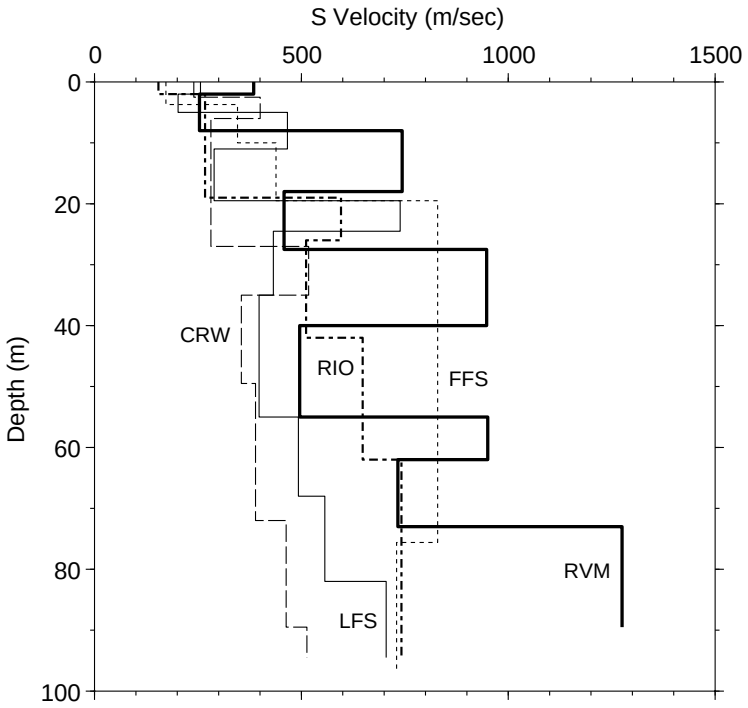
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

BOREHOLE VELOCITY MEASUREMENTS AT FIVE SITES THAT RECORDED THE CAPE MENDOCINO, CALIFORNIA EARTHQUAKE OF 25 APRIL, 1992

by

James F. Gibbs[1], John C. Tinsley[1], and David M. Boore[1]



U.S. Geological Survey Open-File Report OF 02-203

[1]Menlo Park, CA 94025

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INTRODUCTION

The U.S. Geological Survey (USGS), as part of an ongoing program to aquire seismic velocity and geologic data at locations that recorded strong-ground motion during earthquakes, has investigated five sites in the Fortuna, California region (Figure 1). We selected drill sites at strong-motion stations that recorded high accelerations (Table 1) from the Cape Mendocino earthquake (**M** 7.0) of 25 April 1992 (Oppenheimer *et al.*, 1993). The boreholes were drilled to a nominal depth of 95 meters (310 ft.) and cased with schedule 80 pvc-casing grouted in place at each location. S-wave and P-wave data were acquired at each site using a surface source and a borehole three-component geophone. This report contains the velocity models interpreted from the borehole data and gives reference to locations and peak accelerations at the selected strong-motion stations.

P- AND *S*-WAVE TRAVEL-TIME DATA

Shear waves were generated at the ground surface by an air-powered horizontal ram (Liu *et al.*, 1988) striking an anvil at either end of an aluminum channel 2.3 m long. The ram was driven first in one direction and then in the other to generate pulses of opposite polarity. A switch attached to the shear source triggered the recorder and established the reference for the timing of arrivals. *P*-waves were generated by striking a steel plate with a sledge hammer. The recorder was triggered by a switch attached to the handle of the sledge hammer. *P*- and *S*-wave sources were offset from the borehole (same horizontal distance but different locations) to minimize the effect of waves traveling down the grout surrounding the casing. The source offset was 4 meters except at Rio Dell where available space limited the offset to 3.5 meters. These offsets are shown in the data tables.

Downhole measurements were made at 2.5 m intervals (starting at 2 meters depth) with a three-component geophone clamped to the casing by an electrically-activated lever arm. A second three-component geophone was placed on the surface 5 to 10 m from the shear source for recording an on-scale reference trace (useful for amplitude studies and timing verification). The data were recorded on diskettes using a 12-channel recording system.

VELOCITY PROFILES

The procedure for determining velocities is summarized in Figure 2. Because the orientation of the downhole geophone could not be controlled when moving from one depth to the next, the azimuth of the horizontal geophones relative to the source was unknown and changed with depth. To minimize the effects of those changes, the horizontal components were rotated to the direction that maximized the integral square amplitude within a time interval containing the shear wave (Boatwright *et al.*, 1986). *P*- and *S*-wave first-arrival times were determined from the time series displayed at each depth on a 20-inch computer screen. The *P*-wave arrival-time was obtained from the vertical trace, and the *S*-wave

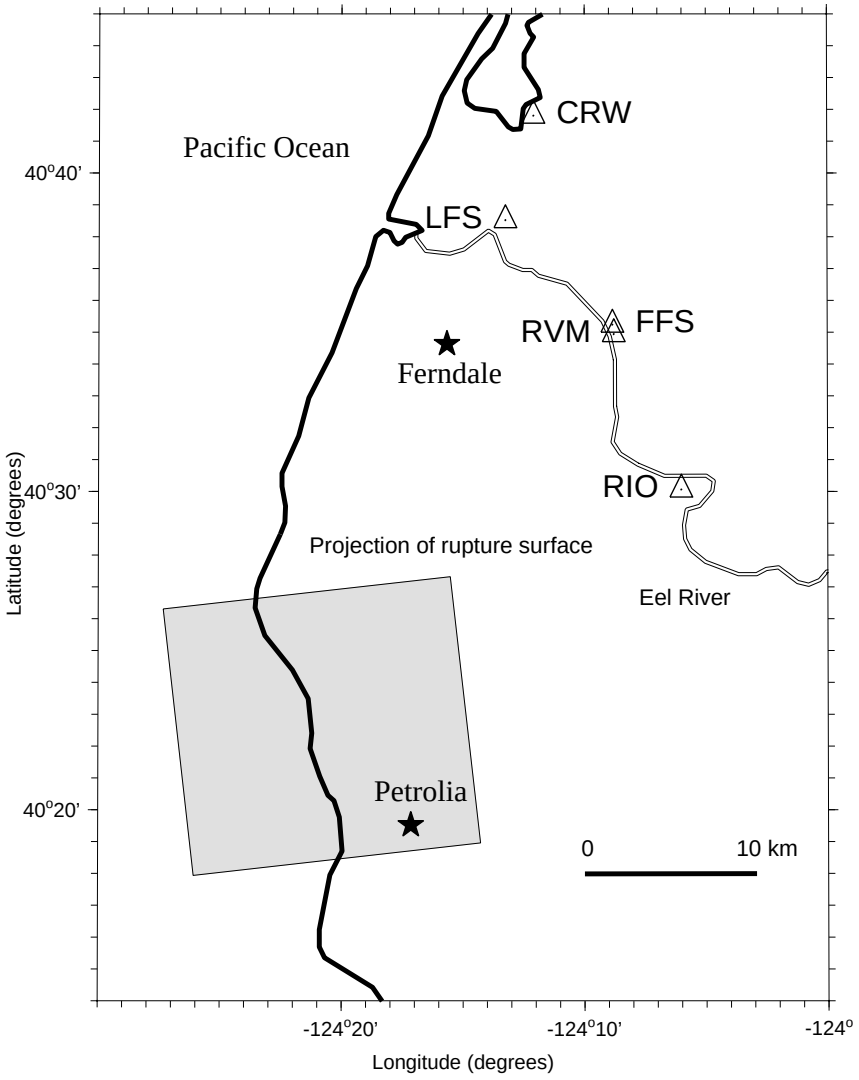

Figure 1. Regional map showing the locations of boreholes (triangles) included in this report. LFS and RIO are in the towns of Loleta and Rio Dell, respectively, and RVM and FFS are in the town of Fortuna. Locations of river and coastline are approximate. The projection of the fault rupture for the 1992 Cape Mendocino mainshock (shaded) corresponds to model B of Murray *et al.* (1996).

Table 1. Site names, station codes, coordinates using North American Datum of 1927 (NAD27) and 1983 (NAD83), and peak horizontal accelerations.

Station Name	StaCode	Lat:NAD27	Long:NAD27	Lat:NAD83	Long:NAD83	pga (cm/s^2)
College of the Redwoods	CRW	40.69913	-124.20045	40.69898	-124.20162	171
Fortuna Fire Station	FFS	40.58969	-124.14630	40.58954	-124.14746	349
Loleta Fire Station	LFS	40.64438	-124.21976	40.64423	-124.22093	252
Redwood Village Mall (Fortuna)	RVM	40.58472	-124.14538	40.58457	-124.14654	114
Rio Dell	RIO	40.50334	-124.09913	40.50320	-124.10029	539

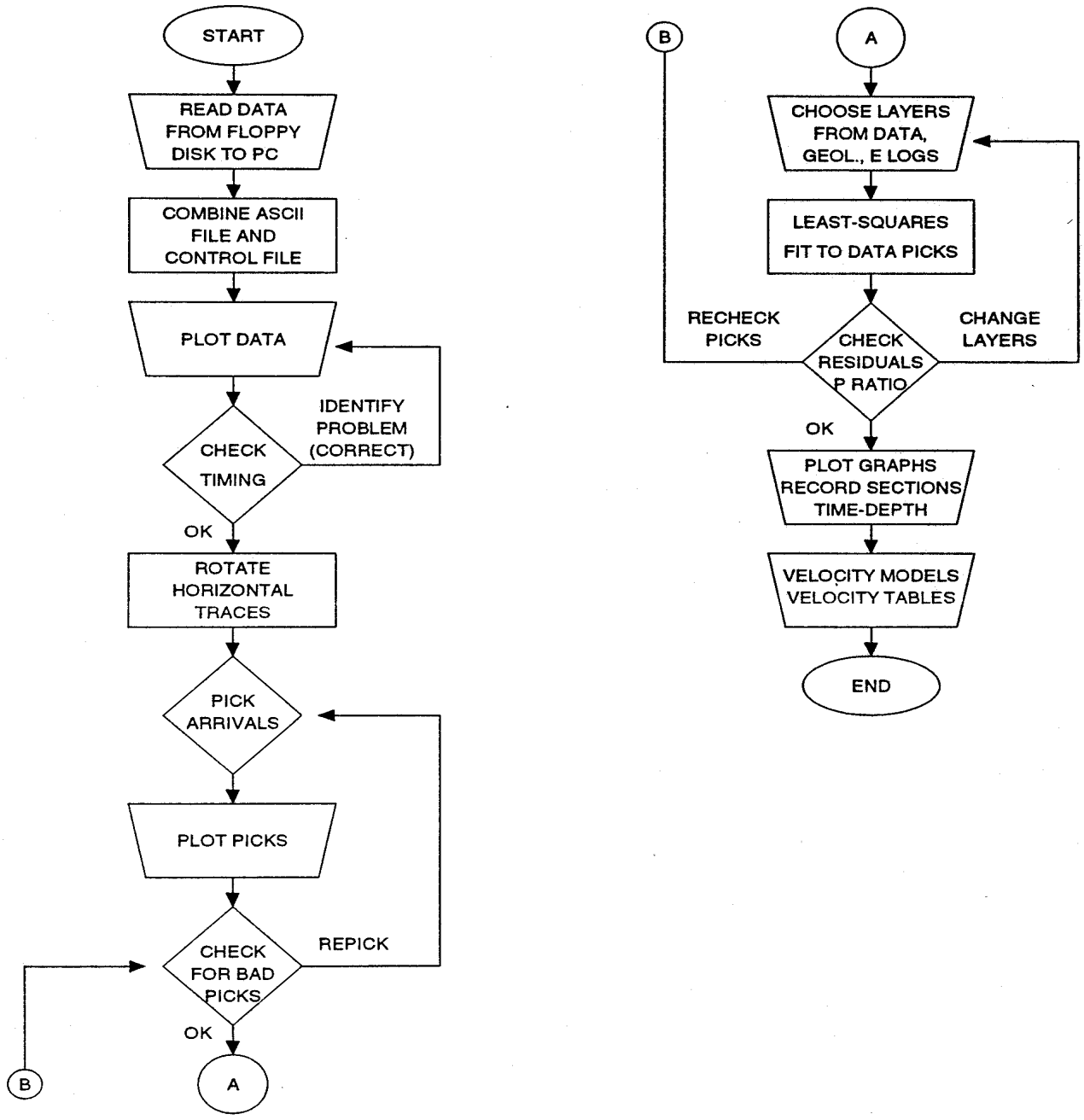

Figure 2. Flow-chart outlining the data processing and steps in the interpretation.

arrival-times were obtained from the average of the rotated horizontal traces for ram strikes in opposite directions. The arrivals were timed to the nearest millisecond, probably a realistic precision for clear arrivals uncontaminated by noise.

A trial set of layer boundaries was chosen for the S-wave model, based on the lithologic descriptions and geophysical logs. The travel-time data were fit in a least-squares sense by a model made up of constant velocity layers, taking into account refraction across the interfaces between layers. The travel times were weighted by the inverse of an assigned normalized variance. A normalized standard deviation of 1 was assigned to the clear arrivals and values up to 5 were assigned to the others. The residuals were examined, and layer boundaries were added, if necessary, to reduce large residuals or to remove systematic trends in the residuals. This was an iterative process conducted by the team of authors of this report. The process continued until the team was satisfied that the interfaces were consistent with the borehole seismic data as well as available geological and geophysical logs. The P-wave travel time data were analyzed initially with the set of layer boundaries finally determined for the S-wave data. Layer boundaries were then added if needed to fit the data and deleted if not needed. Commonly, an additional layer boundary corresponding to the top of the zone of water saturation was needed to fit the P-wave data.

Some of the dynamic Poisson's ratios σ, calculated with initial velocity models, resulted in ratios that were out of the accepted range of values (0.0–0.5). To obtain a value in the acceptable range we made minor adjustments to the velocities using one or more of the following procedures: repicking shallow arrivals (usually P arrivals because small changes in P travel-times have greater effect on σ), adding a shallow layer, and/or adjusting layer thickness to ensure that Poisson's ratio was in the range 0.0–0.5. In most cases the small changes were made in the P-wave velocities at shallow depths (for more details see, Gibbs *et al.*, 2000). Overall, the changes in velocity required to produce acceptable values of σ were small and were only in a few layers.

SUMMARY VELOCITY PROFILES

Figures 3 and 4 show the S- and P-wave velocity profiles determined from the borehole measurements at the five sites. The velocity profiles are plotted at the same scale for ease of comparison.

DESCRIPTION OF APPENDICES

Appendix A contains for each site: a location map, S- and P-wave time-series records, a time-depth plot, velocity profiles with a generalized geologic log, and tables giving arrival times and velocity values. The upper and lower bounds on the velocity plots show approximate 68 percent confidence limits. The bounds are not symmetrical because they are based on the inverse velocities in the layers. Appendix B contains tables of P- and S-wave velocity models and the Poisson's ratios obtained from those models.

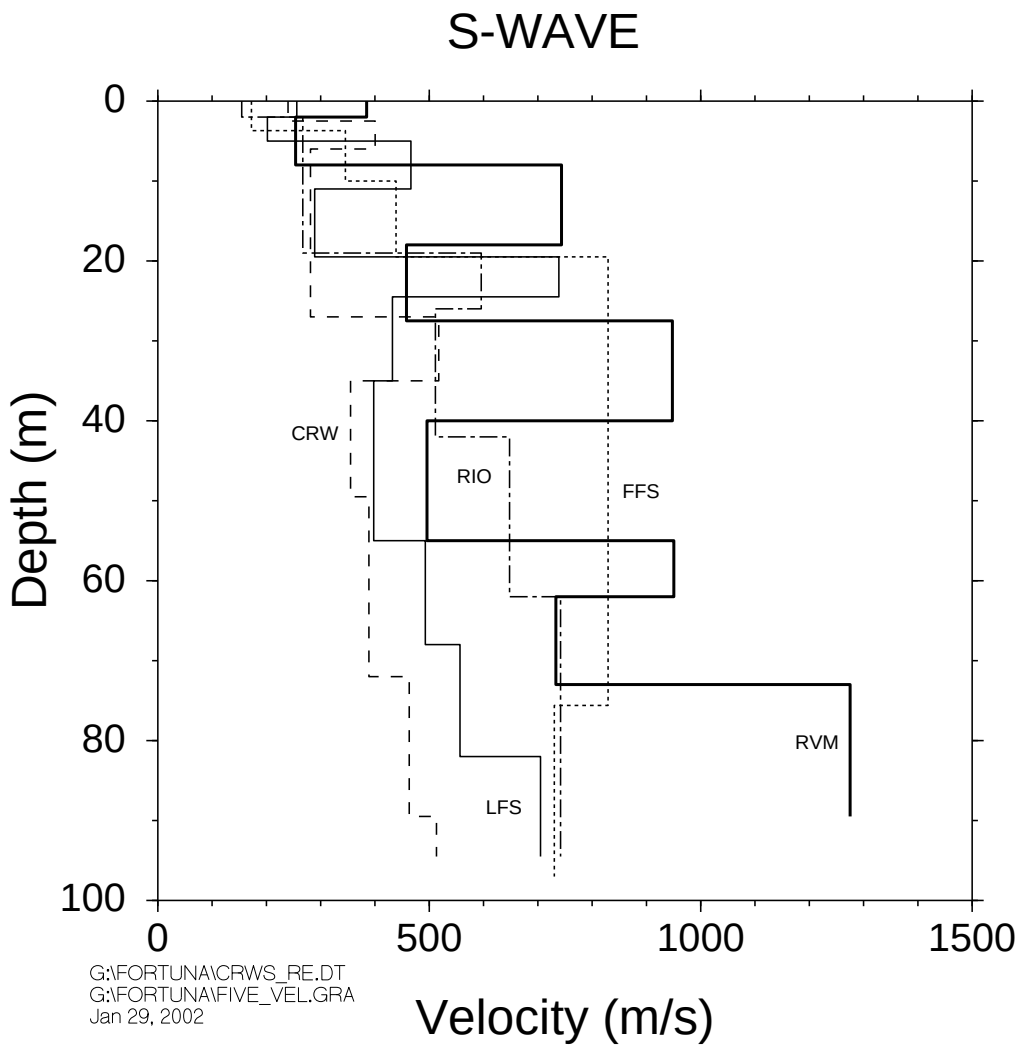

Figure 3. S-wave velocity models from all five boreholes (see Figure 1, Table 1) shown on the same figure for comparison.

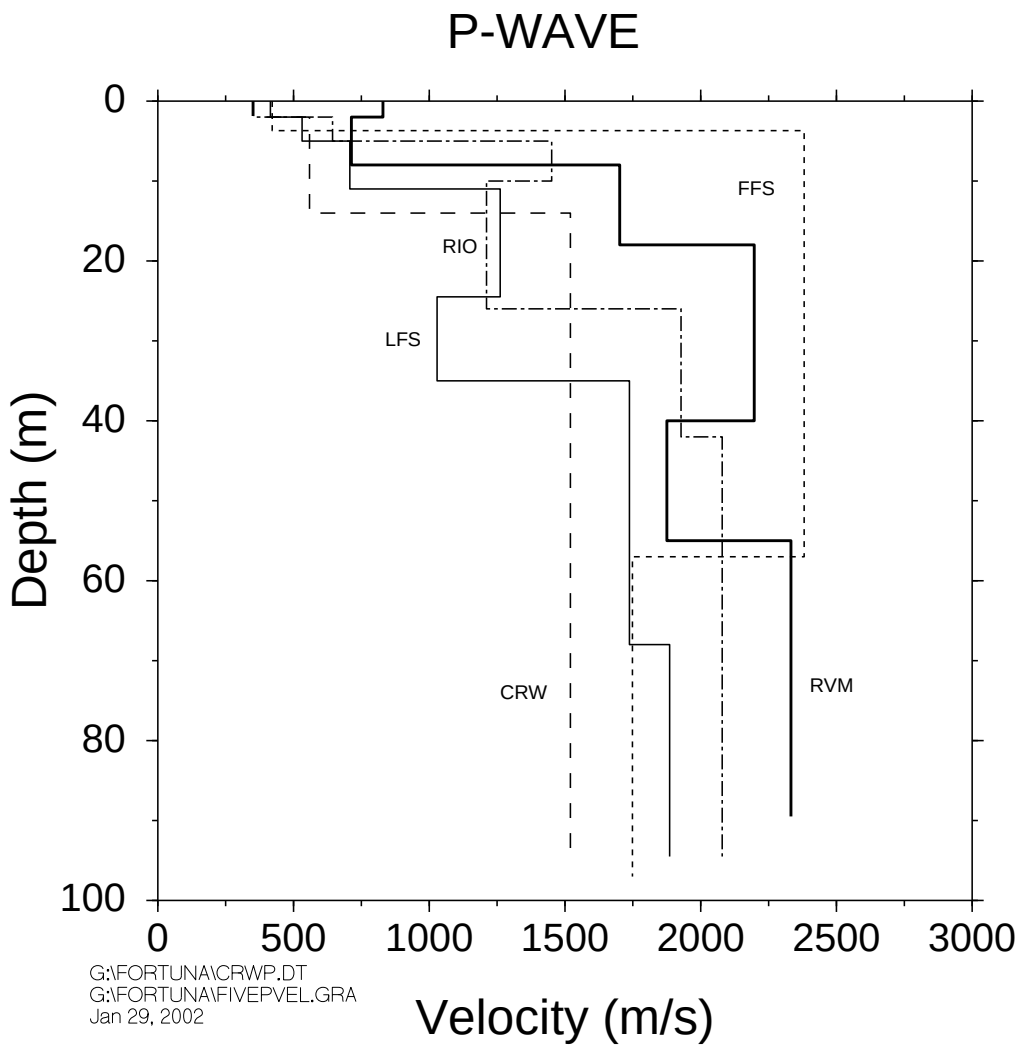

Figure 4. S-wave velocity models from all five boreholes (see Figure 1, Table 1) shown on the same figure for comparison.

ACKNOWLEDGMENTS

We could not have completed these studies without the assistance of many individuals who helped us to gain access to the sites, assisted with utilities clearances and granted permission to conduct the studies. We thank Tom Fumal for his careful review of the manuscript.

