U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Data Report for 1991 Active-Source Seismic Profiles in the San Francisco Bay Area, California

by

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Open-File Report 92-570

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INTRODUCTION

To address questions raised by the 1989 Loma Prieta earthquake, the USGS conducted two seismic refraction/wide angle reflection surveys in the San Francisco Bay area during 1991. The depth and wave propagation characteristics of the 1989 Loma Prieta earthquake pointed out the need for a more detailed understanding of the crustal structure within the greater San Francisco Bay area. To better understand the Loma Prieta epicentral region, a 25-km-long high resolution profile was recorded across the Santa Cruz Mountains; the LP profile (figure 1). A 180-km-long profile (SF profile) was recorded along the San Francisco and Marin Peninsulas to determine the wave propagation effects in the San Francisco region. During the 1989 Loma Prieta earthquake, areas of higher-than-normal destruction far from the source (~100 km), implied crustal structure, as well as local site geology, may have played an important role in the level of strong ground motion and, therefore, the distribution of intense damage. Along the SF profile (figure 1), the correlation between the areas of greatest damage and focusing of seismic energy from deep reflections are being studied.

The data have been archived at the National Geophysical Data Center in Boulder, Colorado. Tapes are available from:

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
325 Broad
Boulder, CO 80303

DESCRIPTION OF THE SURVEYS

The survey consisted of a 180-km-long, northwest-southeast profile (SF profile) with 1-km spacing between seismic recorders and a short 25-km-long, northeast-southwest profile (LP profile) with a 100-m receiver spacing. Five shots were recorded on each profile (figure 1). A Global Positioning System (GPS), the Trimble Navigation Path Finder, was used to determine locations and elevations for all shot points and for most of the seismic recorder stations. These locations are estimated to be accurate to within 5 meters. Locations for seismic recorder stations 1095-1098, and 1193-1199 were determined from USGS 1:24,000 topographic maps. These locations are estimated to be accurate to within 15 meters. Shot point locations are listed in table 1 and Instrument locations are given in appendix A.

Seismic sources were produced by explosions in drilled holes. The shallow hole at shot point 8 was drilled with an auger and loaded with seven

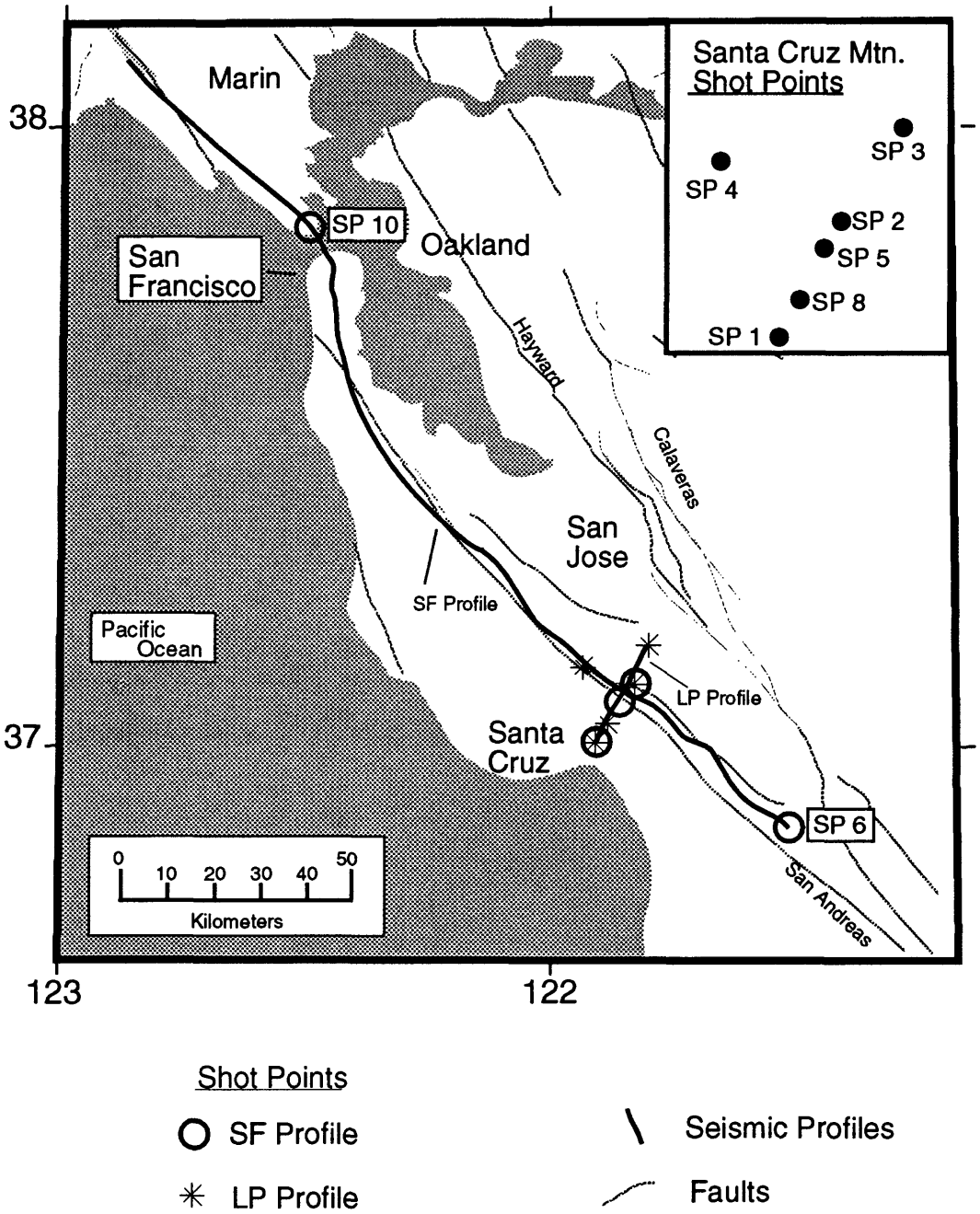

Fig. 1. Map of the San Francisco Bay Area showing the locations of the seismic profiles recorded in 1991.

1-lb, nitrate-based boosters. All other shot points consisted of a 20-cm-diameter drill hole filled with an ammonium nitrate blasting agent. The depth of each drill hole and the amount of explosive are listed in table 1. At shot time, a signal from a USGS master reference clock triggered the shooting system to fire an electric blasting cap, which sequentially caused the primacord, boosters, and blasting agent to detonate. The shot origin times are determined by the master clocks, assuming that the explosives detonated at the exact time of the cap break. The reported shot times (table 1) are accurate to within ± 1 millisecond.

INSTRUMENTATION

Seismic Group Recorders (SGR's) were used to collect data during this experiment. These SGR-III recorders were designed by Amoco Production Company, built by Globe Universal Sciences, Inc., and modified by the USGS. The SGR-III is a single channel, digital seismic recorder with a theoretical dynamic range of 156 dB. Data are sampled at 500 samples per second by a 12 bit A/D with gain ranging from 0-90 dB in 6 dB steps. These SGR's have been modified to turn on at preset times instead of using the standard radio turn on. Timing is provided by a temperature compensated internal oscillator that is sychronized to a USGS master clock prior to deployment. The USGS master clocks drift approximately one millisecond per week and are checked periodically against satellite clocks. The digital data and a drift rate are recorded on cartridge tape. The drift rate is used to calculate a chronometer correction at shot time. For this experiment, the SGR-III pre-amplifier was set to 50 mV, the low-cut filter was "out", and the 60-Hz notch filter was "in". Figure 2 shows the phase characteristics associated with these filter settings. Each SGR III was connected to a single string of 6 modified Marks Products L-10B vertical component geophones connected in series. The total system response is shown in figure 3.

RECORD SECTIONS

Record sections are plotted with maximum trace amplitudes normalized to a common value. The horizontal axis represents distance in kilometers and the vertical axis represents reduced travel time in seconds ($T = t - x/6.0$). Shots 1, 2, 3, 5, 6, 7, 8, and 10 are plotted with distances relative to the shot point (Figures 4, 5, 6, 8, 9, 10, 11, and 13, respectively). For the LP line, distances are positive to the northeast and negative to the southwest. For the SF line, distances are positive to the northwest and negative to the southeast. Shots 4 and 9 are plotted as psuedo-fan record sections (Figures 7 and 12, respectively). In the psuedo-fan record sections, distances are plotted relative

to the southwestern most recorder location on the LP line (1016) for shot 4 and the southeastern most recorder location on the SF line (2163) for shot 9.

ARCHIVE DATA TAPE FORMAT

Archive data tapes are written in standard SEG-Y 32-bit IBM floating point format (Barry et al., 1975). The tape recording density is 6250 bpi and each tape has the standard SEG-Y EBCDIC reel header. Minor modifications to the trace headers allow refraction data to be archived in this format. A list of the header fields used for this data is shown below. For a more compete description of the tape format see Appendix B. Appendix B can be used as an include file in fortran programs that read SEG-Y data tapes.

Binary area of file (or reel) Identification Header	
1-4	Not used
5-8	Not used
9-12	Reel number
13-14	Not used
15-16	Not used
17-18	Sample interval in microseconds
19-20	Sample interval in microseconds
21-22	No of samples per trace
23-24	(field data) No of samples per trace
25-26	Data sample format code (1 = IBM Floating point)
27-28	Not used
29-30	Trace sorting code (1 = as recorded)
31-32	Not used
33-34	Not used
35-36	Not used
37-38	Not used
39-40	Not used
41-42	Not used
43-44	Not used
45-46	Not used
47-48	Not used
49-50	Correlated data traces (1 = no)
51-52	Binary gain recovered (1 = yes)
53-54	Not used
55-56	Not used
57-58	Not used

59-60	Not used
61-62	Number of traces in the file
63-64	Not used
65-68	Not used
69-70	Domain of data
71-72	unused to allow alignment of four byte boundaries.
73-76	Not used
77-80	Not used
81-84	Not used
85-86	Not used
87-88	Not used
89-90	Not used
91-92	Not used
93-398	Not used

Trace Identification Header (total of 240 bytes)

1-4	Trace sequence number within line
5-8	Trace sequence number within line
9-12	Shot number
13-16	Recorder location number
17-20	Shot point location number
21-24	Original field order of shots for each deployment
25-28	Trace sequence number within shot ensemble
29-30	Trace identification code (1 = seismic data)
31-32	Number of vertically summed traces yielding this trace
33-34	Not used
35-36	Not used
37-40	Distance from source to receiver (for sign definition see text)
41-44	Receiver group elevation (m)
45-48	Surface elevation of source (m)
49-52	Shot depth
53-56	Receiver elevation
57-60	Shot point elevation
61-64	Not used
65-68	Not used
69-70	Scalar multiplier/divisor for bytes 41-68
71-72	Scalar multiplier/divisor for bytes 73-88
73-76	Source coordinate X or longitude (East positive)
77-80	Source coordinate Y or latitude (North positive)
81-84	Group coordinate X or longitude (East positive)
85-88	Group coordinate Y or latitude (North positive)

89-90	Coordinate units
91-92	Not used
93-94	Not used
95-96	Not used
97-98	Not used
99-100	Not used
101-102	Not used
103-104	Not used
105-106	Not used
107-108	Not used
109-110	Delay recording time (reduced start time) (msec)
111-112	Not used
113-114	Not used
115-116	No of samples in this trace
117-118	Sampling interval in microseconds
119-120	Gain type (1=fixed 2=binary 3=floating)
121-122	Gain constant
123-124	Instrument or initial gain in DB
125-126	Correlated 1=no 2=yes
127-128	Not used
129-130	Not used
131-132	Not used
133-134	Not used
135-136	Not used
137-138	Not used
139-140	Not used
141-142	Not used
143-144	Not used
145-146	Not used
147-148	Not used
149-150	Not used
151-152	Not used
153-154	Not used
155-156	Not used
157-158	Year of start of trace
159-160	Day of start of trace
161-162	Hour of start of trace
163-164	Minute of start of trace
165-166	Second of start of trace
167-168	Not used
169-170	Not used
171-172	Not used
173-174	Not used
175-176	Not used
177-178	Distance-azimuth calculation algorithm
179-180	Earth dimension code

