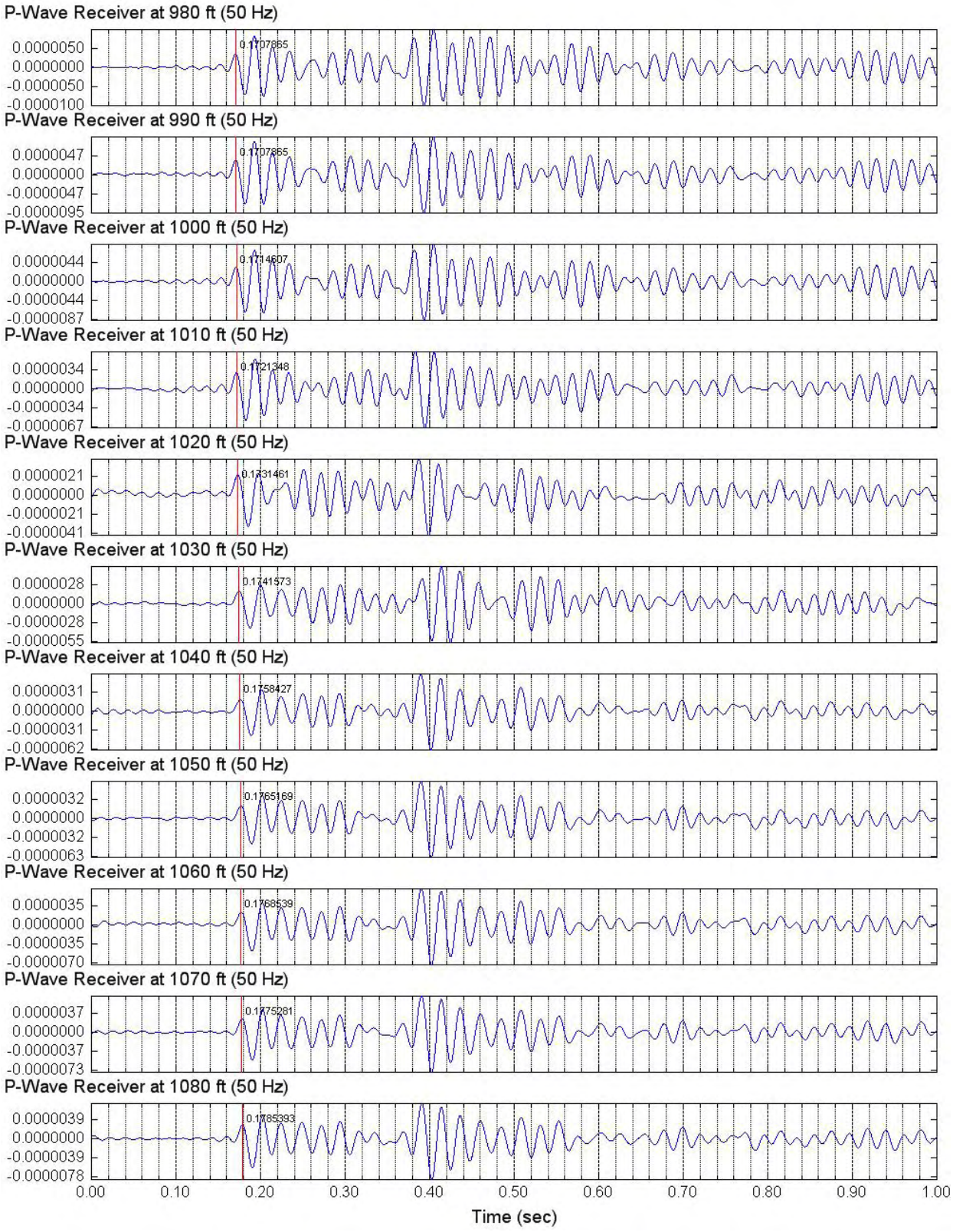


Figure 7.8 Filtered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 970 to 1110 ft; Input Signal: 4 Cycles of 20-Hz Sine Wave; Low Pass 25 Hz

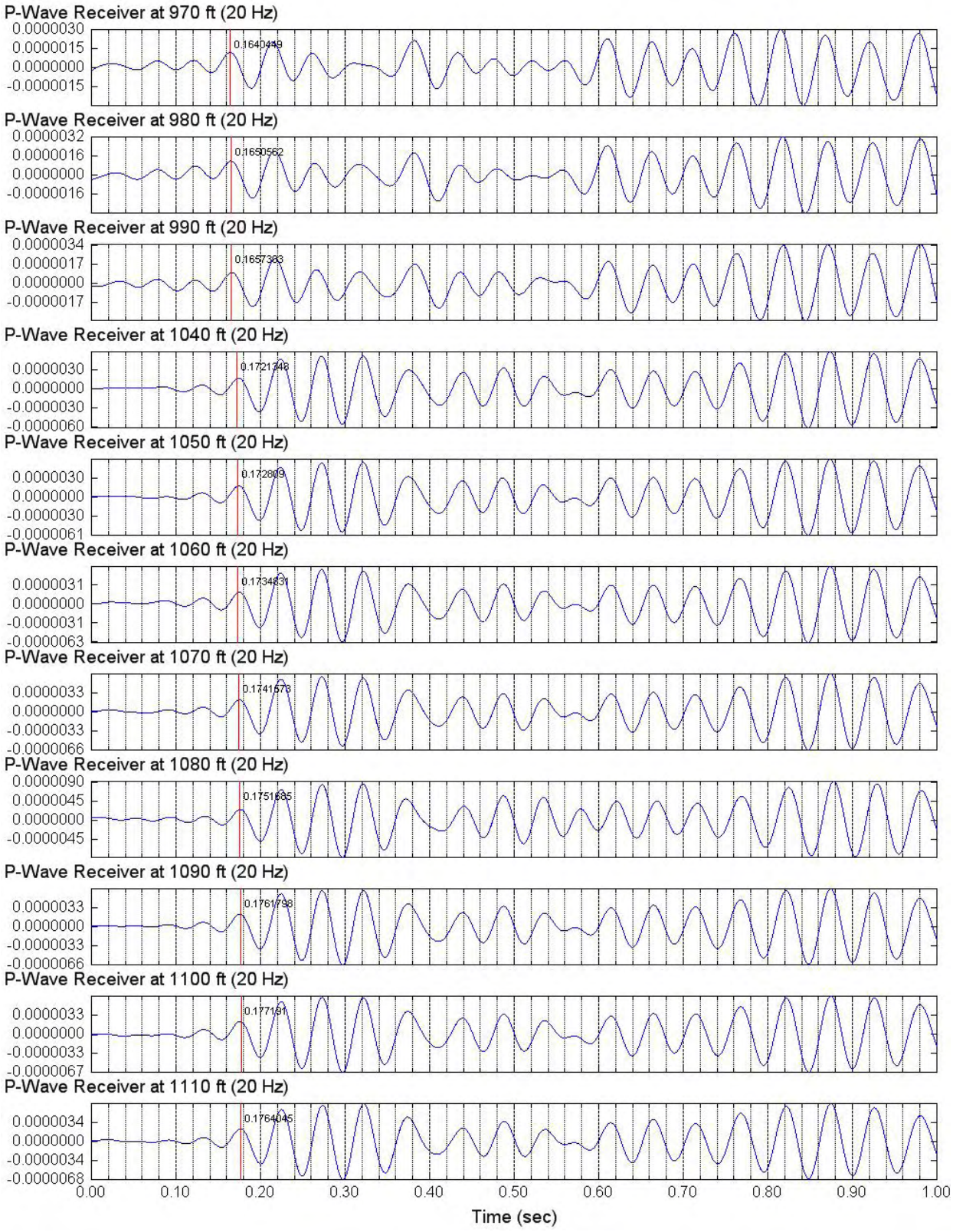
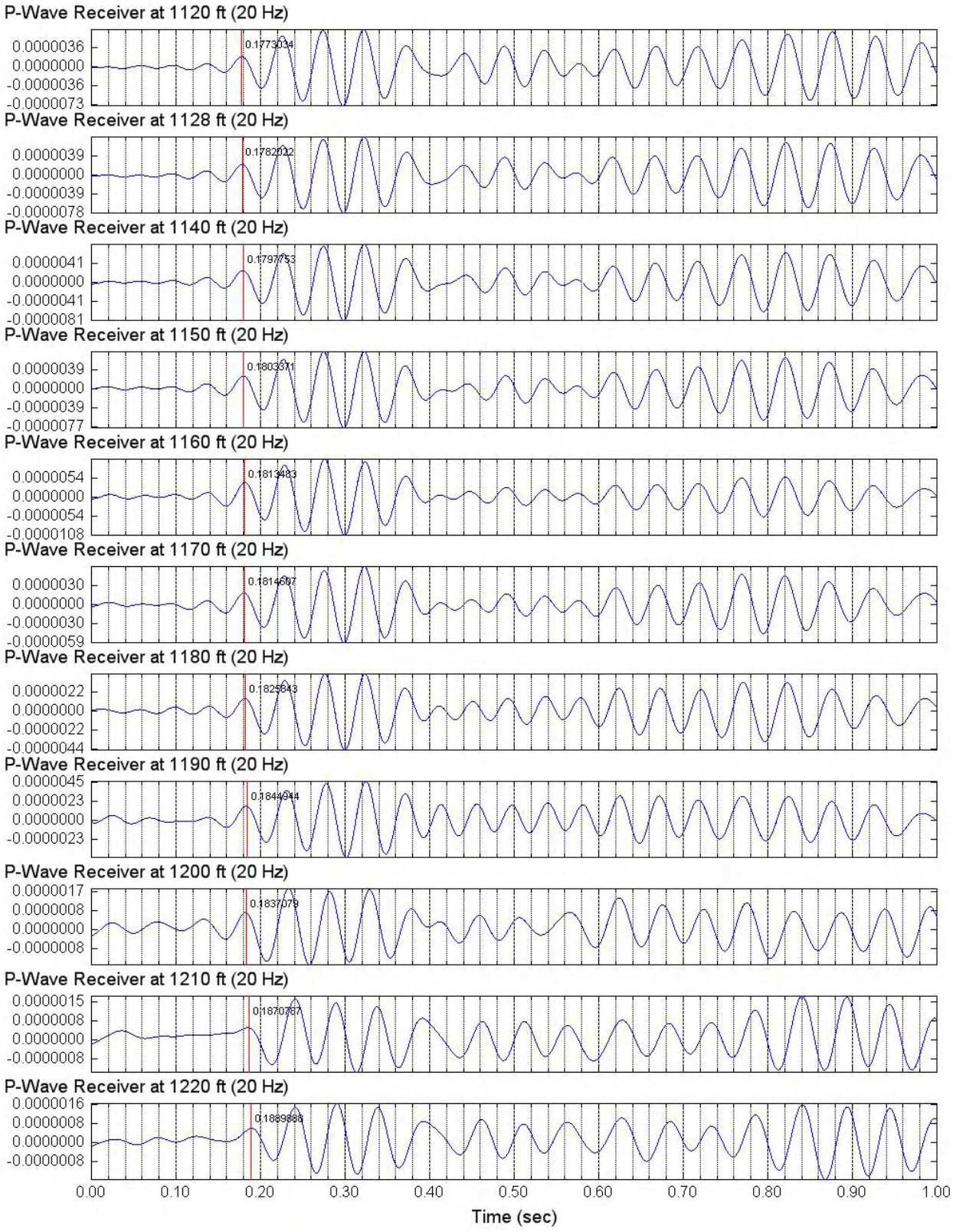


Figure 7.9 Filtered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 1120 to 1220 ft; Input Signal: 4 Cycles of 20-Hz Sine Wave; Low Pass 25 Hz



Section 8: Filtered P-Wave Signals of Reaction Mass Acceleration

1. Figure 8.1 presents filtered reaction mass vertical (P-wave) acceleration at Borehole C4997, depths 390 to 490 ft; FFT low pass 57 Hz; input signal: 5 cycles of 50-Hz sine wave.
2. Figures 8.2 to 8.7 present filtered reaction mass vertical (P-wave) acceleration at Borehole C4997, depths 495 to 1080 ft; FFT low pass 57 Hz; input signal: 10 cycles of 50-Hz sine wave.
3. Figures 8.8 to 8.9 present filtered reaction mass vertical (P-wave) acceleration at Borehole C4997, depths 970 to 1220 ft; FFT low pass 25 Hz; input signal: 4 cycles of 20-Hz sine wave.

Figure 8.1 Filtered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 390 to 490 ft; Input Signal: 5 Cycles of 50-Hz Sine Wavee; Low Pass 57 Hz

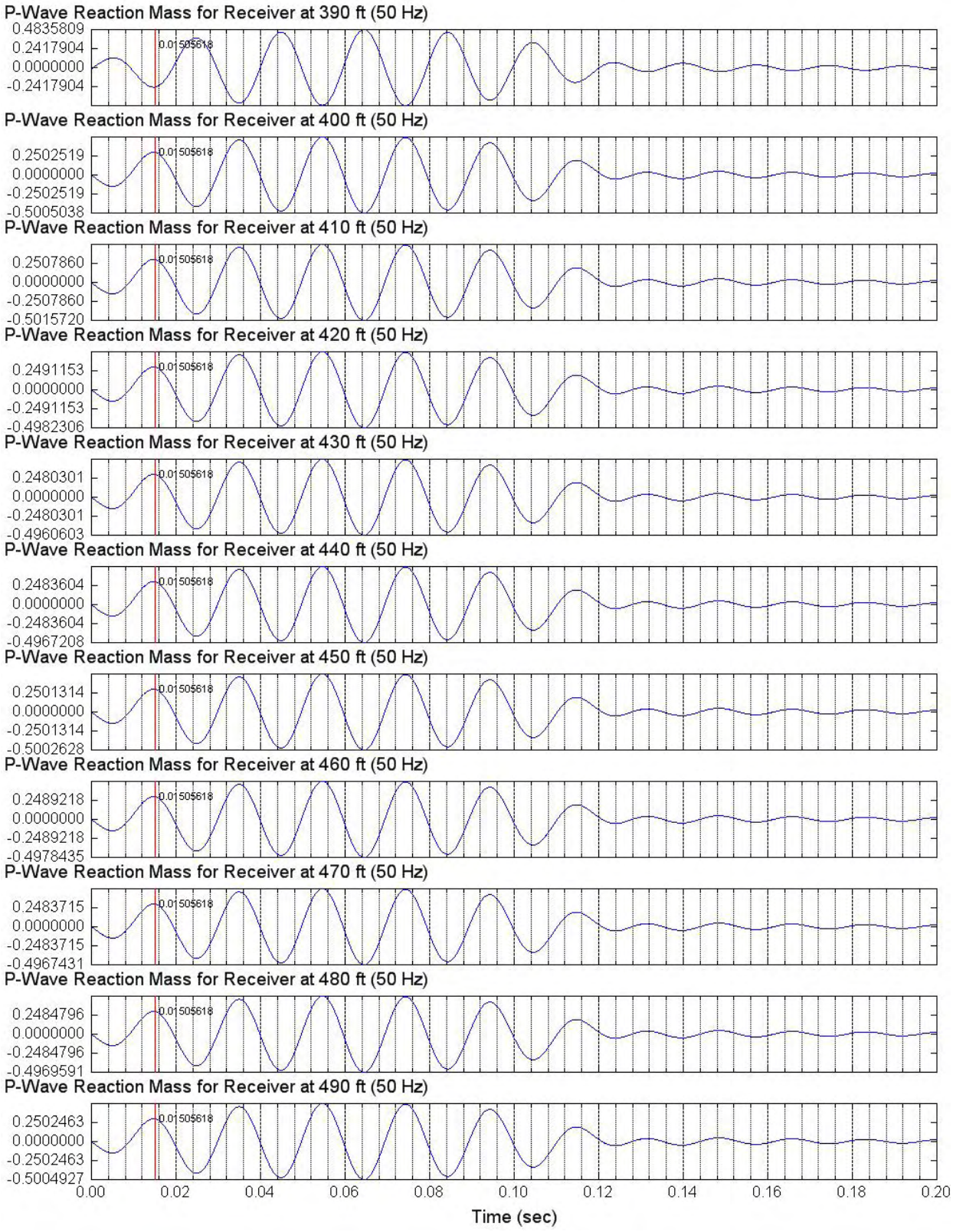


Figure 8.2 Filtered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 495 to 560 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

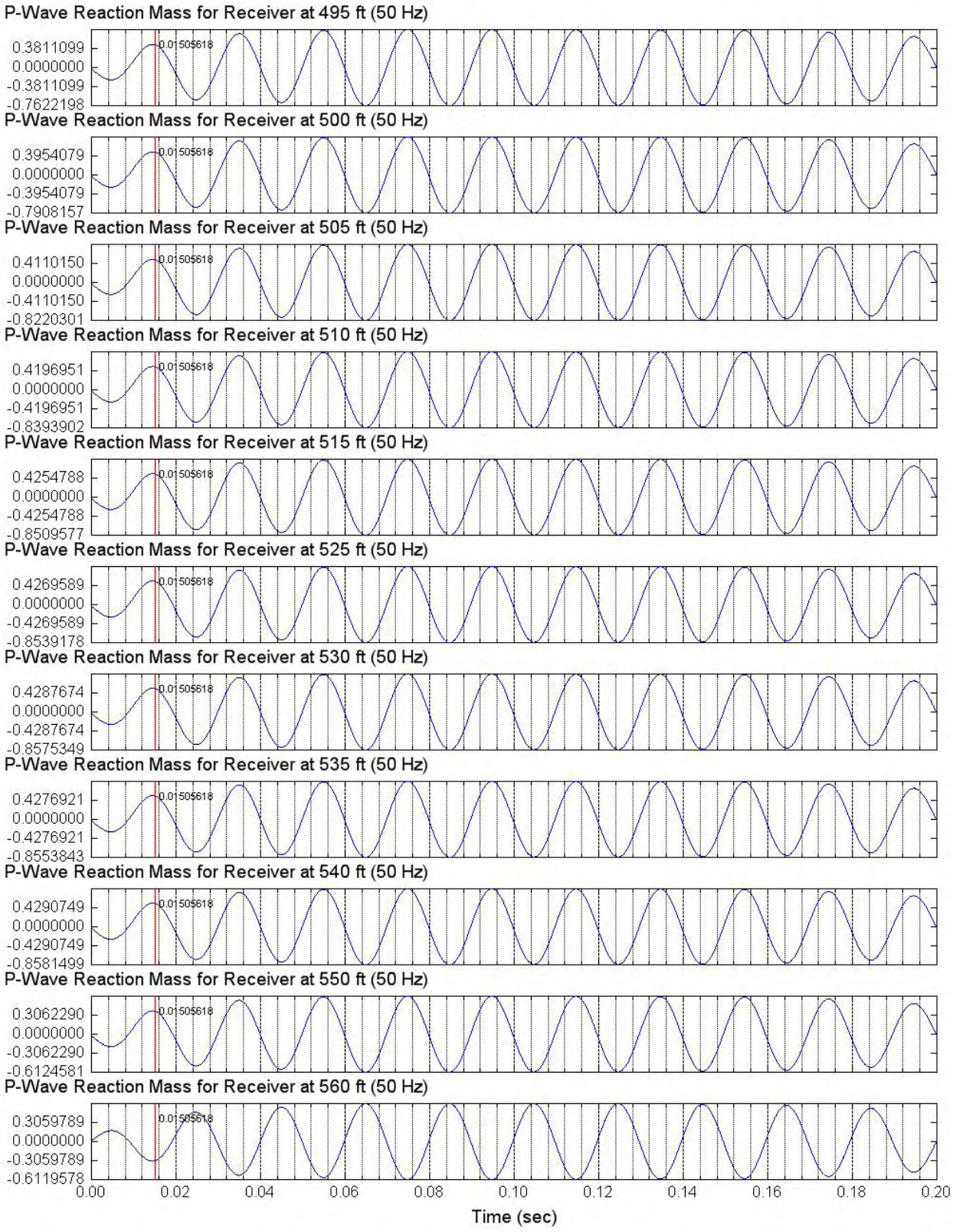


Figure 8.3 Filtered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 570 to 670 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