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APPENDIX—A

Detailed Results

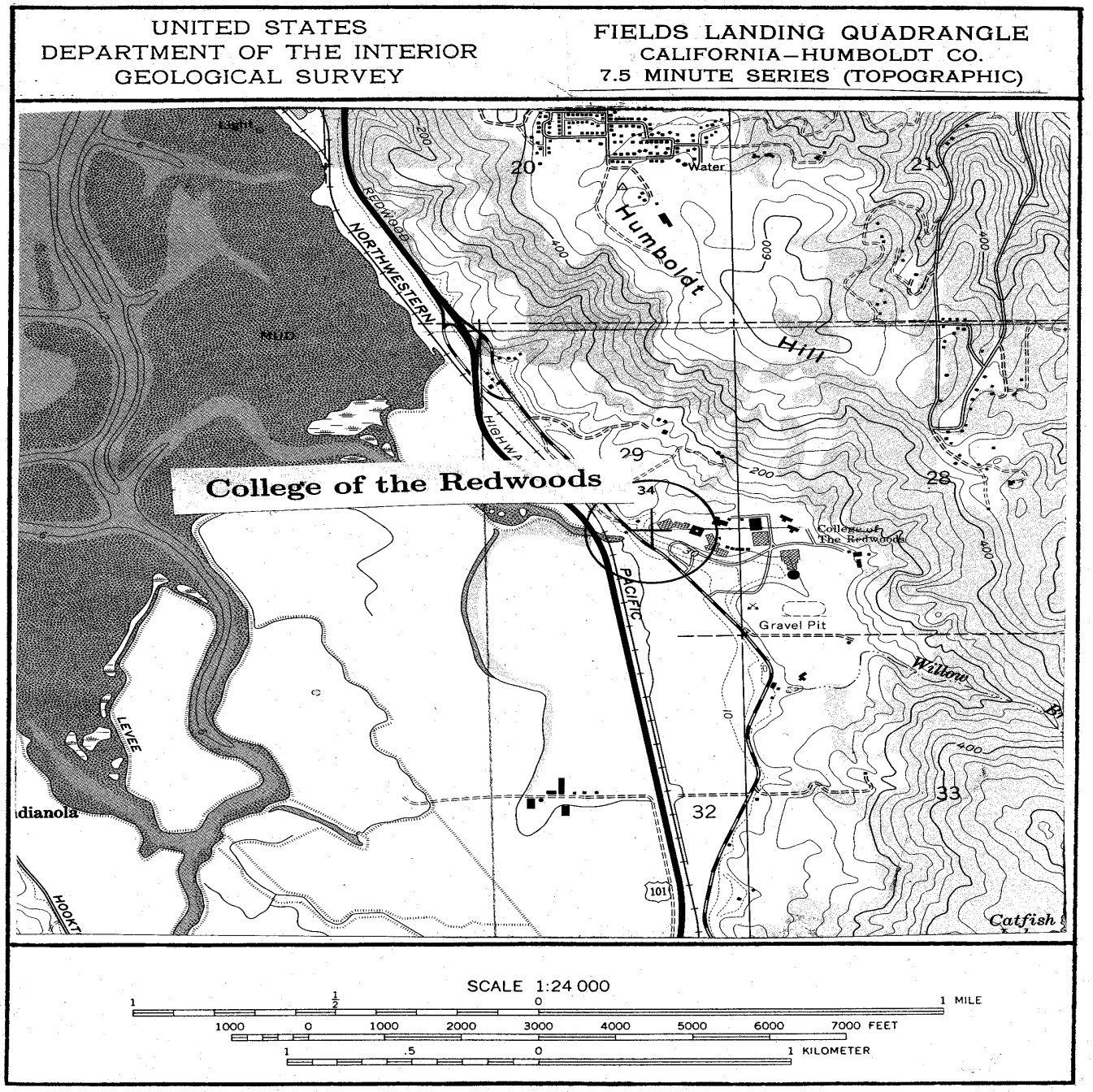

Figure A-1. Site location map for the borehole at College of the Redwoods. The accelerograph is located approximately 30 meters from the borehole.

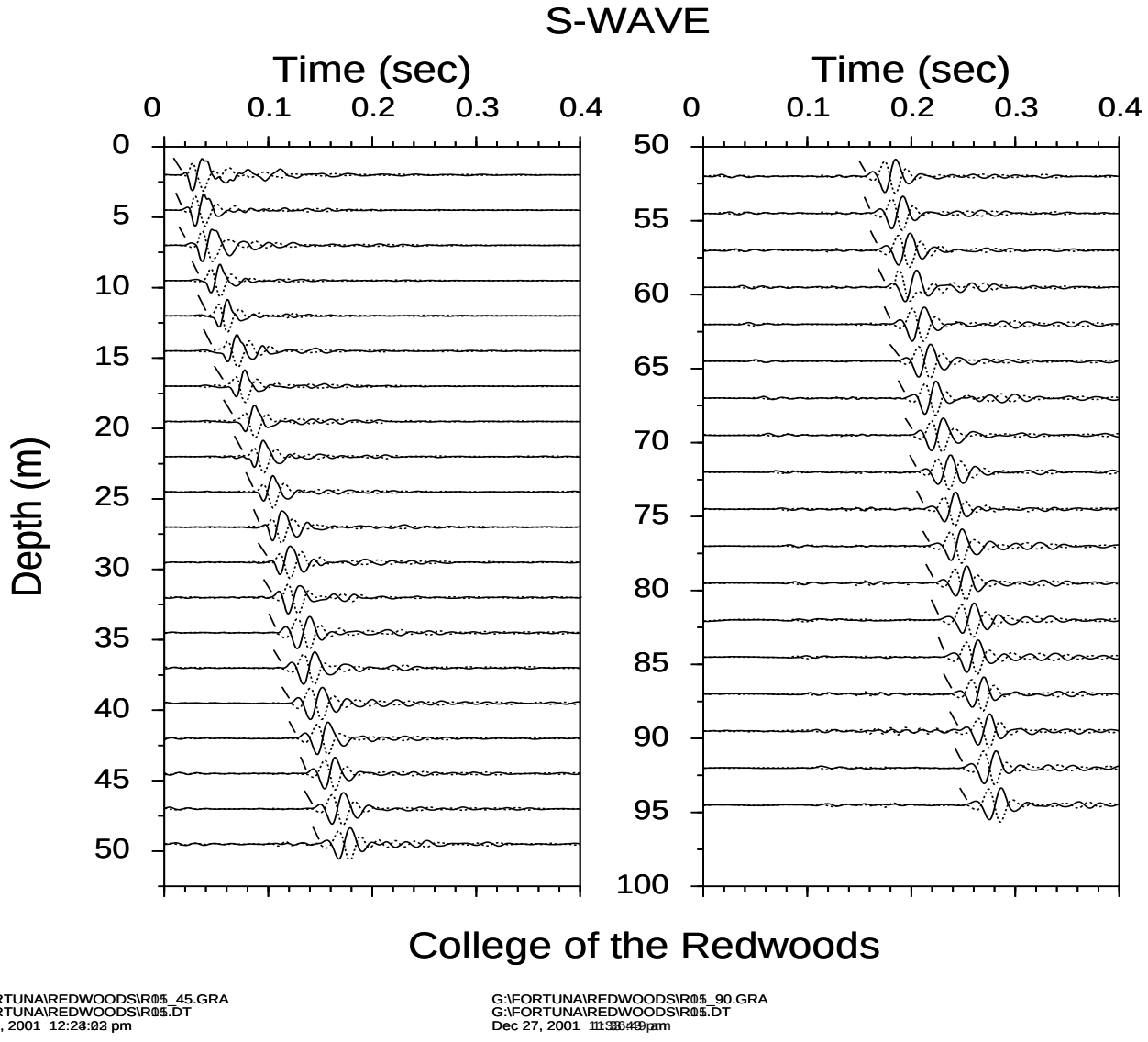

Figure A-2. Horizontal component record section (from impacts in opposite directions) superimposed for identification of S-wave onset. Approximate S-wave time picks are indicated by the hatch marks.

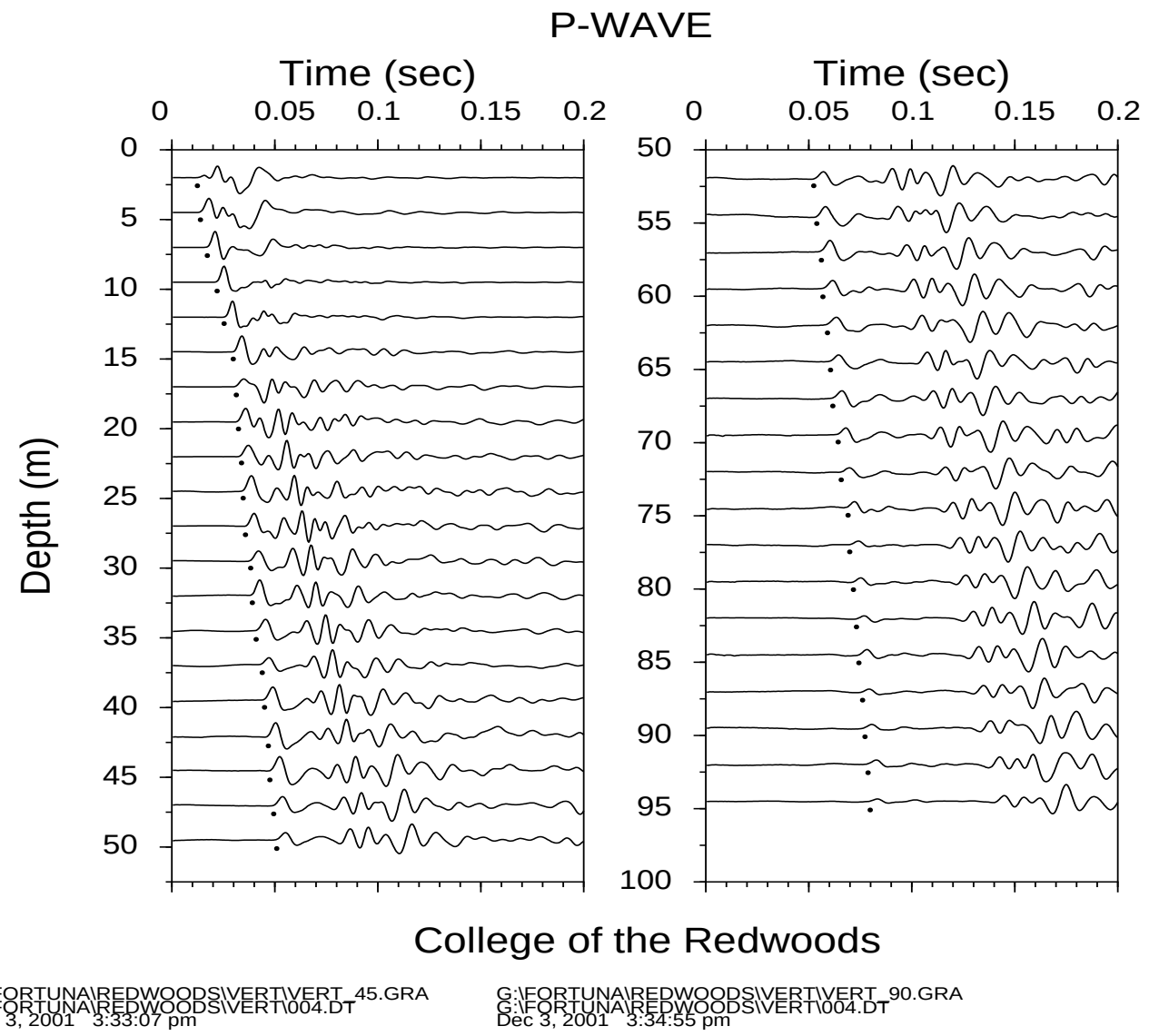

Figure A-3. Vertical component record section. Approximate P-wave arrivals are indicated by the dots.

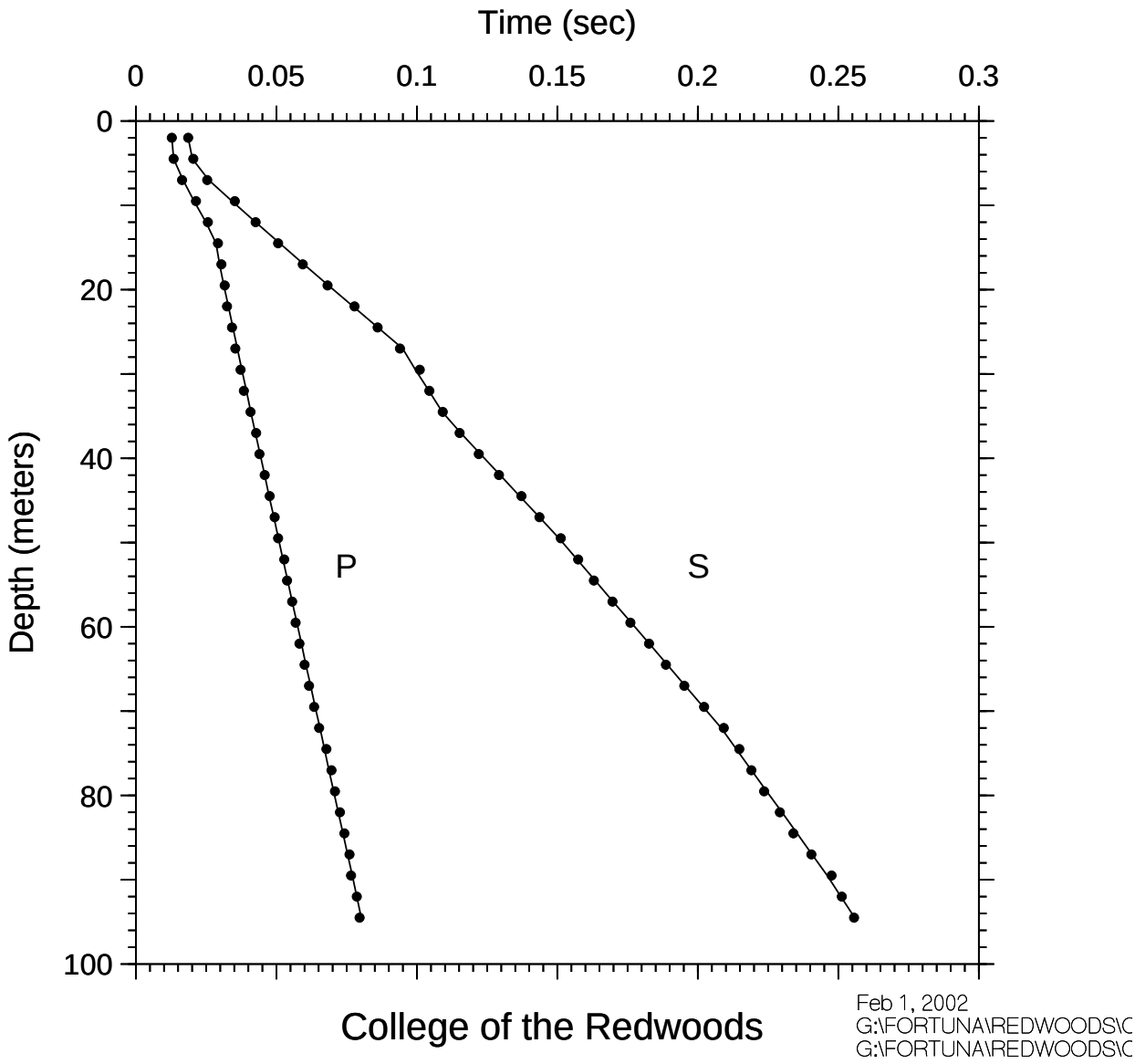

Figure A-4. Time-depth graph of P-wave and S-wave picks. Line segments are straightline interpolations of model predictions at the observation depths. The times for zero depth, not shown, are given by the horizontal offset ($hoffset$) divided by the velocity in the uppermost layer (see accompanying tables of velocities for specific values).

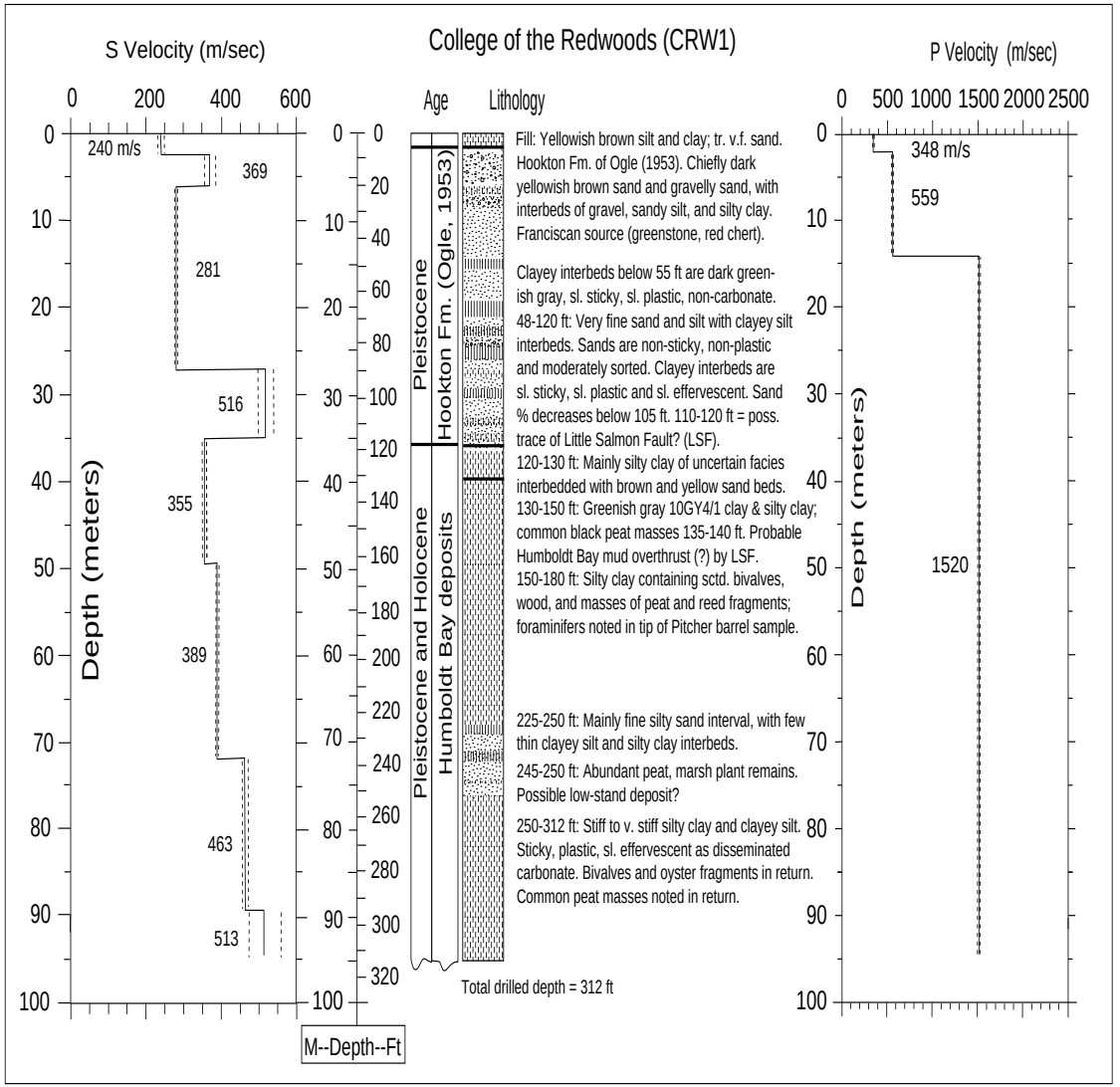

Figure A-5. S- and P-wave velocity profiles with dashed lines representing one standard deviation.

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TABLE A-1. S-wave arrival times and velocity summaries.

