UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TECHNICAL LETTER NUMBER 26

SEISMIC-REFRACTION MEASUREMENTS OF CRUSTAL STRUCTURE BETWEEN NEVADA TEST SITE AND LUDLOW, CALIFORNIA*

by

J. F. Gibbs** and J. C. Roller**

DENVER, COLORADO

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Technical Letter
Crustal Studies-26
December 1, 1964

Dr. Charles C. Bates
Chief, VELA UNIFORM Branch
Advanced Research Projects Agency
Department of Defense
Pentagon
Washington 25, D. C.

Dear Dr. Bates:

Transmitted herewith are 10 copies of:

TECHNICAL LETTER NUMBER 26

SEISMIC-REFRACTION MEASUREMENTS OF

CRUSTAL STRUCTURE BETWEEN

NEVADA TEST SITE AND LUDLOW, CALIFORNIA*

by

J. F. Gibbs** and J. C. Roller**

We intend to submit this report for publication in an early volume of the Geological Survey Annual Review.

Sincerely,

L. C. Pakiser

L. C. Pakiser, Chief
Branch of Crustal Studies

* Work performed under ARPA Order No. 193-64.
** U. S. Geological Survey, Denver, Colorado.

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Abstract

Seismic-refraction measurements from nuclear and chemical explosions were made along a line from the Nevada Test Site (NTS) to Ludlow, California, and additional recordings from nuclear explosions were made southward toward Calexico, California. The time of first arrivals from the Ludlow shotpoint is expressed as $T_0 = 0.00 + \Delta/2.50$ (assumed), $T_1 = 1.00 + \Delta/6.10$, $T_2 = 2.81 + \Delta/6.80$, and $T_3 = 5.48 + \Delta/7.76$, where T is in seconds and distance Δ is in km. First arrival times from NTS fit the lines $T_1 = 0.74 + \Delta/6.10$, $T_2 = 2.81 + \Delta/6.80$ (assumed), $T_3 = 6.70 + \Delta/8.04$ to a distance of 265 km, beyond 265 km $T_3 = 5.83 + \Delta/7.75$. The difference in the apparent velocities of the P_n (T_3) arrival is caused by variations in the dip of the Mohorovicic discontinuity.

The thickness of the successive layers at NTS are $H_0 = 1.0$ km ($V_0 = 2.5$ km/sec), $H_1 = 13$ km ($V_1 = 6.1$ km/sec), and $H_2 = 20$ km ($V_2 = 6.8$ km/sec); the total crustal thickness is 34 km. The successive crustal layers at Ludlow have a thickness of $H_0 = 1.4$ km, $H_1 = 13$ km, and $H_2 = 13$ km; the total crustal thickness is 27 km.

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Introduction

The U. S. Geological Survey recorded a reversed seismic-refraction profile between the Nevada Test Site and Ludlow, California, in August 1962 (Fig. 1). Recordings from the Ludlow shotpoint were made at 26 locations from 3 chemical explosions of 4,000, 8,000, and 12,000 pounds. The Ludlow shotpoint was located at lat 34°49.36'N and long 116°11.02'W. The first charge (Table 1) was in a single drill hole; the larger two charges were distributed, respectively, in 3 and 4 drill holes 50 ft apart. The alluvium underlying the drill holes was calculated to be 1.4 km (4600 ft.) thick from close-in recordings. The reverse of this profile was obtained from 5 underground nuclear explosions at the Nevada Test Site. Recordings were made at 14 locations between NTS and Ludlow, plus 12 locations beyond Ludlow southward towards Calexico, California (Table 1). Ten seismic-recording units (Warrick and others, 1961) were used to make the recordings. Jackson and others (1963) have described the field procedures used in this study.