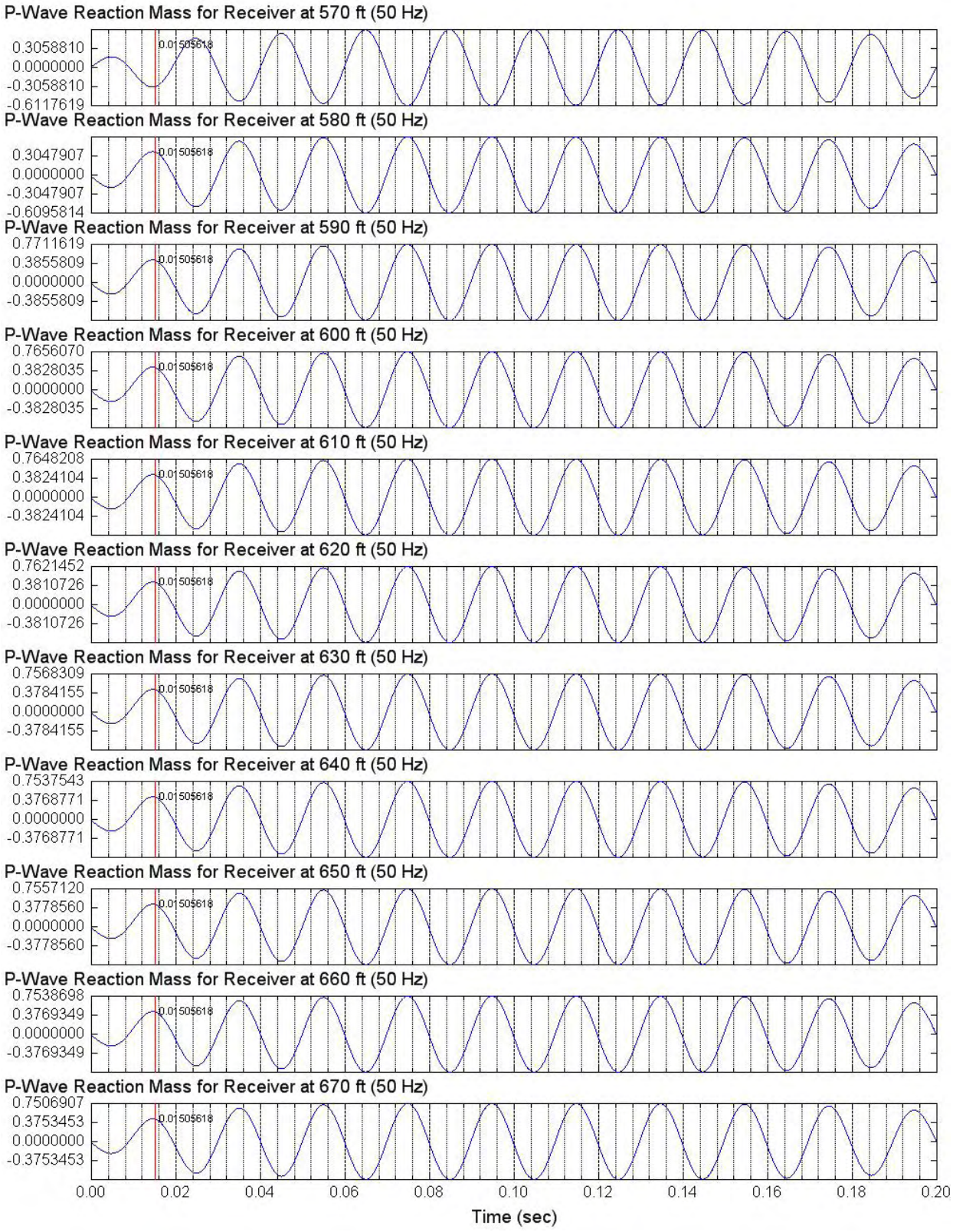


Figure 8.4 Filtered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 680 to 770 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

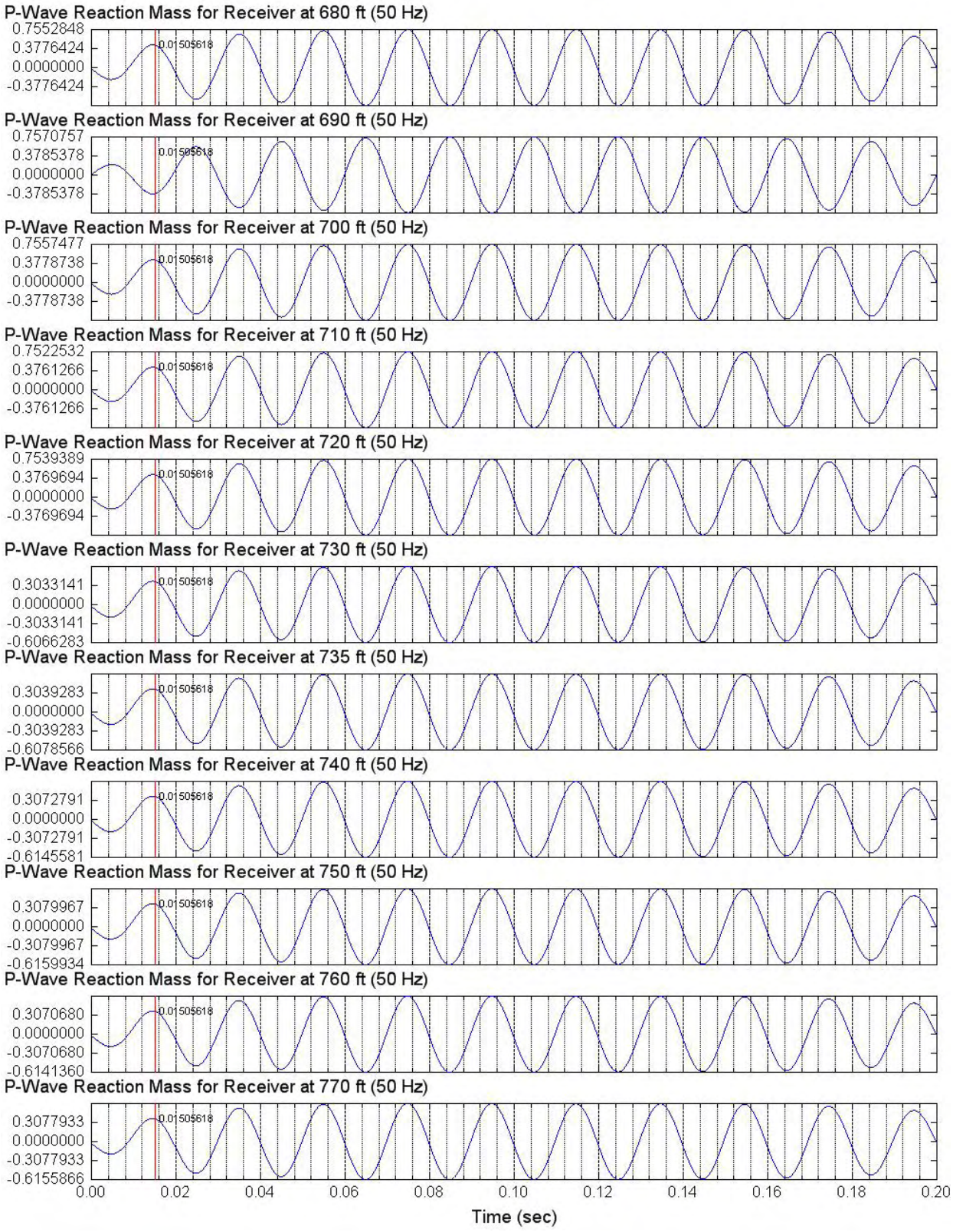


Figure 8.5 Filtered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 780 to 865 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

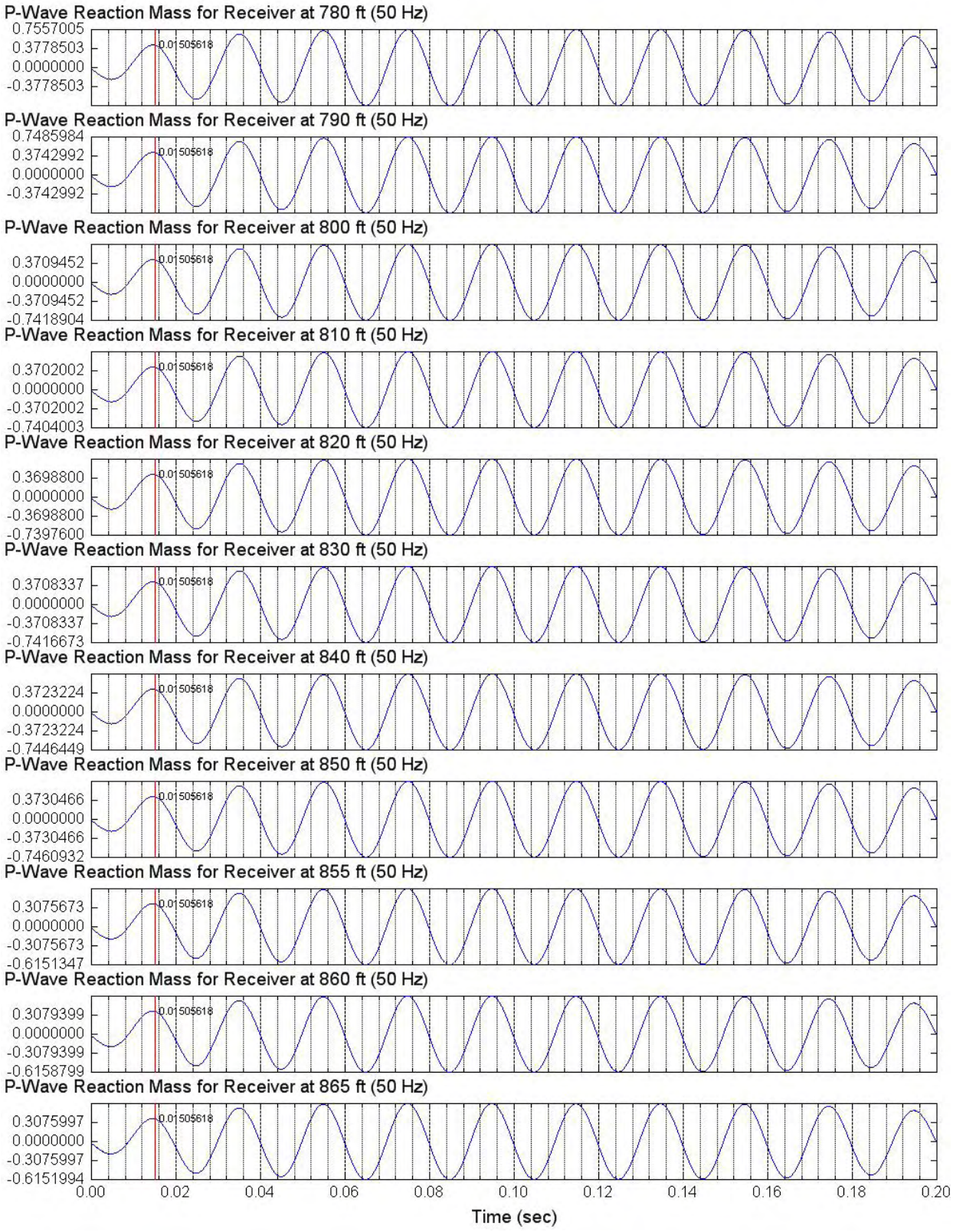


Figure 8.6 Filtered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 870 to 970 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

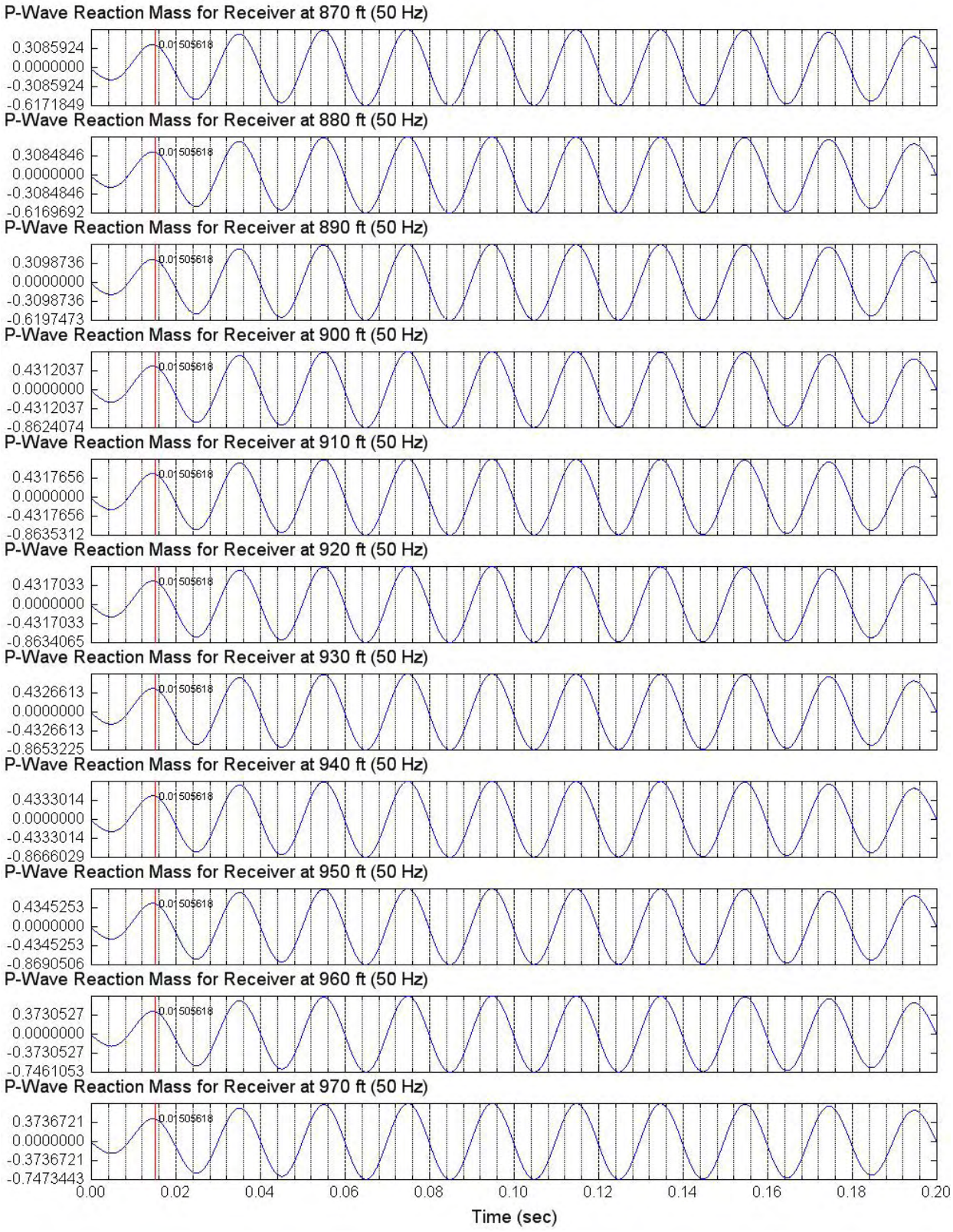


Figure 8.7 Filtered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 980 to 1080 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

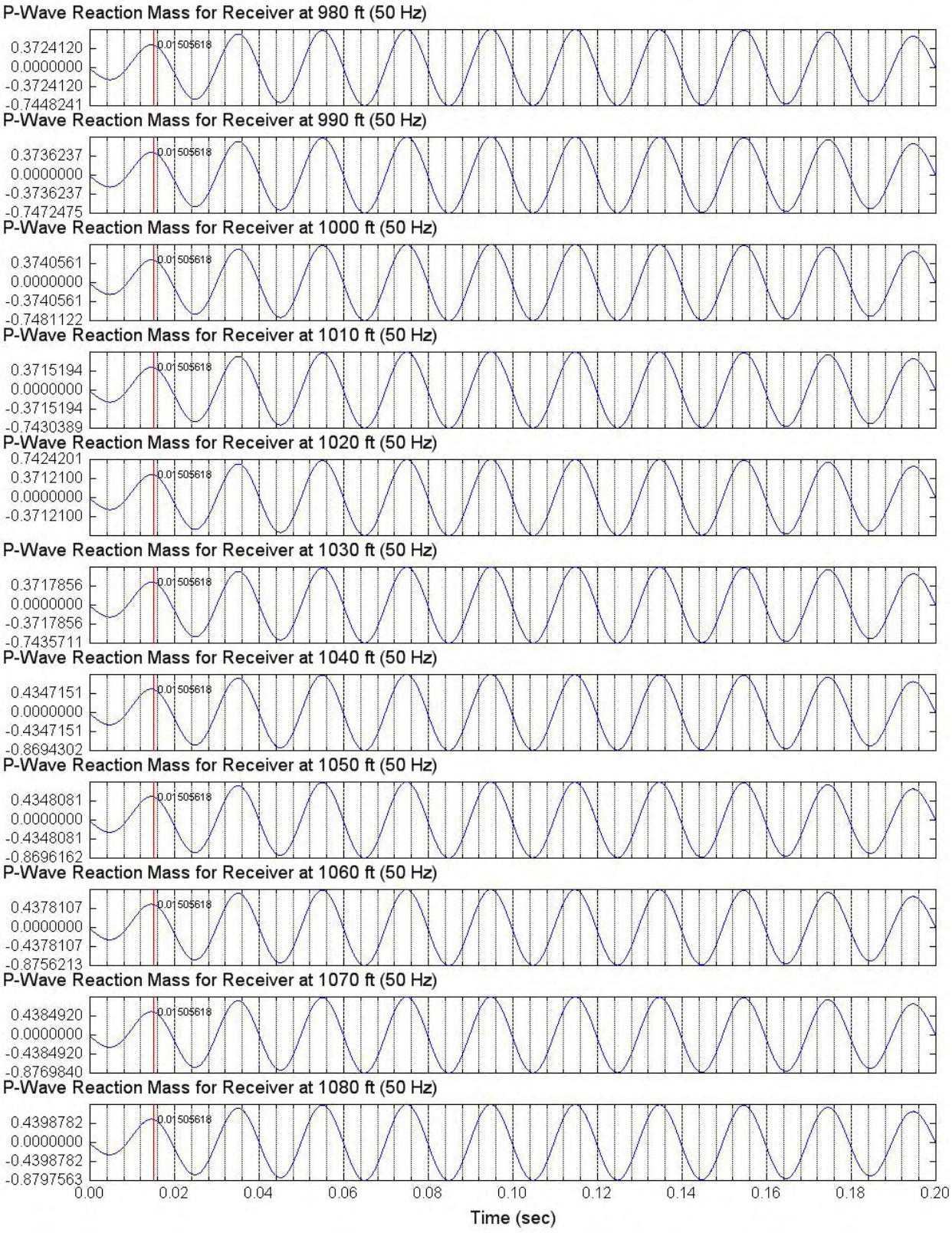


Figure 8.8 Filtered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 970 to 1110 ft; Input Signal: 4 Cycles of 20-Hz Sine Wave; Low Pass 25 Hz