Location: College of the Redwoods: S Coordinates: 40.69913 -124.20045 Hole_Code: 308
hoffset = 4.00 travel-time file: G:\FORTUNA\REDWOODS\CRWS_RE.TT
nlayers = 8

d(m)	d(ft)	tsl(s)	tvrt(s)	vavg(m/s)	sig	rsdl(sec)	dtb(m)	thk(m)	v(m/s)	vl(m/s)	vu(m/s)	dtb(ft)	thk(ft)	v(ft/s)	vl(ft/s)	vu(ft/s)
2.0	6.6	0.0186	0.0083	240	1	-0.0001	2.0	2.0	240	231	249	6.6	6.6	786	758	817
4.5	14.8	0.0204	0.0151	298	1	0.0005	6.0	4.0	369	354	386	19.7	13.1	1210	1160	1265
7.0	23.0	0.0254	0.0227	308	1	-0.0006	27.0	21.0	281	279	284	88.6	68.9	923	916	931
9.5	31.2	0.0352	0.0316	300	1	0.0010	35.0	8.0	516	497	538	114.8	26.2	1694	1630	1764
12.0	39.4	0.0426	0.0405	296	1	0.0000	49.5	14.5	355	350	360	162.4	47.6	1165	1147	1182
14.5	47.6	0.0506	0.0494	293	1	-0.0006	72.0	22.5	389	385	393	236.2	73.8	1276	1264	1288
17.0	55.8	0.0594	0.0583	291	1	-0.0004	89.5	17.5	463	456	471	293.6	57.4	1520	1496	1545
19.5	64.0	0.0682	0.0672	290	1	-0.0003	94.5	5.0	513	474	560	310.0	16.4	1684	1555	1837
22.0	72.2	0.0778	0.0761	289	1	0.0005										
24.5	80.4	0.0860	0.0850	288	1	0.0000										
27.0	88.6	0.0940	0.0939	288	1	-0.0008										
29.5	96.8	0.1010	0.0988	299	1	0.0015										
32.0	105.0	0.1044	0.1036	309	1	0.0001										
34.5	113.2	0.1092	0.1084	318	1	0.0002										
37.0	121.4	0.1152	0.1150	322	1	-0.0004										
39.5	129.6	0.1220	0.1221	324	1	-0.0006										
42.0	137.8	0.1292	0.1291	325	1	-0.0004										
44.5	146.0	0.1372	0.1362	327	1	0.0006										
47.0	154.2	0.1436	0.1432	328	1	0.0000										
49.5	162.4	0.1512	0.1503	329	1	0.0006										
52.0	170.6	0.1574	0.1567	332	1	0.0004										
54.5	178.8	0.1630	0.1631	334	1	-0.0004										
57.0	187.0	0.1696	0.1695	336	1	-0.0002										
59.5	195.2	0.1760	0.1760	338	1	-0.0003										
62.0	203.4	0.1826	0.1824	340	1	-0.0001										
64.5	211.6	0.1886	0.1888	342	1	-0.0005										
67.0	219.8	0.1952	0.1952	343	1	-0.0003										
69.5	228.0	0.2022	0.2017	345	1	0.0003										
72.0	236.2	0.2092	0.2081	346	1	0.0009										
74.5	244.4	0.2148	0.2135	349	1	0.0011										
77.0	252.6	0.2190	0.2189	352	1	-0.0001										
79.5	260.8	0.2236	0.2243	354	1	-0.0009										
82.0	269.0	0.2292	0.2297	357	1	-0.0007										
84.5	277.2	0.2340	0.2351	359	1	-0.0013										
87.0	285.4	0.2404	0.2405	362	1	-0.0002										
89.5	293.6	0.2476	0.2459	364	1	0.0016										
92.0	301.8	0.2512	0.2508	367	1	0.0003										
94.5	310.0	0.2556	0.2556	370	1	-0.0002										

Explanation:

d(m) = depth in meters
d(ft) = depth in feet
tsl(s) = observed arrival time in seconds (from source to receiver, along a slant path). For the arrival times used in the S-wave model, the times are the average of picks from traces obtained from hammer blows differing in direction by 180 degrees.
tvrt(s) = vertical travel time computed from the model
vavg(m/s) = average velocity from the surface to each depth, computed as avg_vel = d(m)/tvrt(s)
sig = sigma, standard deviation normalized to the standard deviation of best picks
rsdl(sec) = residual (observed - fitted travel time), in secs
dtb(m) = depth to bottom of layer in meters
thk(m) = thickness of layer in meters
v(m/s) = velocity of layer in meters per second
vl(m/s) = lower limit of velocity in meters per second (see text for explanation of velocity limits)
vu(m/s) = upper limit of velocity in meters per second
dtb(ft) = depth to bottom of layer in feet
thk(ft) = thickness of layer in feet
v(ft/s) = velocity of layer in feet per second
vl(ft/s) = lower limit of velocity in feet per second
vu(ft/s) = upper limit of velocity in feet per second

TABLE A-2. P-wave arrival times and velocity summaries.

Location: College of the Redwoods: P Coordinates: 40.69913 -124.20045 Hole_Code: 308
hoffset = 4.00 travel-time file: G:\FORTUNA\REDWOODS\CRWP.TT
nlayers = 3

d(m)	d(ft)	tsl(s)	tvrt(s)	vavg(m/s)	sig	rsdl(sec)	dtb(m)	thk(m)	v(m/s)	vl(m/s)	vu(m/s)	dtb(ft)	thk(ft)	v(ft/s)	vl(ft/s)	vu(ft/s)
2.0	6.6	0.0128	0.0057	348	1	0.0000	2.0	2.0	348	336	361	6.6	6.6	1143	1104	1185
4.5	14.8	0.0134	0.0102	440	1	0.0000	14.0	12.0	559	552	566	45.9	39.4	1833	1810	1857
7.0	23.0	0.0164	0.0147	476	1	-0.0004	94.6	80.6	1520	1512	1528	310.4	264.4	4986	4960	5013
9.5	31.2	0.0214	0.0192	496	1	0.0007										
12.0	39.4	0.0256	0.0236	508	1	0.0007										
14.5	47.6	0.0292	0.0275	526	1	0.0007										
17.0	55.8	0.0304	0.0292	582	1	0.0006										
19.5	64.0	0.0316	0.0308	632	1	0.0003										
22.0	72.2	0.0324	0.0325	677	1	-0.0005										
24.5	80.4	0.0342	0.0341	718	1	-0.0003										
27.0	88.6	0.0354	0.0358	755	1	-0.0007										
29.5	96.8	0.0372	0.0374	789	1	-0.0005										
32.0	105.0	0.0384	0.0391	819	1	-0.0009										
34.5	113.2	0.0408	0.0407	848	1	-0.0001										
37.0	121.4	0.0428	0.0423	874	1	0.0003										
39.5	129.6	0.0440	0.0440	898	1	-0.0002										
42.0	137.8	0.0458	0.0456	920	1	0.0000										
44.5	146.0	0.0476	0.0473	941	1	0.0002										
47.0	154.2	0.0494	0.0489	961	1	0.0003										
49.5	162.4	0.0506	0.0506	979	1	-0.0001										
52.0	170.6	0.0528	0.0522	996	1	0.0005										
54.5	178.8	0.0538	0.0539	1012	1	-0.0002										
57.0	187.0	0.0556	0.0555	1027	1	0.0000										
59.5	195.2	0.0568	0.0571	1041	1	-0.0005										
62.0	203.4	0.0582	0.0588	1055	1	-0.0007										
64.5	211.6	0.0600	0.0604	1067	1	-0.0005										
67.0	219.8	0.0616	0.0621	1079	1	-0.0006										
69.5	228.0	0.0634	0.0637	1091	1	-0.0004										
72.0	236.2	0.0652	0.0654	1101	1	-0.0003										
74.5	244.4	0.0678	0.0670	1112	1	0.0007										
77.0	252.6	0.0696	0.0687	1121	1	0.0009										
79.5	260.8	0.0708	0.0703	1131	1	0.0004										
82.0	269.0	0.0726	0.0720	1140	1	0.0006										
84.5	277.2	0.0742	0.0736	1148	1	0.0005										
87.0	285.4	0.0760	0.0752	1156	1	0.0007										
89.5	293.6	0.0766	0.0769	1164	1	-0.0004										
92.0	301.8	0.0786	0.0785	1172	1	0.0000										
94.5	310.0	0.0796	0.0802	1179	1	-0.0006										

Explanation:

- d(m) = depth in meters
- d(ft) = depth in feet
- tsl(s) = observed arrival time in seconds (from source to receiver, along a slant path). For the arrival times used in the S-wave model, the times are the average of picks from traces obtained from hammer blows differing in direction by 180 degrees.
- tvrt(s) = vertical travel time computed from the model
- vavg(m/s) = average velocity from the surface to each depth, computed as avg_vel = d(m)/tvrt(s)
- sig = sigma, standard deviation normalized to the standard deviation of best picks
- rsdl(sec) = residual (observed - fitted travel time), in secs
- dtb(m) = depth to bottom of layer in meters
- thk(m) = thickness of layer in meters
- v(m/s) = velocity of layer in meters per second
- vl(m/s) = lower limit of velocity in meters per second (see text for explanation of velocity limits)
- vu(m/s) = upper limit of velocity in meters per second
- dtb(ft) = depth to bottom of layer in feet
- thk(ft) = thickness of layer in feet
- v(ft/s) = velocity of layer in feet per second
- vl(ft/s) = lower limit of velocity in feet per second
- vu(ft/s) = upper limit of velocity in feet per second

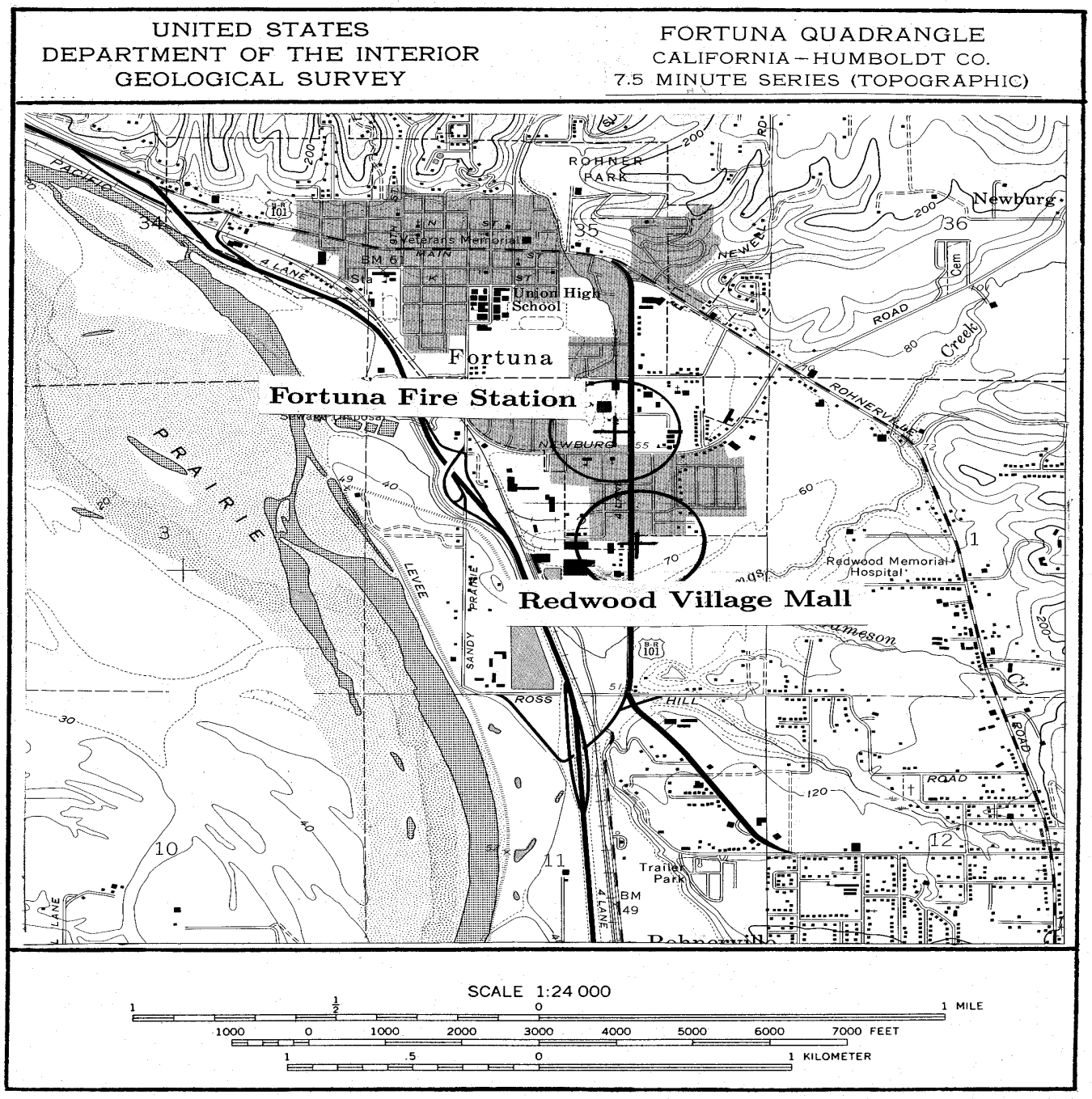

Figure A-6. Site location map for the borehole at Fortuna Fire Station. The accelerograph is located approximately 35 meters from the borehole.

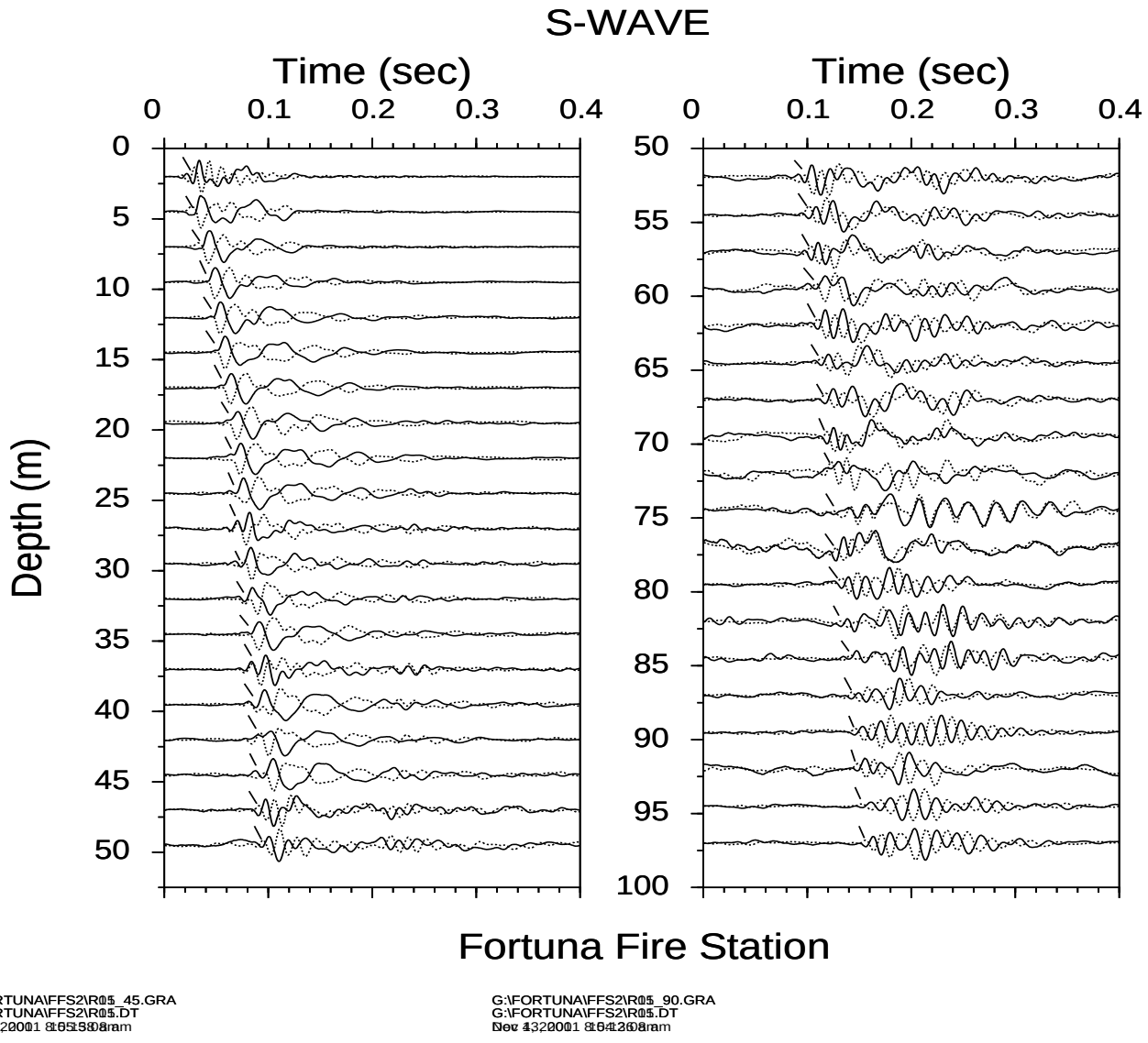

Figure A-7. Horizontal component record section (from impacts in opposite directions) superimposed for identification of S-wave onset. Approximate S-wave time picks are indicated by the hatch marks.

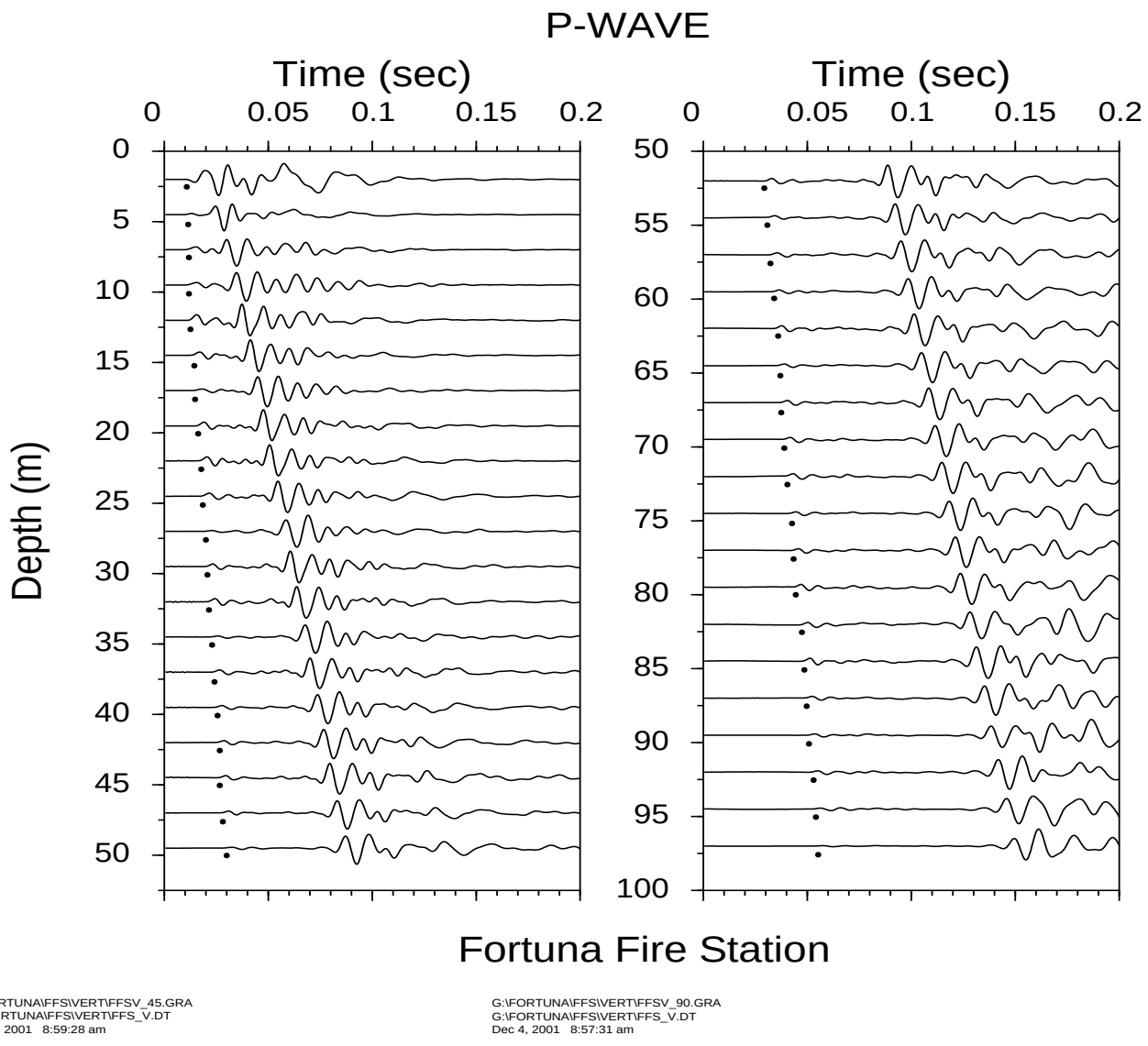

Figure A-8. Vertical component record section. Approximate P-wave arrivals are indicated by the dots.

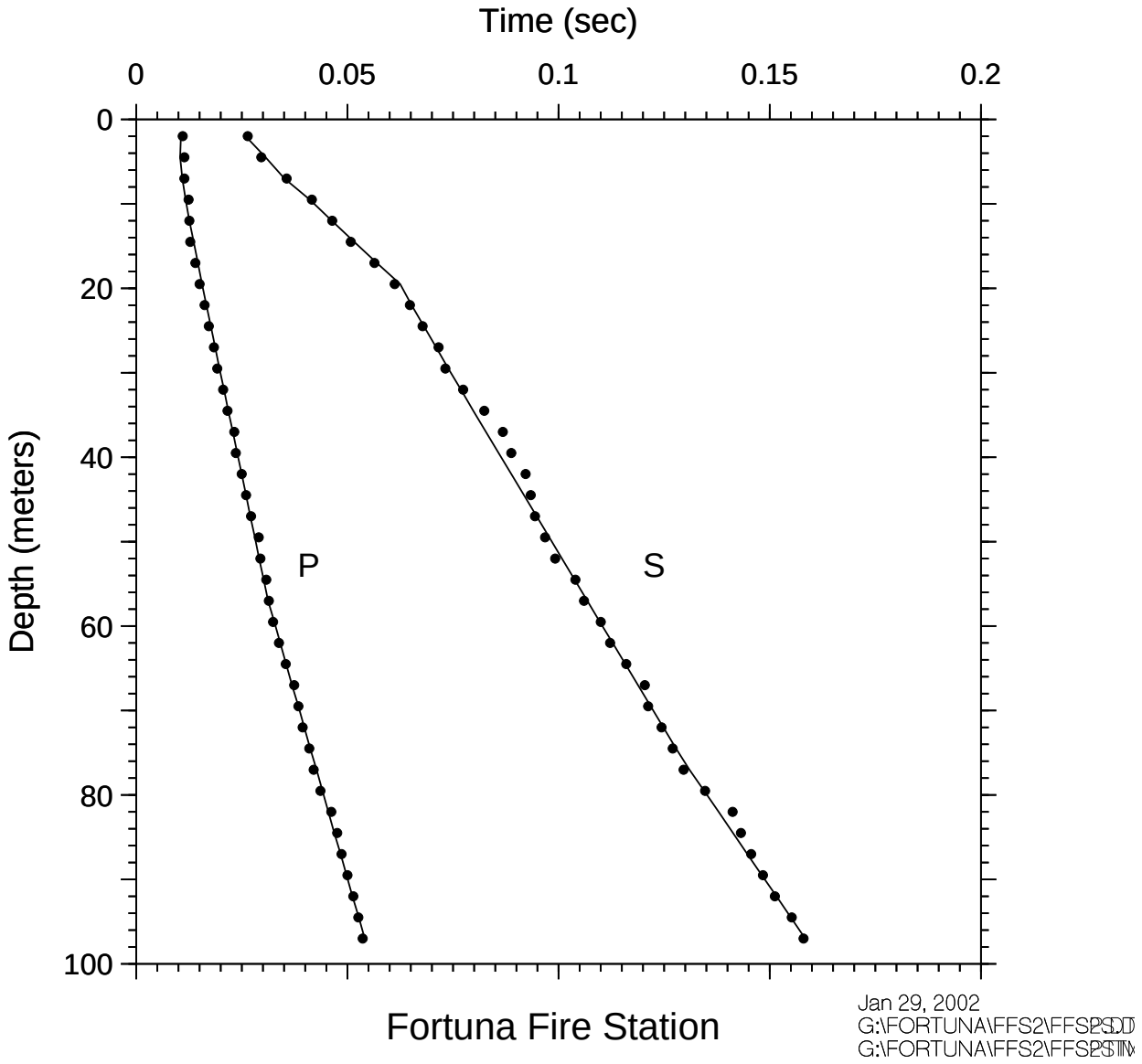

Figure A-9. Time-depth graph of P-wave and S-wave picks. Line segments are straightline interpolations of model predictions at the observation depths. For the depth intervals 37–44.5 m and 72–87 m arrival times were difficult to pick and were downweighted in fitting the model. The times for zero depth, not shown, are given by the horizontal offset ($hoffset$) divided by the velocity in the uppermost layer (see accompanying tables of velocities for specific values).