181-183	Microseconds of trace start time
185-186	Millisecond of timing correction
187-188	Not used
189-190	Shot time - Year
191-192	Shot time - Day
193-194	Shot time - Hour
195-196	Shot time - Minute
197-198	Shot time - Second
199-202	Shot time - Microsecond
203-204	Azimuth of receiver from shot (minutes of arc)
205-206	Not used
207-208	Not used
209-212	Not used
213-216	Not used
217-220	Not used
221-223	Not used
224-228	Not used
229-232	Not used
233-236	Not used
237-240	Not used

TABLE 1 SHOT LIST

SHOT	LOCATION NUMBER	LATITUDE	LONGITUDE	ELEV (m)	DEPTH (m)	CHARGE (lbs)	SHOT TIME J-DAY	SHOT TIME HR:MIN:SEC
1	1	37.021353	-121.902786	79	38	1000	142	06:00:00.00
2	2	37.105612	-121.847205	1034	33	1000	142	06:02:00.00
3	3	37.172819	-121.791568	175	33	1000	142	06:04:00.00
4	4	37.147456	-121.953758	268	24	500	142	06:05:00.00
5	8	37.048383	-121.882774	433	3	7	142	07:01:00.00
6	5	37.085045	-121.861415	530	54	3000	144	07:00:00.00
7	6	36.857161	-121.561372	122	45	2000	144	07:02:00.00
8	2	37.105612	-121.847205	1034	27	1000	144	07:04:00.00
9	1	37.021353	-121.902786	79	*	1000	144	08:04:00.00
10	10	37.827884	-122.490028	15	57	3000	150	09:30:00.00

* Reloaded open hole. Exact depth unknown

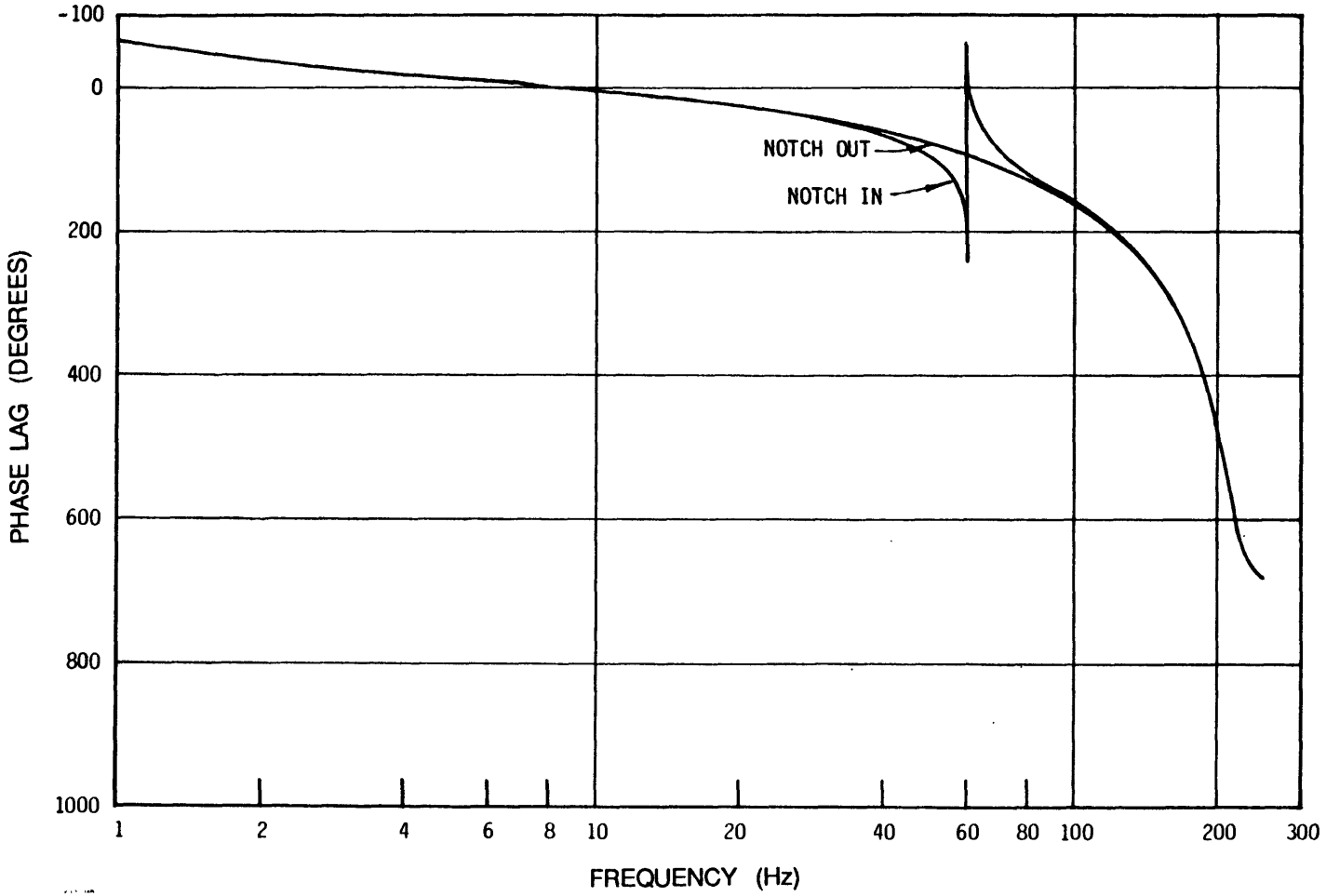

Figure 2. The phase characteristics of the SGRs with the filters as described in the text.

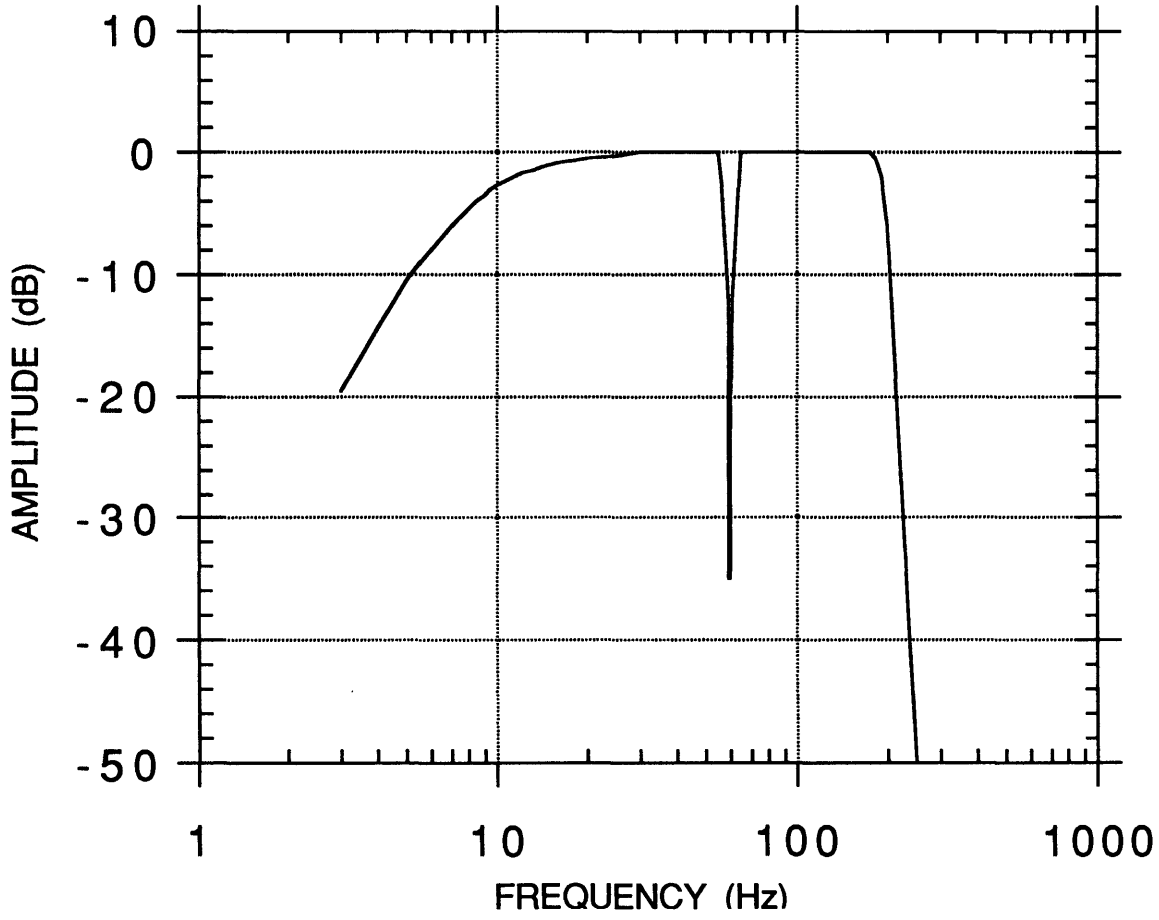

Figure 3. The total system response.