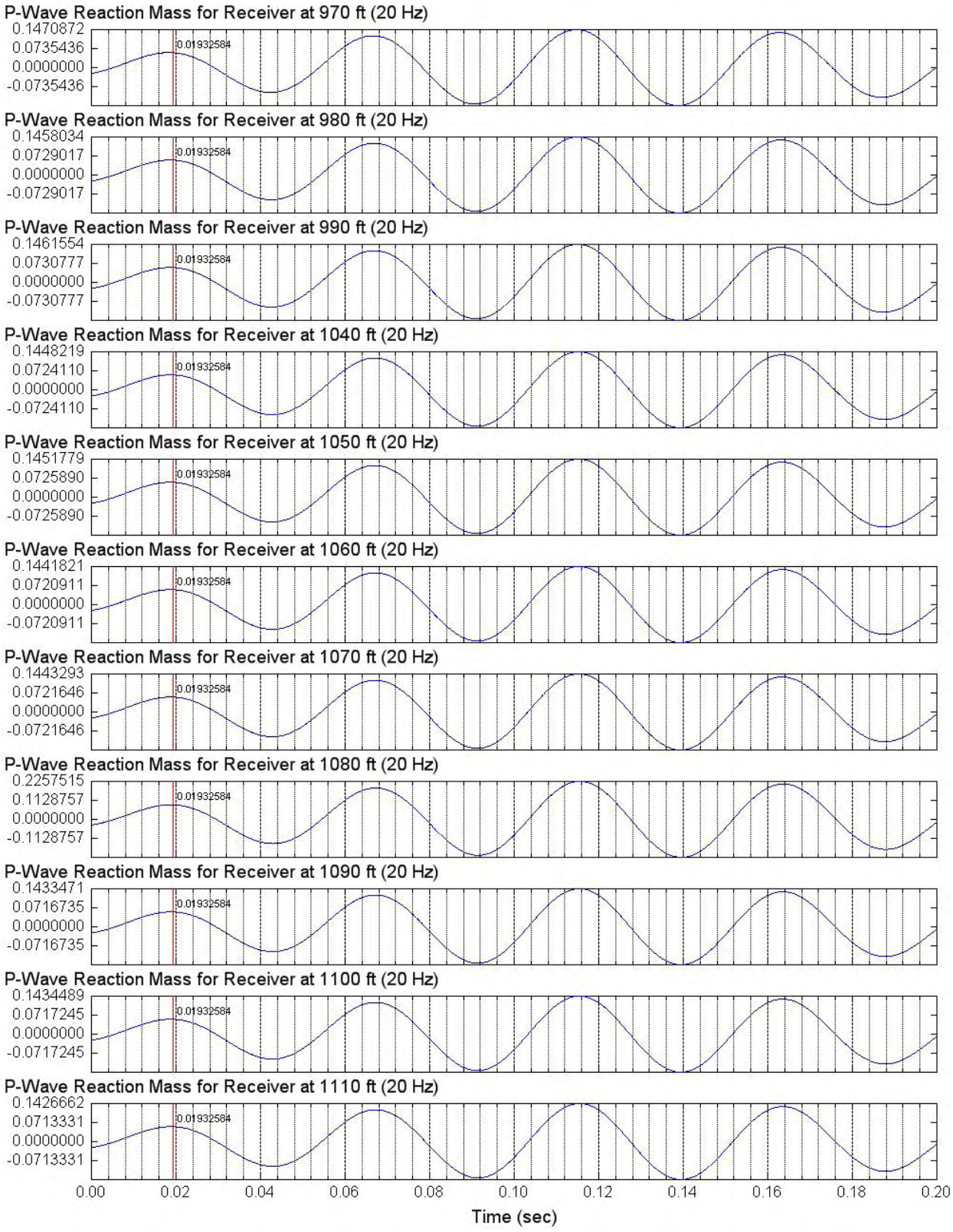
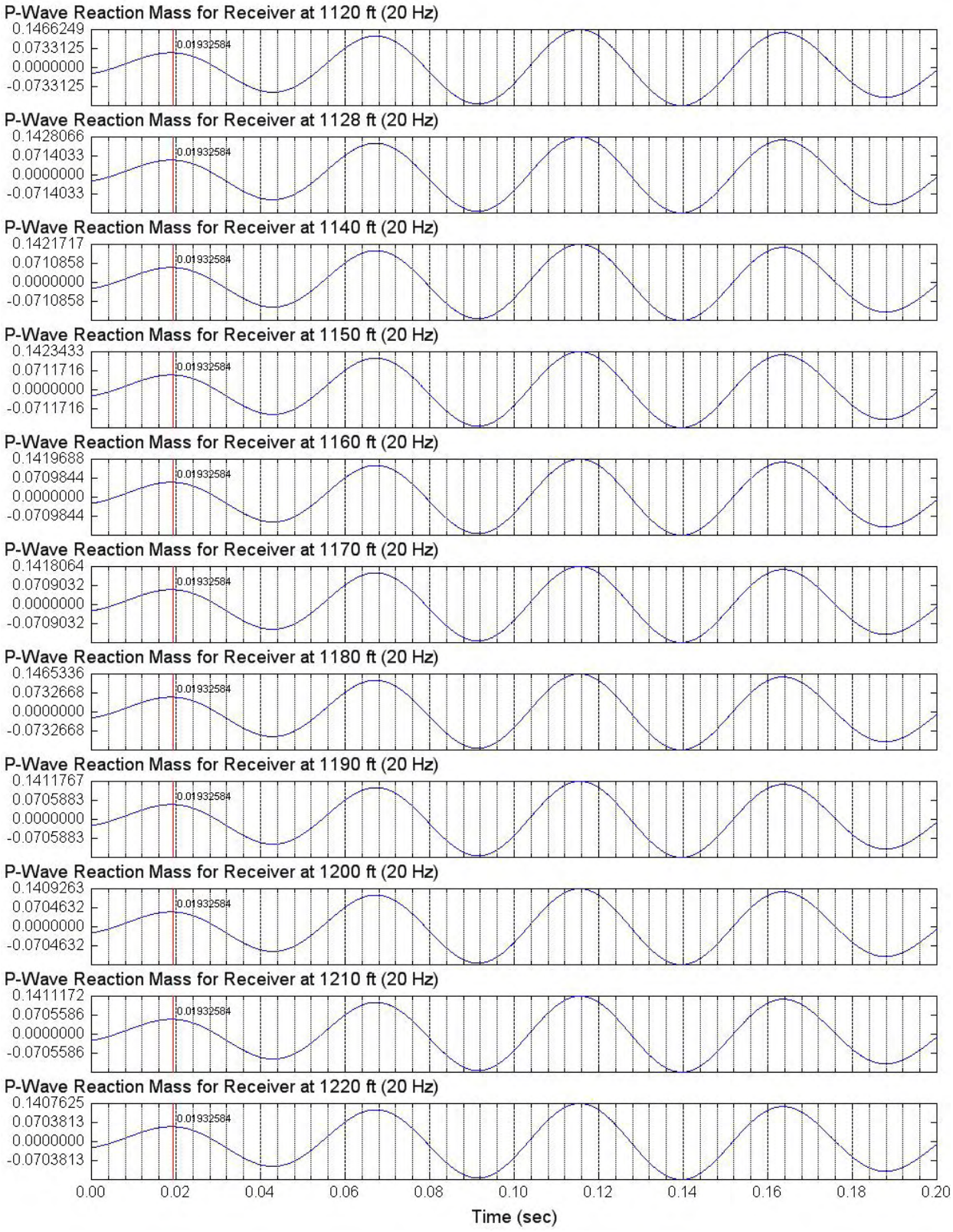


Figure 8.9 Filtered Reaction Mass Vertical (P-Wave) Acceleration in Borehole C4997

Depths 1120 to 1220 ft; Input Signal: 4 Cycles of 20-Hz Sine Wave; Low Pass 25 Hz



Section 9: Filtered P-Wave Signals of Reference Receiver

1. Figure 9.1 presents filtered reference vertical receiver (P-wave) signals in Borehole C4997, depths 390 to 490 ft; FFT low pass 57 Hz; input signal: 5 cycles of 50-Hz sine wave.
2. Figures 9.2 to 9.8 present filtered reference vertical receiver (P-wave) signals in Borehole C4997, depths 495 to 1080 ft; FFT low pass 57 Hz; input signal: 10 cycles of 50-Hz sine wave.
3. Figures 9.9 to 9.10 present filtered reference vertical receiver (P-wave) signals in Borehole C4997, depths 970 to 1220 ft; FFT low pass 25 Hz; input signal: 4 cycles of 20-Hz sine wave.

Figure 9.1 Filtered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

Lower Receiver Depths 390 to 490 ft; Reference Receiver Depth 40 ft;
Input Signal: 5 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

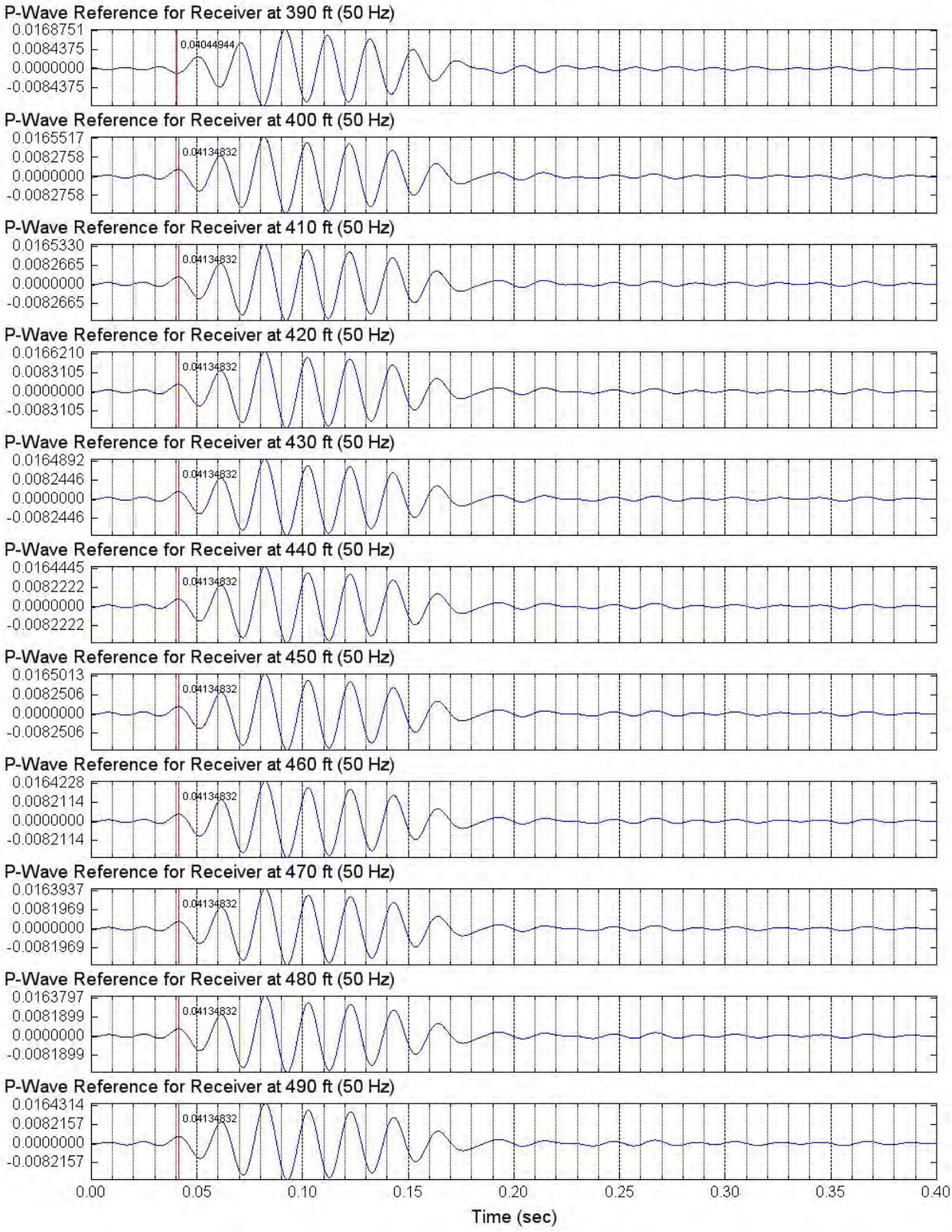


Figure 9.2 Filtered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

Lower Receiver Depths 495 to 580 ft; Reference Receiver Depth 27.5 ft;
Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

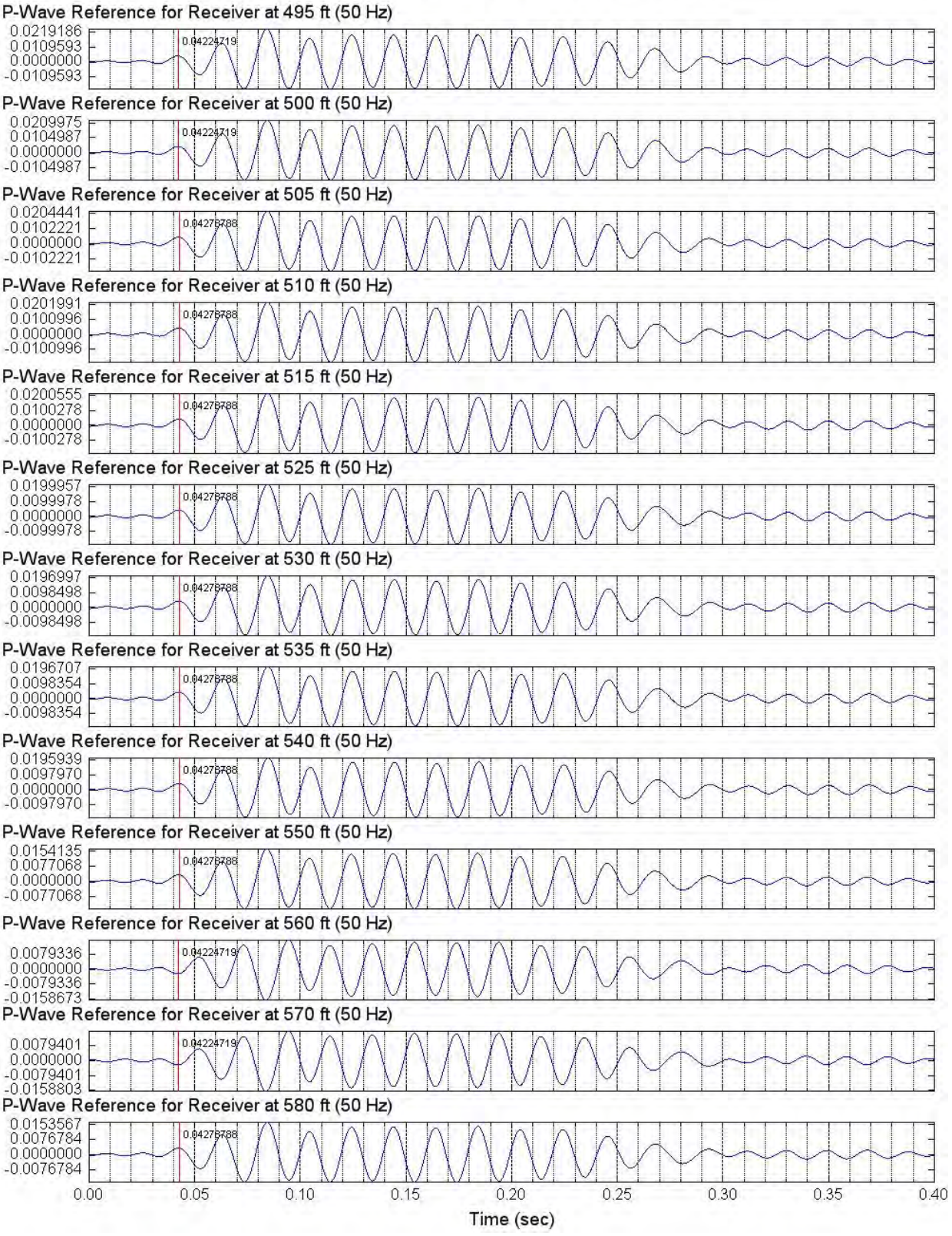


Figure 9.3 Filtered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

Lower Receiver Depths 590 to 720 ft; Reference Receiver Depth 40 ft;
Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