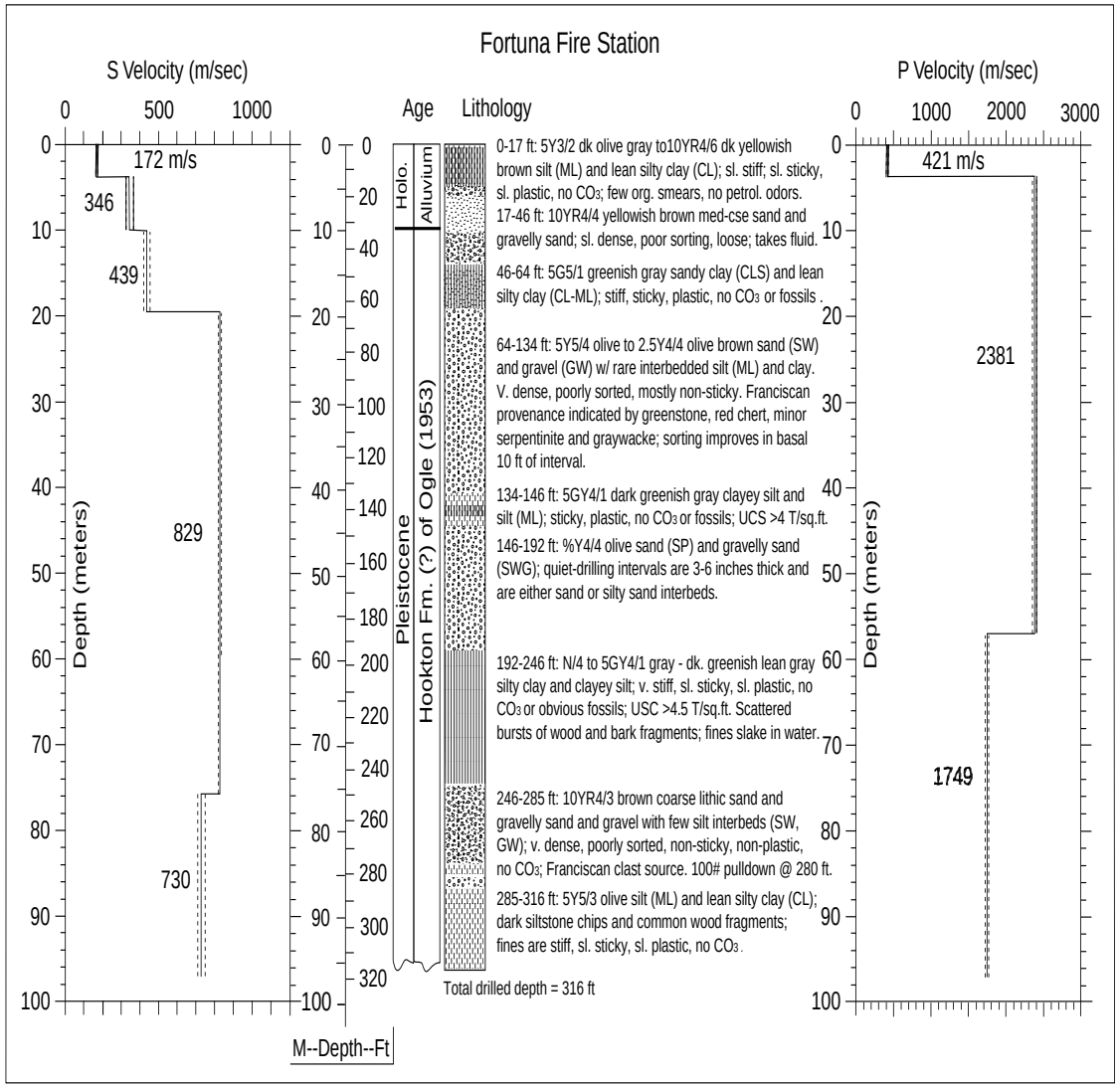

Figure A-10. S- and P-wave velocity profiles with lithology. Dashed lines represent plus and minus one standard deviation of velocities.

TABLE A-3. S-wave arrival times and velocity summaries.

Location: Fortuna Fire Station 2: S Coordinates: 40.58969 -124.14630 Hole_Code: 309
hoffset = 4.00 travel-time file: G:\FORTUNA\FFS2\FFS2S.TT
nlayers = 5

d(m)	d(ft)	tsl(s)	tvrt(s)	vavg(m/s)	sig	rsdl(sec)	dtb(m)	thk(m)	v(m/s)	vl(m/s)	vu(m/s)	dtb(ft)	thk(ft)	v(ft/s)	vl(ft/s)	vu(ft/s)
2.0	6.6	0.0264	0.0116	172	1	0.0005	3.7	3.7	172	167	178	12.1	12.1	566	548	585
4.5	14.8	0.0296	0.0238	189	1	-0.0010	10.0	6.3	346	327	366	32.8	20.7	1134	1073	1202
7.0	23.0	0.0356	0.0310	225	1	0.0005	19.5	9.5	439	423	456	64.0	31.2	1439	1388	1495
9.5	31.2	0.0416	0.0383	248	1	0.0005	75.6	56.1	829	821	838	248.0	184.1	2721	2694	2749
12.0	39.4	0.0464	0.0443	271	1	0.0001	97.0	21.4	730	711	751	318.2	70.2	2396	2332	2463
14.5	47.6	0.0508	0.0500	290	1	-0.0008										
17.0	55.8	0.0564	0.0557	305	1	-0.0006										
19.5	64.0	0.0612	0.0614	318	1	-0.0013										
22.0	72.2	0.0648	0.0644	342	1	-0.0004										
24.5	80.4	0.0678	0.0674	364	1	-0.0003										
27.0	88.6	0.0716	0.0704	383	1	0.0006										
29.5	96.8	0.0732	0.0734	402	1	-0.0007										
32.0	105.0	0.0774	0.0764	419	1	0.0005										
34.5	113.2	0.0824	0.0795	434	1	0.0026										
37.0	121.4	0.0868	0.0825	449	2	0.0040										
39.5	129.6	0.0888	0.0855	462	2	0.0030										
42.0	137.8	0.0922	0.0885	475	2	0.0034										
44.5	146.0	0.0934	0.0915	486	2	0.0016										
47.0	154.2	0.0944	0.0945	497	1	-0.0004										
49.5	162.4	0.0968	0.0975	507	1	-0.0010										
52.0	170.6	0.0992	0.1006	517	1	-0.0016										
54.5	178.8	0.1040	0.1036	526	1	0.0002										
57.0	187.0	0.1060	0.1066	535	1	-0.0008										
59.5	195.2	0.1100	0.1096	543	1	0.0002										
62.0	203.4	0.1122	0.1126	550	1	-0.0006										
64.5	211.6	0.1160	0.1156	558	1	0.0002										
67.0	219.8	0.1204	0.1187	565	1	0.0016										
69.5	228.0	0.1212	0.1217	571	1	-0.0006										
72.0	236.2	0.1244	0.1247	577	2	-0.0004										
74.5	244.4	0.1270	0.1277	583	3	-0.0008										
77.0	252.6	0.1296	0.1309	588	1	-0.0014										
79.5	260.8	0.1347	0.1344	592	1	0.0002										
82.0	269.0	0.1412	0.1378	595	2	0.0033										
84.5	277.2	0.1432	0.1412	598	3	0.0019										
87.0	285.4	0.1456	0.1446	601	3	0.0009										
89.5	293.6	0.1484	0.1481	604	1	0.0003										
92.0	301.8	0.1512	0.1515	607	1	-0.0004										
94.5	310.0	0.1552	0.1549	610	1	0.0002										
97.0	318.2	0.1580	0.1583	613	1	-0.0004										

Explanation:

- d(m) = depth in meters
- d(ft) = depth in feet
- tsl(s) = observed arrival time in seconds (from source to receiver, along a slant path). For the arrival times used in the S-wave model, the times are the average of picks from traces obtained from hammer blows differing in direction by 180 degrees.
- tvrt(s) = vertical travel time computed from the model
- vavg(m/s) = average velocity from the surface to each depth, computed as avg_vel = d(m)/tvrt(s)
- sig = sigma, standard deviation normalized to the standard deviation of best picks
- rsdl(sec) = residual (observed - fitted travel time), in secs
- dtb(m) = depth to bottom of layer in meters
- thk(m) = thickness of layer in meters
- v(m/s) = velocity of layer in meters per second
- vl(m/s) = lower limit of velocity in meters per second (see text for explanation of velocity limits)
- vu(m/s) = upper limit of velocity in meters per second
- dtb(ft) = depth to bottom of layer in feet
- thk(ft) = thickness of layer in feet
- v(ft/s) = velocity of layer in feet per second
- vl(ft/s) = lower limit of velocity in feet per second
- vu(ft/s) = upper limit of velocity in feet per second

TABLE A-4. P-wave arrival times and velocity summaries.

Location: Fortuna Fire Station: P Coordinates: 40.58969 -124.14630 Hole_Code: 309
hoffset = 4.00 travel-time file: G:\FORTUNA\FFS\VERT\FFSP.TT
nlayers = 3

d(m)	d(ft)	tsl(s)	tvrt(s)	vavg(m/s)	sig	rsdl(sec)	dtb(m)	thk(m)	v(m/s)	vl(m/s)	vu(m/s)	dtb(ft)	thk(ft)	v(ft/s)	vl(ft/s)	vu(ft/s)
2.0	6.6	0.0110	0.0048	421	1	0.0004	3.7	3.7	421	413	430	12.1	12.1	1382	1354	1410
4.5	14.8	0.0114	0.0091	493	1	0.0010	57.0	53.3	2381	2352	2410	187.0	174.9	7811	7716	7908
7.0	23.0	0.0114	0.0102	688	1	0.0005	97.0	40.0	1749	1726	1772	318.2	131.2	5737	5663	5813
9.5	31.2	0.0124	0.0112	846	1	0.0007										
12.0	39.4	0.0126	0.0123	978	1	0.0000										
14.5	47.6	0.0128	0.0133	1088	1	-0.0008										
17.0	55.8	0.0140	0.0144	1183	1	-0.0006										
19.5	64.0	0.0150	0.0154	1264	1	-0.0006										
22.0	72.2	0.0162	0.0165	1335	1	-0.0004										
24.5	80.4	0.0172	0.0175	1398	1	-0.0005										
27.0	88.6	0.0184	0.0186	1454	1	-0.0003										
29.5	96.8	0.0192	0.0196	1503	1	-0.0005										
32.0	105.0	0.0206	0.0207	1548	1	-0.0002										
34.5	113.2	0.0216	0.0217	1588	1	-0.0002										
37.0	121.4	0.0232	0.0228	1625	1	0.0003										
39.5	129.6	0.0236	0.0238	1658	1	-0.0003										
42.0	137.8	0.0250	0.0249	1688	1	0.0000										
44.5	146.0	0.0260	0.0259	1717	1	0.0000										
47.0	154.2	0.0272	0.0270	1742	1	0.0002										
49.5	162.4	0.0290	0.0280	1766	1	0.0009										
52.0	170.6	0.0294	0.0291	1789	1	0.0003										
54.5	178.8	0.0308	0.0301	1809	1	0.0006										
57.0	187.0	0.0314	0.0312	1828	1	0.0002										
59.5	195.2	0.0324	0.0326	1825	1	-0.0003										
62.0	203.4	0.0338	0.0340	1822	1	-0.0003										
64.5	211.6	0.0354	0.0355	1819	1	-0.0001										
67.0	219.8	0.0374	0.0369	1816	1	0.0005										
69.5	228.0	0.0384	0.0383	1814	1	0.0000										
72.0	236.2	0.0394	0.0398	1811	1	-0.0004										
74.5	244.4	0.0410	0.0412	1809	1	-0.0002										
77.0	252.6	0.0420	0.0426	1807	1	-0.0007										
79.5	260.8	0.0436	0.0440	1805	1	-0.0005										
82.0	269.0	0.0462	0.0455	1803	1	0.0007										
84.5	277.2	0.0476	0.0469	1802	1	0.0007										
87.0	285.4	0.0486	0.0483	1800	1	0.0002										
89.5	293.6	0.0500	0.0498	1799	1	0.0002										
92.0	301.8	0.0514	0.0512	1797	1	0.0002										
94.5	310.0	0.0526	0.0526	1796	1	-0.0001										
97.0	318.2	0.0536	0.0540	1795	1	-0.0005										

Explanation:

- d(m) = depth in meters
- d(ft) = depth in feet
- tsl(s) = observed arrival time in seconds (from source to receiver, along a slant path). For the arrival times used in the S-wave model, the times are the average of picks from traces obtained from hammer blows differing in direction by 180 degrees.
- tvrt(s) = vertical travel time computed from the model
- vavg(m/s) = average velocity from the surface to each depth, computed as avg_vel = d(m)/tvrt(s)
- sig = sigma, standard deviation normalized to the standard deviation of best picks
- rsdl(sec) = residual (observed - fitted travel time), in secs
- dtb(m) = depth to bottom of layer in meters
- thk(m) = thickness of layer in meters
- v(m/s) = velocity of layer in meters per second
- vl(m/s) = lower limit of velocity in meters per second (see text for explanation of velocity limits)
- vu(m/s) = upper limit of velocity in meters per second
- dtb(ft) = depth to bottom of layer in feet
- thk(ft) = thickness of layer in feet
- v(ft/s) = velocity of layer in feet per second
- vl(ft/s) = lower limit of velocity in feet per second
- vu(ft/s) = upper limit of velocity in feet per second

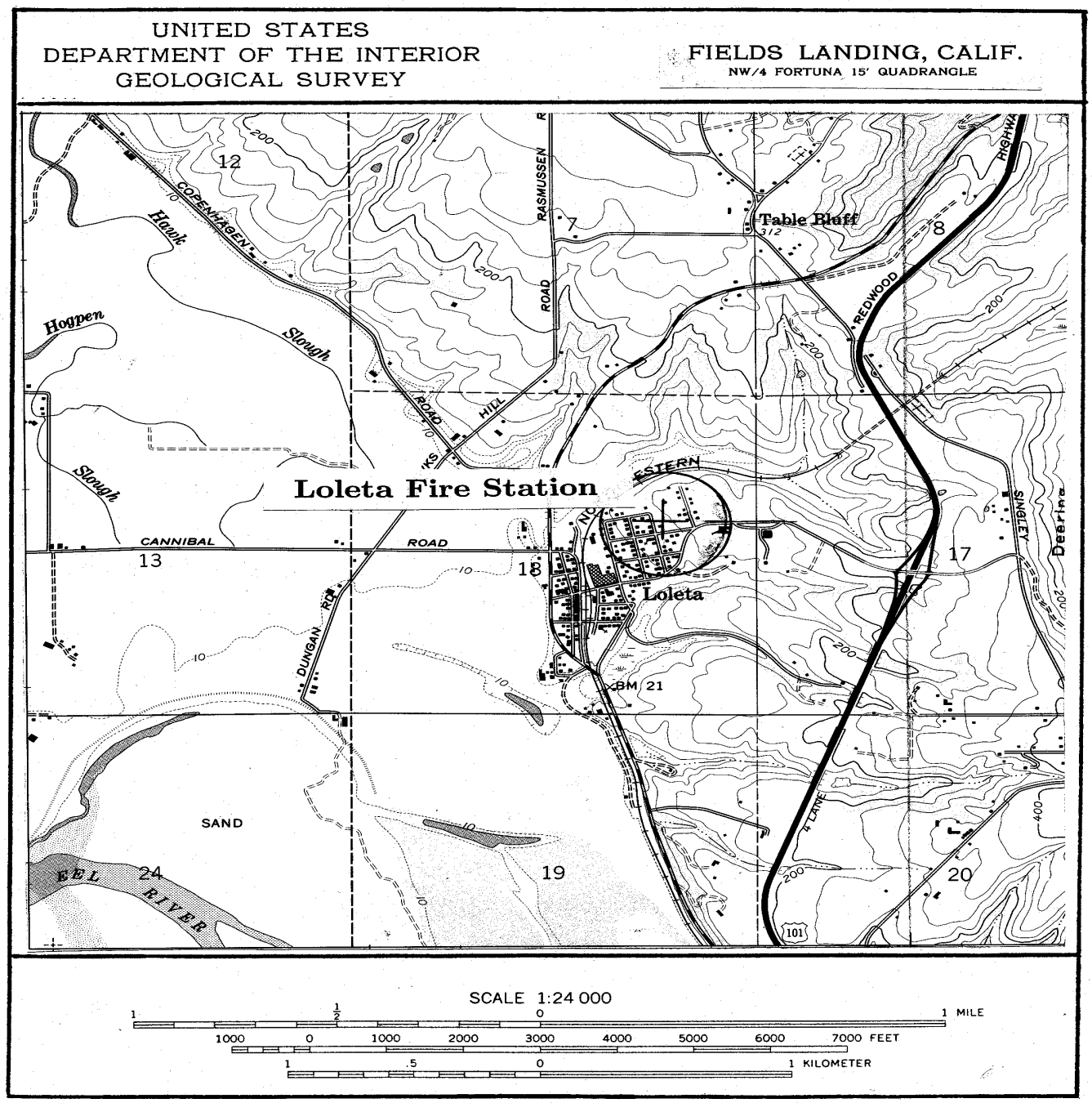

Figure A-1. Site location map for the borehole at Loleta Fire Station. The accelerograph is located approximately 15 meters from the borehole.

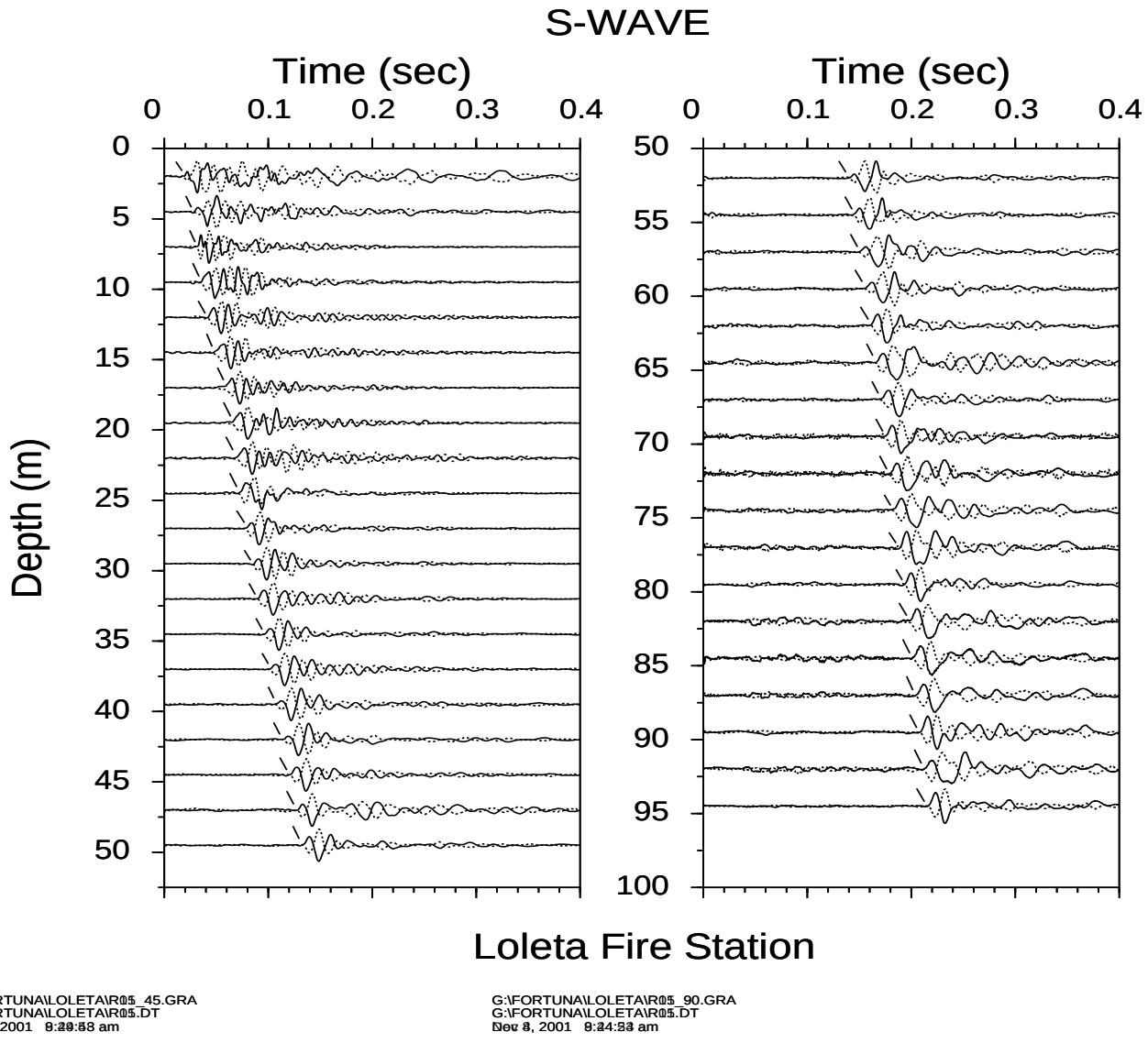

Figure A-12. Horizontal component record section (from impacts in opposite directions) superimposed for identification of S-wave onset. Approximate S-wave time picks are indicated by the hatch marks.