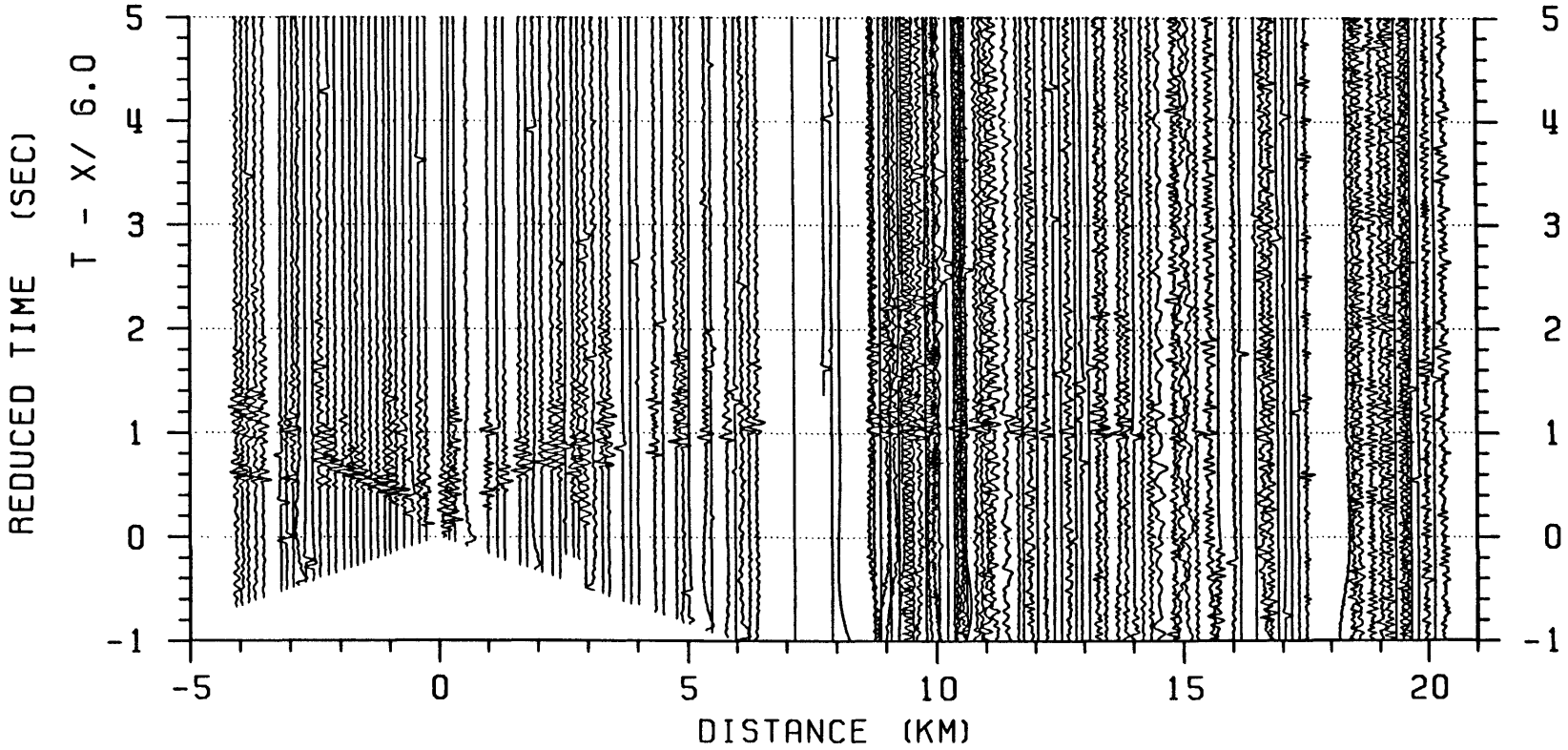

FIGURE 4. LP PROFILE
SHOT 1 SHOT POINT 1

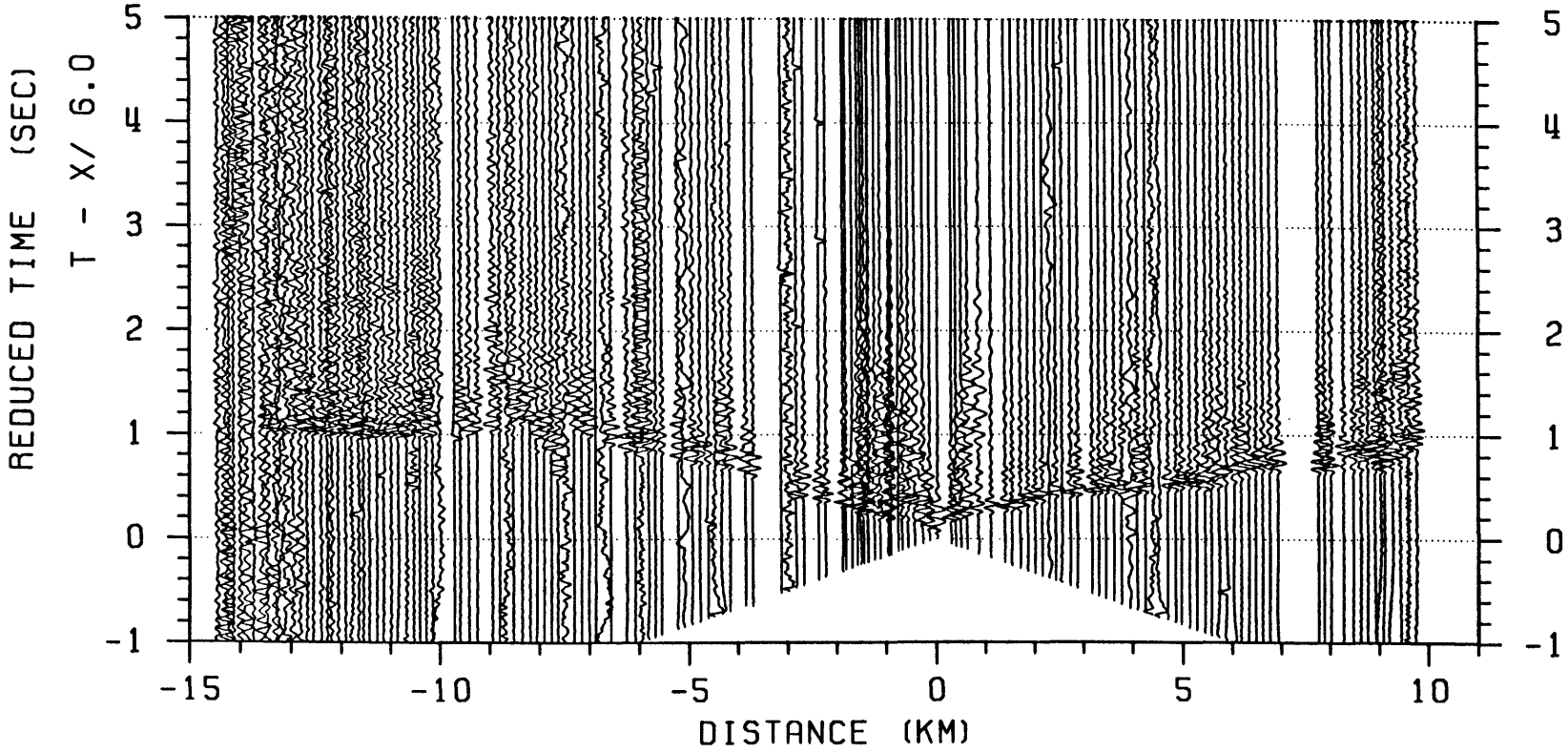

FIGURE 5. LP PROFILE
SHOT 2 SHOT POINT 2

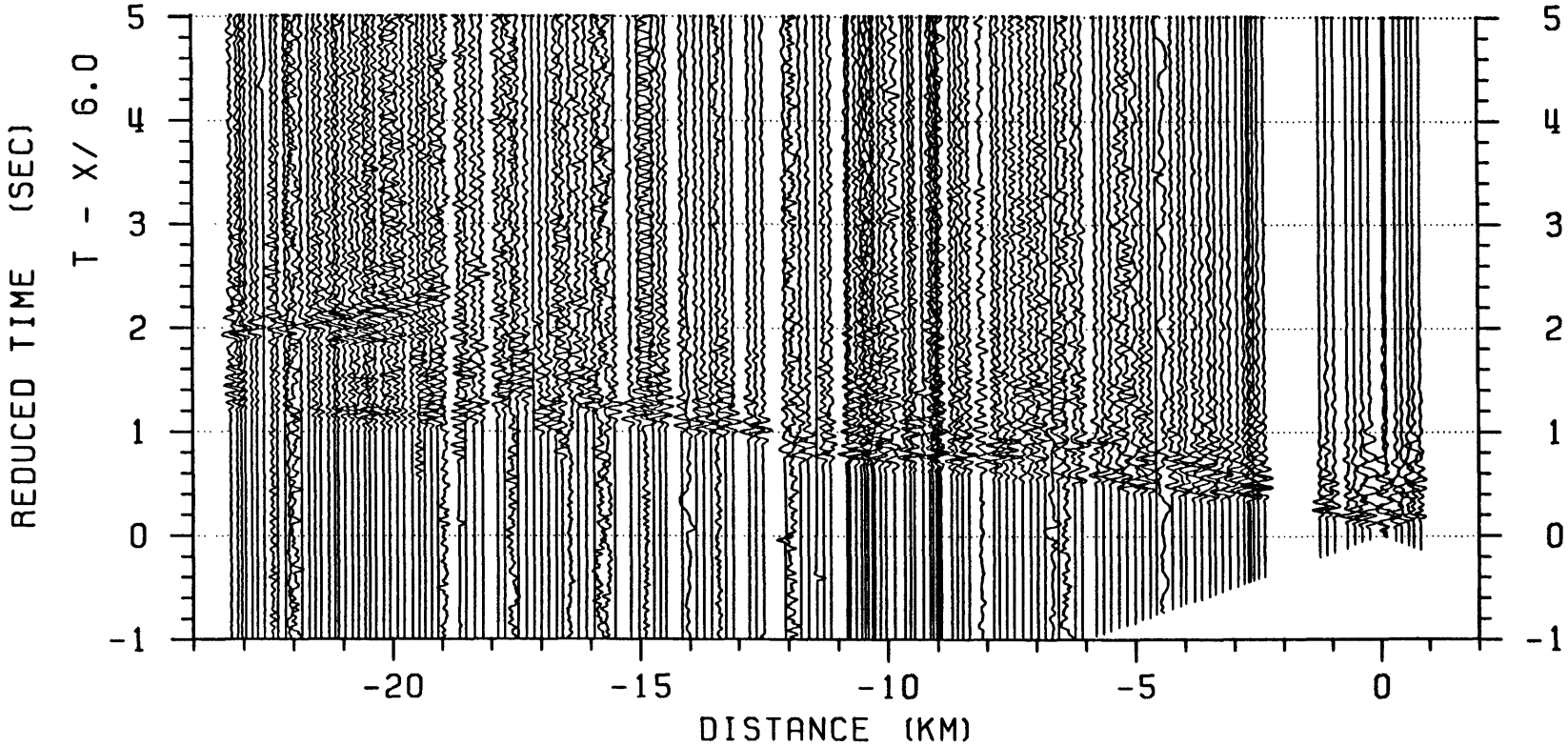

FIGURE 6. LP PROFILE
SHOT 3 SHOT POINT 3

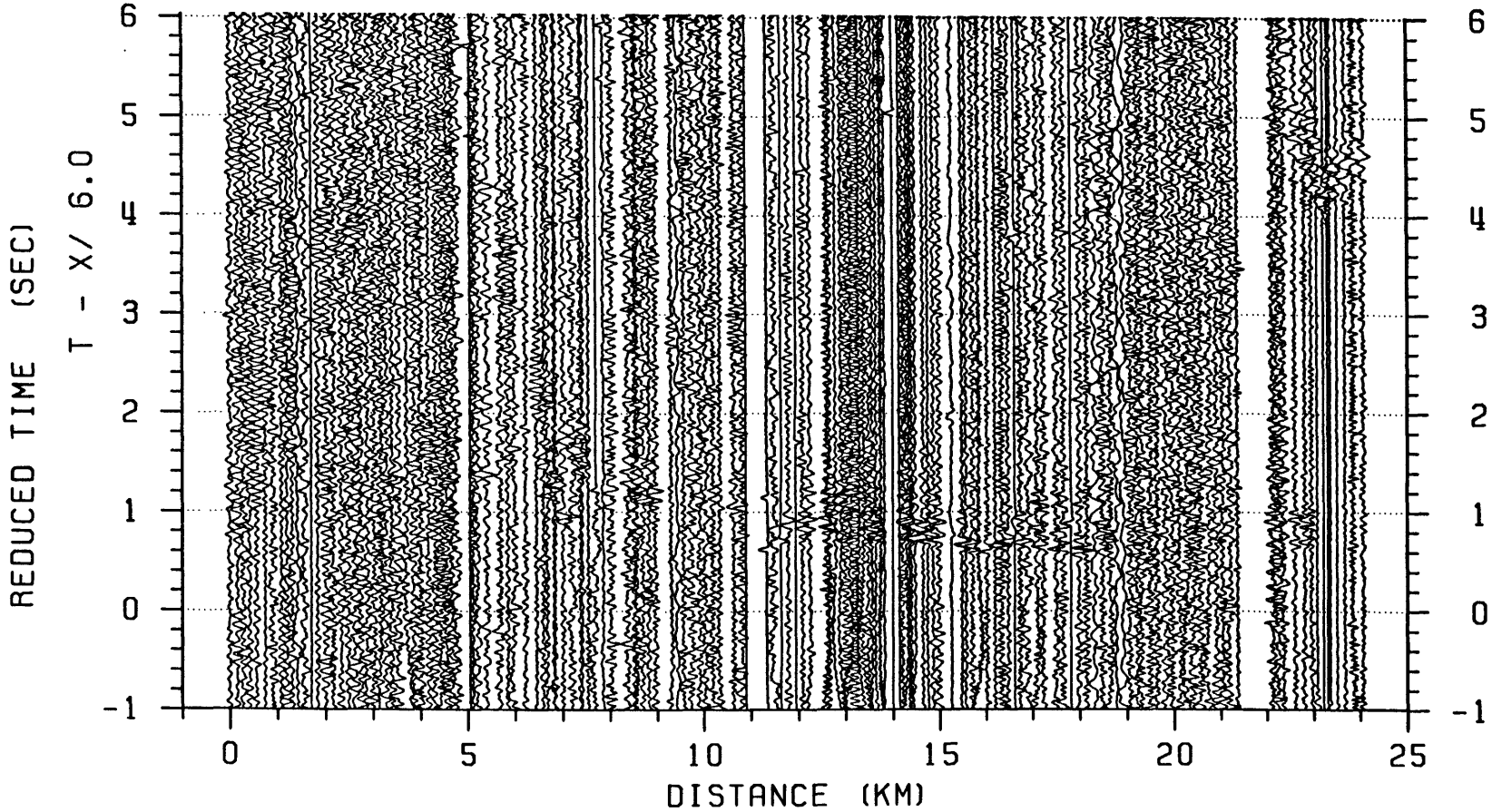

FIGURE 7. LP PROFILE
SHOT 4 SHOT POINT 4

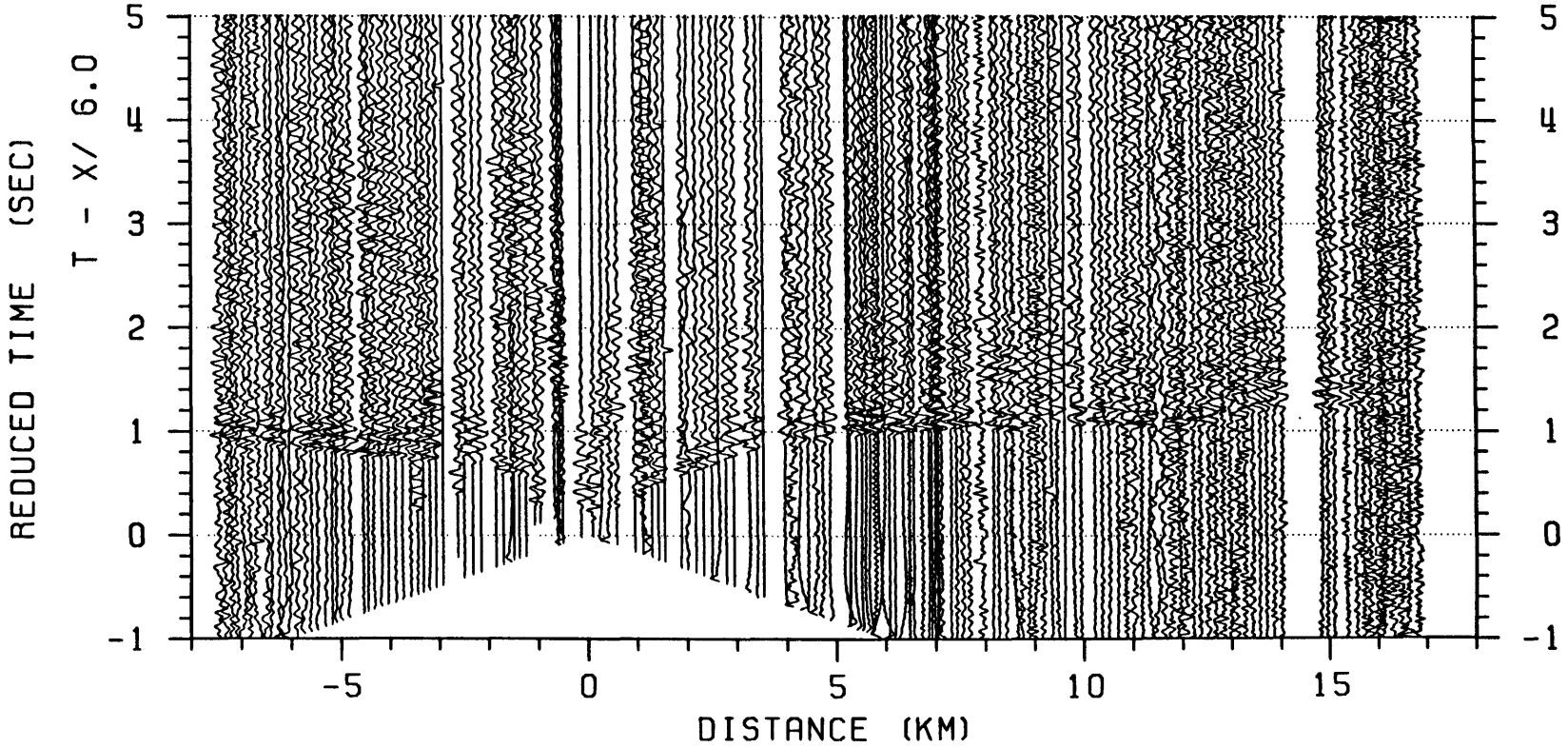

FIGURE 8. LP PROFILE
SHOT 5 SHOT POINT 8

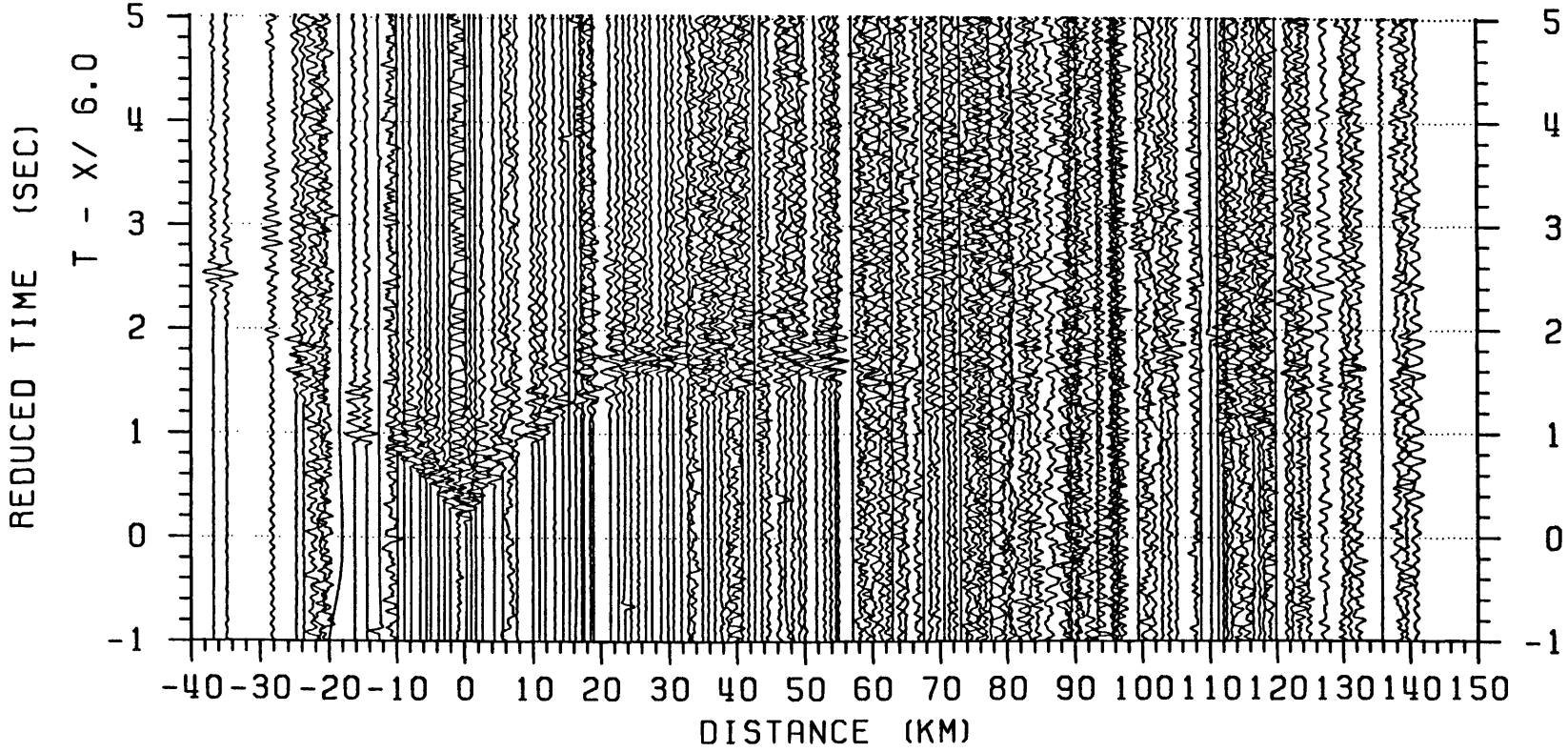

FIGURE 9. SF PROFILE
SHOT 6 SHOT POINT 5

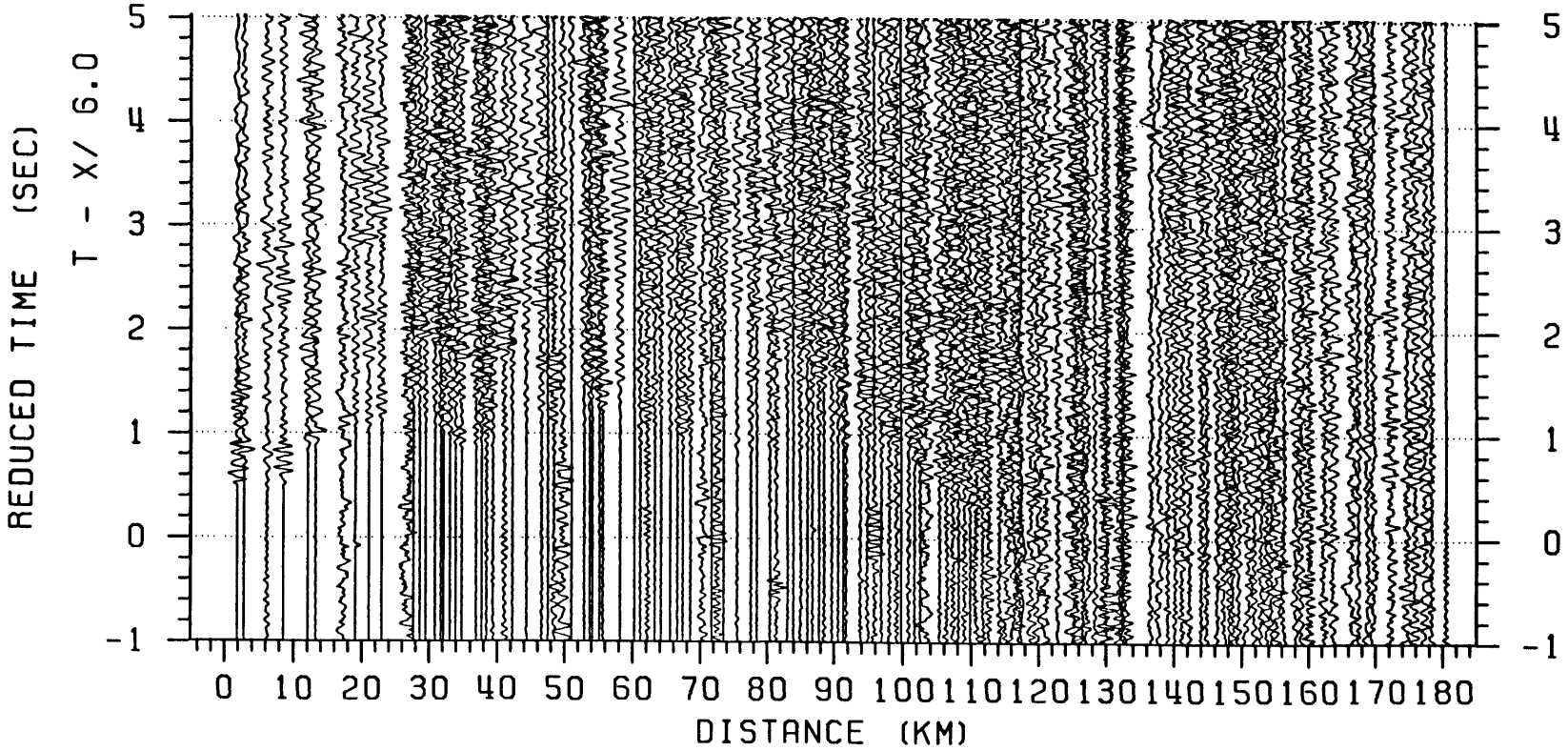

FIGURE 10. SF PROFILE
SHOT 7 SHOT POINT 6

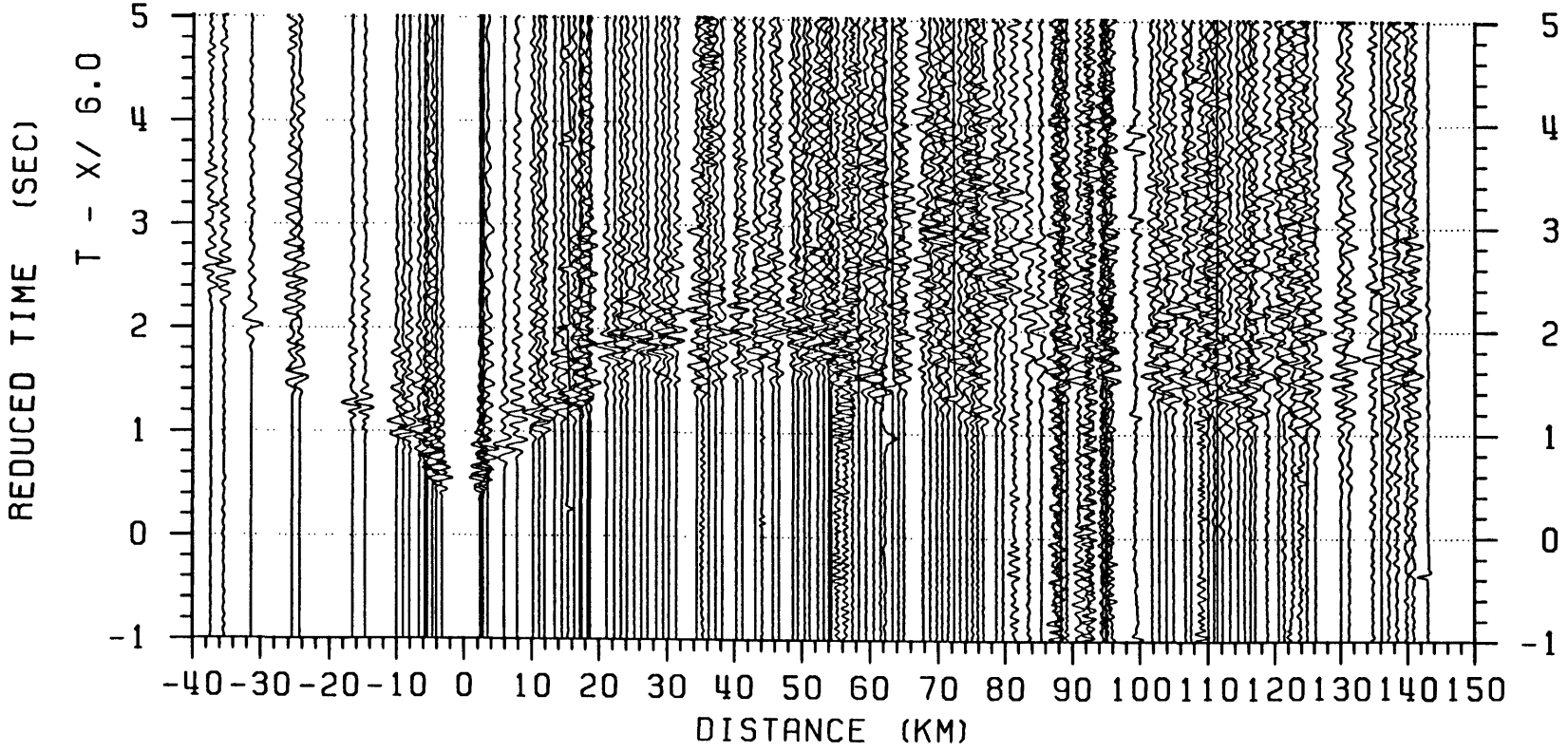

FIGURE 11. SF PROFILE
SHOT 8 SHOT POINT 2

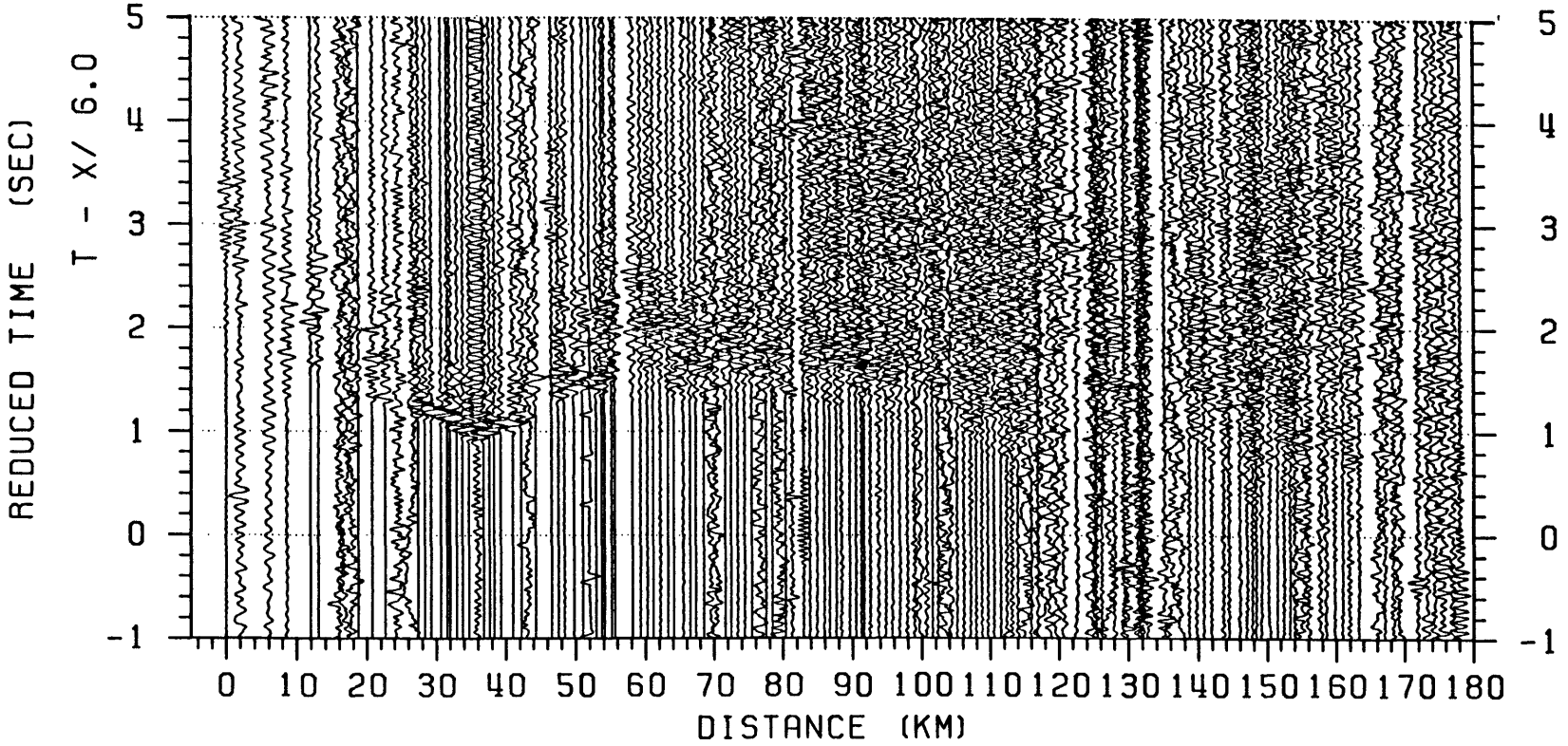

FIGURE 12. SF PROFILE
SHOT 9 SHOT POINT 1

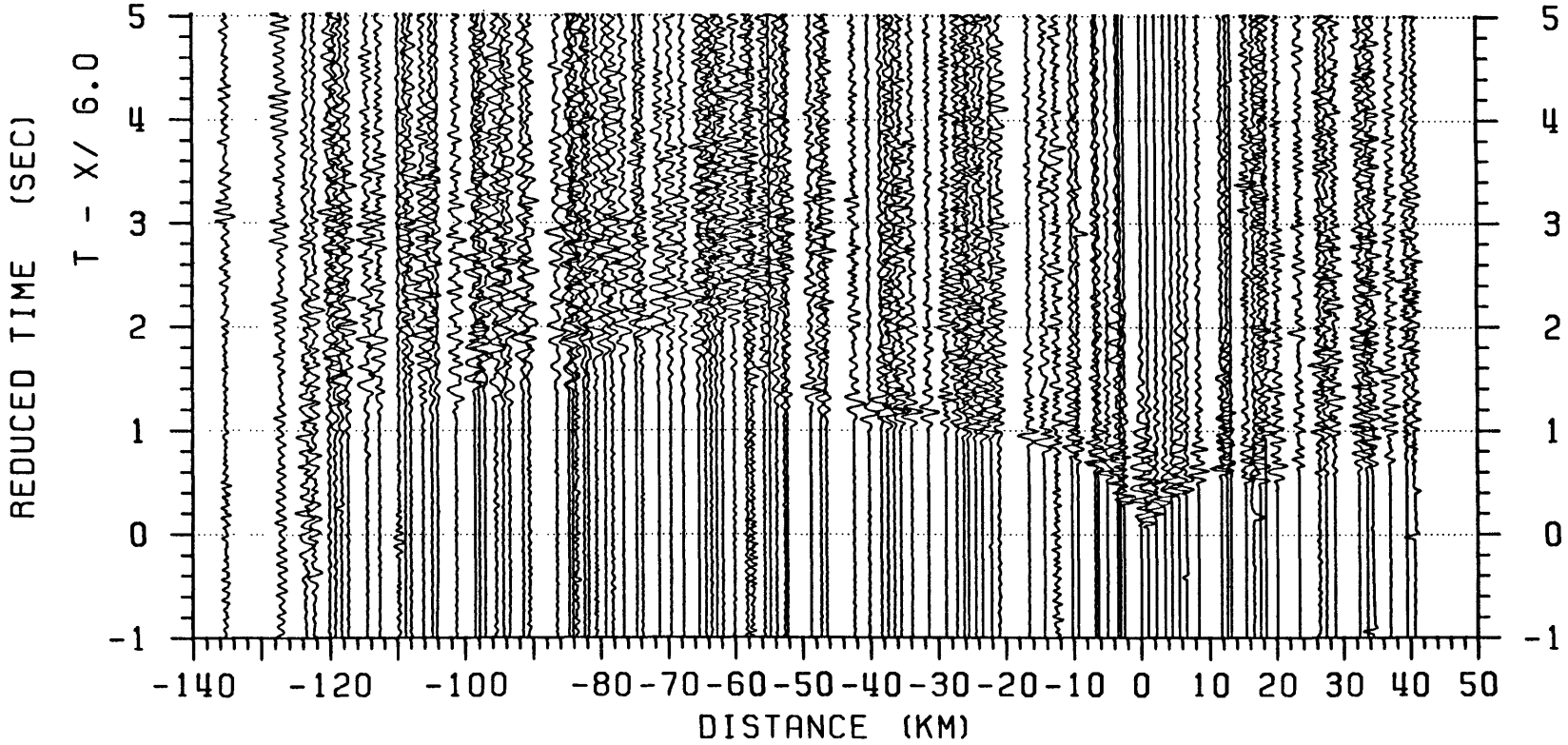

FIGURE 13. SF PROFILE
SHOT 10 SHOT POINT 10

APPENDIX A

SEISMIC RECORDER STATION LOCATIONS

LOCATIONS FOR LP PROFILE

LOCATION NUMBER	LATITUDE	LONGITUDE	ELEV (m)
1016	36.983229	-121.902656	37
1017	36.984661	-121.902844	44