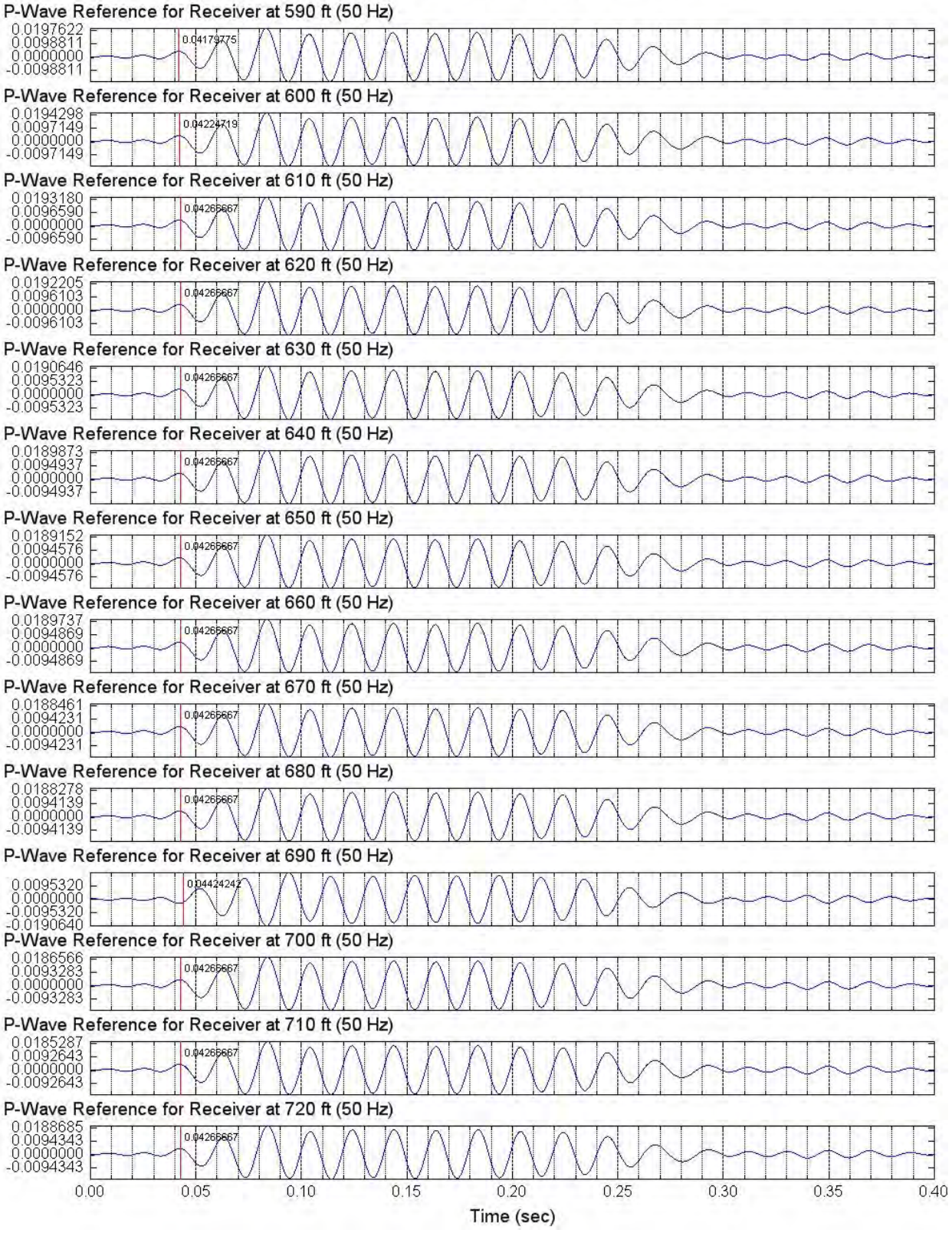


Figure 9.4 Filtered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

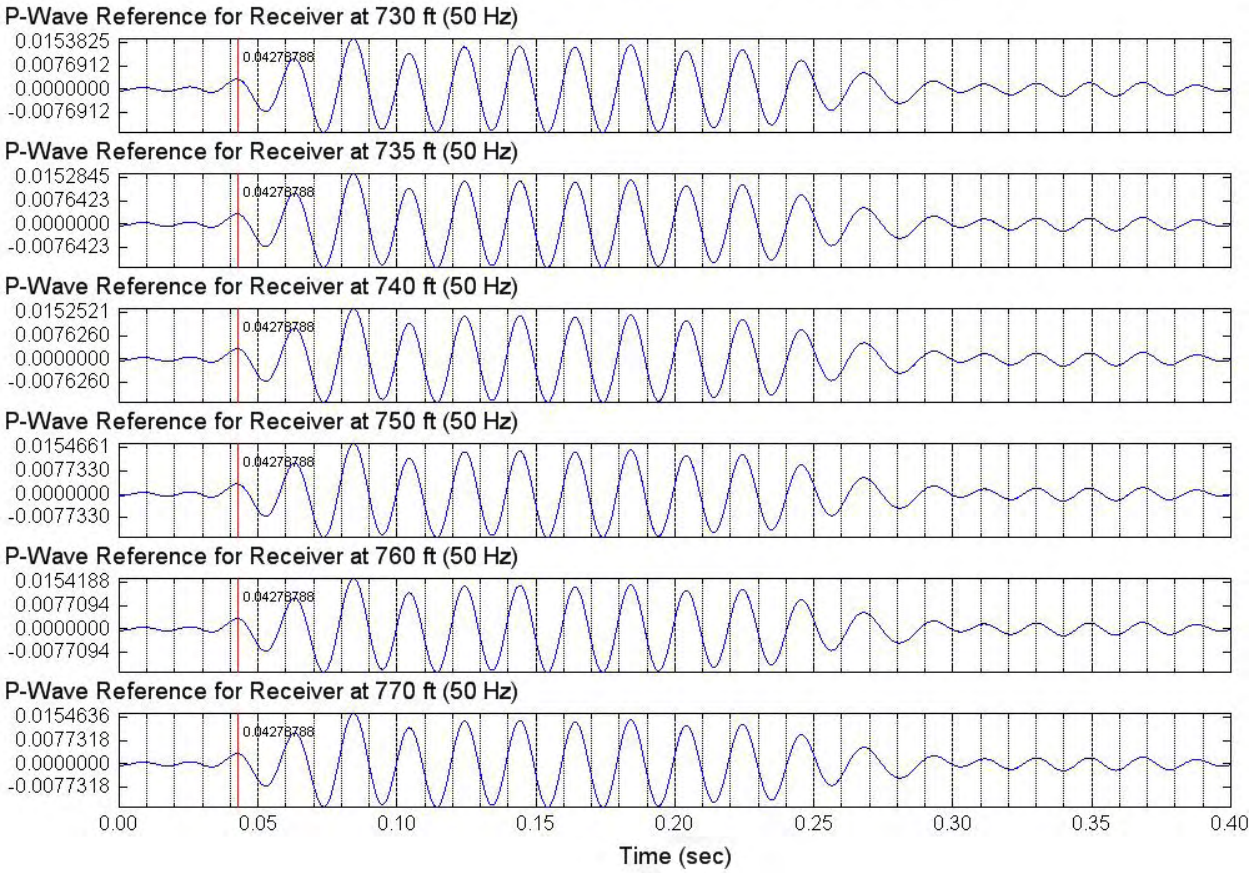


Figure 9.5 Filtered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

Lower Receiver Depths 780 to 850 ft; Reference Receiver Depth 40 ft;
Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

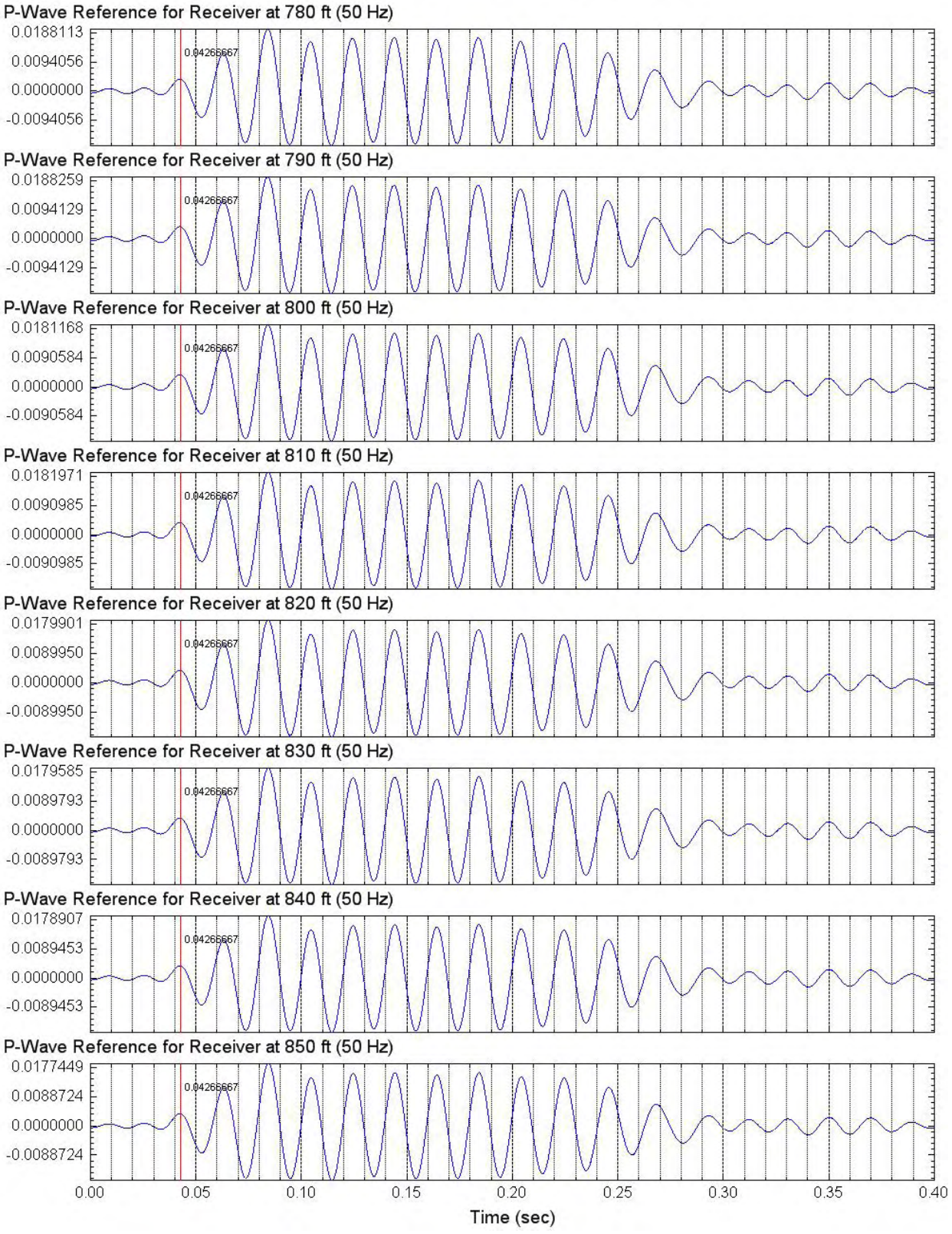


Figure 9.6 Filtered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

Lower Receiver Depths 855 to 950 ft; Reference Receiver Depth 27.5 ft;
Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

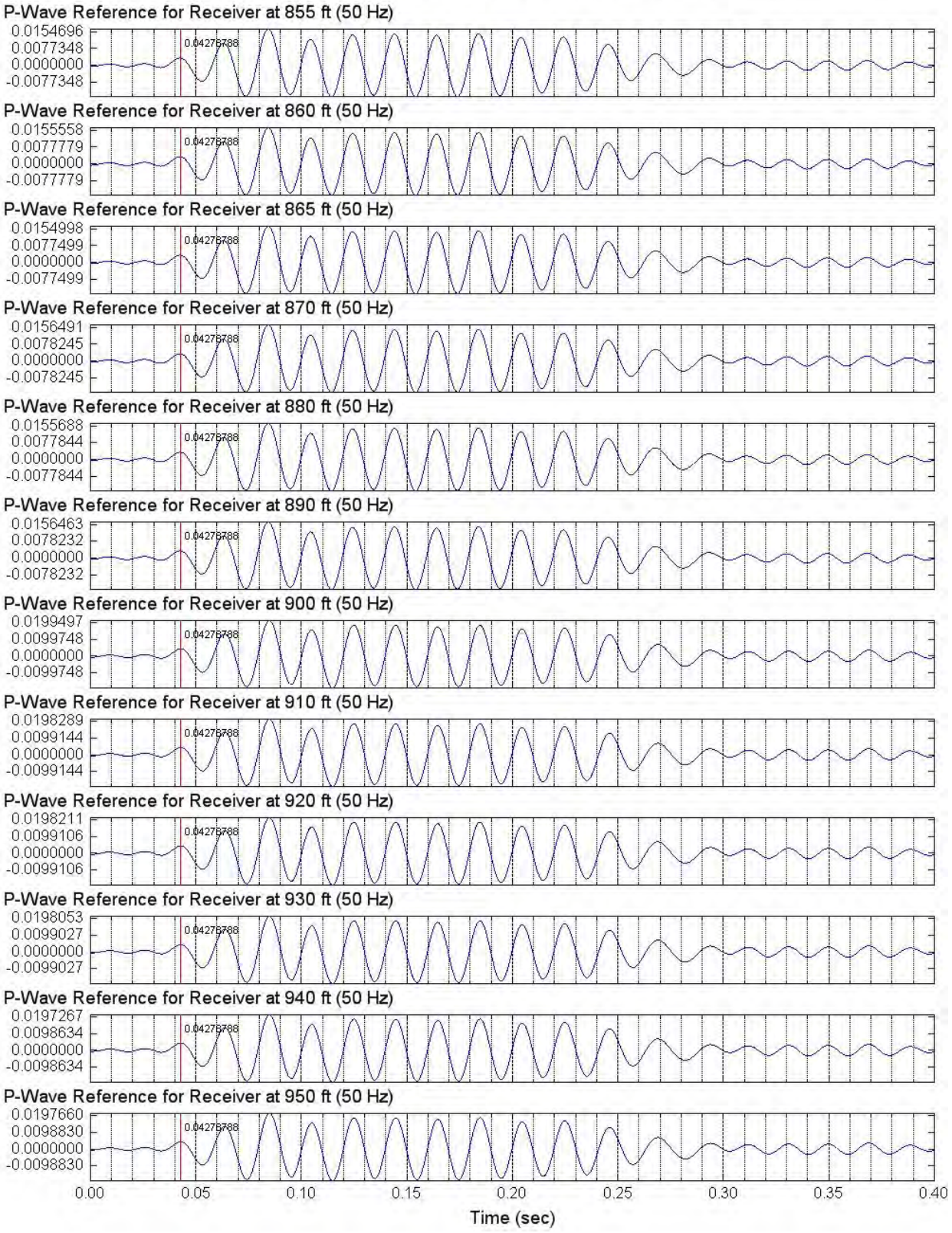


Figure 9.7 Filtered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

Lower Receiver Depths 960 to 1030 ft; Reference Receiver Depth 40 ft;
Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

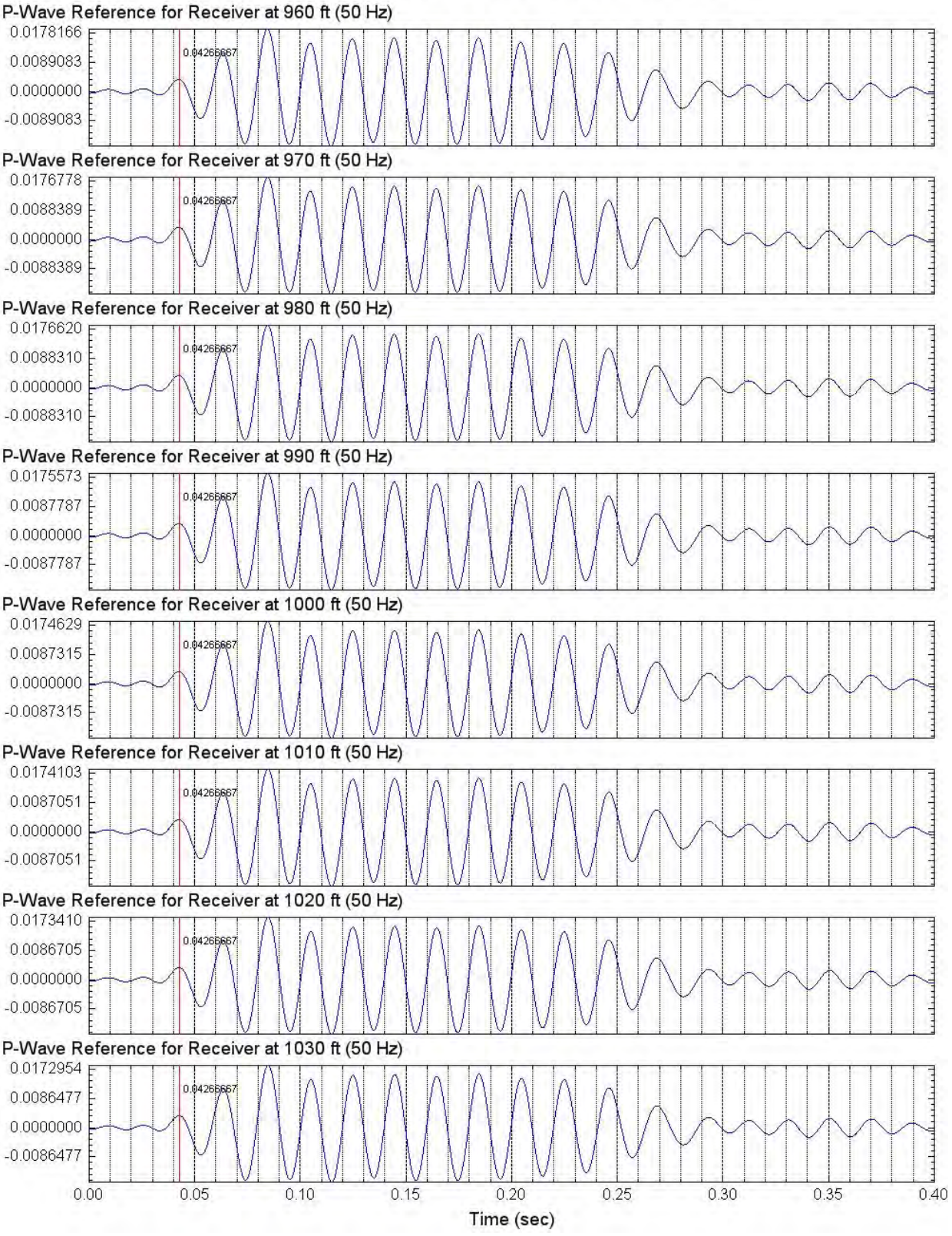


Figure 9.8 Filtered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

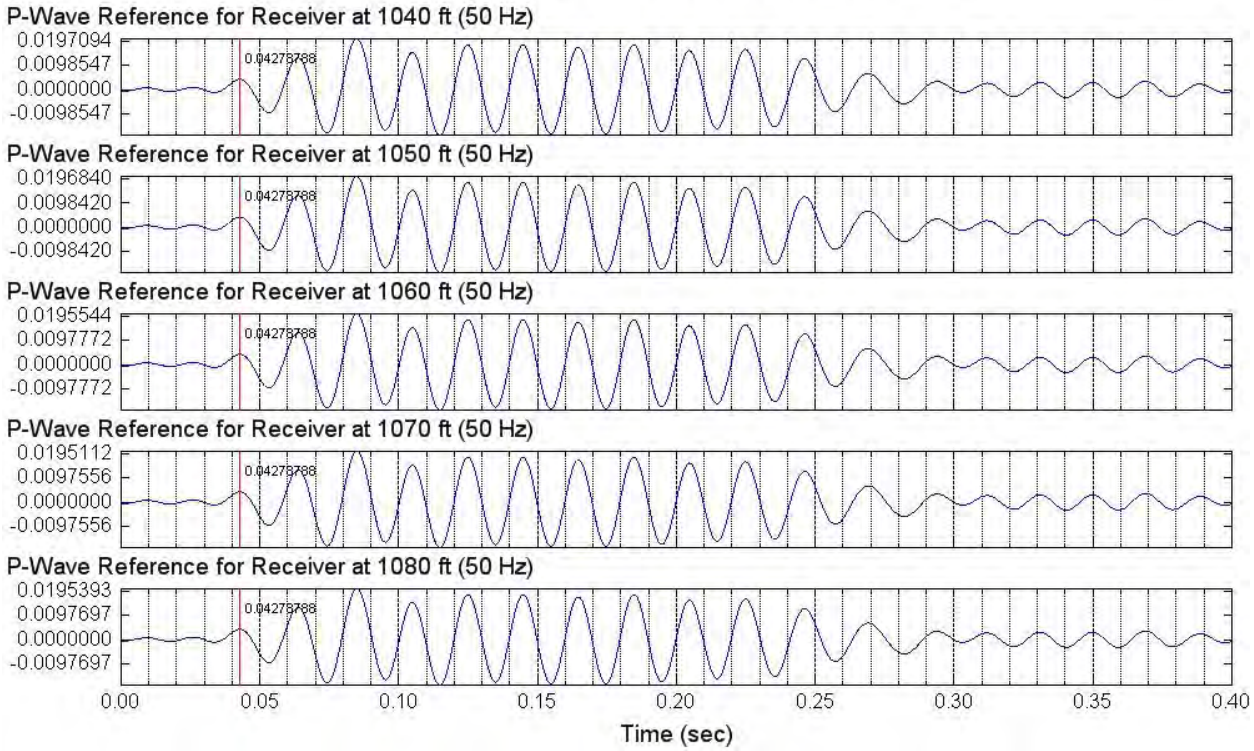


Figure 9.9 Filtered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

Lower Receiver Depths 970 to 1110 ft; Reference Receiver Depth 27.5 ft;
Input Signal: 4 Cycles of 20-Hz Sine Wave; Low Pass 25 Hz