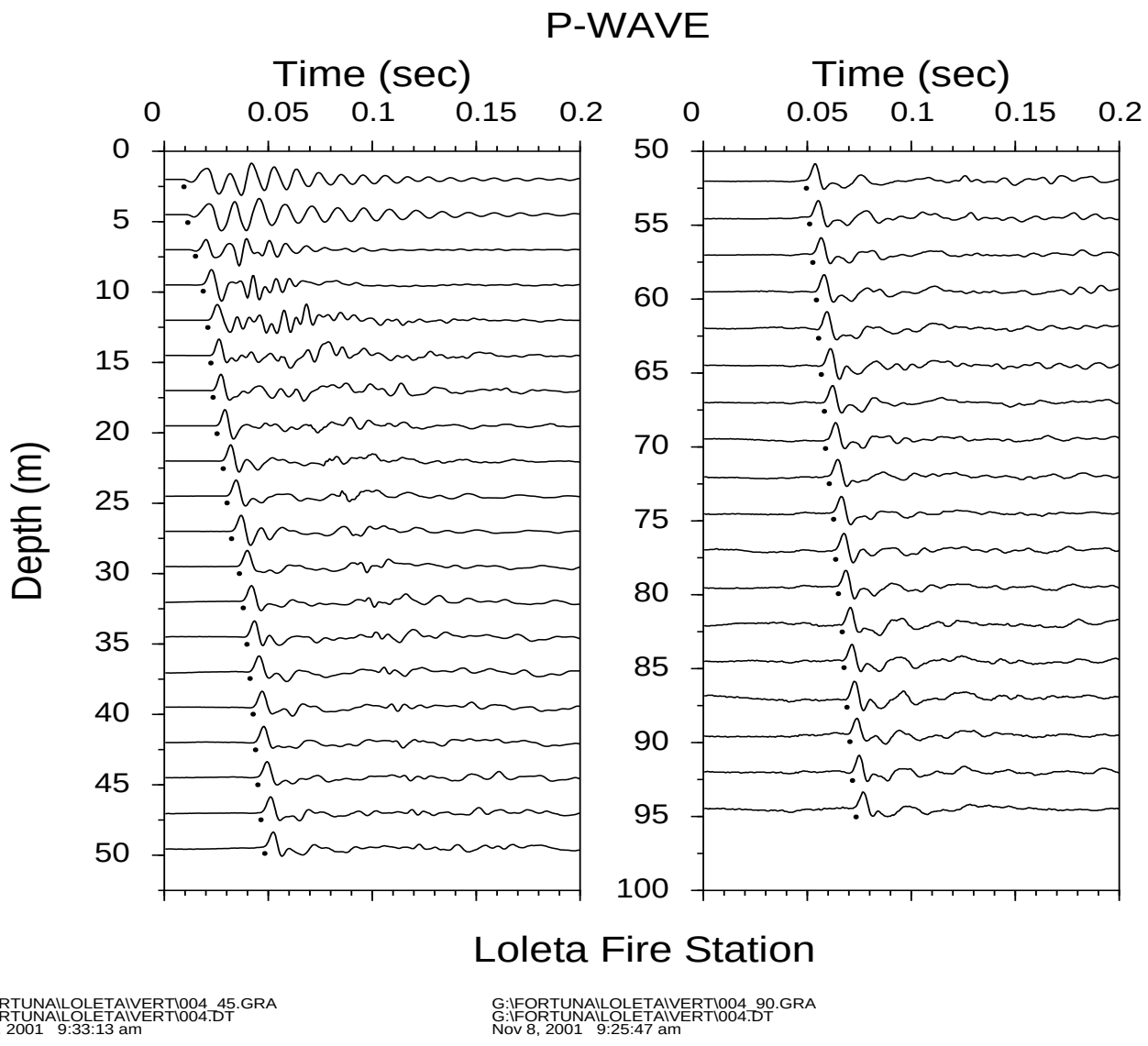

Figure A-13. Vertical component record section. Approximate P-wave arrivals are indicated by the dots.

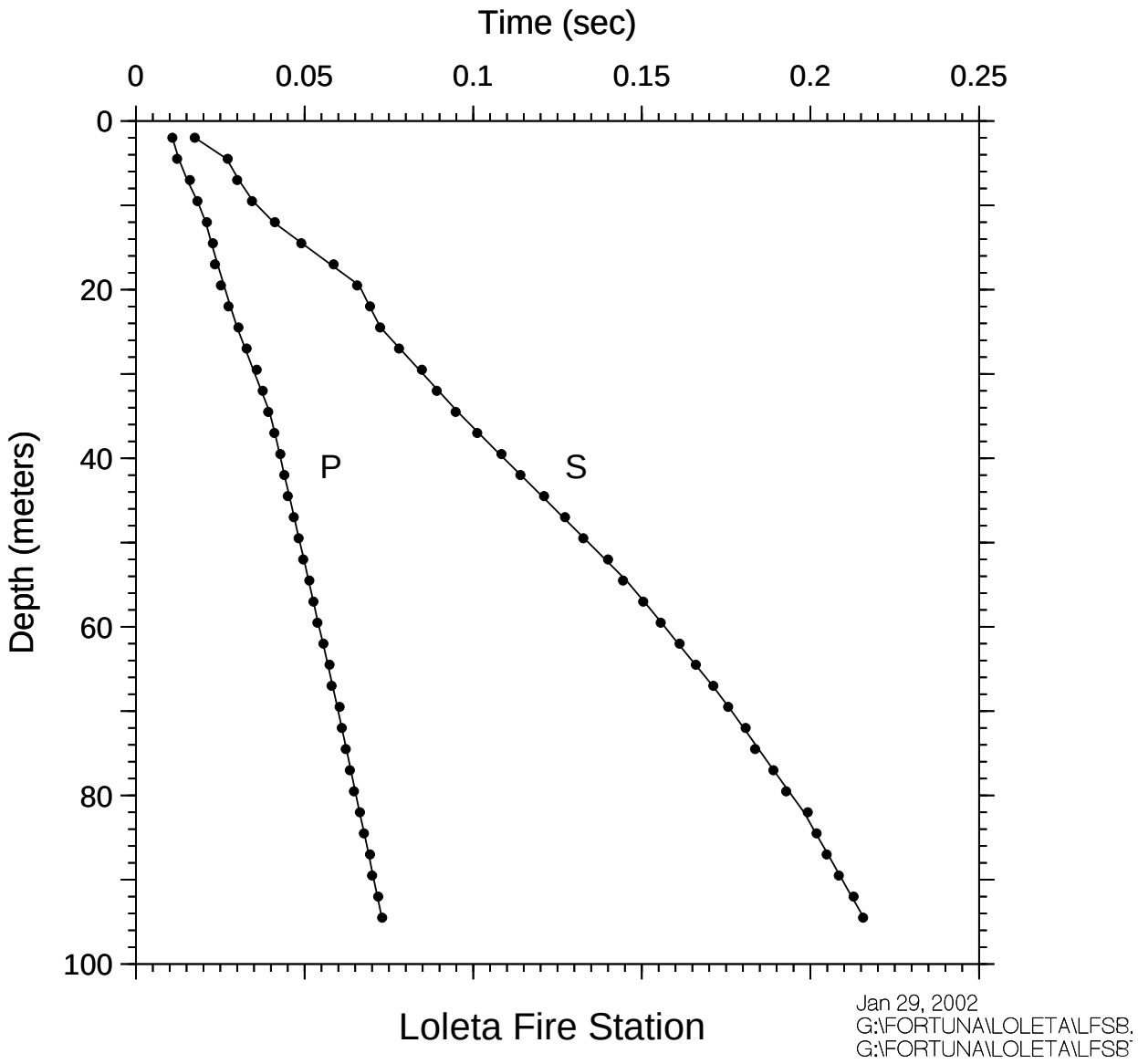

Figure A-14. Time-depth graph of P-wave and S-wave picks. Line segments are straightline interpolations of model predictions at the observation depths. The times for zero depth, not shown, are given by the horizontal offset ($hoffset$) divided by the velocity in the uppermost layer (see accompanying tables of velocities for specific values).

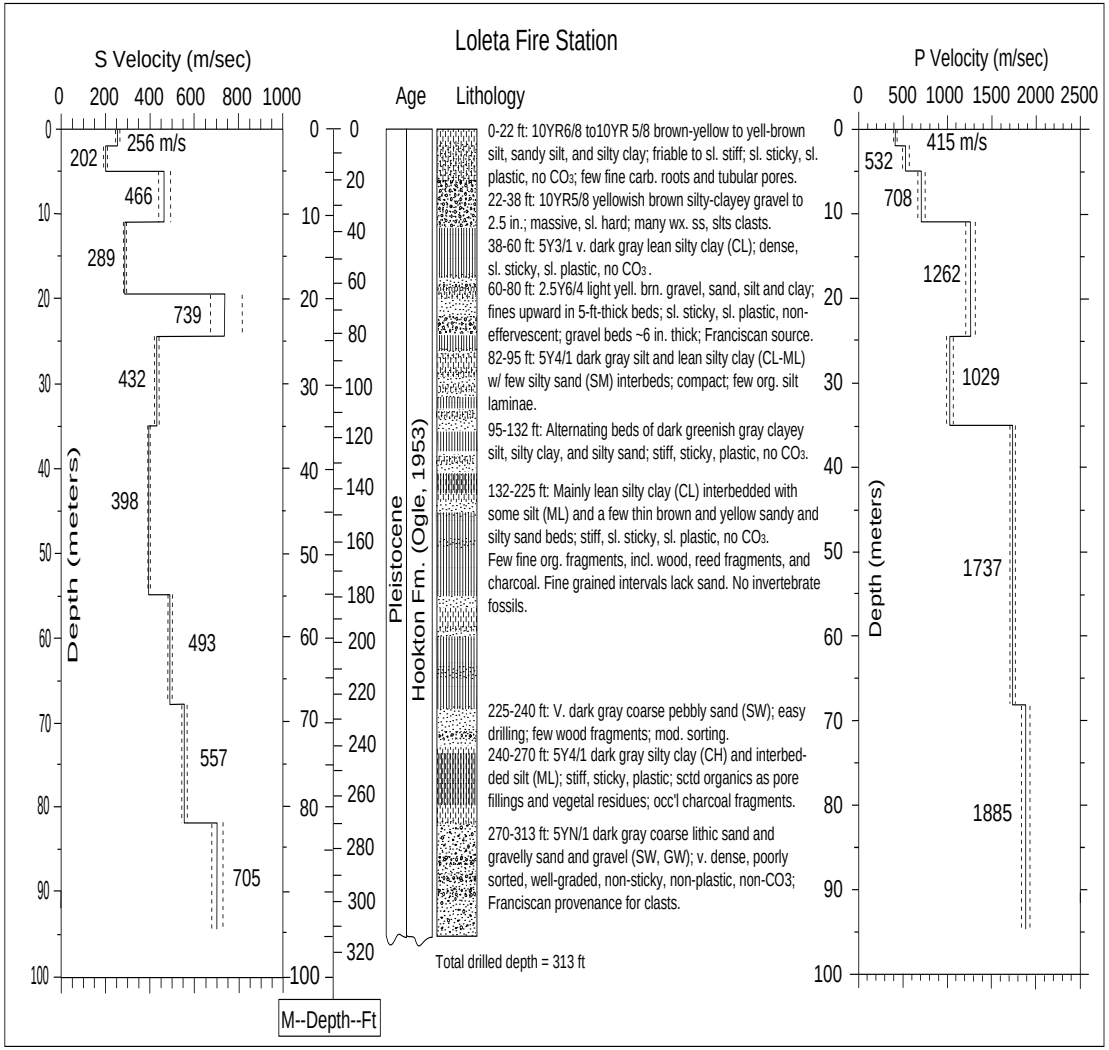

Figure A-15. S- and P-wave velocity profiles with lithology. Dashed lines represent plus and minus one standard deviation of velocities.

TABLE A-5. S-wave arrival times and velocity summaries.

Location: Loleta Fire Station: S Coordinates: 40.64438 -124.21976 Hole_Code: 310
hoffset = 4.00 travel-time file: G:\FORTUNA\LOLETA\LFSS.TT
nlayers = 10

d(m)	d(ft)	tsl(s)	tvrt(s)	vavg(m/s)	sig	rsdl(sec)	dtb(m)	thk(m)	v(m/s)	vl(m/s)	vu(m/s)	dtb(ft)	thk(ft)	v(ft/s)	vl(ft/s)	vu(ft/s)
2.0	6.6	0.0174	0.0078	256	1	-0.0001	2.0	2.0	256	247	265	6.6	6.6	840	812	871
4.5	14.8	0.0272	0.0202	223	1	0.0003	5.0	3.0	202	193	211	16.4	9.8	662	634	692
7.0	23.0	0.0300	0.0270	260	1	-0.0005	11.0	6.0	466	441	494	36.1	19.7	1529	1447	1622
9.5	31.2	0.0344	0.0323	294	1	-0.0003	19.5	8.5	289	282	296	64.0	27.9	948	925	971
12.0	39.4	0.0412	0.0390	308	1	0.0004	24.5	5.0	739	674	817	80.4	16.4	2424	2212	2679
14.5	47.6	0.0490	0.0477	304	1	-0.0002	35.0	10.5	432	422	443	114.8	34.4	1418	1384	1453
17.0	55.8	0.0586	0.0563	302	1	0.0009	55.0	20.0	398	393	402	180.4	65.6	1305	1291	1318
19.5	64.0	0.0656	0.0650	300	1	-0.0006	68.0	13.0	493	483	503	223.1	42.7	1616	1585	1649
22.0	72.2	0.0694	0.0683	322	1	0.0001	82.0	14.0	557	545	569	269.0	45.9	1826	1787	1868
24.5	80.4	0.0724	0.0717	342	1	-0.0001	94.5	12.5	705	681	731	310.0	41.0	2313	2233	2399
27.0	88.6	0.0780	0.0775	348	1	-0.0002										
29.5	96.8	0.0848	0.0833	354	1	0.0008										
32.0	105.0	0.0892	0.0891	359	1	-0.0005										
34.5	113.2	0.0948	0.0949	364	1	-0.0006										
37.0	121.4	0.1012	0.1010	366	1	-0.0004										
39.5	129.6	0.1084	0.1073	368	1	0.0006										
42.0	137.8	0.1140	0.1136	370	1	-0.0001										
44.5	146.0	0.1210	0.1199	371	1	0.0006										
47.0	154.2	0.1272	0.1262	373	1	0.0006										
49.5	162.4	0.1326	0.1325	374	1	-0.0003										
52.0	170.6	0.1400	0.1387	375	1	0.0008										
54.5	178.8	0.1444	0.1450	376	1	-0.0010										
57.0	187.0	0.1504	0.1503	379	1	-0.0003										
59.5	195.2	0.1556	0.1554	383	1	-0.0002										
62.0	203.4	0.1612	0.1605	386	1	0.0004										
64.5	211.6	0.1660	0.1655	390	1	0.0001										
67.0	219.8	0.1712	0.1706	393	1	0.0002										
69.5	228.0	0.1756	0.1753	396	1	-0.0001										
72.0	236.2	0.1808	0.1798	400	1	0.0006										
74.5	244.4	0.1836	0.1843	404	1	-0.0010										
77.0	252.6	0.1890	0.1888	408	1	-0.0001										
79.5	260.8	0.1928	0.1933	411	1	-0.0008										
82.0	269.0	0.1992	0.1978	415	1	0.0011										
84.5	277.2	0.2018	0.2013	420	1	0.0002										
87.0	285.4	0.2048	0.2049	425	1	-0.0004										
89.5	293.6	0.2084	0.2084	429	1	-0.0003										
92.0	301.8	0.2128	0.2120	434	1	0.0006										
94.5	310.0	0.2156	0.2155	438	1	-0.0002										

Explanation:

- d(m) = depth in meters
- d(ft) = depth in feet
- tsl(s) = observed arrival time in seconds (from source to receiver, along a slant path). For the arrival times used in the S-wave model, the times are the average of picks from traces obtained from hammer blows differing in direction by 180 degrees.
- tvrt(s) = vertical travel time computed from the model
- vavg(m/s) = average velocity from the surface to each depth, computed as avg_vel = d(m)/tvrt(s)
- sig = sigma, standard deviation normalized to the standard deviation of best picks
- rsdl(sec) = residual (observed - fitted travel time), in secs
- dtb(m) = depth to bottom of layer in meters
- thk(m) = thickness of layer in meters
- v(m/s) = velocity of layer in meters per second
- vl(m/s) = lower limit of velocity in meters per second (see text for explanation of velocity limits)
- vu(m/s) = upper limit of velocity in meters per second
- dtb(ft) = depth to bottom of layer in feet
- thk(ft) = thickness of layer in feet
- v(ft/s) = velocity of layer in feet per second
- vl(ft/s) = lower limit of velocity in feet per second
- vu(ft/s) = upper limit of velocity in feet per second

TABLE A-6. P-wave arrival times and velocity summaries.

Location: Loleta Fire Station: P Coordinates: 40.64438 -124.21976 Hole_Code: 310
hoffset = 4.00 travel-time file: G:\FORTUNA\LOLETA\LFSP.TT
nlayers = 7

d(m)	d(ft)	tsl(s)	tvrt(s)	vavg(m/s)	sig	rsdl(sec)	dtb(m)	thk(m)	v(m/s)	vl(m/s)	vu(m/s)	dtb(ft)	thk(ft)	v(ft/s)	vl(ft/s)	vu(ft/s)
2.0	6.6	0.0108	0.0048	415	1	0.0000	2.0	2.0	415	398	434	6.6	6.6	1361	1305	1423
4.5	14.8	0.0122	0.0095	473	1	-0.0005	5.0	3.0	532	497	572	16.4	9.8	1745	1631	1875
7.0	23.0	0.0160	0.0133	527	1	0.0008	11.0	6.0	708	669	751	36.1	19.7	2321	2195	2463
9.5	31.2	0.0182	0.0168	565	1	0.0000	24.5	13.5	1262	1211	1317	80.4	44.3	4139	3972	4322
12.0	39.4	0.0210	0.0197	608	1	0.0003	35.0	10.5	1029	994	1067	114.8	34.4	3377	3260	3502
14.5	47.6	0.0228	0.0217	668	1	0.0004	68.0	33.0	1737	1708	1767	223.1	108.3	5700	5605	5799
17.0	55.8	0.0234	0.0237	718	1	-0.0008	94.5	26.5	1885	1839	1934	310.0	86.9	6186	6035	6344
19.5	64.0	0.0252	0.0257	760	1	-0.0009										
22.0	72.2	0.0274	0.0276	796	1	-0.0006										
24.5	80.4	0.0304	0.0296	827	1	0.0004										
27.0	88.6	0.0328	0.0321	842	1	0.0004										
29.5	96.8	0.0358	0.0345	855	1	0.0010										
32.0	105.0	0.0376	0.0369	867	1	0.0004										
34.5	113.2	0.0392	0.0393	877	1	-0.0004										
37.0	121.4	0.0410	0.0410	903	1	-0.0002										
39.5	129.6	0.0428	0.0424	931	1	0.0002										
42.0	137.8	0.0440	0.0439	957	1	0.0000										
44.5	146.0	0.0450	0.0453	982	1	-0.0005										
47.0	154.2	0.0468	0.0467	1006	1	-0.0001										
49.5	162.4	0.0482	0.0482	1027	1	-0.0001										
52.0	170.6	0.0496	0.0496	1048	1	-0.0002										
54.5	178.8	0.0514	0.0511	1067	1	0.0002										
57.0	187.0	0.0526	0.0525	1086	1	0.0000										
59.5	195.2	0.0538	0.0539	1103	1	-0.0002										
62.0	203.4	0.0556	0.0554	1120	1	0.0001										
64.5	211.6	0.0574	0.0568	1135	1	0.0005										
67.0	219.8	0.0580	0.0583	1150	1	-0.0003										
69.5	228.0	0.0604	0.0596	1166	1	0.0007										
72.0	236.2	0.0610	0.0610	1181	1	0.0000										
74.5	244.4	0.0622	0.0623	1196	1	-0.0002										
77.0	252.6	0.0634	0.0636	1211	1	-0.0003										
79.5	260.8	0.0646	0.0649	1224	1	-0.0004										
82.0	269.0	0.0664	0.0663	1238	1	0.0001										
84.5	277.2	0.0676	0.0676	1250	1	-0.0001										
87.0	285.4	0.0694	0.0689	1262	1	0.0004										
89.5	293.6	0.0700	0.0702	1274	1	-0.0003										
92.0	301.8	0.0718	0.0716	1286	1	0.0002										
94.5	310.0	0.0730	0.0729	1296	1	0.0001										

Explanation:
- d(m) = depth in meters
- d(ft) = depth in feet
- tsl(s) = observed arrival time in seconds (from source to receiver, along a slant path). For the arrival times used in the S-wave model, the times are the average of picks from traces obtained from hammer blows differing in direction by 180 degrees.
- tvrt(s) = vertical travel time computed from the model
- vavg(m/s) = average velocity from the surface to each depth, computed as avg_vel = d(m)/tvrt(s)
- sig = sigma, standard deviation normalized to the standard deviation of best picks
- rsdl(sec) = residual (observed - fitted travel time), in secs
- dtb(m) = depth to bottom of layer in meters
- thk(m) = thickness of layer in meters
- v(m/s) = velocity of layer in meters per second
- vl(m/s) = lower limit of velocity in meters per second (see text for explanation of velocity limits)
- vu(m/s) = upper limit of velocity in meters per second
- dtb(ft) = depth to bottom of layer in feet
- thk(ft) = thickness of layer in feet
- v(ft/s) = velocity of layer in feet per second
- vl(ft/s) = lower limit of velocity in feet per second
- vu(ft/s) = upper limit of velocity in feet per second