1018	36.985725	-121.903571	46
1019	36.986789	-121.904191	46
1020	36.988133	-121.904325	50
1021	36.989567	-121.905294	50
1022	36.991042	-121.905536	55
1023	36.992712	-121.905454	55
1024	36.993731	-121.905534	52
1025	36.994857	-121.904508	61
1026	36.995855	-121.904966	56
1027	36.997136	-121.905450	55
1028	36.998458	-121.905206	56
1029	36.999693	-121.904558	59
1030	37.001226	-121.905232	49
1031	37.002590	-121.905681	64
1032	37.004110	-121.905429	64
1033	37.005389	-121.905580	64
1034	37.006619	-121.906594	58
1035	37.007707	-121.906040	67
1036	37.008991	-121.905542	67
1037	37.010313	-121.905666	67
1038	37.011595	-121.905331	73
1039	37.012614	-121.905478	79
1040	37.013722	-121.905302	79
1041	37.015007	-121.904562	79
1042	37.016587	-121.905040	79
1043	37.017914	-121.904516	73
1044	37.019240	-121.904127	70
1045	37.020741	-121.903551	70
1046	37.022066	-121.903225	79
1047	37.023195	-121.903022	79
1048	37.024220	-121.902305	82
1049	37.025201	-121.901507	91
1050	37.026012	-121.900275	98
1051	37.027550	-121.900697	104
1052	37.028645	-121.899091	113