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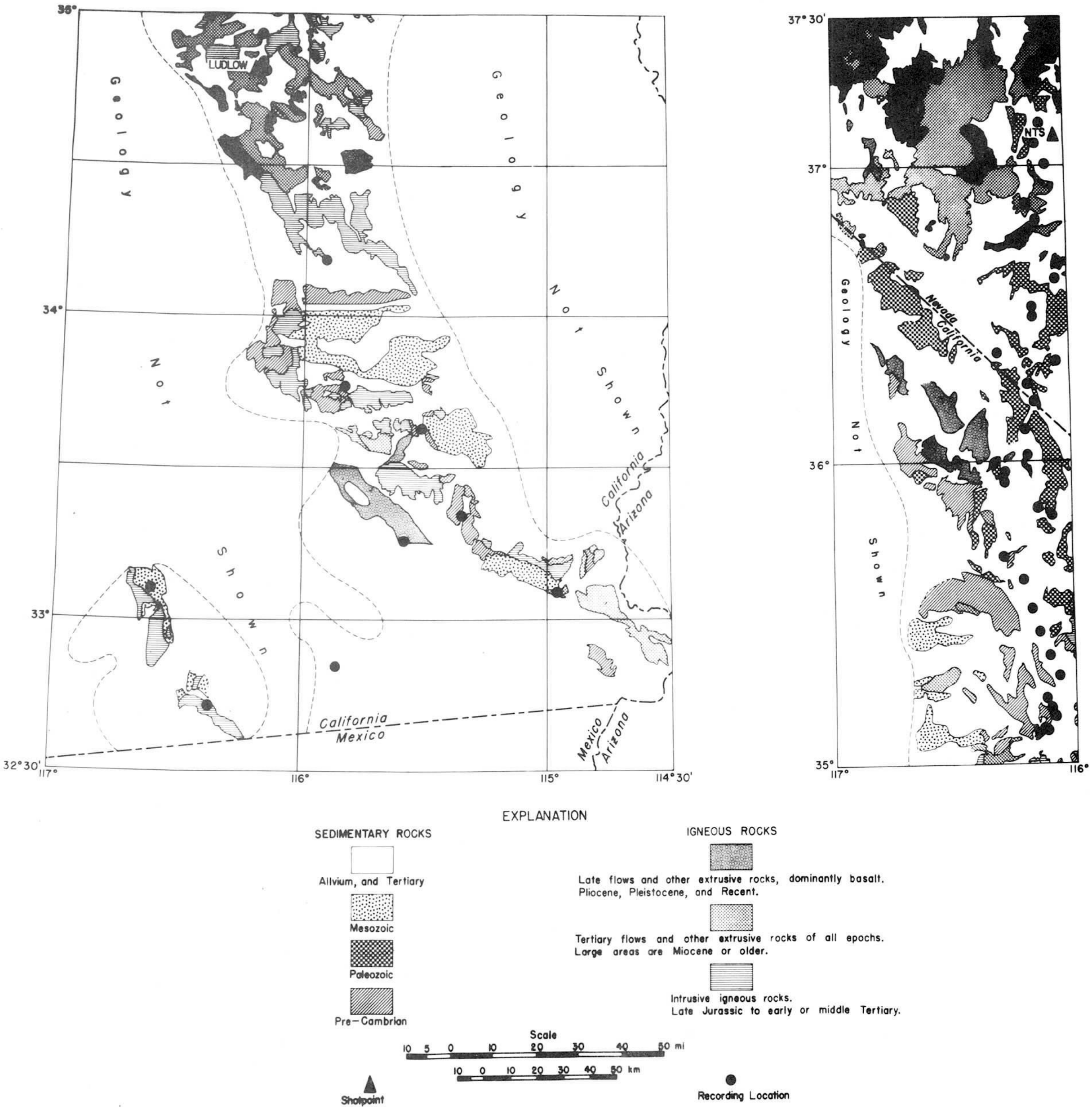

Figure 1.--Index map showing location of shot areas (triangles), seismic stations (round dots), and generalized geology at recording locations.

Table 1.--Recording locations

Shot: Ludlow 4* 4,000 lbs.