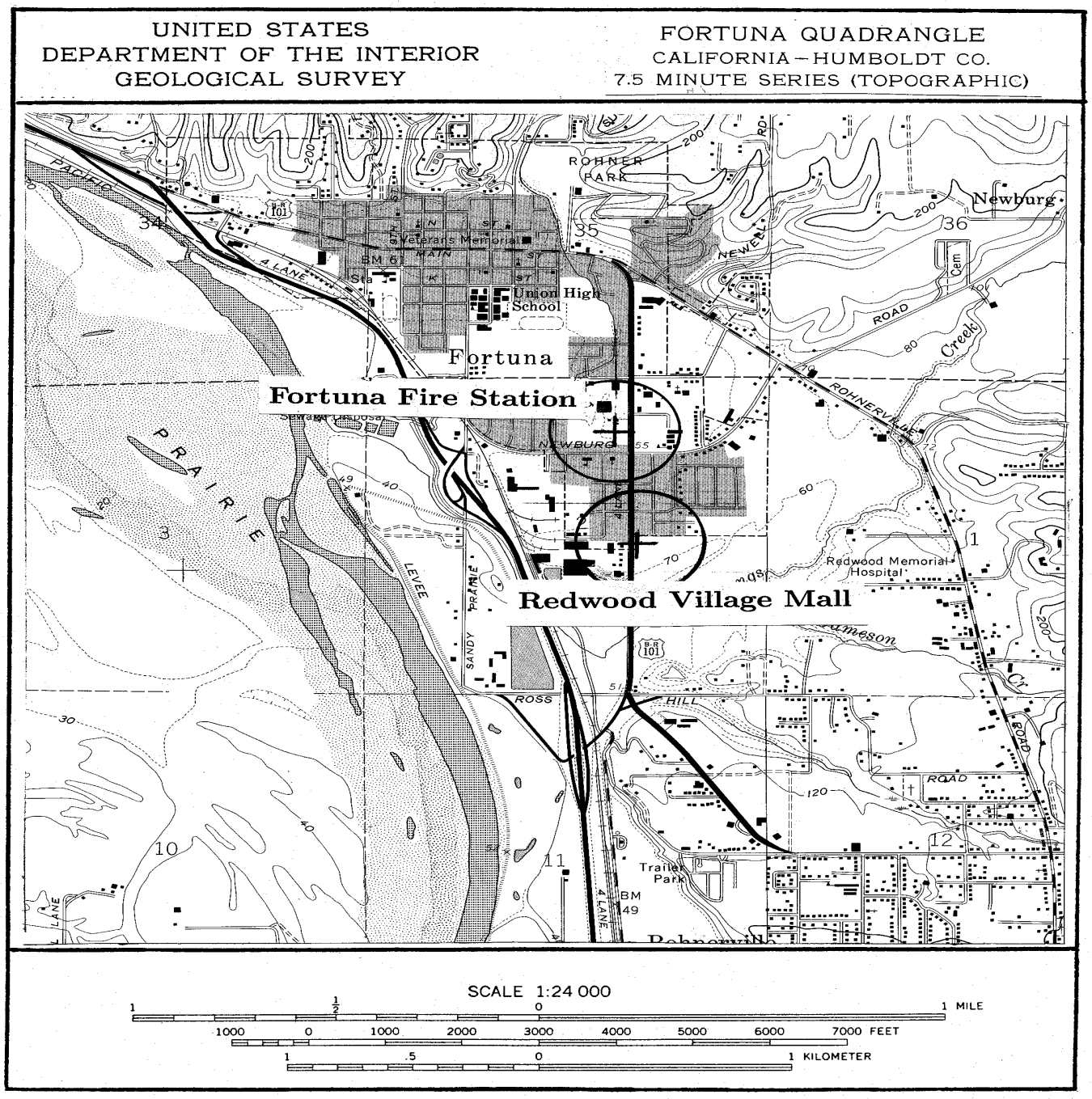

Figure A-16. Site location map for the borehole at Redwood Village Mall. The accelerograph is located approximately 10 meters from the borehole.

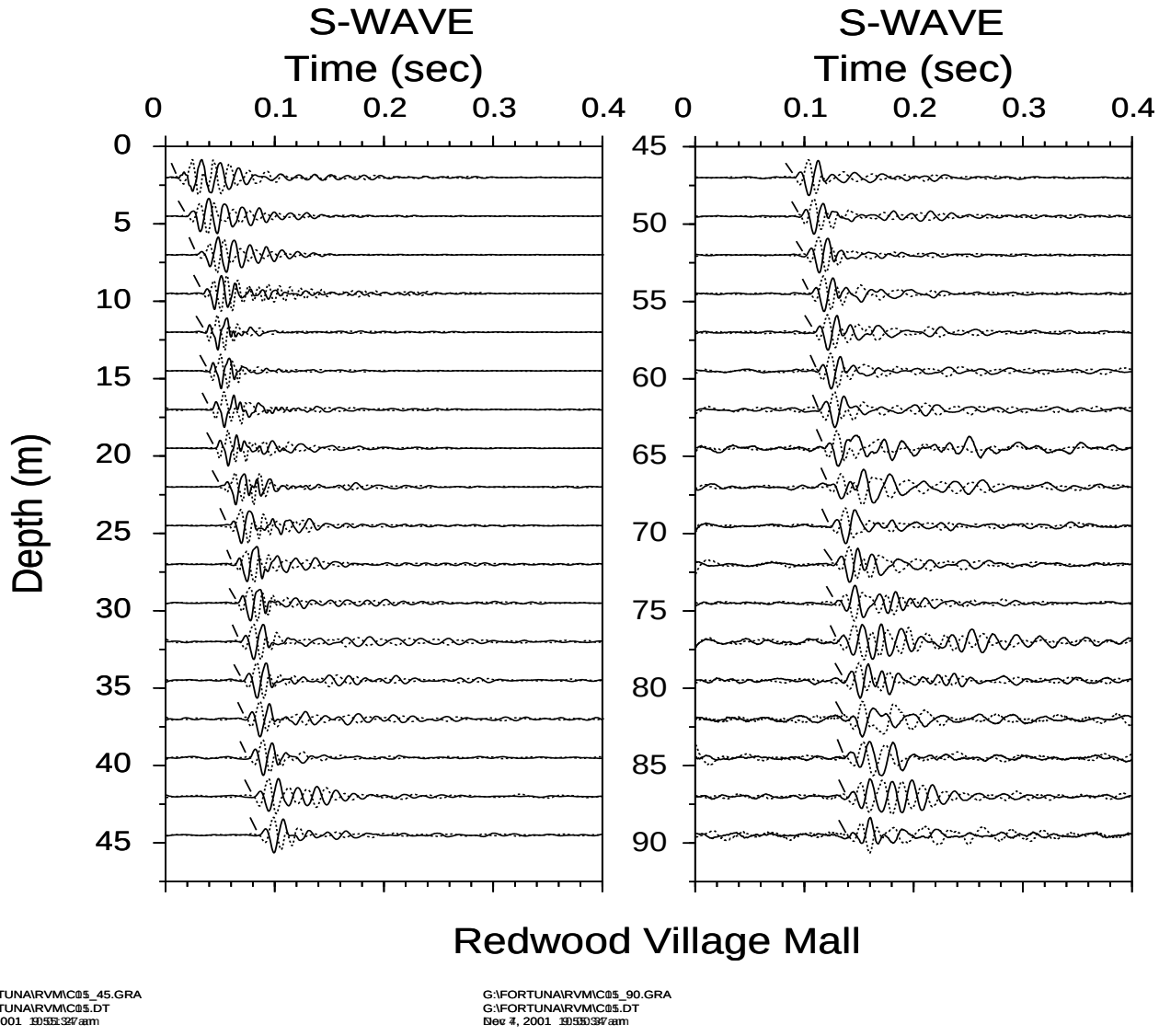

Figure A-17. Horizontal component record section (from impacts in opposite directions) superimposed for identification of S-wave onset. Approximate S-wave time picks are indicated by the hatch marks.

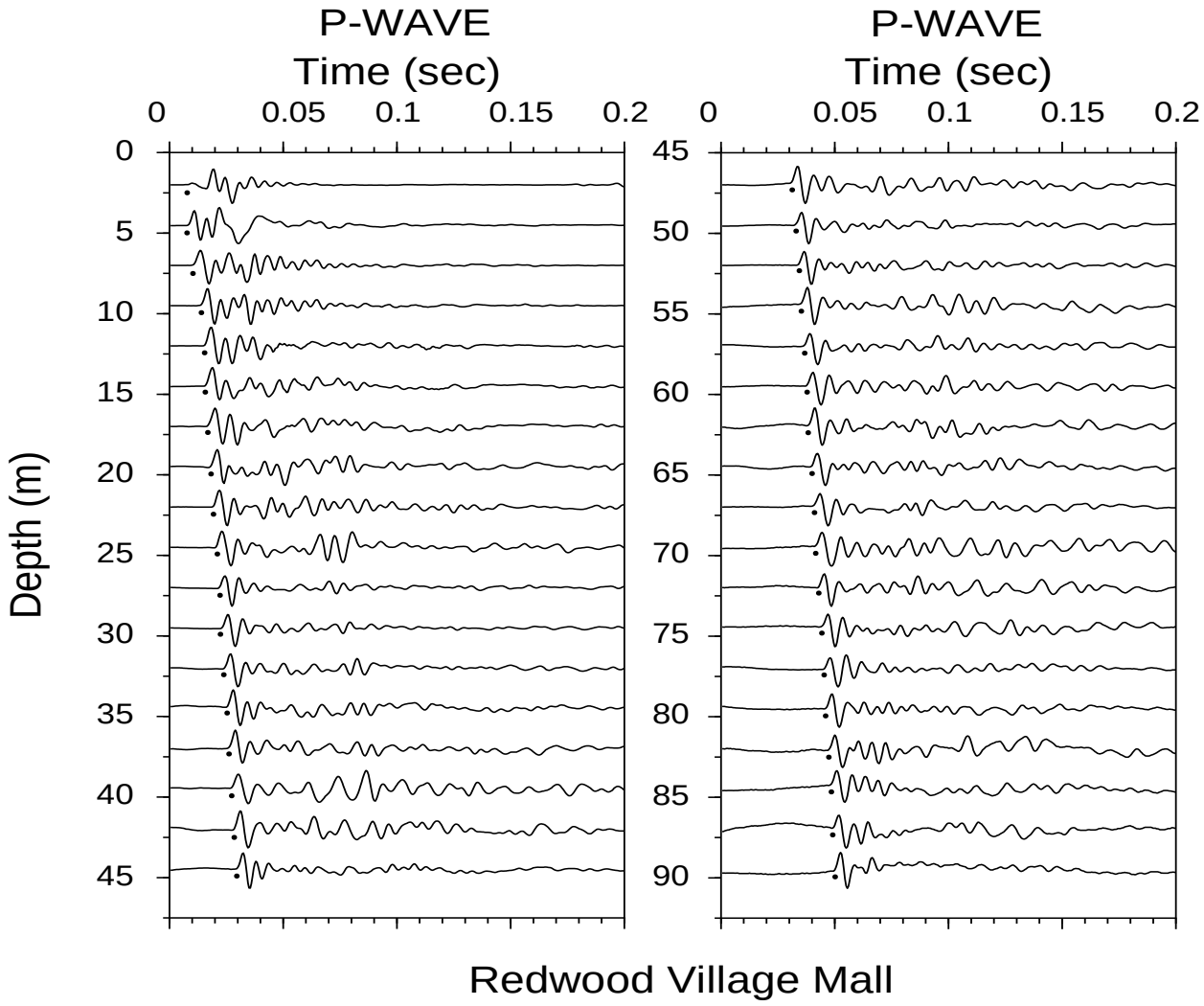

Figure A-18. Vertical component record section. Approximate P-wave arrivals are indicated by the dots.

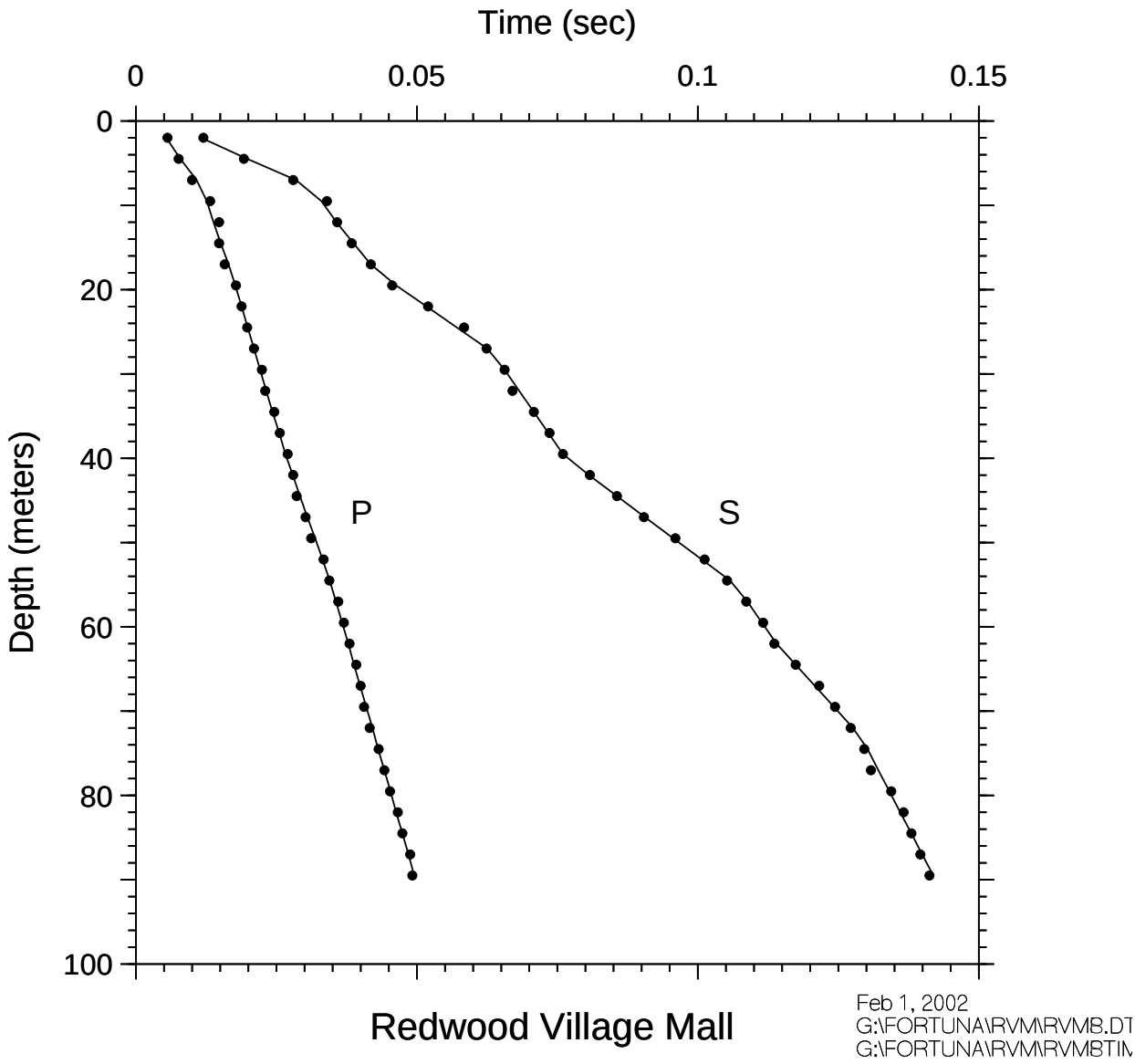

Figure A-19. Time-depth graph of P-wave and S-wave picks. Line segments are straightline interpolations of model predictions at the observation depths. The times for zero depth, not shown, are given by the horizontal offset ($hoffset$) divided by the velocity in the uppermost layer (see accompanying tables of velocities for specific values).

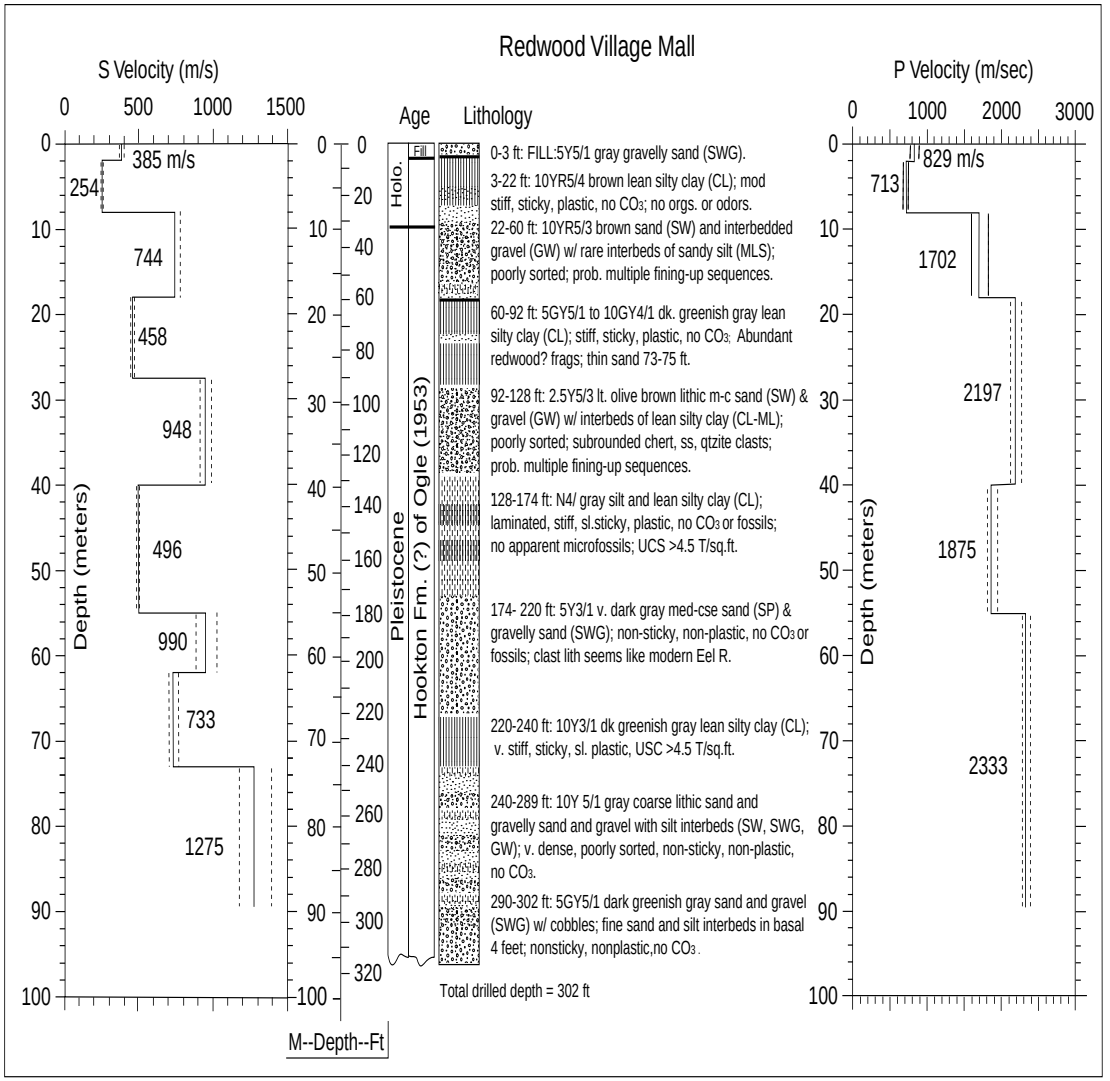

Figure A-20. S- and P-wave velocity profiles with lithology. Dashed lines represent plus and minus one standard deviation of velocities.

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TABLE A-7. S-wave arrival times and velocity summaries.

Location: Redwood Village Mall: S Coordinates: 40.58472 -124.14538 Hole_Code: 311
hoffset = 4.00 travel-time file: G:\FORTUNA\RVM\RVMS.TT
nlayers = 9

d(m)	d(ft)	tsl(s)	tvrt(s)	vavg(m/s)	sig	rsdl(sec)	dtb(m)	thk(m)	v(m/s)	vl(m/s)	vu(m/s)	dtb(ft)	thk(ft)	v(ft/s)	vl(ft/s)	vu(ft/s)
2.0	6.6	0.0120	0.0052	385	1	0.0004	2.0	2.0	385	369	402	6.6	6.6	1262	1210	1319
4.5	14.8	0.0192	0.0150	299	1	-0.0006	8.0	6.0	254	248	259	26.2	19.7	832	815	851
7.0	23.0	0.0280	0.0249	281	1	-0.0005	18.0	10.0	744	712	778	59.1	32.8	2440	2336	2553
9.5	31.2	0.0340	0.0308	308	1	0.0010	27.5	9.5	458	446	470	90.2	31.2	1503	1464	1543
12.0	39.4	0.0358	0.0342	351	1	0.0001	40.0	12.5	948	912	986	131.2	41.0	3110	2993	3235
14.5	47.6	0.0384	0.0376	386	1	-0.0003	55.0	15.0	496	487	505	180.4	49.2	1627	1599	1656
17.0	55.8	0.0418	0.0409	416	1	0.0000	62.0	7.0	950	885	1026	203.4	23.0	3118	2905	3366
19.5	64.0	0.0456	0.0455	428	1	-0.0007	73.0	11.0	733	703	766	239.5	36.1	2405	2308	2512
22.0	72.2	0.0520	0.0510	431	1	0.0003	89.5	16.5	1275	1176	1393	293.6	54.1	4184	3857	4570
24.5	80.4	0.0584	0.0564	434	1	0.0013										
27.0	88.6	0.0624	0.0619	436	1	-0.0001										
29.5	96.8	0.0656	0.0651	453	1	0.0000										
32.0	105.0	0.0670	0.0677	472	1	-0.0012										
34.5	113.2	0.0708	0.0704	490	1	0.0000										
37.0	121.4	0.0736	0.0730	507	1	0.0002										
39.5	129.6	0.0760	0.0757	522	1	0.0000										
42.0	137.8	0.0808	0.0802	524	1	0.0002										
44.5	146.0	0.0856	0.0853	522	1	0.0000										
47.0	154.2	0.0904	0.0903	520	1	-0.0002										
49.5	162.4	0.0960	0.0953	519	1	0.0004										
52.0	170.6	0.1012	0.1004	518	1	0.0005										
54.5	178.8	0.1052	0.1054	517	1	-0.0005										
57.0	187.0	0.1086	0.1085	525	1	-0.0002										
59.5	195.2	0.1116	0.1112	535	1	0.0002										
62.0	203.4	0.1136	0.1138	545	1	-0.0004										
64.5	211.6	0.1174	0.1172	550	1	0.0000										
67.0	219.8	0.1216	0.1206	555	1	0.0008										
69.5	228.0	0.1244	0.1240	560	1	0.0002										
72.0	236.2	0.1272	0.1274	565	1	-0.0004										
74.5	244.4	0.1296	0.1300	573	2	-0.0006										
77.0	252.6	0.1308	0.1319	584	3	-0.0013										
79.5	260.8	0.1344	0.1339	594	1	0.0003										
82.0	269.0	0.1366	0.1359	604	3	0.0006										
84.5	277.2	0.1380	0.1378	613	3	0.0000										
87.0	285.4	0.1396	0.1398	622	3	-0.0003										
89.5	293.6	0.1412	0.1417	631	3	-0.0007										

Explanation:

- d(m) = depth in meters
- d(ft) = depth in feet
- tsl(s) = observed arrival time in seconds (from source to receiver, along a slant path). For the arrival times used in the S-wave model, the times are the average of picks from traces obtained from hammer blows differing in direction by 180 degrees.
- tvrt(s) = vertical travel time computed from the model
- vavg(m/s) = average velocity from the surface to each depth, computed as avg_vel = d(m)/tvrt(s)
- sig = sigma, standard deviation normalized to the standard deviation of best picks
- rsdl(sec) = residual (observed - fitted travel time), in secs
- dtb(m) = depth to bottom of layer in meters
- thk(m) = thickness of layer in meters
- v(m/s) = velocity of layer in meters per second
- vl(m/s) = lower limit of velocity in meters per second (see text for explanation of velocity limits)
- vu(m/s) = upper limit of velocity in meters per second
- dtb(ft) = depth to bottom of layer in feet
- thk(ft) = thickness of layer in feet
- v(ft/s) = velocity of layer in feet per second
- vl(ft/s) = lower limit of velocity in feet per second
- vu(ft/s) = upper limit of velocity in feet per second

TABLE A-8. P-wave arrival times and velocity summaries.