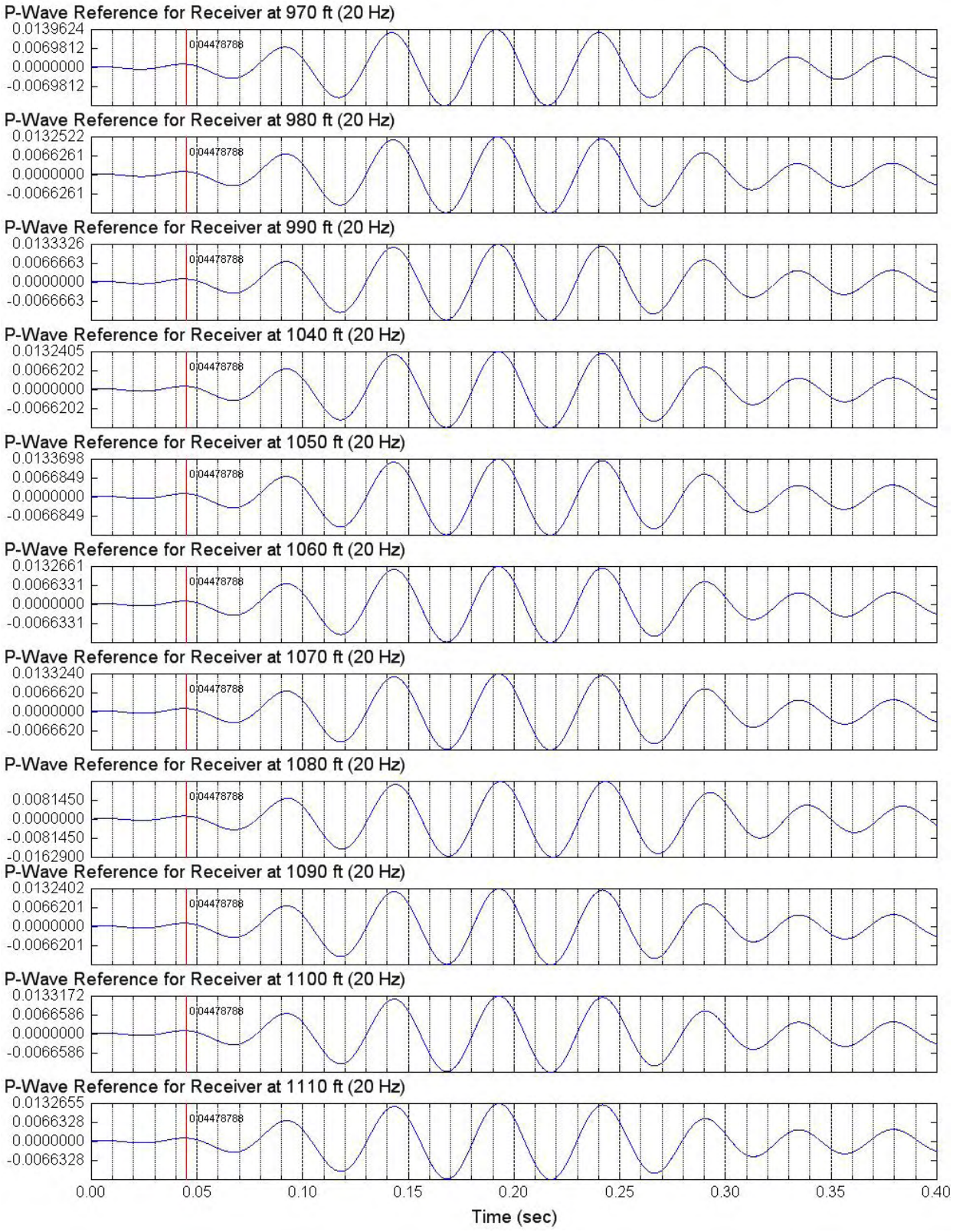
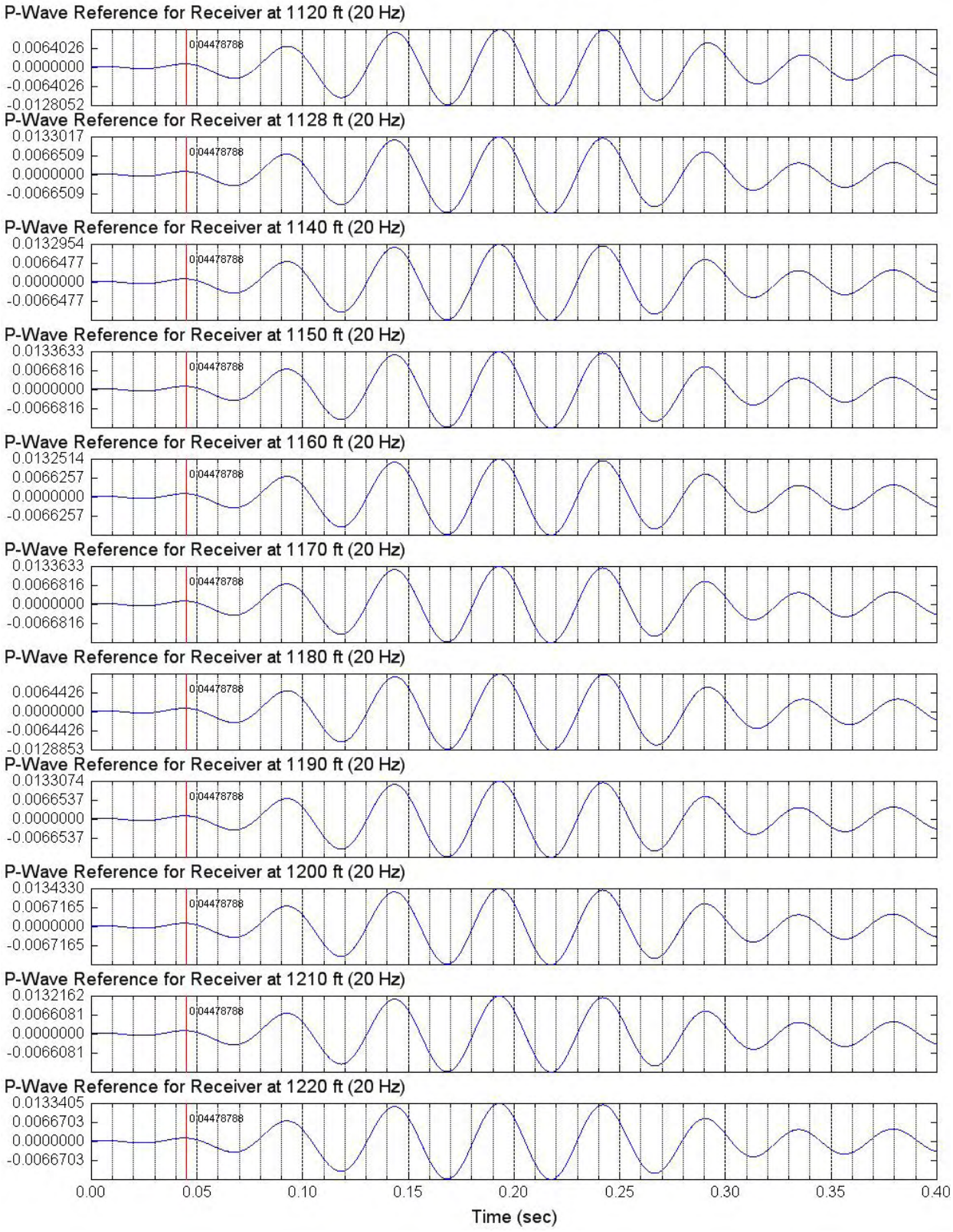


Figure 9.10 Filtered Reference Vertical Receiver (P-Wave) Signals in Borehole C4997

Lower Receiver Depths 1120 to 1220 ft; Reference Receiver Depth 27.5 ft;
Input Signal: 4 Cycles of 20-Hz Sine Wave; Low Pass 25 Hz



Section 10: Expanded and Filtered P-Wave Signals of Lower Vertical Receiver

1. Figure 10.1 presents expanded lower vertical receiver (P-wave) signals in Borehole C4997, depths 390 to 490 ft; FFT low pass 57 Hz; input signal: 5 cycles of 50-Hz sine wave.
2. Figures 10.2 to 10.7 present expanded lower vertical receiver (P-wave) signals in Borehole C4997, depths 495 to 1080 ft; FFT low pass 57 Hz; input signal: 10 cycles of 50-Hz sine wave.
3. Figures 10.8 to 10.9 present expanded lower vertical receiver (P-wave) signals in Borehole C4997, depths 970 to 1220 ft; FFT low pass 25 Hz; input signal: 4 cycles of 20-Hz sine wave.

Figure 10.1 Expanded Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 390 to 490 ft; Input Signal: 5 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

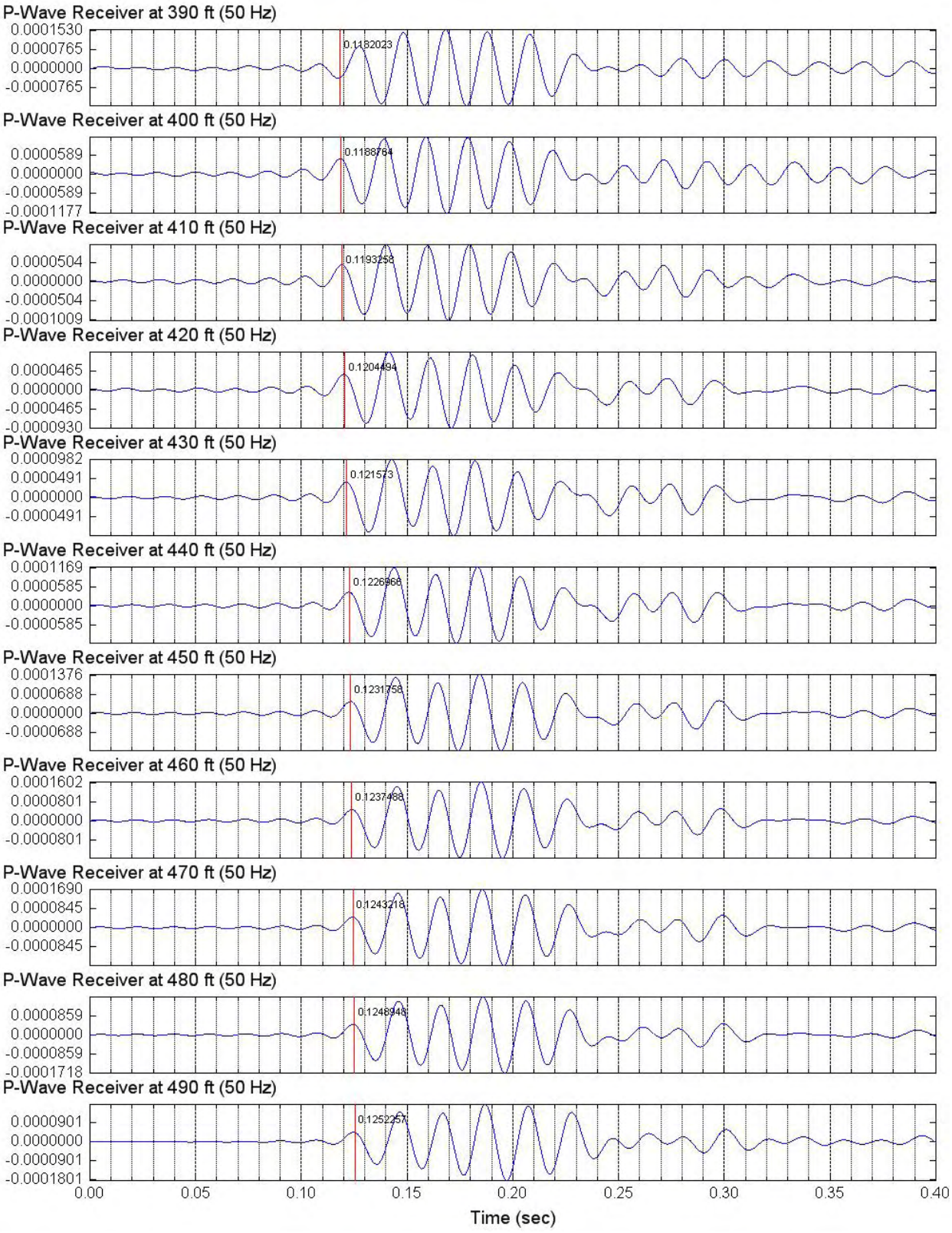


Figure 10.2 Expanded Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 495 to 560 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

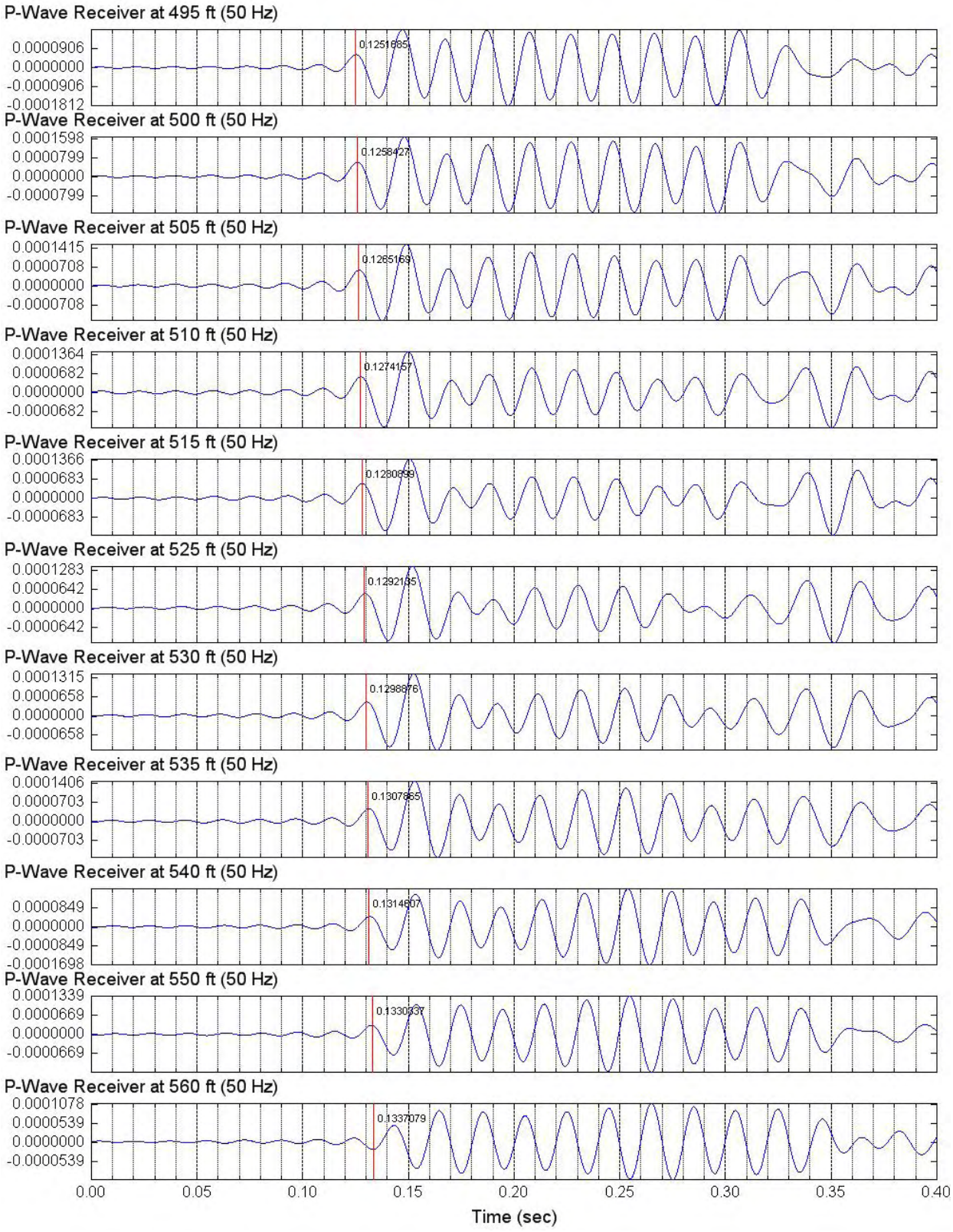


Figure 10.3 Expanded Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 570 to 670 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

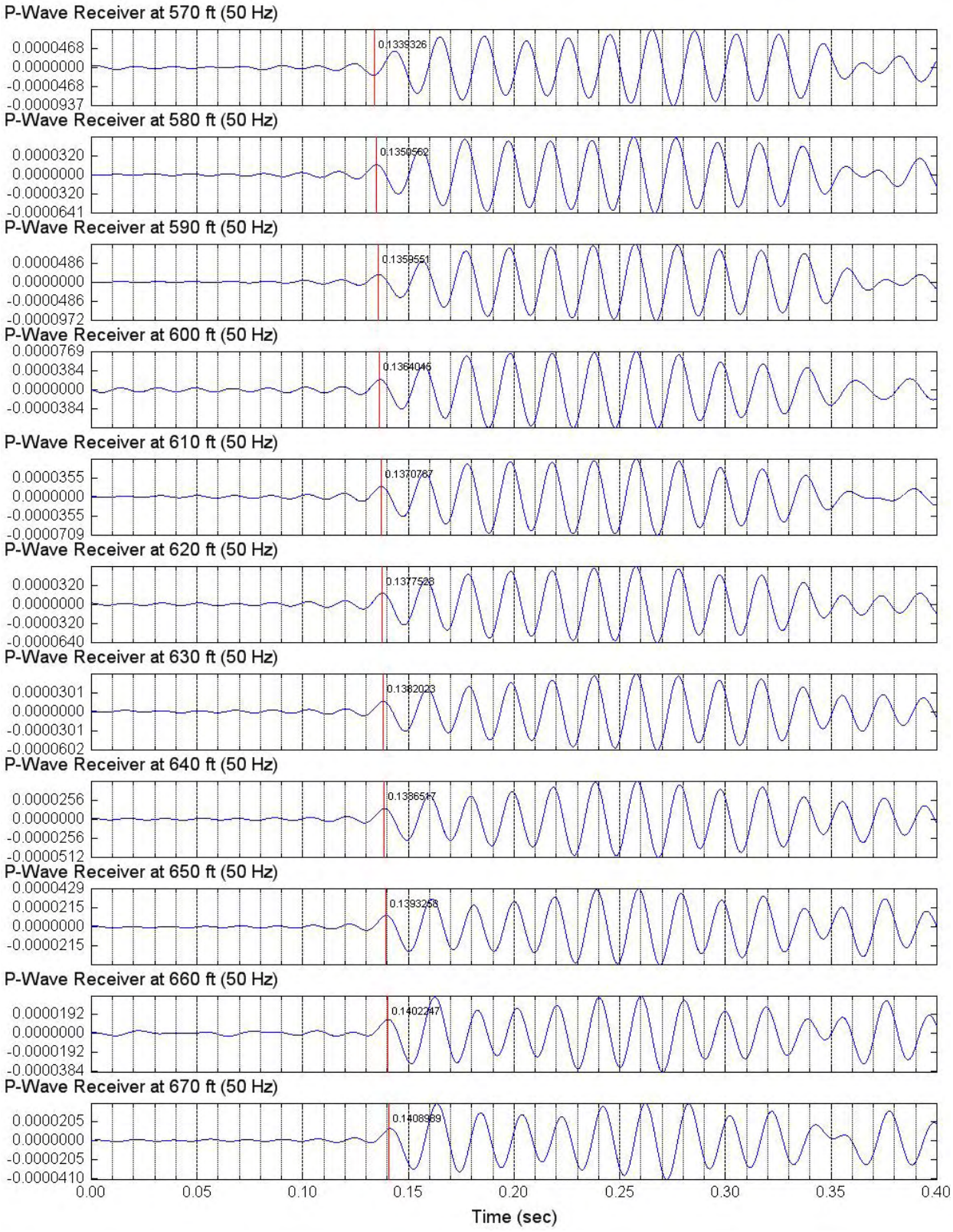


Figure 10.4 Expanded Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 680 to 770 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