Recording unit	End of spread	Latitude, North	Longitude, West	Altitude**, meters
H	W	35°31.71'	116°10.72'	
	E	35°30.41'	116°10.32'	229
I	W	35°36.35'	116°14.75'	
	E	35°35.34'	116°13.64'	229
J	W	35°21.74'	116°06.29'	
	E	35°20.80'	116°05.10'	274
K	W	35°07.78'	116°06.38'	
	E	35°06.50'	116°06.34'	290
L	W	34°56.65'	116°11.21'	
	E	34°58.00'	116°11.09'	411
P	W	34°52.29'	116°11.56'	
	E	34°50.98'	116°11.12'	411
Q	W	35°11.40'	116°07.61'	
	E	35°10.41'	116°06.56'	290
R	W	35°18.12'	116°04.91'	
	E	35°16.80'	116°04.50'	274
S	W	35°26.36'	116°09.19'	
	E	35°25.20'	116°08.31'	229
T	W	35°10.17'	116°06.40'	
	E	35°08.89'	116°06.36'	290

* Ludlow shots 1, 2, and 3 were recorded along another profile.

** Altitude at center of spread.

Table 1.--Recording locations (continued)

Shot: Ludlow 5 8,000 lbs.

Recording unit	End of spread	Latitude, North	Longitude, West	Altitude, meters
H	W	36°20.67'	116°02.97'	
	E	36°19.38'	116°02.52'	914
I	W	36°25.74'	116°04.26'	
	E	36°24.39'	116°03.96'	1021
J	W	36°11.66'	116°08.02'	
	E	36°10.50'	116°07.18'	777
K	W	35°48.95'	116°08.86'	
	E	35°50.14'	116°08.39'	610
L	W	35°47.68'	116°05.77'	
	E	35°46.44'	116°05.54'	686
P	W	35°41.10'	116°17.64'	
	E	35°39.78'	116°17.37'	152
Q	W	36°00.81'	116°11.79'	
	E	36°02.15'	116°11.40'	945
R	W	36°05.56'	116°11.24'	
	E	36°06.90'	116°10.90'	823
S	W	36°15.75'	116°10.08'	
	E	36°14.46'	116°09.43'	777
T	W	35°55.89'	116°15.87'	
	E	35°54.60'	116°15.78'	457

Table 1.--Recording locations (continued)

Shot: Ludlow 6 12,000 lbs.

Recording unit	End of spread	Latitude, North	Longitude, West	Altitude, meters
H	W	37°09.75'	116°05.81'	
	E	37°08.59'	116°04.93'	1357
I	N	37°05.64'	116°07.12'	
	S	37°04.29'	116°07.12'	1341
J	W	37°01.30'	116°04.97'	
	E	36°59.96'	116°04.75'	1250
K	W	36°38.80'	116°05.70'	
	E	36°38.00'	116°04.37'	1158
L	W	36°36.15'	116°03.51'	
	E	36°37.26'	116°02.64'	991
P	W	36°30.30'	116°08.34'	
	E	36°28.92'	116°08.19'	762
Q	W	36°50.05'	116°08.12'	
	E	36°49.00'	116°07.16'	1295
R	W	36°44.70'	116°01.11'	
	E	36°43.61'	116°00.30'	1036
T	W	36°54.27'	116°10.37'	
	E	36°52.97'	116°09.95'	1433

Table 1.--Recording locations (continued)

Shot: NTS 1***

Recording unit	End of spread	Latitude, North	Longitude, West	Altitude, meters
I	W	35°10.10'	116°06.50'	
	E	35°08.80'	116°06.38'	290
J	W	35°21.75'	116°06.30'	
	E	35°20.75'	116°05.10'	274
K	W	35°31.75'	116°10.72'	
	E	35°30.40'	116°10.22'	229
L	W	34°49.36'	116°11.02'	
	E	34°48.17'	116°10.30'	396
P	N	34°39.85'	116°09.00'	
	S	34°38.70'	116°09.00'	579

*** Numbers assigned to NTS shots were chosen arbitrarily.

Table 1.--Recording locations (continued)

Shot: NTS 2

Recording unit	End of spread	Latitude, North	Longitude, West	Altitude, meters
I	W	35°10.97'	116°07.05'	
	E	35°09.17'	116°06.45'	290
J	W	35°47.53'	116°05.70'	
	E	35°46.53'	116°05.60'	686
K	W	35°40.60'	116°17.93'	
	E	35°39.25'	116°17.65'	152
P	W	35°31.75'	116°10.78'	
	E	35°30.40'	116°10.35'	229
S	W	35°05.97'	116°08.00'	
	E	35°07.20'	116°07.28'	335
T	W	34°56.45'	116°11.13'	
	E	34°57.80'	116°11.10'	411