Location: Redwood Village Mall: P Coordinates: 40.58472 -124.14538 Hole_Code: 311
hoffset = 4.00 travel-time file: G:\FORTUNA\RVM\VERT\RVMP.TT
nlayers = 6

d(m)	d(ft)	tsl(s)	tvrt(s)	vavg(m/s)	sig	rsdl(sec)	dtb(m)	thk(m)	v(m/s)	vl(m/s)	vu(m/s)	dtb(ft)	thk(ft)	v(ft/s)	vl(ft/s)	vu(ft/s)
2.0	6.6	0.0056	0.0024	829	1	0.0002	2.0	2.0	829	773	895	6.6	6.6	2721	2535	2936
4.5	14.8	0.0076	0.0059	760	1	-0.0003	8.0	6.0	713	683	746	26.2	19.7	2340	2242	2448
7.0	23.0	0.0100	0.0094	743	1	-0.0008	18.0	10.0	1702	1594	1824	59.1	32.8	5582	5231	5985
9.5	31.2	0.0132	0.0117	811	1	0.0006	40.0	22.0	2197	2125	2274	131.2	72.2	7208	6973	7460
12.0	39.4	0.0148	0.0132	911	1	0.0010	55.0	15.0	1875	1808	1948	180.4	49.2	6153	5933	6390
14.5	47.6	0.0148	0.0146	990	1	-0.0003	89.5	34.5	2333	2283	2384	293.6	113.2	7653	7490	7823
17.0	55.8	0.0158	0.0161	1055	1	-0.0007										
19.5	64.0	0.0178	0.0174	1122	1	0.0001										
22.0	72.2	0.0188	0.0185	1188	1	0.0000										
24.5	80.4	0.0198	0.0197	1246	1	-0.0001										
27.0	88.6	0.0210	0.0208	1298	1	0.0000										
29.5	96.8	0.0224	0.0219	1345	1	0.0003										
32.0	105.0	0.0230	0.0231	1387	1	-0.0002										
34.5	113.2	0.0246	0.0242	1425	1	0.0003										
37.0	121.4	0.0256	0.0254	1459	1	0.0001										
39.5	129.6	0.0270	0.0265	1491	1	0.0004										
42.0	137.8	0.0280	0.0278	1512	1	0.0001										
44.5	146.0	0.0286	0.0291	1528	1	-0.0006										
47.0	154.2	0.0302	0.0305	1544	1	-0.0003										
49.5	162.4	0.0312	0.0318	1557	1	-0.0007										
52.0	170.6	0.0334	0.0331	1570	1	0.0002										
54.5	178.8	0.0344	0.0345	1582	1	-0.0001										
57.0	187.0	0.0360	0.0356	1602	1	0.0004										
59.5	195.2	0.0370	0.0366	1624	1	0.0003										
62.0	203.4	0.0380	0.0377	1644	1	0.0002										
64.5	211.6	0.0392	0.0388	1663	1	0.0004										
67.0	219.8	0.0400	0.0399	1681	1	0.0001										
69.5	228.0	0.0406	0.0409	1698	1	-0.0004										
72.0	236.2	0.0416	0.0420	1714	1	-0.0005										
74.5	244.4	0.0432	0.0431	1730	1	0.0001										
77.0	252.6	0.0442	0.0441	1744	1	0.0000										
79.5	260.8	0.0452	0.0452	1758	1	-0.0001										
82.0	269.0	0.0466	0.0463	1771	1	0.0003										
84.5	277.2	0.0474	0.0474	1784	1	0.0000										
87.0	285.4	0.0488	0.0484	1796	1	0.0003										
89.5	293.6	0.0492	0.0495	1808	1	-0.0003										

Explanation:

- d(m) = depth in meters
- d(ft) = depth in feet
- tsl(s) = observed arrival time in seconds (from source to receiver, along a slant path). For the arrival times used in the S-wave model, the times are the average of picks from traces obtained from hammer blows differing in direction by 180 degrees.
- tvrt(s) = vertical travel time computed from the model
- vavg(m/s) = average velocity from the surface to each depth, computed as avg_vel = d(m)/tvrt(s)
- sig = sigma, standard deviation normalized to the standard deviation of best picks
- rsdl(sec) = residual (observed - fitted travel time), in secs
- dtb(m) = depth to bottom of layer in meters
- thk(m) = thickness of layer in meters
- v(m/s) = velocity of layer in meters per second
- vl(m/s) = lower limit of velocity in meters per second (see text for explanation of velocity limits)
- vu(m/s) = upper limit of velocity in meters per second
- dtb(ft) = depth to bottom of layer in feet
- thk(ft) = thickness of layer in feet
- v(ft/s) = velocity of layer in feet per second
- vl(ft/s) = lower limit of velocity in feet per second
- vu(ft/s) = upper limit of velocity in feet per second

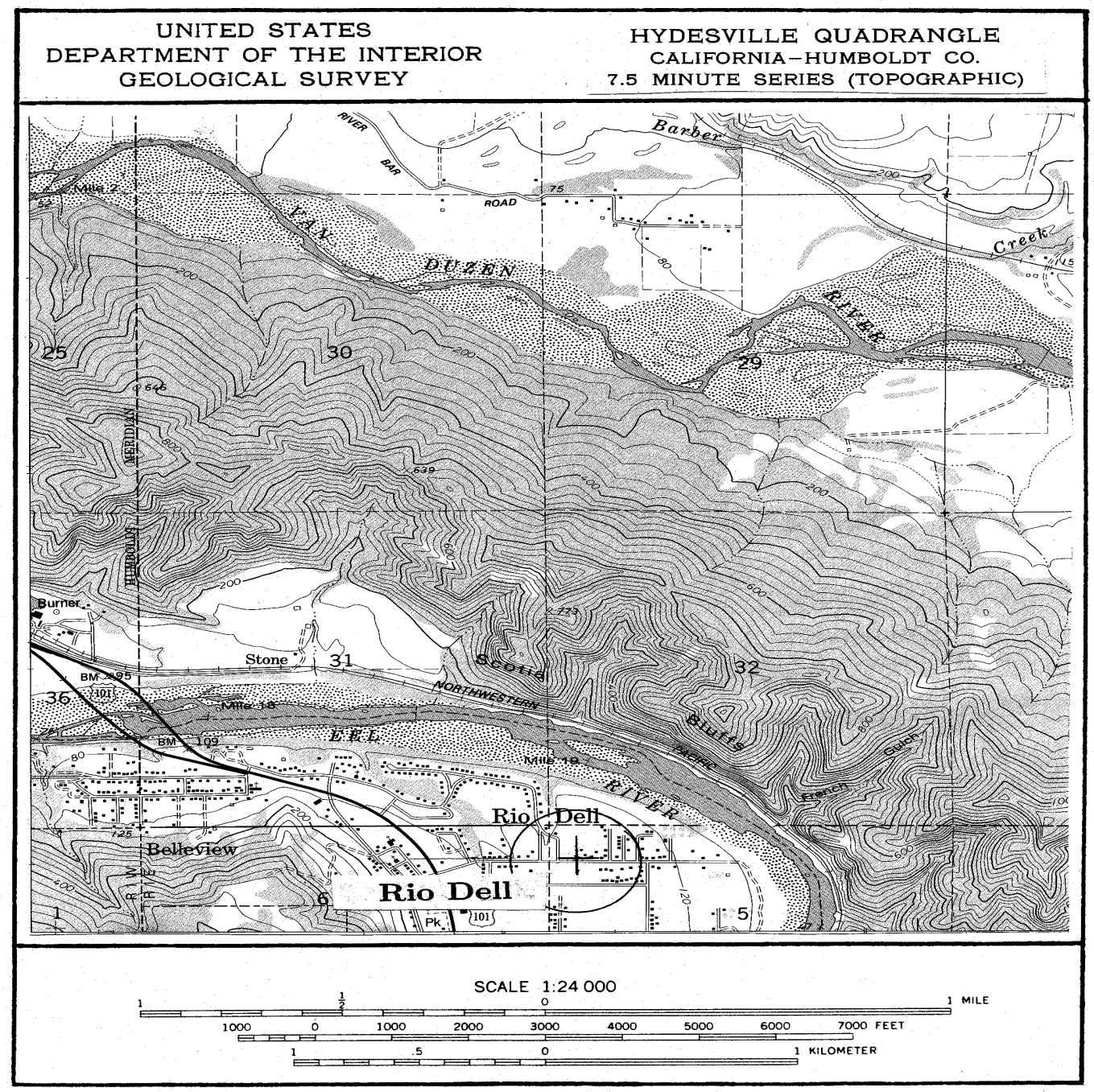

Figure A-21. Site location map for the borehole at Rio Dell. The highway (US 101) has been rerouted and is close to the borehole. The accelerograph is located approximately 10 meters from the borehole.

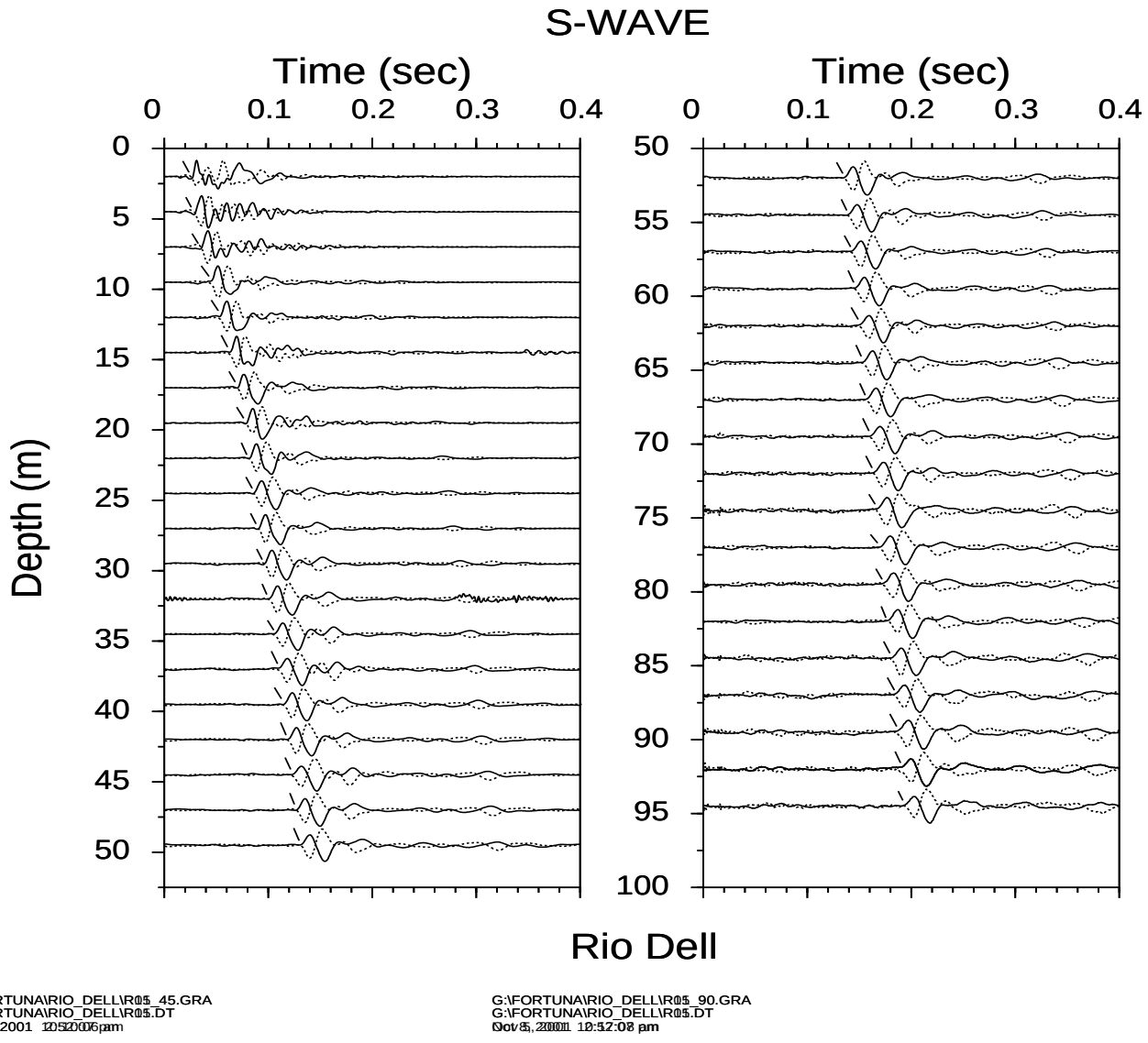

Figure A-22. Horizontal component record section (from impacts in opposite directions) superimposed for identification of S-wave onset. Approximate S-wave time picks are indicated by the hatch marks.

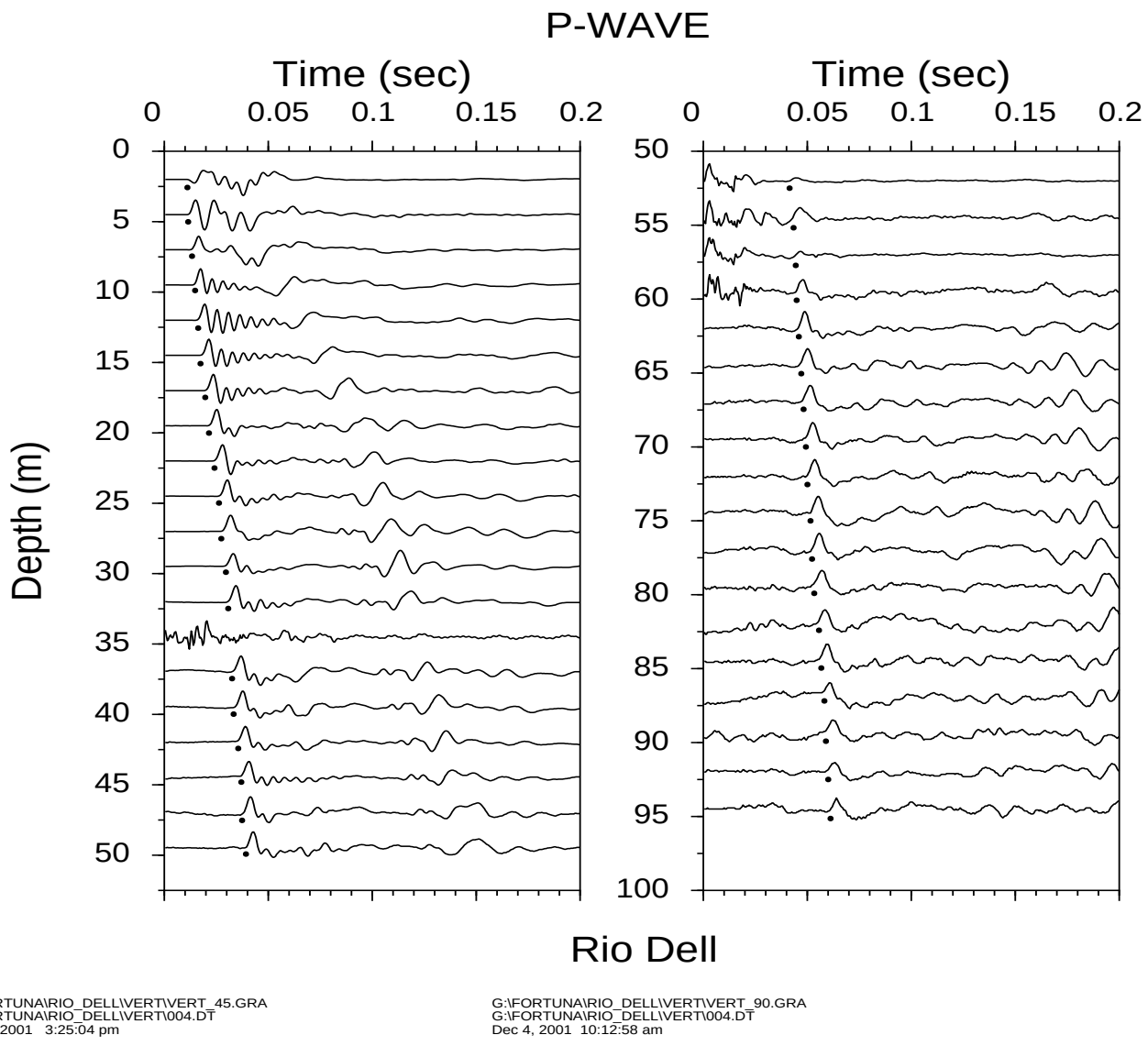

Figure A-23. Vertical component record section. Approximate P-wave arrivals are indicated by the dots.

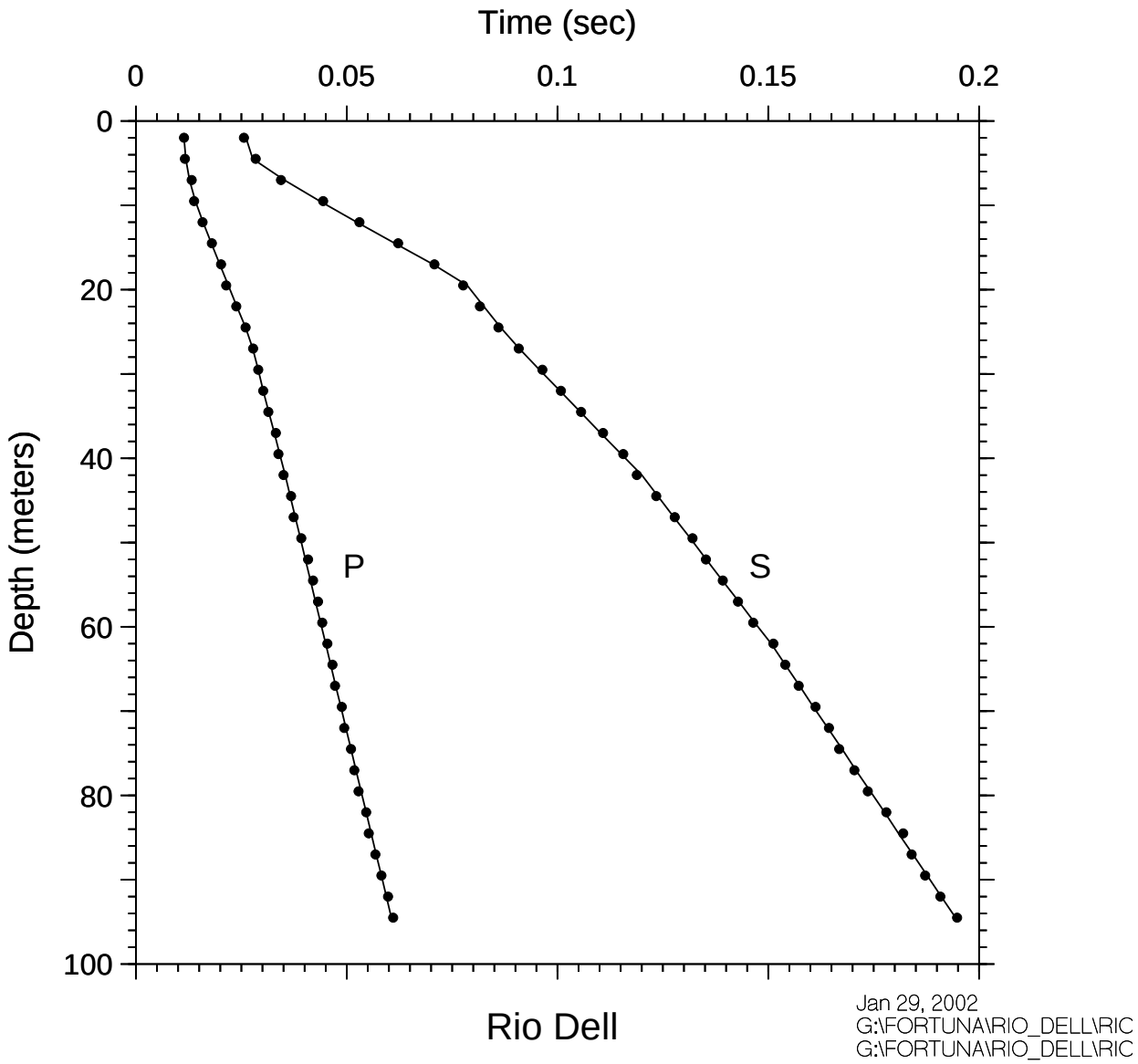

Figure A-24. Time-depth graph of P-wave and S-wave picks. Line segments are straightline interpolations of model predictions at the observation depths. The times for zero depth, not shown, are given by the horizontal offset ($hoffset$) divided by the velocity in the uppermost layer (see accompanying tables of velocities for specific values).