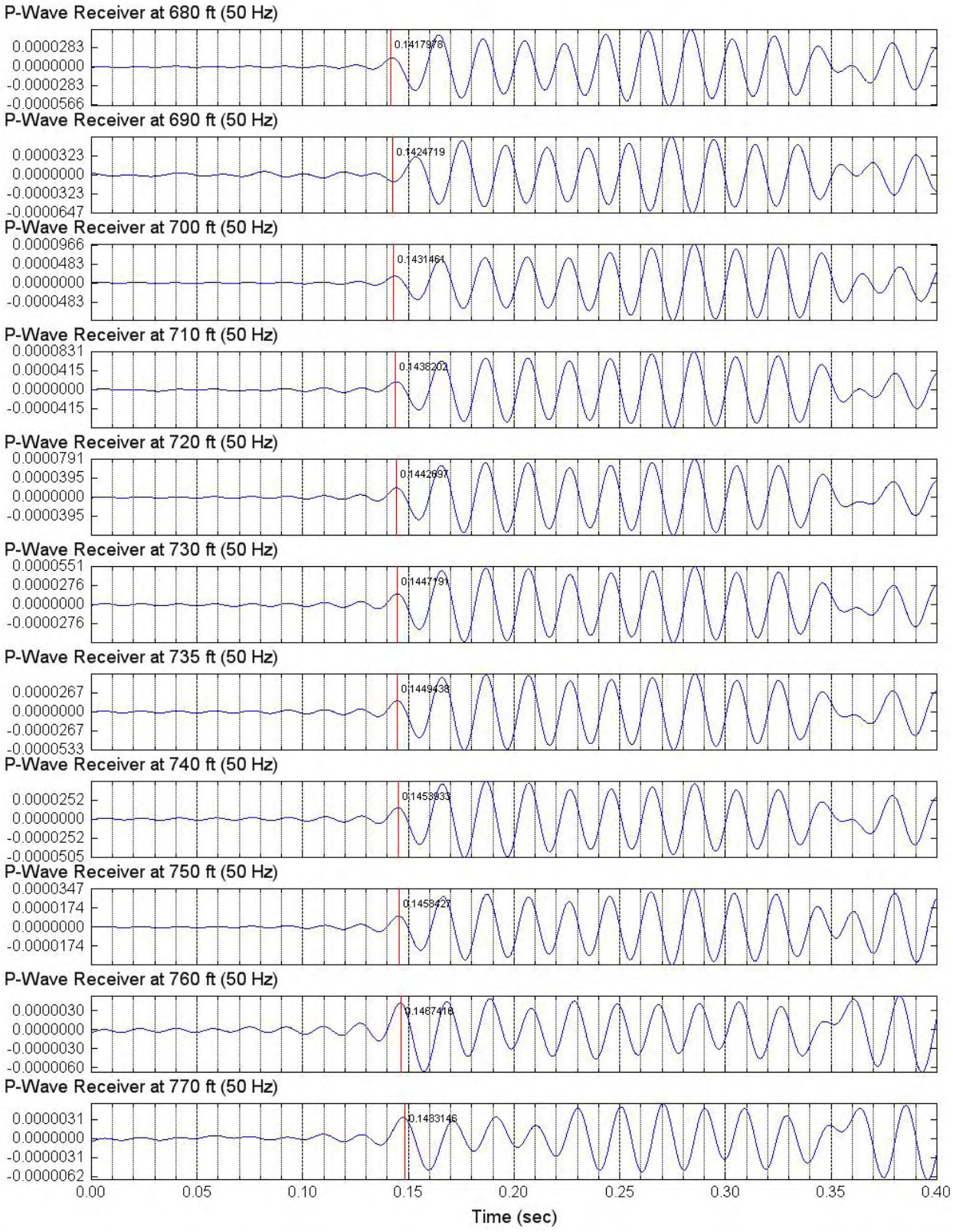


Figure 10.5 Expanded Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 780 to 865 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

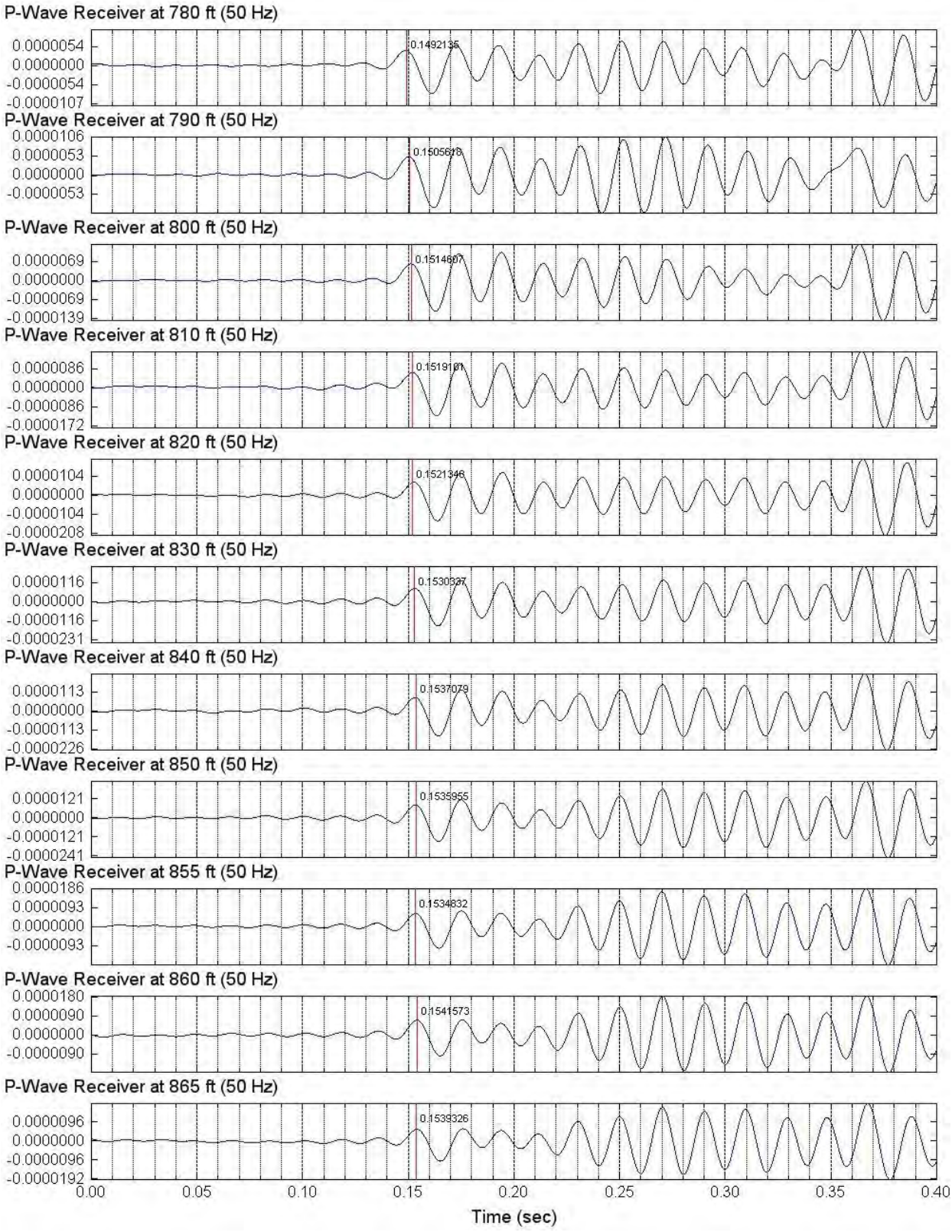


Figure 10.6 Expanded Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 870 to 970 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

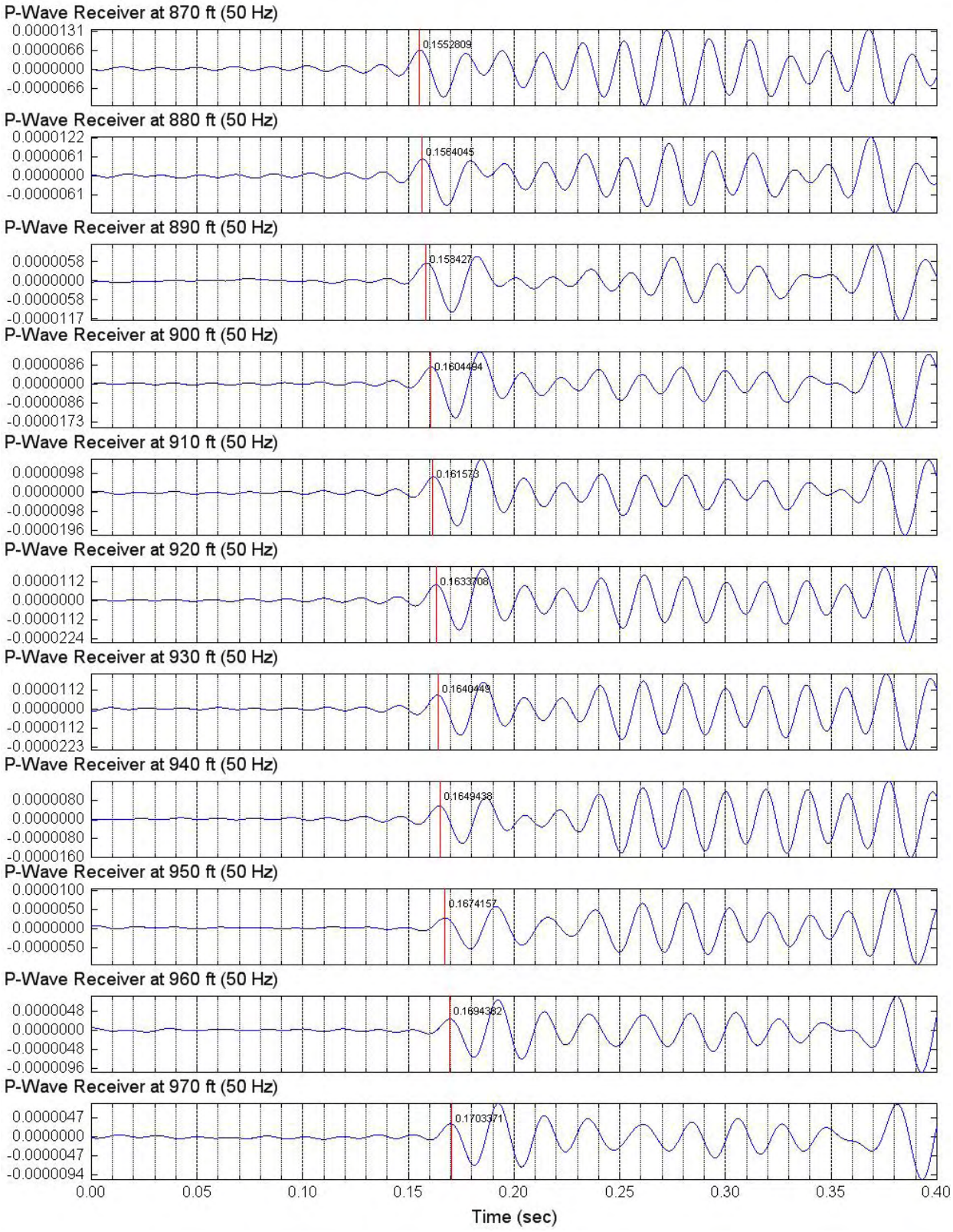


Figure 10.7 Expanded Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 980 to 1080 ft; Input Signal: 10 Cycles of 50-Hz Sine Wave; Low Pass 57 Hz

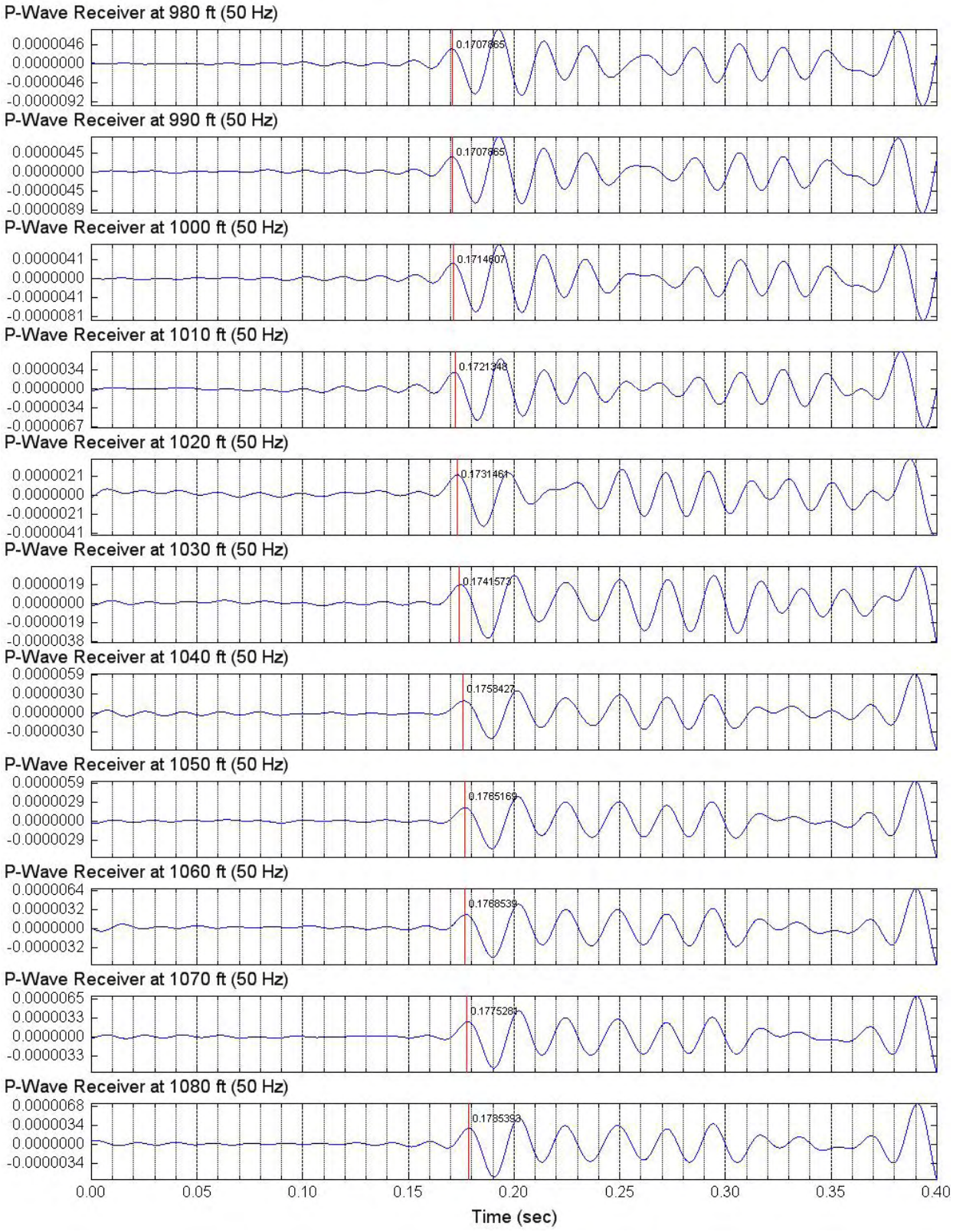


Figure 10.8 Expanded Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 970 to 1110 ft; Input Signal: 4 Cycles of 20-Hz Sine Wave; Low Pass 25 Hz