1053	37.029049	-121.897126	110
1054	37.029694	-121.894543	113
1055	37.031534	-121.894914	134
1056	37.033116	-121.894986	177
1057	37.033889	-121.893133	201
1058	37.035342	-121.893095	213
1059	37.036540	-121.892246	226
1060	37.038993	-121.894890	323
1061	37.041114	-121.895454	329
1062	37.042377	-121.894659	341
1063	37.042954	-121.892804	347
1064	37.044259	-121.892252	347
1065	37.043686	-121.887578	384
1066	37.045392	-121.888460	396
1067	37.047211	-121.888912	396
1068	37.048732	-121.888417	408
1069	37.048394	-121.884231	433
1070	37.049294	-121.882650	433
1071	37.050830	-121.883153	445
1072	37.052200	-121.882574	463
1073	37.053717	-121.882672	469
1074	37.058558	-121.887853	500
1075	37.056949	-121.882547	518
1076	37.058321	-121.881726	512
1077	37.057424	-121.876779	555
1078	37.058708	-121.876226	567
1079	37.059690	-121.875293	585
1080	37.060948	-121.875280	597
1081	37.062216	-121.874155	628
1082	37.063950	-121.874430	640
1083	37.065076	-121.874155	658
1084	37.065959	-121.872240	664
1085	37.067627	-121.872420	658