Table 1.--Recording locations (continued)

Shot: NTS 3

Recording unit	End of spread	Latitude, North	Longitude, West	Altitude, meters
J	W	35°47.70'	116°05.82'	
	E	35°46.45'	116°05.60'	686
K	N	36°23.50'	116°18.08'	
	S	36°22.06'	116°18.08'	671
P	W	35°58.03'	116°16.13'	
	E	35°56.75'	116°16.11'	457
Q	W	36°11.70'	116°08.00'	
	E	36°10.50'	116°07.17'	777
R	W	36°31.80'	116°08.50'	
	E	36°30.44'	116°08.30'	777

Table 1.--Recording locations (continued)

Shot: NTS 4

Recording unit	End of spread	Latitude, North	Longitude, West	Altitude, meters
I	W	32°49.02'	115°58.33'	
	E	32°47.99'	115°57.38'	34
P	W	33°44.93'	115°49.47'	
	E	33°46.21'	115°49.14'	886
Q	W	33°37.64'	115°31.91'	
	E	33°36.27'	115°31.88'	533
R	N	33°16.39'	115°34.75'	
	S	33°15.06'	115°34.75'	-67
S	W	34°10.77'	115°57.93'	
	E	34°11.96'	115°57.60'	518
T	W	35°10.98'	116°07.06'	
	E	35°09.89'	116°06.48'	290

Table 1.--Recording locations (concluded)

Shot: NTS 5

Recording unit	End of spread	Latitude, North	Longitude, West	Altitude, meters
I	W	33°18.45'	115°21.15'	
	E	33°19.65'	115°20.37'	366
K	W	33°05.98'	114°56.73'	
	E	33°04.75'	114°56.49'	335
P	W	33°44.93'	115°49.47'	
	E	33°46.21'	115°49.14'	886
Q	W	33°07.43'	116°36.04'	
	E	33°06.15'	116°36.02'	1387
R	W	32°44.43'	116°21.61'	
	E	32°43.77'	116°21.48'	1158
S	W	33°38.55'	116°38.22'	
	E	33°39.60'	116°37.38'	1524
T	W	33°44.93'	115°49.47'	
	E	33°46.21'	115°49.14'	886

Geology and Physiography

The profile lies entirely within the Basin and Range Province, starting in the south end of the Great Basin and terminating in the Sonoran Desert (Fenneman, 1946). The complex geology of the region is characterized by a series of basins, ranges, and associated faults that generally strike northwest. All the major divisions of geologic time are represented by the rocks exposed in this region (Nolan, 1943). The Precambrian rocks have been studied little, but several unconformable series have been distinguished. The Paleozoic and early Mesozoic deposits suggest a persistent geosyncline, in which many thousands of feet of sediments were deposited. In mid-Mesozoic time, the sea was expelled from the province, and later Mesozoic and Cenozoic deposits are composed of widely distributed local accumulations of non-marine sedimentary beds and intrusive and extrusive igneous rocks (Nolan, 1943). The seismic profile traverses many of the northwestward striking ranges. Some of the major topographic features include the Spectre Range, Spring Mountains, Pahrump Valley, Nopah Range, Silurian Hills, Shadow Range, Soda Mountains, Bristol Range and the Cody Mountains. The average altitude of the recording locations is 671 m with the highest station at 1524 m in the San Jacinto Mountains and the lowest -67 m near the Salton Sea.

Characteristics of Seismograms

Ludlow

The Ludlow shotpoint proved to be relatively efficient in converting explosive energy to seismic energy. Seismograms recorded from Ludlow are of good quality to a distance of about 175 km; beyond that distance they are generally useable although they have higher background noise and the first upward compressional motion cannot be observed on all seismograms.