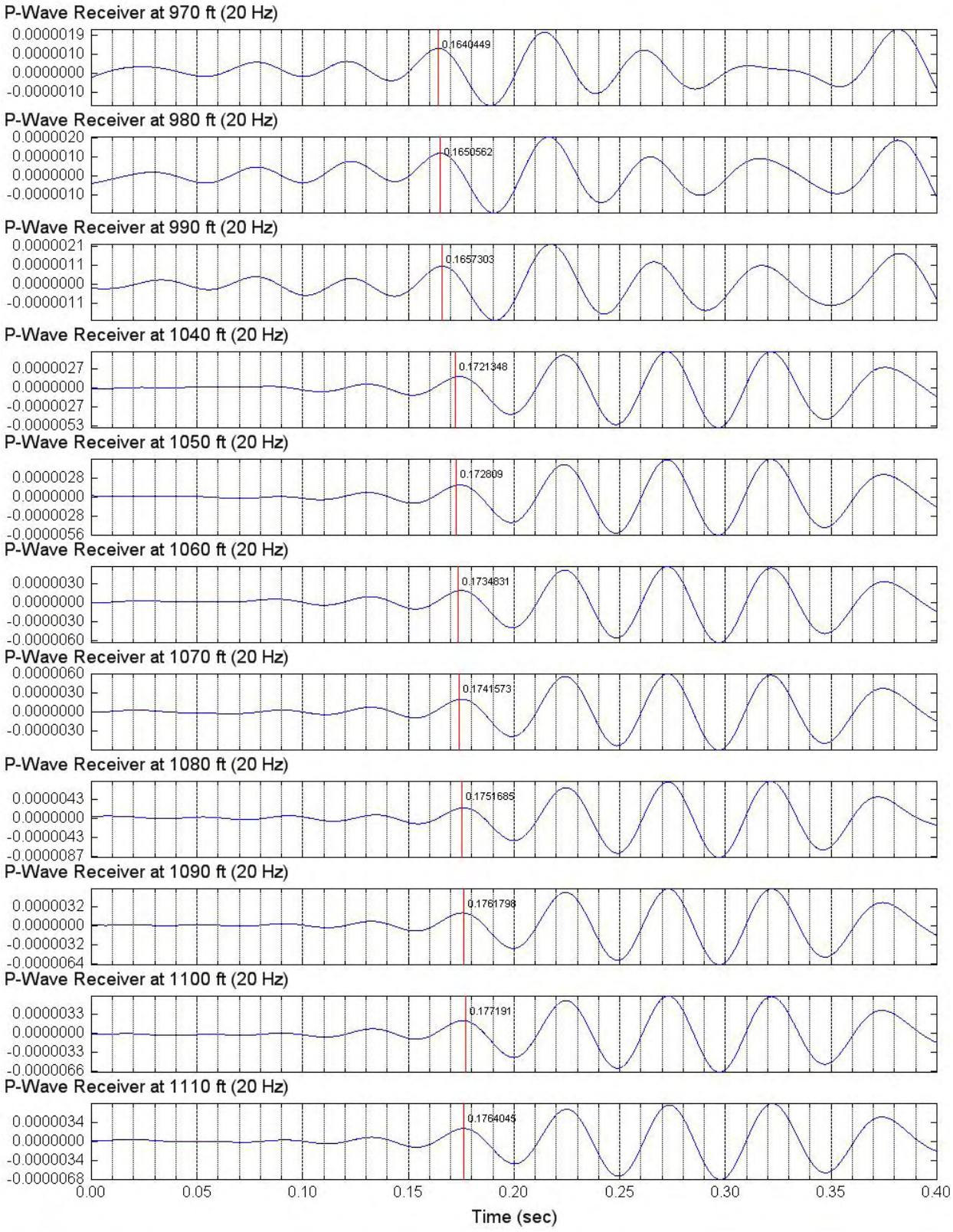
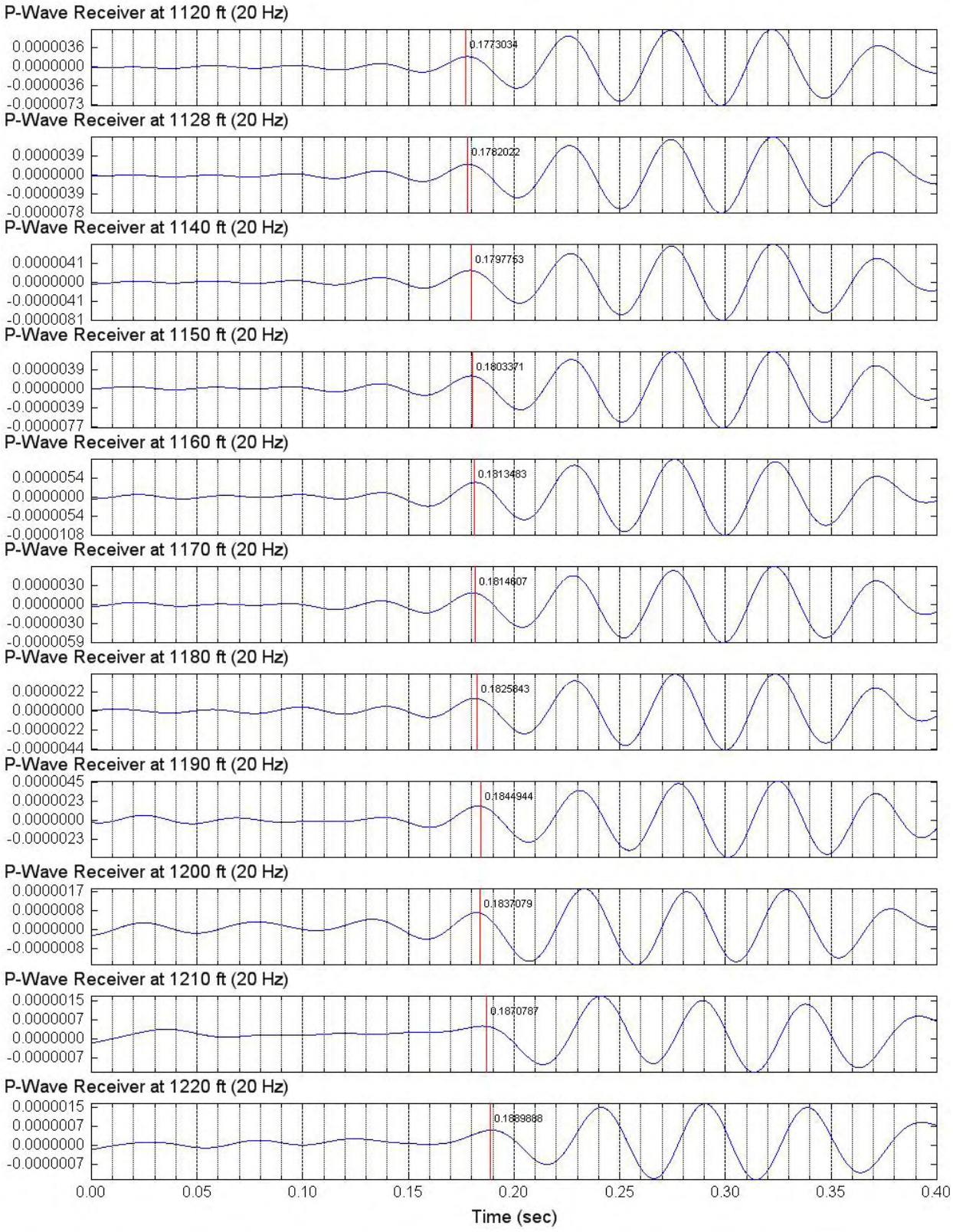


Figure 10.9 Expanded Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 1120 to 1220 ft; Input Signal: 4 Cycles of 20-Hz Sine Wave; Low Pass 25 Hz



Section 11: Waterfall Plots of Unfiltered P-Wave Signals of Lower Vertical Receiver

1. Figures 11.1 to 11.3 present waterfall plots of unfiltered lower vertical receiver (P-wave) signals in Borehole C4997, depths 390 to 1080 ft; input signal is 5 or 10 cycles of 50-Hz sine wave; time shifted by reaction mass acceleration.
2. Figure 11.4 presents the waterfall plot of unfiltered lower vertical receiver (P-wave) signals in Borehole C4997, depths 970 to 1220 ft; input signal is 4 cycles of 20-Hz sine wave; time shifted by reaction mass acceleration.

Figure 11.1 Waterfall Plot of Unfiltered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

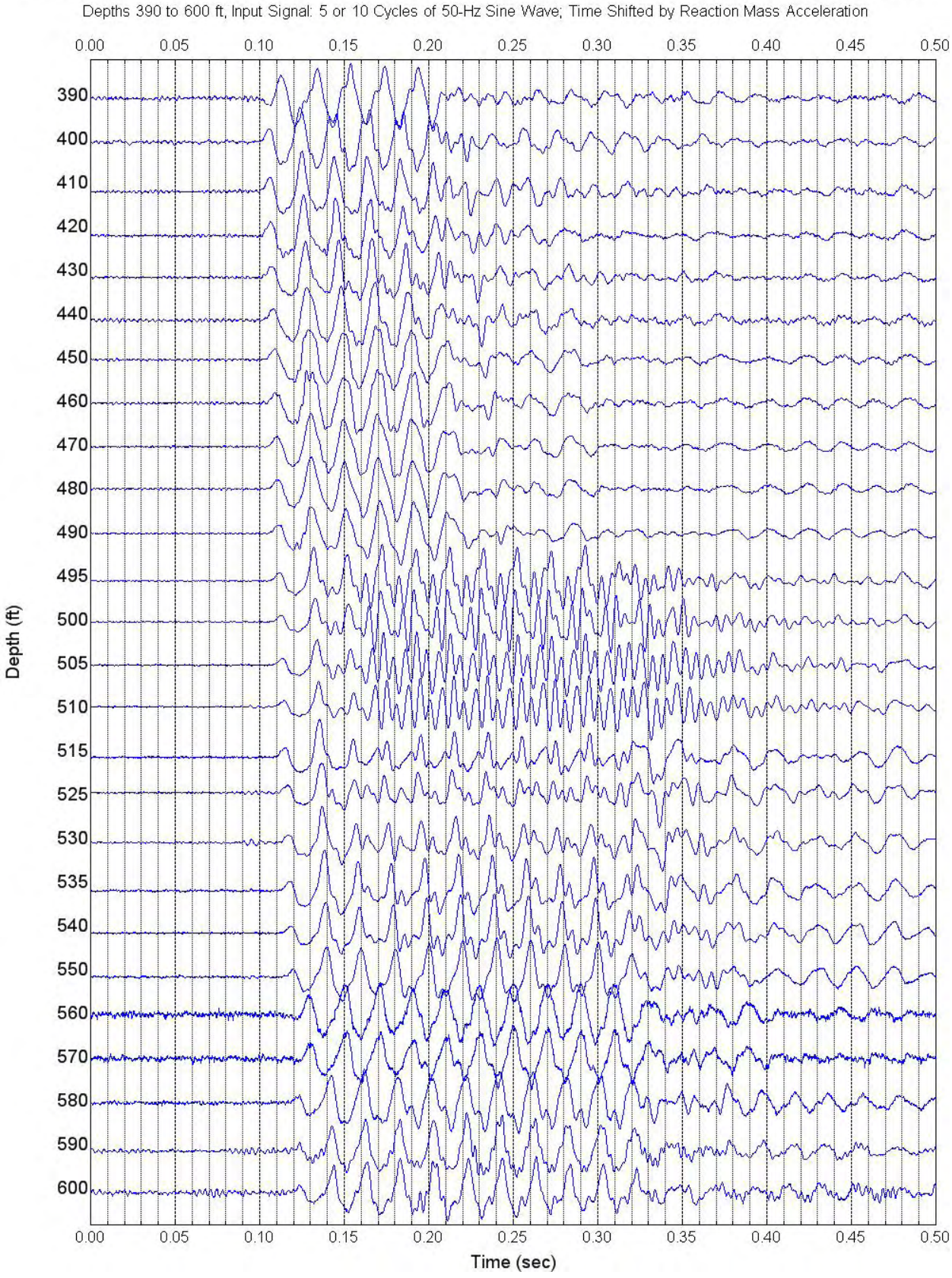


Figure 11.2 Waterfall Plot of Unfiltered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

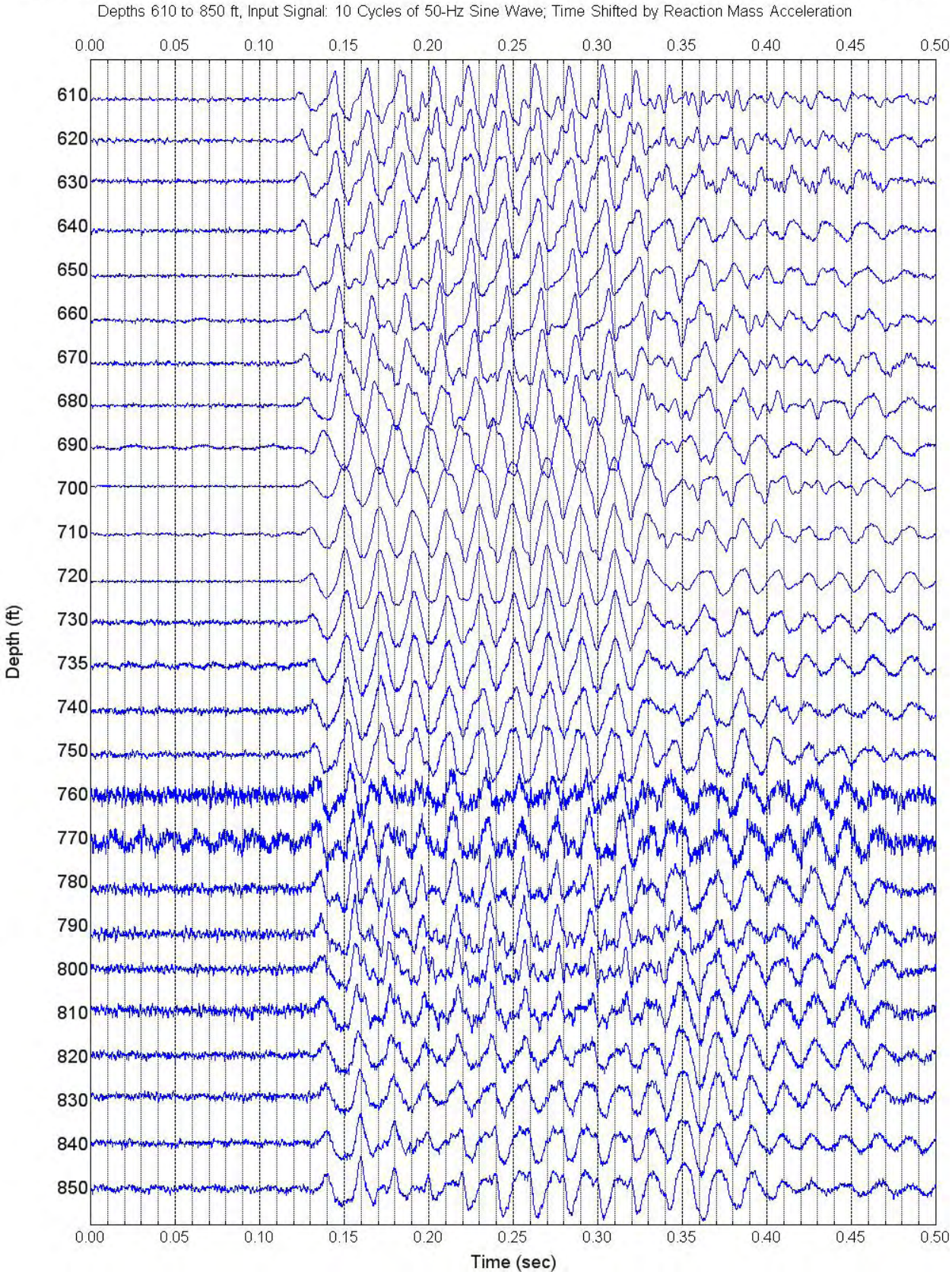


Figure 11.3 Waterfall Plot of Unfiltered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

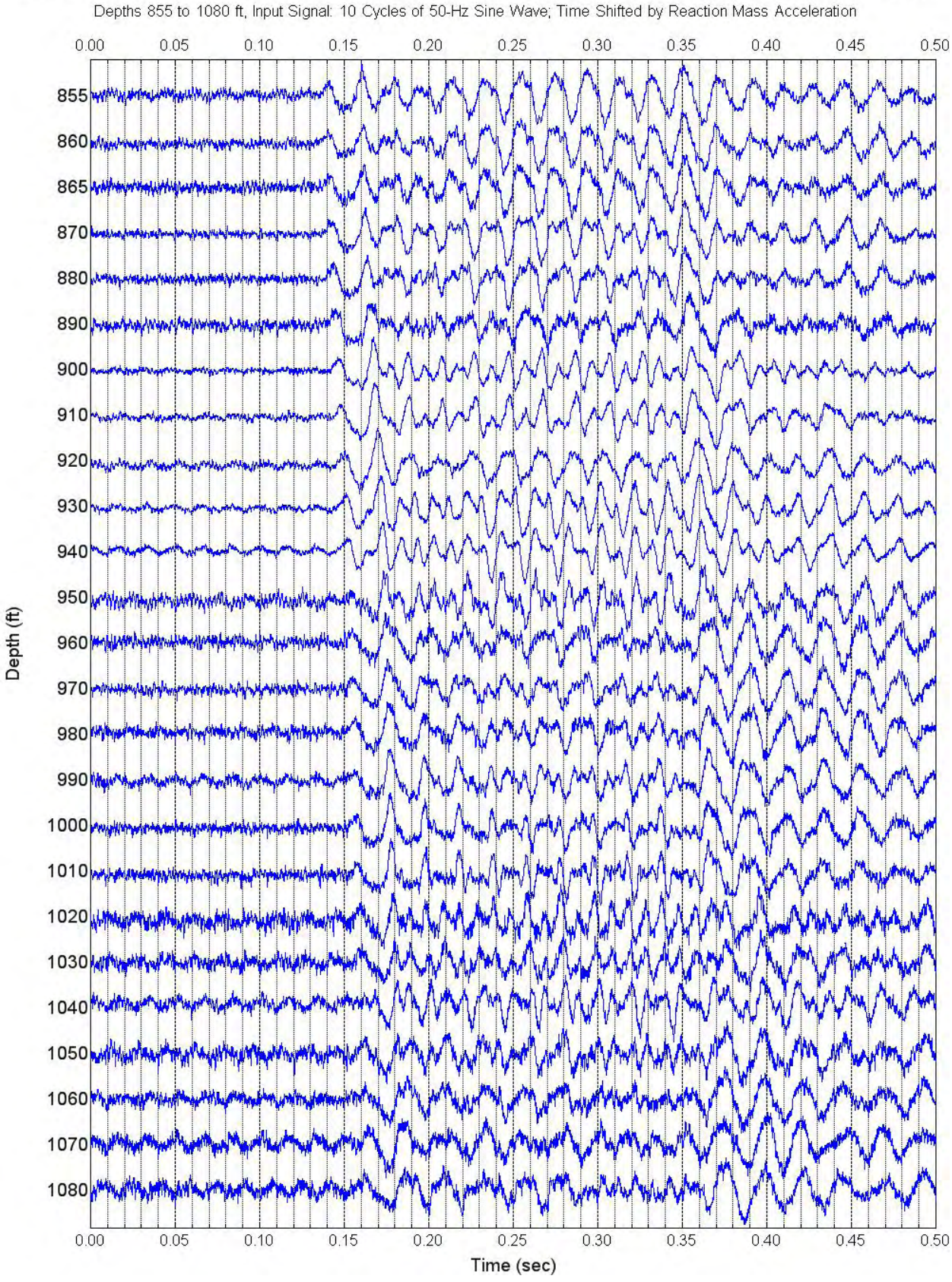
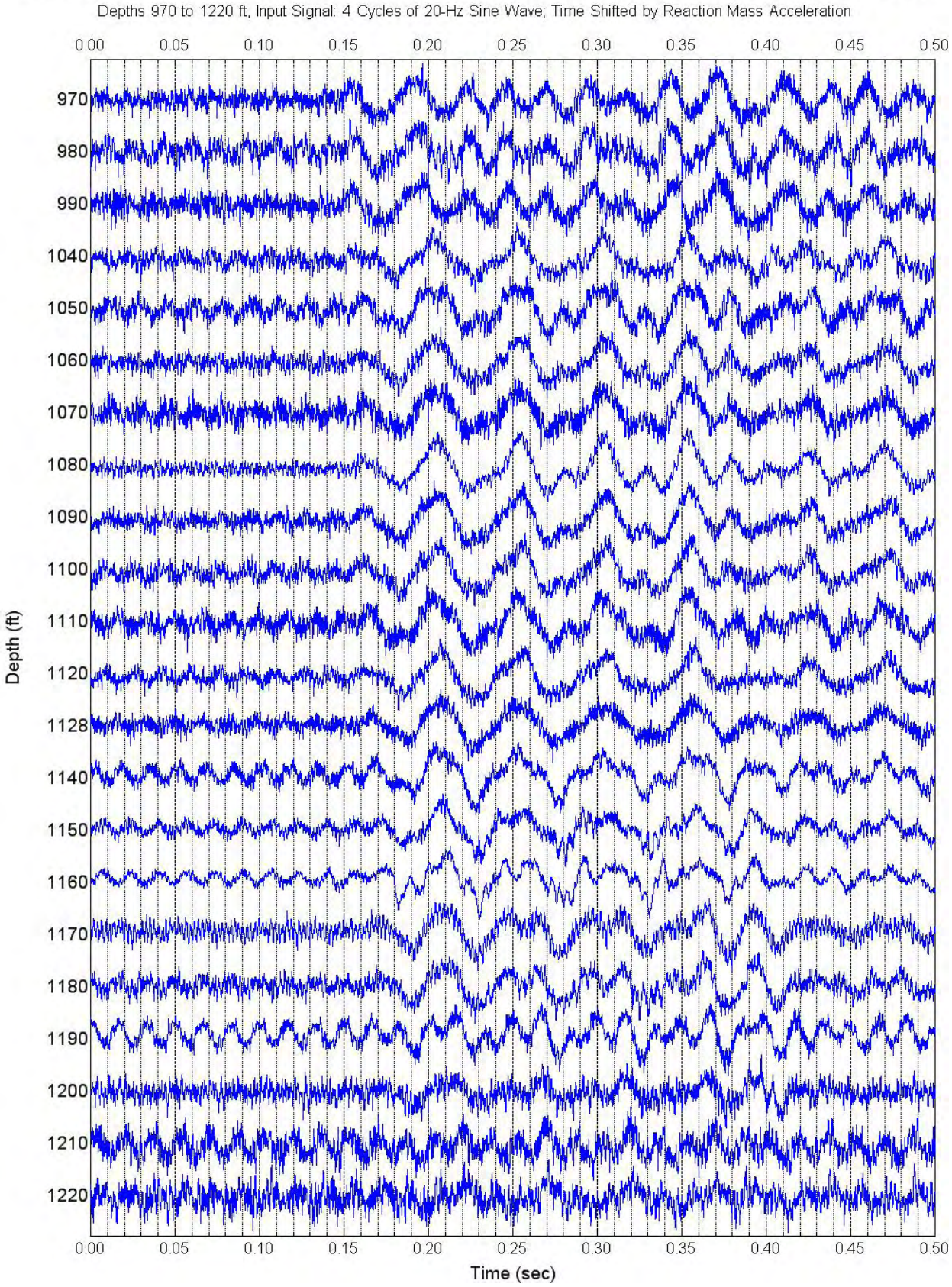