LOCATIONS FOR LP PROFILE

LOCATION NUMBER	LATITUDE	LONGITUDE	ELEV (m)
1086	37.069099	-121.871902	673
1087	37.070028	-121.870848	683
1088	37.071348	-121.870303	713
1089	37.072515	-121.869221	732
1090	37.073291	-121.867630	750
1091	37.074871	-121.867273	774
1092	37.076540	-121.867587	762
1093	37.076684	-121.864680	768
1094	37.077961	-121.864109	771
1095	37.079241	-121.863021	713
1096	37.080129	-121.862264	668
1097	37.081299	-121.861642	597
1098	37.082511	-121.860427	549
1099	37.083733	-121.859695	524
1100	37.084965	-121.858613	488
1101	37.086133	-121.858015	524
1102	37.087454	-121.857551	604
1171	37.090880	-121.857417	783
1172	37.091163	-121.856727	786
1173	37.092139	-121.855874	793
1174	37.093334	-121.856007	802
1175	37.094436	-121.856781	821
1176	37.095537	-121.857556	840
1177	37.096572	-121.857704	849
1178	37.097617	-121.858662	883
1179	37.098328	-121.857683	895
1180	37.099038	-121.856704	907
1181	37.098662	-121.852586	886
1182	37.098681	-121.849532	916
1183	37.097245	-121.845257	927
1184	37.097608	-121.843459	956
1185	37.098249	-121.842951	971
1186	37.099886	-121.842631	1002
1187	37.101040	-121.842106	1024
1188	37.101946	-121.842805	1045
1189	37.103033	-121.843597	1033
1190	37.104015	-121.844907	1040
1191	37.104811	-121.846066	1015
1192	37.105768	-121.846986	1025
1193	37.106532	-121.845452	1042
1194	37.106510	-121.843997	1042
1195	37.107311	-121.843294	1061
1196	37.108112	-121.842457	1067
1197	37.109064	-121.841565	1073
1198	37.110190	-121.840619	1097
1199	37.111533	-121.841047	1109
1200	37.111963	-121.840405	1012
1201	37.113067	-121.838864	1076
1202	37.113314	-121.837019	1083
1203	37.114269	-121.835713	1078
1204	37.115304	-121.834763	1038
1205	37.116676	-121.833732	1064
1206	37.118224	-121.833386	1046
1207	37.119203	-121.832271	1046
1208	37.120182	-121.831157	1046
1209	37.121292	-121.830223	1013
1210	37.122065	-121.829194	994
1211	37.123581	-121.829106	966
1212	37.125474	-121.829033	920
1213	37.126448	-121.827895	878
1214	37.127249	-121.826460	823
1215	37.128072	-121.825106	774
1216	37.129523	-121.824913	774
1217	37.131192	-121.825044	719
1218	37.132644	-121.824392	674
1219	37.134052	-121.823767	634
1220	37.135342	-121.822789	598
1221	37.136982	-121.822909	609
1222	37.138621	-121.822811	638
1223	37.139646	-121.821980	633

LOCATIONS FOR LP PROFILE

LOCATION NUMBER	LATITUDE	LONGITUDE	ELEV (m)
1224	37.140766	-121.821232	633
1225	37.141511	-121.819027	625
1226	37.142367	-121.817427	611
1227	37.142924	-121.816149	625
1228	37.144589	-121.815850	556
1229	37.145630	-121.814848	523
1230	37.147221	-121.814513	491
1231	37.148781	-121.814884	478
1232	37.150090	-121.814301	482
1233	37.151400	-121.813718	487
1234	37.152437	-121.812453	524
1235	37.153778	-121.812173	503
1236	37.156054	-121.813746	479
1237	37.158179	-121.815411	471
1238	37.159677	-121.815763	488
1239	37.161160	-121.815733	506
1240	37.162603	-121.815124	496
1300	37.165734	-121.802574	232
1301	37.166274	-121.801058	232
1302	37.166987	-121.799514	207
1303	37.167679	-121.797808	195
1304	37.168524	-121.797211	189
1305	37.170518	-121.796965	168
1306	37.171471	-121.795610	165
1307	37.172099	-121.793997	182
1308	37.172774	-121.792223	190
1309	37.172979	-121.790398	176
1310	37.172637	-121.788107	161
1311	37.173650	-121.786916	162
1312	37.174819	-121.785661	152
1313	37.176532	-121.785606	152
1314	37.179577	-121.787834	156

LOCATIONS FOR SF PROFILE

LOCATION NUMBER	LATITUDE	LONGITUDE	ELEV (m)
2001	37.935139	-122.697281	3
2002	37.947429	-122.709586	49
2003	37.955081	-122.712830	67
2004	37.963881	-122.721561	137
2005	37.972317	-122.729282	128
2006	37.979967	-122.736167	122
2007	37.989182	-122.745886	113
2008	37.997798	-122.754334	58
2009	38.010870	-122.763616	51
2010	38.018202	-122.769792	52
2011	38.027795	-122.777514	46
2012	38.035556	-122.781864	24
2013	38.048977	-122.791904	11
2014	38.056154	-122.797635	6
2015	38.063271	-122.810349	3
2016	38.068195	-122.821859	3
2017	38.077301	-122.830215	3
2018	38.087731	-122.840170	3
2019	38.094605	-122.847911	3
2020	38.109285	-122.863898	3
2021	37.827254	-122.489755	12
2022	37.836039	-122.496554	99
2023	37.844304	-122.505718	85
2024	37.855232	-122.510370	241
2025	37.860831	-122.520985	265
2026	37.868339	-122.528569	11
2027	37.872727	-122.541257	177
2028	37.884772	-122.554063	207
2029	37.893328	-122.555352	223
2030	37.902355	-122.569181	235
2031	37.909605	-122.576248	280
2032	37.915093	-122.582579	293
2033	37.912678	-122.596190	366
2034	37.914807	-122.607052	637
2035	37.915732	-122.626393	613
2036	37.923566	-122.635619	536
2037	37.929981	-122.642995	500
2038	37.939229	-122.657293	463
2039	37.943875	-122.666099	366
2040	37.935991	-122.649475	466
2041	37.809611	-122.475243	06
2042	37.806289	-122.469206	23
2043	37.798795	-122.477066	84
2044	37.790895	-122.481170	18
2045	37.783645	-122.492814	76
2046	37.771676	-122.480972	64
2047	37.767926	-122.478223	67
2048	37.757144	-122.470747	160
2049	37.751031	-122.447922	244
2050	37.737829	-122.454040	247
2051	37.736210	-122.481588	27
2052	37.715729	-122.484542	08
2053	37.707562	-122.485268	14
2054	37.701771	-122.456891	191
2055	37.694331	-122.452977	91
2056	37.681312	-122.454214	64
2057	37.670633	-122.450376	29
2058	37.656236	-122.453247	76
2059	37.642379	-122.448116	130
2060	37.630319	-122.460602	198
2061	37.496676	-122.368271	274
2062	37.504768	-122.372109	335
2063	37.512691	-122.374760	328
2064	37.521040	-122.378334	322
2065	37.526851	-122.385959	322
2066	37.532770	-122.394317	328
2067	37.539256	-122.401913	328
2068	37.544830	-122.410952	338
2069	37.550775	-122.416321	328
2070	37.557932	-122.421163	259

LOCATIONS FOR SF PROFILE

LOCATION NUMBER	LATITUDE	LONGITUDE	ELEV (m)
2071	37.564114	-122.427240	329
2072	37.571812	-122.431973	351
2073	37.577174	-122.441093	411
2074	37.584870	-122.445390	381
2075	37.594516	-122.445654	347
2076	37.599658	-122.452783	335
2077	37.609365	-122.456577	384
2078	37.617948	-122.460800	312
2081	37.487315	-122.362638	321
2082	37.482071	-122.358385	387
2083	37.471421	-122.354801	453
2084	37.464573	-122.345236	509
2085	37.457101	-122.337792	580
2086	37.447899	-122.334010	614
2087	37.442417	-122.324196	634
2088	37.433880	-122.315787	618
2089	37.427245	-122.309545	622
2090	37.416761	-122.315666	701
2091	37.413551	-122.307537	686
2092	37.405939	-122.302464	685
2093	37.398969	-122.292078	685
2094	37.393867	-122.286676	615
2095	37.389156	-122.276979	511
2096	37.388621	-122.266212	456
2097	37.378563	-122.261571	511
2101	37.371665	-122.253648	543
2102	37.365486	-122.246941	561
2103	37.357492	-122.245364	568
2104	37.351143	-122.238287	598
2105	37.346665	-122.228549	634
2106	37.341188	-122.219257	609
2107	37.333277	-122.214087	668
2108	37.327561	-122.206922	709
2109	37.321925	-122.198288	738
2110	37.316632	-122.187951	718
2111	37.312927	-122.176839	655
2112	37.308407	-122.166891	668
2113	37.300502	-122.161279	672
2114	37.292473	-122.157325	705
2115	37.282157	-122.148726	711
2116	37.274041	-122.146471	763
2117	37.267603	-122.137353	779
2118	37.259991	-122.128441	793
2119	37.257151	-122.119174	816
2120	37.249634	-122.112005	853
2121	37.238624	-122.103762	890
2122	37.232344	-122.097053	916
2123	37.223631	-122.089873	945
2124	37.221466	-122.076701	889
2125	37.216692	-122.069150	875
2126	37.212521	-122.059278	834
2127	37.206386	-122.048767	772
2128	37.196452	-122.039758	738
2129	37.188679	-122.030624	730
2130	37.182284	-122.030421	739
2131	37.173481	-122.024493	704
2132	37.166917	-122.025415	655
2133	37.165661	-122.014932	619
2134	37.159930	-122.007038	660
2135	37.154520	-121.998936	645
2136	37.144676	-121.990063	681
2137	37.142483	-121.973349	557
2138	37.136699	-121.966166	499
2139	37.131574	-121.957642	502
2140	37.127742	-121.945440	493
2141	37.123491	-121.932758	491
2142	37.117956	-121.922602	489
2143	37.112386	-121.913873	524
2144	37.107258	-121.901512	582
2145	37.101139	-121.894974	574

LOCATIONS FOR SF PROFILE

LOCATION NUMBER	LATITUDE	LONGITUDE	ELEV (m)
2146	37.098326	-121.885805	575
2147	37.094477	-121.876039	591
2148	37.090788	-121.869033	575
2149	37.087334	-121.860659	530
2150	37.083250	-121.851697	491
2151	37.076617	-121.840474	517
2152	37.070754	-121.833341	533
2153	37.067993	-121.823843	674
2154	37.065467	-121.811650	841
2155	37.067854	-121.802162	890
2156	37.063776	-121.793381	827
2157	37.056584	-121.780276	798
2158	37.052691	-121.770539	766
2159	37.048191	-121.760876	766
2160	37.044657	-121.751185	723
2161	36.858957	-121.530287	61
2162	36.863699	-121.541623	60
2163	36.869783	-121.548261	61
2164	36.876146	-121.553168	50
2165	36.882544	-121.563209	51
2166	36.887594	-121.575402	153
2167	36.890973	-121.585421	197
2168	36.897355	-121.596950	120
2169	36.902195	-121.602090	48
2170	36.908021	-121.614805	46
2171	36.910782	-121.630086	42
2172	36.914068	-121.654474	33
2174	36.939356	-121.650274	442
2175	36.950972	-121.653800	437
2176	36.961075	-121.662959	463
2177	36.972009	-121.660601	408
2178	36.980554	-121.662286	374
2179	36.986341	-121.669860	505
2180	36.992436	-121.678553	481
2181	36.996928	-121.686517	210
2183	37.005643	-121.708481	508
2184	37.011308	-121.714093	549
2185	37.017907	-121.722940	638
2186	37.024090	-121.729354	659
2187	37.028382	-121.739087	687
2188	37.036701	-121.746254	714
8040	37.941200	-122.682523	174