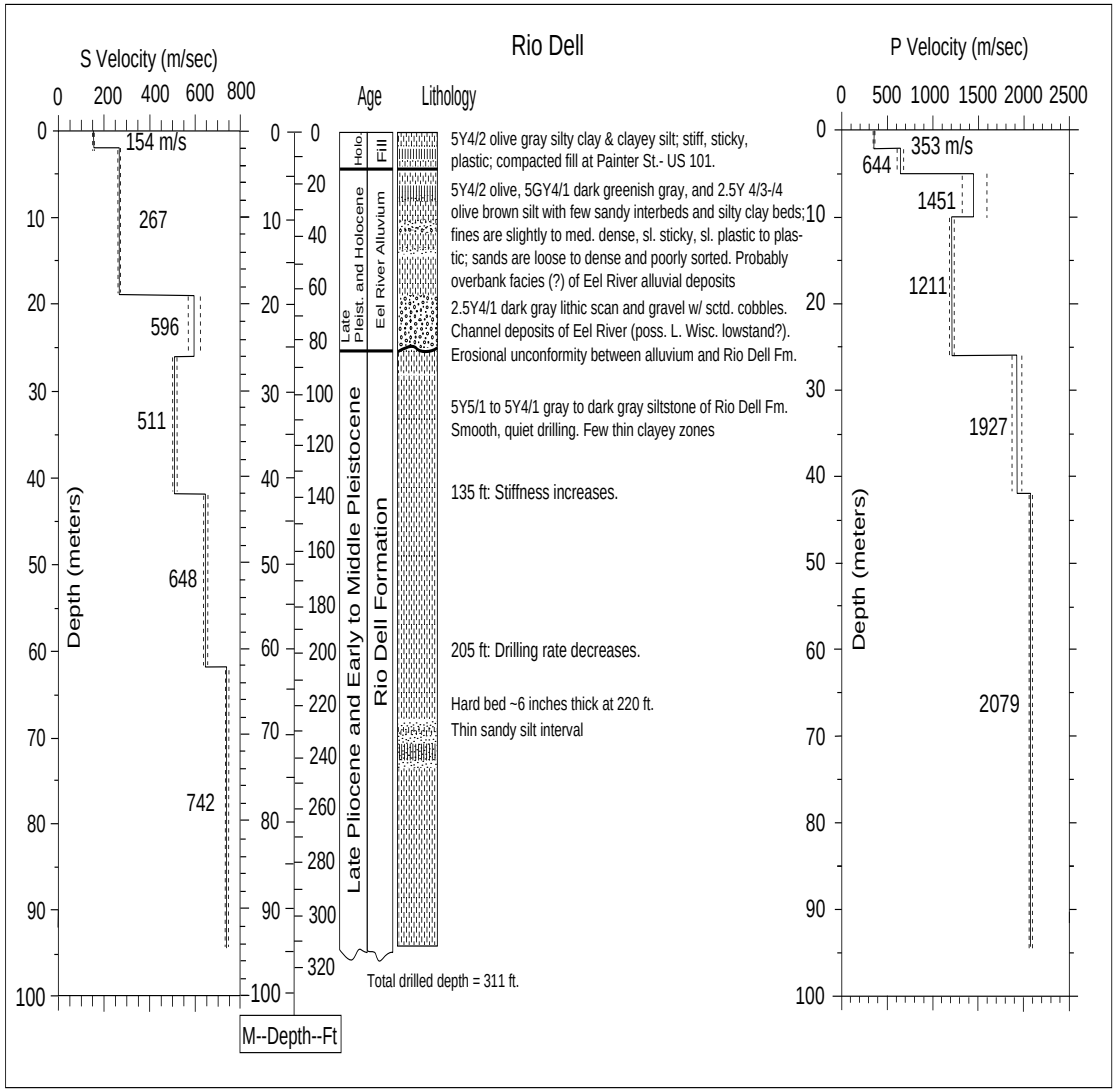

Figure A-25. S- and P-wave velocity profiles with lithology. Dashed lines represent plus and minus one standard deviation of velocities.

TABLE A-9. S-wave arrival times and velocity summaries.

Location: Rio Dell: S Coordinates: 40.50334 -124.09914 Hole_Code: 312
hoffset = 3.50 travel-time file: G:\FORTUNA\RIO_DELL\RIOS.TT
nlayers = 6

d(m)	d(ft)	tsl(s)	tvrt(s)	vavg(m/s)	sig	rsdl(sec)	dtb(m)	thk(m)	v(m/s)	vl(m/s)	vu(m/s)	dtb(ft)	thk(ft)	v(ft/s)	vl(ft/s)	vu(ft/s)
2.0	6.6	0.0256	0.0130	154	1	-0.0005	2.0	2.0	154	151	158	6.6	6.6	506	496	517
4.5	14.8	0.0284	0.0224	201	1	0.0007	19.0	17.0	267	265	269	62.3	55.8	877	870	884
7.0	23.0	0.0344	0.0317	221	1	-0.0008	26.0	7.0	596	570	624	85.3	23.0	1955	1869	2048
9.5	31.2	0.0444	0.0411	231	1	0.0008	42.0	16.0	511	503	520	137.8	52.5	1678	1650	1707
12.0	39.4	0.0530	0.0504	238	1	0.0006	62.0	20.0	648	639	657	203.4	65.6	2126	2096	2157
14.5	47.6	0.0622	0.0598	242	1	0.0008	94.5	32.5	742	734	750	310.0	106.6	2434	2409	2460
17.0	55.8	0.0708	0.0692	246	1	0.0003										
19.5	64.0	0.0776	0.0775	252	1	-0.0010										
22.0	72.2	0.0816	0.0817	269	1	-0.0009										
24.5	80.4	0.0860	0.0859	285	1	-0.0005										
27.0	88.6	0.0908	0.0904	299	1	-0.0001										
29.5	96.8	0.0964	0.0953	310	1	0.0007										
32.0	105.0	0.1008	0.1001	320	1	0.0002										
34.5	113.2	0.1056	0.1050	328	1	0.0002										
37.0	121.4	0.1108	0.1099	337	1	0.0006										
39.5	129.6	0.1156	0.1148	344	1	0.0005										
42.0	137.8	0.1188	0.1197	351	1	-0.0012										
44.5	146.0	0.1234	0.1236	360	1	-0.0004										
47.0	154.2	0.1278	0.1274	369	1	0.0002										
49.5	162.4	0.1320	0.1313	377	1	0.0005										
52.0	170.6	0.1352	0.1351	385	1	-0.0001										
54.5	178.8	0.1392	0.1390	392	1	0.0001										
57.0	187.0	0.1428	0.1429	399	1	-0.0002										
59.5	195.2	0.1464	0.1467	406	1	-0.0004										
62.0	203.4	0.1512	0.1506	412	1	0.0005										
64.5	211.6	0.1540	0.1539	419	1	0.0000										
67.0	219.8	0.1572	0.1573	426	1	-0.0002										
69.5	228.0	0.1612	0.1607	433	1	0.0005										
72.0	236.2	0.1644	0.1641	439	1	0.0003										
74.5	244.4	0.1668	0.1674	445	1	-0.0007										
77.0	252.6	0.1704	0.1708	451	1	-0.0004										
79.5	260.8	0.1736	0.1742	456	1	-0.0006										
82.0	269.0	0.1780	0.1775	462	1	0.0004										
84.5	277.2	0.1820	0.1809	467	1	0.0011										
87.0	285.4	0.1840	0.1843	472	1	-0.0003										
89.5	293.6	0.1872	0.1876	477	1	-0.0005										
92.0	301.8	0.1908	0.1910	482	1	-0.0002										
94.5	310.0	0.1948	0.1944	486	1	0.0004										

Explanation:

- d(m) = depth in meters
- d(ft) = depth in feet
- tsl(s) = observed arrival time in seconds (from source to receiver, along a slant path). For the arrival times used in the S-wave model, the times are the average of picks from traces obtained from hammer blows differing in direction by 180 degrees.
- tvrt(s) = vertical travel time computed from the model
- vavg(m/s) = average velocity from the surface to each depth, computed as avg_vel = d(m)/tvrt(s)
- sig = sigma, standard deviation normalized to the standard deviation of best picks
- rsdl(sec) = residual (observed - fitted travel time), in secs
- dtb(m) = depth to bottom of layer in meters
- thk(m) = thickness of layer in meters
- v(m/s) = velocity of layer in meters per second
- vl(m/s) = lower limit of velocity in meters per second (see text for explanation of velocity limits)
- vu(m/s) = upper limit of velocity in meters per second
- dtb(ft) = depth to bottom of layer in feet
- thk(ft) = thickness of layer in feet
- v(ft/s) = velocity of layer in feet per second
- vl(ft/s) = lower limit of velocity in feet per second
- vu(ft/s) = upper limit of velocity in feet per second

TABLE A-10. P-wave arrival times and velocity summaries.

Location: Rio Dell: P Coordinates: 40.50334 -124.09914 Hole_Code: 312
hoffset = 3.50 travel-time file: G:\FORTUNA\RIO_DELL\RIOP.TT
nlayers = 6

d(m)	d(ft)	tsl(s)	tvrt(s)	vavg(m/s)	sig	rsdl(sec)	dtb(m)	thk(m)	v(m/s)	vl(m/s)	vu(m/s)	dtb(ft)	thk(ft)	v(ft/s)	vl(ft/s)	vu(ft/s)
2.0	6.6	0.0114	0.0057	353	1	0.0000	2.0	2.0	353	344	364	6.6	6.6	1160	1128	1194
4.5	14.8	0.0116	0.0095	471	1	-0.0002	5.0	3.0	644	606	686	16.4	9.8	2112	1988	2251
7.0	23.0	0.0132	0.0117	598	1	0.0005	10.0	5.0	1451	1328	1599	32.8	16.4	4759	4356	5245
9.5	31.2	0.0138	0.0134	708	1	-0.0003	26.0	16.0	1211	1186	1238	85.3	52.5	3974	3889	4062
12.0	39.4	0.0158	0.0154	778	1	-0.0001	42.0	16.0	1927	1874	1983	137.8	52.5	6323	6149	6507
14.5	47.6	0.0180	0.0175	829	1	0.0001	94.5	52.5	2079	2061	2097	310.0	172.2	6821	6761	6881
17.0	55.8	0.0202	0.0196	870	1	0.0003										
19.5	64.0	0.0214	0.0216	902	1	-0.0005										
22.0	72.2	0.0238	0.0237	929	1	-0.0001										
24.5	80.4	0.0260	0.0257	952	1	0.0000										
27.0	88.6	0.0278	0.0275	982	1	0.0001										
29.5	96.8	0.0290	0.0288	1024	1	0.0000										
32.0	105.0	0.0302	0.0301	1063	1	0.0000										
34.5	113.2	0.0314	0.0314	1099	3	-0.0001										
37.0	121.4	0.0332	0.0327	1132	1	0.0004										
39.5	129.6	0.0338	0.0340	1162	1	-0.0003										
42.0	137.8	0.0350	0.0353	1190	1	-0.0004										
44.5	146.0	0.0368	0.0365	1220	1	0.0002										
47.0	154.2	0.0374	0.0377	1247	1	-0.0004										
49.5	162.4	0.0392	0.0389	1273	1	0.0002										
52.0	170.6	0.0408	0.0401	1297	3	0.0006										
54.5	178.8	0.0420	0.0413	1320	3	0.0006										
57.0	187.0	0.0432	0.0425	1341	3	0.0006										
59.5	195.2	0.0442	0.0437	1361	2	0.0004										
62.0	203.4	0.0454	0.0449	1381	1	0.0004										
64.5	211.6	0.0466	0.0461	1399	1	0.0004										
67.0	219.8	0.0472	0.0473	1416	1	-0.0002										
69.5	228.0	0.0488	0.0485	1433	1	0.0002										
72.0	236.2	0.0494	0.0497	1448	1	-0.0004										
74.5	244.4	0.0510	0.0509	1463	1	0.0000										
77.0	252.6	0.0518	0.0521	1477	1	-0.0004										
79.5	260.8	0.0528	0.0533	1491	1	-0.0006										
82.0	269.0	0.0546	0.0545	1504	1	0.0000										
84.5	277.2	0.0552	0.0557	1516	1	-0.0006										
87.0	285.4	0.0568	0.0569	1528	1	-0.0002										
89.5	293.6	0.0582	0.0581	1540	1	0.0000										
92.0	301.8	0.0598	0.0593	1551	1	0.0004										
94.5	310.0	0.0610	0.0605	1561	1	0.0004										

Explanation:

- d(m) = depth in meters
- d(ft) = depth in feet
- tsl(s) = observed arrival time in seconds (from source to receiver, along a slant path). For the arrival times used in the S-wave model, the times are the average of picks from traces obtained from hammer blows differing in direction by 180 degrees.
- tvrt(s) = vertical travel time computed from the model
- vavg(m/s) = average velocity from the surface to each depth, computed as avg_vel = d(m)/tvrt(s)
- sig = sigma, standard deviation normalized to the standard deviation of best picks
- rsdl(sec) = residual (observed - fitted travel time), in secs
- dtb(m) = depth to bottom of layer in meters
- thk(m) = thickness of layer in meters
- v(m/s) = velocity of layer in meters per second
- vl(m/s) = lower limit of velocity in meters per second (see text for explanation of velocity limits)
- vu(m/s) = upper limit of velocity in meters per second
- dtb(ft) = depth to bottom of layer in feet
- thk(ft) = thickness of layer in feet
- v(ft/s) = velocity of layer in feet per second
- vl(ft/s) = lower limit of velocity in feet per second
- vu(ft/s) = upper limit of velocity in feet per second

APPENDIX—B

Poisson's Ratios

Table B-1. Poisson's ratios calculated from the P- and S-wave velocity models determined for the College of the Redwoods site.

P wave - d2bot, pvel, for file: CRWP.VEL

2.00000	348.000
14.0000	559.000
94.6000	1520.00

S wave - d2bot, svel, for file: CRWS_RE.VEL

2.00000	240.000
6.00000	369.000
27.0000	281.000
35.0000	516.000
49.5000	355.000
72.0000	389.000
89.5000	463.000
94.5000	513.000

d2bot_p	d2bot_s	d2bot	thick	pvel	svel	pssnrat
2.000E+00	2.000E+00	2.000E+00	2.000E+00	3.480E+02	2.400E+02	0.05
1.400E+01	6.000E+00	6.000E+00	4.000E+00	5.590E+02	3.690E+02	0.11
1.400E+01	2.700E+01	1.400E+01	8.000E+00	5.590E+02	2.810E+02	0.33
9.460E+01	2.700E+01	2.700E+01	1.300E+01	1.520E+03	2.810E+02	0.48
9.460E+01	3.500E+01	3.500E+01	8.000E+00	1.520E+03	5.160E+02	0.43
9.460E+01	4.950E+01	4.950E+01	1.450E+01	1.520E+03	3.550E+02	0.47
9.460E+01	7.200E+01	7.200E+01	2.250E+01	1.520E+03	3.890E+02	0.46
9.460E+01	8.950E+01	8.950E+01	1.750E+01	1.520E+03	4.630E+02	0.45
9.460E+01	9.450E+01	9.450E+01	5.000E+00	1.520E+03	5.130E+02	0.44

Table B-2. Poisson's ratios calculated from the P- and S-wave velocity models determined for the Fortuna Fire Station site.

```
 P wave - d2bot,   pvel,   for file:   FFSP.VEL
    3.70000            421.000
    57.0000            2381.00
    97.0000            1749.00

 S wave - d2bot,   svel,   for file:   ffs2S.VEL
    3.70000            172.000
    10.0000            346.000
    19.5000            439.000
    75.6000            829.000
    97.0000            730.000
```

d2bot_p	d2bot_s	d2bot	thick	pvel	svel	pssnrat
3.700E+00	3.700E+00	3.700E+00	3.700E+00	4.210E+02	1.720E+02	0.40
5.700E+01	1.000E+01	1.000E+01	6.300E+00	2.381E+03	3.460E+02	0.49
5.700E+01	1.950E+01	1.950E+01	9.500E+00	2.381E+03	4.390E+02	0.48
5.700E+01	7.560E+01	5.700E+01	3.750E+01	2.381E+03	8.290E+02	0.43
9.700E+01	7.560E+01	7.560E+01	1.860E+01	1.749E+03	8.290E+02	0.36
9.700E+01	9.700E+01	9.700E+01	2.140E+01	1.749E+03	7.300E+02	0.39

Table B-3. Poisson's ratios calculated from the P- and S-wave velocity models determined for the Loleta Fire Station site.

P wave - d2bot, pvel, for file: LFSP.VEL

2.00000	415.000
5.00000	532.000
11.0000	708.000
24.5000	1262.00
35.0000	1029.00
68.0000	1737.00
94.5000	1885.00

S wave - d2bot, svel, for file: LFSS.VEL

2.00000	256.000
5.00000	202.000
11.0000	466.000
19.5000	289.000
24.5000	739.000
35.0000	432.000
55.0000	398.000
68.0000	493.000
82.0000	557.000
94.5000	705.000

d2bot_p	d2bot_s	d2bot	thick	pvel	svel	pssnrat
2.000E+00	2.000E+00	2.000E+00	2.000E+00	4.150E+02	2.560E+02	0.19
5.000E+00	5.000E+00	5.000E+00	3.000E+00	5.320E+02	2.020E+02	0.42
1.100E+01	1.100E+01	1.100E+01	6.000E+00	7.080E+02	4.660E+02	0.12
2.450E+01	1.950E+01	1.950E+01	8.500E+00	1.262E+03	2.890E+02	0.47
2.450E+01	2.450E+01	2.450E+01	5.000E+00	1.262E+03	7.390E+02	0.24
3.500E+01	3.500E+01	3.500E+01	1.050E+01	1.029E+03	4.320E+02	0.39
6.800E+01	5.500E+01	5.500E+01	2.000E+01	1.737E+03	3.980E+02	0.47
6.800E+01	6.800E+01	6.800E+01	1.300E+01	1.737E+03	4.930E+02	0.46
9.450E+01	8.200E+01	8.200E+01	1.400E+01	1.885E+03	5.570E+02	0.45
9.450E+01	9.450E+01	9.450E+01	1.250E+01	1.885E+03	7.050E+02	0.42

Table B-4. Poisson's ratios calculated from the P- and S-wave velocity models determined for the Redwood Village Mall site.

P wave - d2bot, pvel, for file: RVMP.VEL

2.00000	829.000
8.00000	713.000
18.0000	1702.00
40.0000	2197.00
55.0000	1875.00
89.5000	2333.00

S wave - d2bot, svel, for file: RVMS.VEL

2.00000	385.000
8.00000	254.000
18.0000	744.000
27.5000	458.000
40.0000	948.000
55.0000	496.000
62.0000	950.000
73.0000	733.000
89.5000	1275.00

d2bot_p	d2bot_s	d2bot	thick	pvel	svel	pssnrat
2.000E+00	2.000E+00	2.000E+00	2.000E+00	8.290E+02	3.850E+02	0.36
8.000E+00	8.000E+00	8.000E+00	6.000E+00	7.130E+02	2.540E+02	0.43
1.800E+01	1.800E+01	1.800E+01	1.000E+01	1.702E+03	7.440E+02	0.38
4.000E+01	2.750E+01	2.750E+01	9.500E+00	2.197E+03	4.580E+02	0.48
4.000E+01	4.000E+01	4.000E+01	1.250E+01	2.197E+03	9.480E+02	0.39
5.500E+01	5.500E+01	5.500E+01	1.500E+01	1.875E+03	4.960E+02	0.46
8.950E+01	6.200E+01	6.200E+01	7.000E+00	2.333E+03	9.500E+02	0.40
8.950E+01	7.300E+01	7.300E+01	1.100E+01	2.333E+03	7.330E+02	0.45
8.950E+01	8.950E+01	8.950E+01	1.650E+01	2.333E+03	1.275E+03	0.29

Table B-5. Poisson's ratio calculated from P- and S-wave velocity models determined for the Rio Dell site.

P wave - d2bot, pvel, for file: RIOP.VEL

2.00000	353.000
5.00000	644.000
10.0000	1451.00
26.0000	1211.00
42.0000	1927.00
94.5000	2079.00

S wave - d2bot, svel, for file: RIOS.VEL

2.00000	154.000
19.0000	267.000
26.0000	596.000
42.0000	511.000
62.0000	648.000
94.5000	742.000

d2bot_p	d2bot_s	d2bot	thick	pvel	svel	pssnrat
2.000E+00	2.000E+00	2.000E+00	2.000E+00	3.530E+02	1.540E+02	0.38
5.000E+00	1.900E+01	5.000E+00	3.000E+00	6.440E+02	2.670E+02	0.40
1.000E+01	1.900E+01	1.000E+01	5.000E+00	1.451E+03	2.670E+02	0.48
2.600E+01	1.900E+01	1.900E+01	9.000E+00	1.211E+03	2.670E+02	0.47
2.600E+01	2.600E+01	2.600E+01	7.000E+00	1.211E+03	5.960E+02	0.34
4.200E+01	4.200E+01	4.200E+01	1.600E+01	1.927E+03	5.110E+02	0.46
9.450E+01	6.200E+01	6.200E+01	2.000E+01	2.079E+03	6.480E+02	0.45
9.450E+01	9.450E+01	9.450E+01	3.250E+01	2.079E+03	7.420E+02	0.43