Figure 11.4 Waterfall Plot of Unfiltered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997



Section 12: Waterfall Plot of Filtered P-Wave Signals of Lower Vertical Receiver

1. Figures 12.1 to 12.3 present waterfall plots of filtered lower vertical receiver (P-wave) signals in Borehole C4997, depths 390 to 1080 ft; input signal is 5 or 10 cycles of 50-Hz sine wave; time shifted by reaction mass acceleration, and depth scaled.
2. Figure 12.4 presents waterfall plots of filtered lower vertical receiver (P-wave) signals in Borehole C4997, depths 970 to 1220 ft; input signal is 4 cycles of 20-Hz sine wave; time shifted by reaction mass acceleration, and depth scaled.

Figure 12.1 Waterfall Plot of Filtered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 390 to 600 ft, Input Signal: 50-Hz Sine Wave; Time Shifted by Reaction Mass Acceleration; Low Pass 57 Hz; Depth Scaled

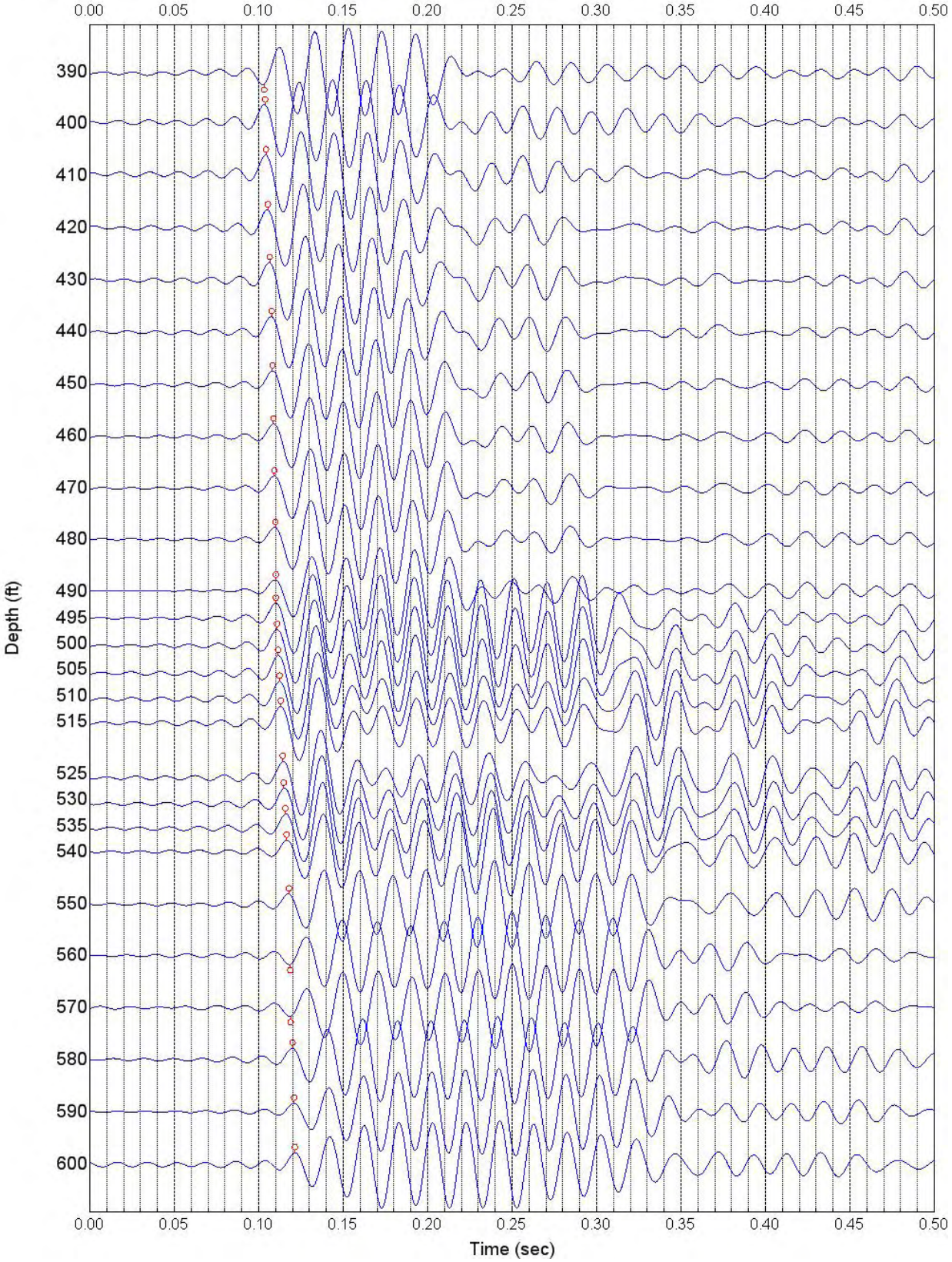


Figure 12.2 Waterfall Plot of Filtered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 610 to 850 ft; Input Signal: 50-Hz Sine Wave; Time Shifted by Reaction Mass Acceleration; Low Pass 57 Hz; Depth Scaled

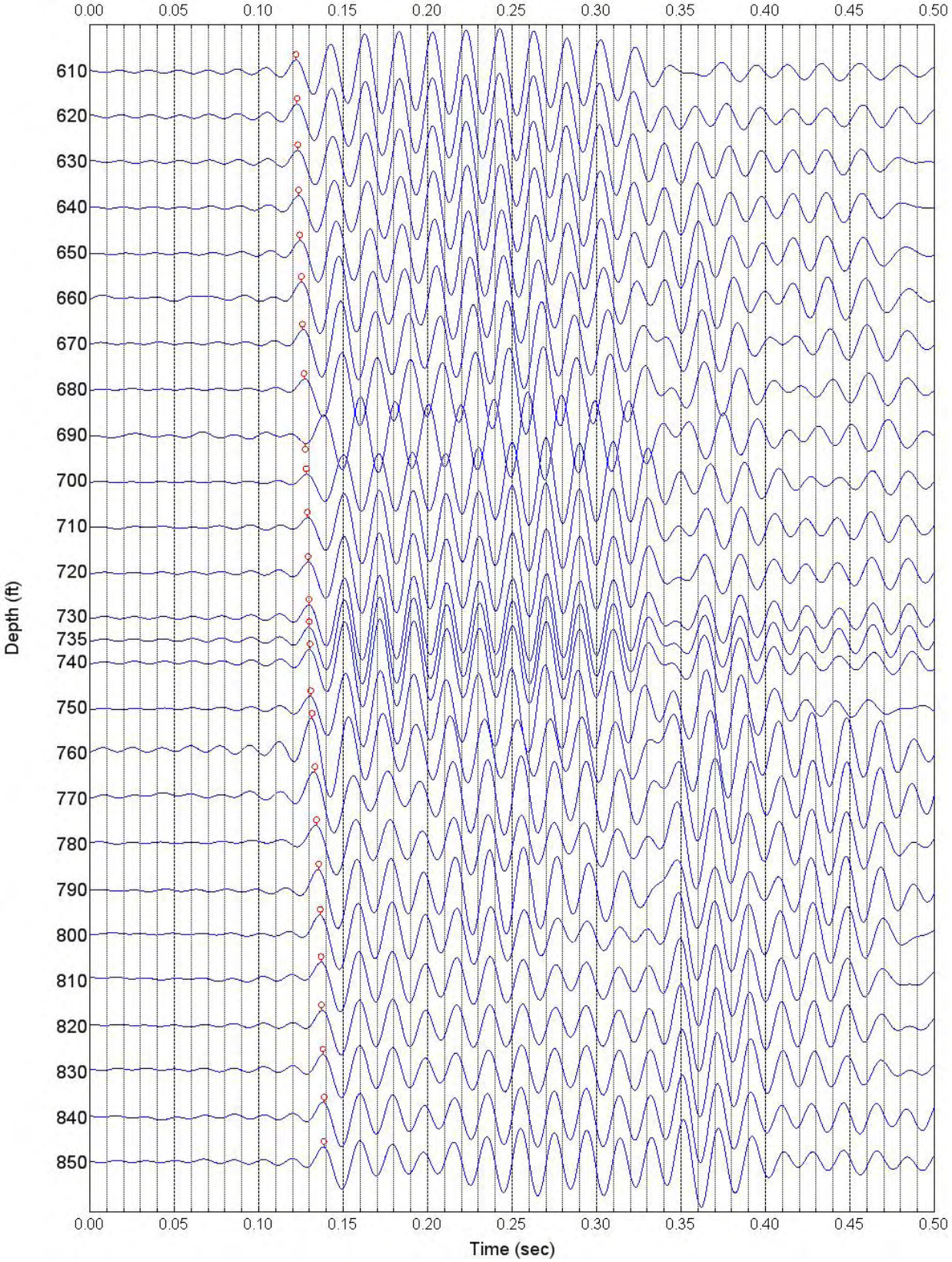


Figure 12.3 Waterfall Plot of Filtered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 855 to 1080 ft; Input Signal: 50-Hz Sine Wave; Time Shifted by Reaction Mass Acceleration; Low Pass 57 Hz; Depth Scaled

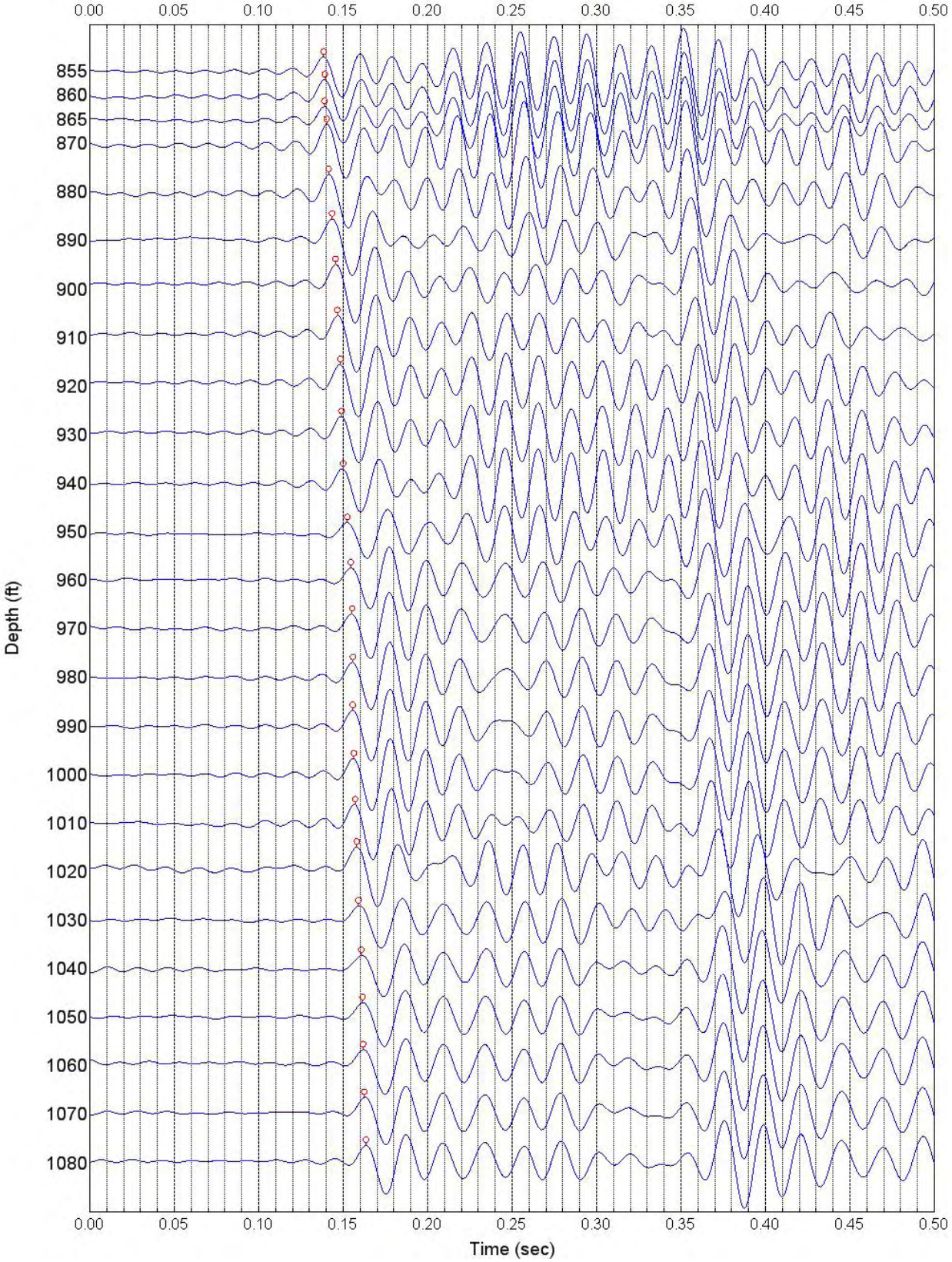
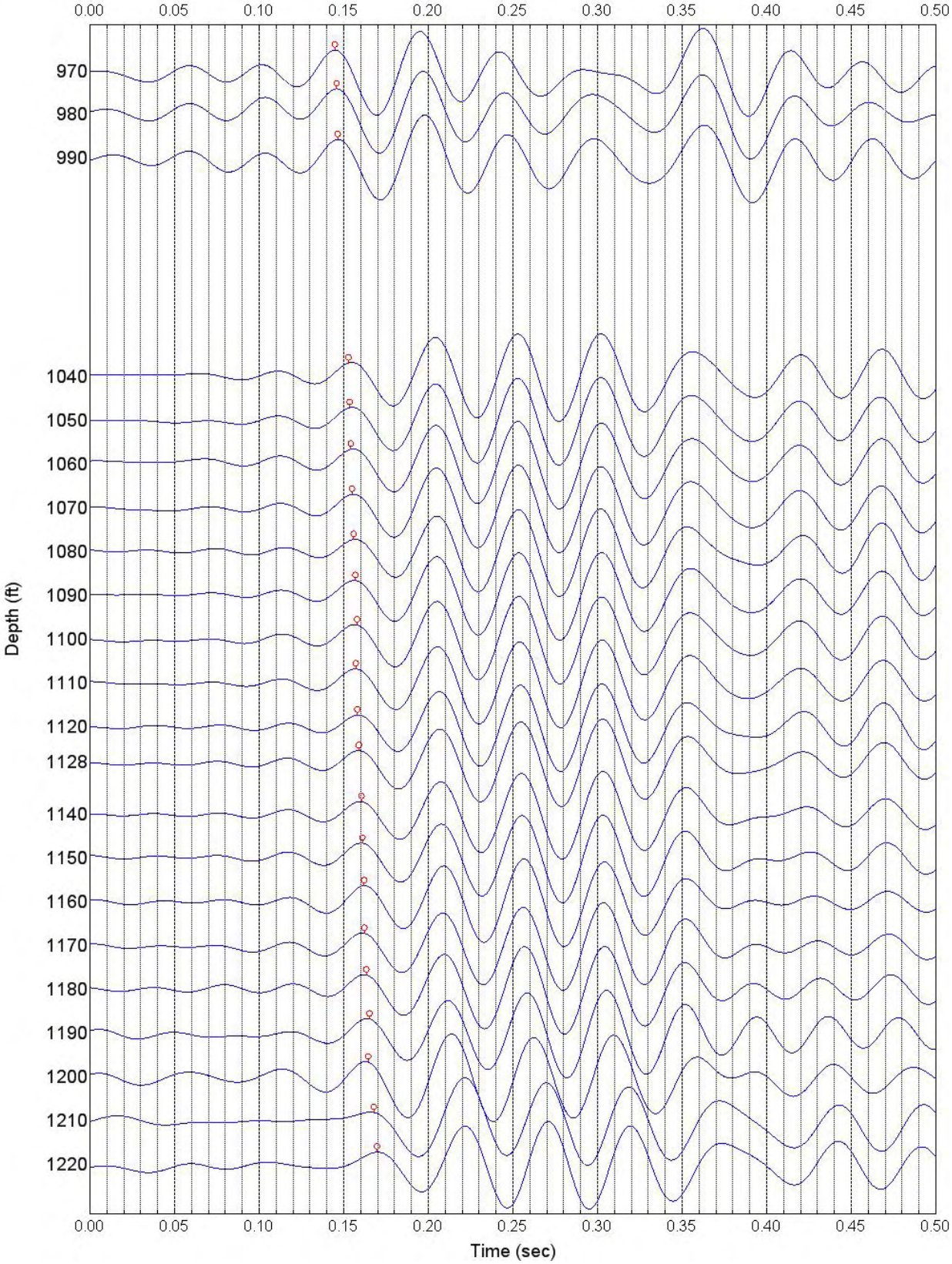


Figure 12.4 Waterfall Plot of Filtered Lower Vertical Receiver (P-Wave) Signals in Borehole C4997

Depths 970 to 1220 ft, Input Signal: 20-Hz Sine Wave; Time Shifted by Reaction Mass Acceleration; Low Pass 25 Hz; Depth Scaled



Section 13 References

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