APPENDIX B

SEG-Y Data File Format

```
c
c     INCLUDE FILE FOR FORTRAN PROGRAMS TO READ SEGY DATA FILES
c
c This file is an implicit definition of SEGY format with additions
c for refraction work.  It is the SEGY standard of Barry et al
c Geophysics (1975) with extensions labelled LDS USE and USGS use
c for refraction work.  When used as an include file for a FORTRAN
c program, all variables will be set after reading arrays SEGY1A,
c SEGY1B, and SEGYDB.
c
c Character code is EBCDIC unless IEEE data format (see variable icode)
c If IEEE, then the character code is ASCII.
c
c Written by Carl Spencer and Isa Asudeh  4/2/86 original specification
c This version is compatible with the final Lithoprobe version dated
c     5-DEC-1987.
c
c
c Maximum number of bytes allowed in a trace (system dependent)
c MAXLEN = ((max trace length) * (sample rate) * (bytes per sample))
c                                                          + 240
      parameter (MAXLEN=16620)
c
c
c SEGY REEL IDENTIFICATION HEADER PART 1
      byte  segy1a(3200)
c SEGY REEL IDENTIFICATION HEADER PART 2
      byte  segy1b(400)
c SEGY TRACE DATA BLOCK
      byte segydb(MAXLEN)
      common/segycom/iiopen,segy1a,segy1b,segydb
c
c EBCDIC CARDS
      character*80  cards(40)
      equivalence  (segy1a(1),cards(1))
c
```

```
c TRACE IDENTIFICATION HEADER
      byte  thead(240)
      equivalence  (segydb(1),thead(1))
c
c DATA WORDS
      integer*2     iidata((MAXLEN-240)/2)
      integer*4     jdata((MAXLEN-240)/4)
      real*4        rdata((MAXLEN-240)/4)
      equivalence  (segydb(241),iidata(1),jdata(1),rdata(1))
c
c
c-----------------------------------------------------------------
c Binary area of file (or reel) Identification Header starts here
c-----------------------------------------------------------------
c
c
c
c Job Identification number                          SEGY STANDARD
      integer*4 jobid
      equivalence  (segy1b(1),jobid)
c
c Line number                                        SEGY STANDARD
      integer*4 lineno
      equivalence  (segy1b(5),lineno)
c
c Reel number                                        SEGY STANDARD
      integer*4 reelno
      equivalence  (segy1b(9),reelno)
c
c Number of data traces per record                   SEGY STANDARD
      integer*2 ntrace
      equivalence  (segy1b(13),ntrace)
c
c Number of auxiliary traces per record              SEGY STANDARD
      integer*2 nauxt
      equivalence  (segy1b(15),nauxt)
c
c Sample interval in microseconds - this data        SEGY STANDARD
      integer*2 sint
      equivalence  (segy1b(17),sint)
c
```

```
c Sample interval in microseconds (in field)          SEGY STANDARD
      integer*2  sint2
      equivalence  (segy1b(19),sint2)
c
c No of samples per trace - this data                 SEGY STANDARD
      integer*2  nsam
      equivalence  (segy1b(21),nsam)
c
c No of samples per trace (in field)                  SEGY STANDARD
      integer*2  nsam2
      equivalence  (segy1b(23),nsam2)
c
c Data sample format code                             SEGY STANDARD
c  icode=0001 (1)      IBM FLOATING POINT             SEGY STANDARD
c  icode=0002 (2)      FIXED POINT (4 bytes)          SEGY STANDARD
c  icode=0003 (3)      FIXED POINT (2 bytes)          SEGY STANDARD
c  icode=0004 (4)      FIXED POINT WITH GAIN          SEGY STANDARD
c  icode=0100 (256)    FLOATING POINT - IEEE          VERITAS STANDARD
c  icode=0200 (512)    FIXED POINT (4 bytes) - IEEE
c  icode=0300 (768)    FIXED POINT (2 bytes) - IEEE
c  icode=0500 (1280)   LUNCHBOX FORMAT                LDS USE
c  icode=0600 (1536)   VAX R*4 FORMAT                 LDS USE
      integer*2  icode
      equivalence  (segy1b(25),icode)
c
c Number of traces in CDP ensemble                    SEGY STANDARD
      integer*2  ncdp
      equivalence  (segy1b(27),ncdp)
c
c Trace sorting code                                  SEGY STANDARD
c  itsort=1  as recorded                              SEGY STANDARD
c  itsort=2  CDP ensemble                             SEGY STANDARD
c  itsort=3  Single fold continuous                   SEGY STANDARD
c  itsort=4  Horizontal stack                         SEGY STANDARD
c  No LDS or USGS use.
      integer*2  itsort
      equivalence  (segy1b(29),itsort)
c
```

```
c Vertical sum code                                    SEGY STANDARD
c   vcode=n sum on n traces
      integer*2  vcode
      equivalence  (segy1b(31),vcode)
c
c Start sweep frequency (hz)                           SEGY STANDARD
      integer*2  ssweep
      equivalence  (segy1b(33),ssweep)
c
c End sweep frequency (hz)                             SEGY STANDARD
      integer*2  esweep
      equivalence  (segy1b(35),esweep)
c
c Sweep length in milliseconds                         SEGY STANDARD
      integer*2  sleng
      equivalence  (segy1b(37),sleng)
c
c Sweep type                                           SEGY STANDARD
c  stype=1  Linear                                     SEGY STANDARD
c  stype=2  Parabolic                                  SEGY STANDARD
c  stype=3  Exponential                                SEGY STANDARD
c  stype=4  Other                                      SEGY STANDARD
c  stype=5  Borehole source                            LDS USE
c  stype=6  Water explosive source                     LDS USE
c  stype=7  Airgun source                              LDS USE
      integer*2  stype
      equivalence  (segy1b(39),stype)
c
c Trace number of sweep channel                        SEGY STANDARD
      integer*2  nts
      equivalence  (segy1b(41),nts)
c
c Sweep trace taper in milliseconds at start           SEGY STANDARD
      integer*2  stts
      equivalence  (segy1b(43),stts)
c
c Sweep trace taper in milliseconds at end             SEGY STANDARD
      integer*2  stte
      equivalence  (segy1b(45),stte)
c
```

```
c Taper type                                          SEGY STANDARD
c  ttype=1  Linear                                    SEGY STANDARD
c  ttype=2  cos**2                                    SEGY STANDARD
c  ttype=3  Other                                     SEGY STANDARD
      integer*2  ttype
      equivalence  (segy1b(47),ttype)
c
c Correlated data traces                              SEGY STANDARD
c   cort=1 no  2 yes
      integer*2  cort
      equivalence  (segy1b(49),cort)
c
c Binary gain recovered                               SEGY STANDARD
c    bgr=1   Yes. For USGS data, the data has also been demeaned.
c    bgr=2  No
      integer*2  bgr
      equivalence  (segy1b(51),bgr)
c
c Amplitude recovery methods                          SEGY STANDARD
c   arm=1 none  2 spherical  3 AGC  4 other
      integer*2  arm
      equivalence  (segy1b(53),arm)
c
c Measurement system                                  SEGY STANDARD
c   isys=1 meters  2 feet
      integer*2  isys
      equivalence  (segy1b(55),isys)
c
c Polarity                                            SEGY STANDARD
c   ipol=1 Upward movement gives neg. number          SEGY STANDARD
c   ipol=2 Upward movement gives pos. number          SEGY STANDARD
      integer*2  ipol
      equivalence  (segy1b(57),ipol)
c
c Vibrator polarity code                              SEGY STANDARD
      integer*2  vpc
      equivalence  (segy1b(59),vpc)
c
```

```
c Number of traces in the file                          LDS USE
c   Used for disk files.
      integer*2  notif
      equivalence  (segy1b(61),notif)
c
c Attribute information                                 LDS USE
c  attri=0  velocity/displacement  data
c  attri=1  instantaneous  amplitude
c  attri=2  instantaneous  frequency
c  attri=3  instantaneous  phase
c  attri=4  slowness  (m/ms)
c  attri=5  semblance  (0-1000)
      integer*2  attri
      equivalence  (segy1b(63),attri)
c
c Mean amplitude of all samples                         LDS USE
c    in all traces in file     Used for disk files.
      real*4  meanas
      equivalence  (segy1b(65),meanas)
c
c Domain of data                                        LDS USE
c    domain=0 Time - distance domain
c     domain=1 Frequency - wavenumber domain
c    domain=2 Intercept time - slowness domain
      integer*2  domain
      equivalence  (segy1b(69),domain)
c
c     Bytes 71, 72 unused to align four byte boundaries.
c
c Reduction velocity meters/sec if data is reduced      LDS USE
      integer*4  vred
      equivalence  (segy1b(73),vred)
c
c Minimum of all samples in file.                       LDS USE
      real*4  minass
      equivalence  (segy1b(77),minass)
c
c Maximum of all samples in file.                       LDS USE
      real*4  maxass
      equivalence  (segy1b(81),maxass)
c
```

```
c Recording instrument type                          USGS USE
c  iinstr=1  EDA lunchbox recorder
c  iinstr=2  USGS seismic cassette recorder
c  iinstr=3  GEOS
c  iinstr=99 Mixed
      integer*2 iinstr
      equivalence (segy1b(85),iinstr)
c
c File creation date - Last two digits of year       USGS USE
      integer*2 cryear
      equivalence (segy1b(87),cryear)
c
c File creation date - Month of year                 USGS USE
      integer*2 crmnth
      equivalence (segy1b(89),crmnth)
c
c File creation date - Day of month                  USGS USE
      integer*2 crday
      equivalence (segy1b(91),crday)
c
c   Bytes 93-398 of the binary File Identification Header are not used
c
c  Format version number (x100)
c  Version 0.99   "Discussion version", October 1986.
c  Version 1.00   "Final version", December 5, 1987
      integer*2 fvn
      equivalence (segy1b(399),fvn)
c
```

```
c-----------------------------------------------------------------
c Trace Identification Header (total of 240 bytes) starts here
c-----------------------------------------------------------------
c
c Trace sequence number within line                    SEGY STANDARD
      integer*4  tsnl
      equivalence  (thead(1),tsnl)
c
c Trace sequence number within file                    SEGY STANDARD
      integer*4  tsnt
      equivalence  (thead(5),tsnt)
c
c Original field record number                         SEGY STANDARD
c For LDS use this will be sequential shot number      LDS USE
      integer*4  ofrn
      equivalence  (thead(9),ofrn)
c
c Trace number within original field record            SEGY STANDARD
      integer*4  tnofr
      equivalence  (thead(13),tnofr)
c
c Energy source point number                           SEGY STANDARD
      integer*4  espn
      equivalence  (thead(17),espn)
c
c CDP number                                           SEGY STANDARD
      integer*4  cdp
      equivalence  (thead(21),cdp)
c
c Trace number within CDP                              SEGY STANDARD
      integer*4  tncdp
      equivalence  (thead(25),tncdp)
c
c Trace identification code                            SEGY STANDARD
c  1 = Seismic data,  2 = Dead,    3 = Dummy           SEGY STANDARD
c  4 = Time break,    5 = Uphole,  6 = Sweep           SEGY STANDARD
c  7 = Timing,        8 = Water break                  SEGY STANDARD
c  9 = Deleted trace                                   USGS USE
c  10 = Long Period data (see thead(117),isi)          USGS USE
      integer*2  tic
      equivalence  (thead(29),tic)
c
```

```
c Number of vertically summed traces
c       yielding this trace                          SEGY STANDARD
      integer*2  nvs
      equivalence  (thead(31),nvs)
c
c Number of horizontally stacked traces
c       yielding this trace                          SEGY STANDARD
      integer*2  nhs
      equivalence  (thead(33),nhs)
c
c Data use (1=production 2=test)                     SEGY STANDARD
      integer*2  duse
      equivalence  (thead(35),duse)
c
c Distance from source to receiver                   SEGY STANDARD
      integer*4  idist
      equivalence  (thead(37),idist)
c
c Receiver group elevation                           SEGY STANDARD
      integer*4  irel
      equivalence  (thead(41),irel)
c
c Surface elevation of source                        SEGY STANDARD
      integer*4  ishe
      equivalence  (thead(45),ishe)
c
c Shot depth                                         SEGY STANDARD
      integer*4  ishd
      equivalence  (thead(49),ishd)
c
c Datum elevation at receiver                        SEGY STANDARD
      integer*4  delr
      equivalence  (thead(53),delr)
c
c Datum elevation at source                          SEGY STANDARD
      integer*4  dels
      equivalence  (thead(57),dels)
c
c Water depth at source                              SEGY STANDARD
      integer*4  wds
      equivalence  (thead(61),wds)
c
```

```
c Water depth at receiver                                  SEGY STANDARD
      integer*4  wdr
      equivalence  (thead(65),wdr)
c
c Scalar multiplier/divisor for bytes 41-68                SEGY STANDARD
      integer*2  smul1
      equivalence  (thead(69),smul1)
c
c Scalar multiplier/divisor for bytes 73-88                SEGY STANDARD
      integer*2  smul2
      equivalence  (thead(71),smul2)
c
c Source coordinate X or longitude (East positive)         SEGY STANDARD
      integer*4  ishlo
      equivalence  (thead(73),ishlo)
c
c Source coordinate Y or latitude (North positive)         SEGY STANDARD
      integer*4  ishla
      equivalence  (thead(77),ishla)
c
c Group coordinate X or longitude (East positive)          SEGY STANDARD
      integer*4  irlo
      equivalence  (thead(81),irlo)
c
c Group coordinate Y or latitude (North positive)          SEGY STANDARD
      integer*4  irla
      equivalence  (thead(85),irla)
c
c Coordinate units                                         SEGY STANDARD
c  1:  meters/feet
c  2:  seconds of arc (smul2 holds multiplier)
c  N:  mod  100 = TX zone
c      div  100 = RX zone
      integer*2  cunits
      equivalence  (thead(89),cunits)
c
c Weathering velocity (m/s?)                               SEGY STANDARD
      integer*2  wvel
      equivalence  (thead(91),wvel)
c
```

```
c Subweathering velocity (m/s?)                          SEGY STANDARD
      integer*2 swvel
      equivalence (thead(93),swvel)
c
c Uphole time at source                                  SEGY STANDARD
      integer*2 utimes
      equivalence (thead(95),utimes)
c
c Uphole time at group                                   SEGY STANDARD
      integer*2 utimeg
      equivalence (thead(97),utimeg)
c
c Source static correction (ms?)                         SEGY STANDARD
      integer*2 sstati
      equivalence (thead(99),sstati)
c
c Group static                                           SEGY STANDARD
      integer*2 gstati
      equivalence (thead(101),gstati)
c
c Total static                                           SEGY STANDARD
      integer*2 tstati
      equivalence (thead(103),tstati)
c
c Lag time A                                             SEGY STANDARD
      integer*2 istime
      equivalence (thead(105),istime)
c
c Lag time B                                             SEGY STANDARD
      integer*2 ibtime
      equivalence (thead(107),ibtime)
c
c Delay recording time (reduced start time) (msec)       SEGY STANDARD
      integer*2 ictime
      equivalence (thead(109),ictime)
c
c Mute start time                                        SEGY STANDARD
      integer*2 mtimes
      equivalence (thead(111),mtimes)
c
```

```
c Mute end time                                          SEGY STANDARD
      integer*2  mtimee
      equivalence  (thead(113),mtimee)
c
c No of samples in this trace                            SEGY STANDARD
      integer*2  length
      equivalence  (thead(115),length)
c
c Sampling interval in microseconds                      SEGY STANDARD
c If (thead(29),itic) = 10, in milliseconds              USGS STANDARD
      integer*2  isi
      equivalence  (thead(117),isi)
c
c Gain type (1=fixed 2=binary 3=floating)                SEGY STANDARD
      integer*2  gaint
      equivalence  (thead(119),gaint)
c
c Gain constant                                          SEGY STANDARD
      integer*2  gc
      equivalence  (thead(121),gc)
c
c Instrument or initial gain in DB                       SEGY STANDARD
      integer*2  gidb
      equivalence  (thead(123),gidb)
c
c Correlated 1=no 2=yes                                  SEGY STANDARD
      integer*2  tcorr
      equivalence  (thead(125),tcorr)
c
c Start sweep frequency (hz)                             SEGY STANDARD
      integer*2  tsswee
      equivalence  (thead(127),tsswee)
c
c End sweep frequency (hz)                               SEGY STANDARD
      integer*2  teswee
      equivalence  (thead(129),teswee)
c
c Sweep length in milliseconds                           SEGY STANDARD
      integer*2  tsleng
      equivalence  (thead(131),tsleng)
c
```

```
c Sweep type                                        SEGY STANDARD
c  stype=1 Linear                                   SEGY STANDARD
c  stype=2 Parabolic                                SEGY STANDARD
c  stype=3 Exponential                              SEGY STANDARD
c  stype=4 Other                                    SEGY STANDARD
c  stype=5 Borehole source                          LDS USE
c  stype=6 Water explosive source                   LDS USE
c  stype=7 Airgun source                            LDS USE
      integer*2 tstype
      equivalence (thead(133),tstype)
c
c Sweep trace taper in milliseconds at start        SEGY STANDARD
      integer*2 tstts
      equivalence (thead(135),tstts)
c
c Sweep trace taper in milliseconds at end          SEGY STANDARD
      integer*2 tstte
      equivalence (thead(137),tstte)
c
c Taper type                                        SEGY STANDARD
c  ttype=1 Linear                                   SEGY STANDARD
c  ttype=2 Cos**2                                   SEGY STANDARD
c  ttype=3 Other                                    SEGY STANDARD
      integer*2 tttype
      equivalence (thead(139),tttype)
c
c Antialias filter frequency                        SEGY STANDARD
      integer*2 aif
      equivalence (thead(141),aif)
c
c Alias filter slope                                SEGY STANDARD
      integer*2 ais
      equivalence (thead(143),ais)
c
c Notch filter frequency                            SEGY STANDARD
      integer*2 nif
      equivalence (thead(145),nif)
c
c Notch filter slope                                SEGY STANDARD
      integer*2 nis
      equivalence (thead(147),nis)
c
```

```
c Low cut frequency                                    SEGY STANDARD
      integer*2  flc
      equivalence  (thead(149),flc)
c
c High cut frequency                                   SEGY STANDARD
      integer*2  fhc
      equivalence  (thead(151),fhc)
c
c Low cut slope                                        SEGY STANDARD
      integer*2  slc
      equivalence  (thead(153),slc)
c
c High cut slope                                       SEGY STANDARD
      integer*2  shc
      equivalence  (thead(155),shc)
c
c Year of start of trace                               SEGY STANDARD
      integer*2  tyear
      equivalence  (thead(157),tyear)
c
c Day of start of trace                                SEGY STANDARD
      integer*2  tday
      equivalence  (thead(159),tday)
c
c Hour of start of trace                               SEGY STANDARD
      integer*2  thour
      equivalence  (thead(161),thour)
c
c Minute of start of trace                             SEGY STANDARD
      integer*2  tmin
      equivalence  (thead(163),tmin)
c
c Second of start of trace                             SEGY STANDARD
      integer*2  tsec
      equivalence  (thead(165),tsec)
c
c Time basis code  1=local 2=GMT                       SEGY STANDARD
      integer*2  tbcode
      equivalence  (thead(167),tbcode)
c
```

```
c Trace weighting factor                                  SEGY STANDARD
      integer*2  twf
      equivalence  (thead(169),twf)
c
c Geophone group no. on roll switch first position        SEGY STANDARD
      integer*2  ggrpl
      equivalence  (thead(171),ggrpl)
c
c Geophone group no. trace position 1                     SEGY STANDARD
c    on field record
      integer*2  ggtp
      equivalence  (thead(173),ggtp)
c
c Time code translator error light                        USGS USE
c   1=No error  2=Error
      integer*2  errlt
      equivalence  (thead(175),errlt)
c
c Distance-azimuth calculation algorithm                  USGS USE
c     1 = Sodano algorithm.  The program utilizes the Sodano and Robinson
c         (1963) direct solution of geodesics (Army Map Service, Tech Rep
c       #7, Section IV).
      integer*2  daca
      equivalence  (thead(177),daca)
c
c Earth dimension code                                    USGS USE
c  1  = Fischer spheroid (1960),
c            OMEGA & NASA datums                          6378166.   298.30
c  2  = Clark ellipsoid (1866),
c            N. American datum 1927                       6378206.4  294.98
c  3  = Ref ellipsoid (1967), S. American datum           6378160    298.25
c  4  = Hayford International Ellipsoid (1910)            6378388.   297.00
c  5  = World Geodetic Survey Ellipsoid (1972)            6378135.   298.26
c  6  = Bessel (1841), Tokyo datum                        6377397.   299.15
c  7  = Everest (1830), India datum                       6377276.   300.80
c  8  = Airy (1936),
c            Ordnance survey of Great Britain             6377563.   299.32
c  9  = Hough (1960), Wake-Eniwetok                       6378270.   297.00
c 10  = Fischer (1968), Modified Mercury                  6378150.   298.30
c 11  = Clarke (1880)                                     6378249.   293.47
      integer*2  edc
      equivalence  (thead(179),edc)
```

```
c
c Microseconds of trace start time                    LDS USE
      integer*4  mst
      equivalence  (thead(181),mst)
c
c Millisecond of timing correction                    LDS USE
      integer*2  cor
      equivalence  (thead(185),cor)
c
c Charge size in kg                                   LDS USE
      integer*2  charge
      equivalence  (thead(187),charge)
c
c Shot time - Year                                    LDS USE
      integer*2  syear
      equivalence  (thead(189),syear)
c
c Shot time - Day                                     LDS USE
      integer*2  sday
      equivalence  (thead(191),sday)
c
c Shot time - Hour                                    LDS USE
      integer*2  shour
      equivalence  (thead(193),shour)
c
c Shot time - Minute                                  LDS USE
      integer*2  shmin
      equivalence  (thead(195),shmin)
c
c Shot time - Second                                  LDS USE
      integer*2  sseco
      equivalence  (thead(197),sseco)
c
c Shot time - Microsecond                             LDS USE
      integer*4  ssmic
      equivalence  (thead(199),ssmic)
c
c Azimuth of receiver from shot (minutes of arc)      LDS USE
      integer*2  azimut
      equivalence  (thead(203),azimut)
c
```

```
c Azimuth of geophone orientation axis with
c respect to true north in minutes of arc                LDS USE
      integer*2  geoazi
      equivalence  (thead(205),geoazi)
c
c Angle between geophone orientation axis and
c vertical in minutes of arc                             LDS USE
      integer*2  geover
      equivalence  (thead(207),geover)
c
c Time to be added to recorded trace time to get
c actual trace start time.  To be used when data
c has been reduced but start time is not updated
c so that the actual time can be recovered even if
c distance and shot time have changed
c (microseconds)                                         LDS USE
      integer*4  ttrace
      equivalence  (thead(209),ttrace)
c
c Recording instrument number                            LDS USE
      character*4  scrs
      equivalence  (thead(213),scrs)
c
c Deployment name                                        LDS USE
      character*4  deploy
      equivalence  (thead(217),deploy)
c
c Shotpoint name (shotpoint number)                      LDS USE
      character*4  spname
      equivalence  (thead(221),spname)
c
c Receiver site name (station number)                    LDS USE
      character*4  rstnam
      equivalence  (thead(225),rstnam)
c
c Shot name (shot number)                                LDS USE
      character*4  shotid
      equivalence  (thead(229),shotid)
c
```

```
c Line name                                          LDS USE
      character*4  lineid
      equivalence  (thead(233),lineid)
c
c Geophone orientation eg R40,Z                      LDS USE
      character*4  geoor
      equivalence  (thead(237),geoor)
c
c    End of Trace Identification Header
```