First arrivals for 11 seismograms recorded from Ludlow to a distance of 94 km are identified as P_g, a wave that travels in the upper crust (Table 2). The first upward compressional motion can be observed on most of these recordings (Fig. 2). First arrivals on 5 seismograms recorded at distances ranging from 106 to 150 km are tentatively identified as P*, a wave that is critically refracted from an intermediate layer in the crust. First arrivals on 8 seismograms recorded in the distance range from 150 to 203 km are identified as P_n, the wave that is critically refracted from the upper mantle below the Mohorovicic discontinuity. A large-amplitude wave train that follows P_n by several seconds is identified as $\overline{P}$ (Fig. 2). This event has an apparent velocity of 6.1 km/sec. The nature of $\overline{P}$ has been discussed by Ryall and Stuart (1963), Roller and Healy (1963), and others.

Table 2.--Arrival times of prominent phases. Times within parentheses are for questionable or weak arrivals.

Shot Number	Recording Unit	Distance to nearest seismometer, km	Traveltime in Seconds				
			P_g	P*	P_MP	P_n	$\bar{P}$
Ludlow							
4	P	3.00	1.17				
4	L	13.48	3.27				
4	K	32.48	6.33				
4	T	36.80	7.01				
4	Q	39.51	7.57				
4	R	51.70	9.55				
4	J	58.82	10.73				
4	S	66.81	12.02	12.67	13.48		
4	H	75.91	13.66	14.04	14.80	15.41	
4	I	85.11	15.04	15.32	15.98	16.57	
5	P	94.71	16.72		17.32	17.75	
5	L	105.87		18.49	18.77	19.30	
5	K	110.24	19.29	19.04	19.36	19.80	

Table 2.--Arrival times of prominent phases. Times within parentheses are for questionable or weak arrivals. (Continued)

Shot Number	Recording Unit	Distance to nearest seismometer, km	Traveltime in Seconds				
			P_g	P*	P_MP	P_n	$\bar{P}$
Ludlow							
5	T	120.85		20.82	21.73	21.32	
5	Q	132.12		22.25		22.55	
5	R	140.90		23.71		23.83	24.50
5	J	150.15		24.98(P_n?)			25.97
5	S	157.85		26.16		26.00	27.35
5	H	166.96				27.01	28.70
5	I	176.55		28.87		28.29	30.20
6	P	184.15		30.02		29.41	31.36
6	L	197.80				31.19	33.60
6	K	201.15				31.59	(34.18)
6	R	211.89				(33.02)	36.02
6	T	228.59					38.94
6	I	249.59					42.33

Table 2.--Arrival times of prominent phases. Times within parentheses are for questionable or weak arrivals. (Continued)

Shot Number	Recording Unit	Distance to nearest seismometer, km	Traveltime in Seconds P_g	P^*	P_MP	P_n	$\bar{P}$
NTS							
3	R	67.27	11.74				
3	K	84.17	14.55				
3	Q	103.23	17.58		19.93		
3	P	129.72			23.25		
2	J	140.66			24.99	24.15	
3	J	147.86			26.01	25.29	
2	K	154.85			26.72	25.97	
2	P	170.34			28.84	27.98	
1	J	187.07				30.05	31.97
4	T	206.18				32.60	35.41
2	I	207.89				32.73	35.65
1	I	209.69				32.90	35.75
2	S	215.33				33.63	36.43
2	T	232.51				35.54	39.39

Table 2.--Arrival times of prominent phases. Times within parentheses are for questionable of weak arrivals. (Concluded)

Shot Number	Recording Unit	Distance to nearest seismometer, km	Traveltime in Seconds				
			P_g	P*	P_MP	P_n	$\bar{P}$
NTS							
1	L	247.32				37.44	42.14
1	P	264.29				39.49	44.56
4	S	315.61				46.33	
4	P	363.18				52.73	
5	P	375.51				54.26	
5	T	375.51				54.13	
4	Q	381.17				54.70	
5	S	390.57				56.28	
5	I	428.96				(60.49)	
5	Q	449.37				63.67	
5	K	460.48				(64.53)	
4	I	468.45				(65.00)	
5	R	490.15				69.05	

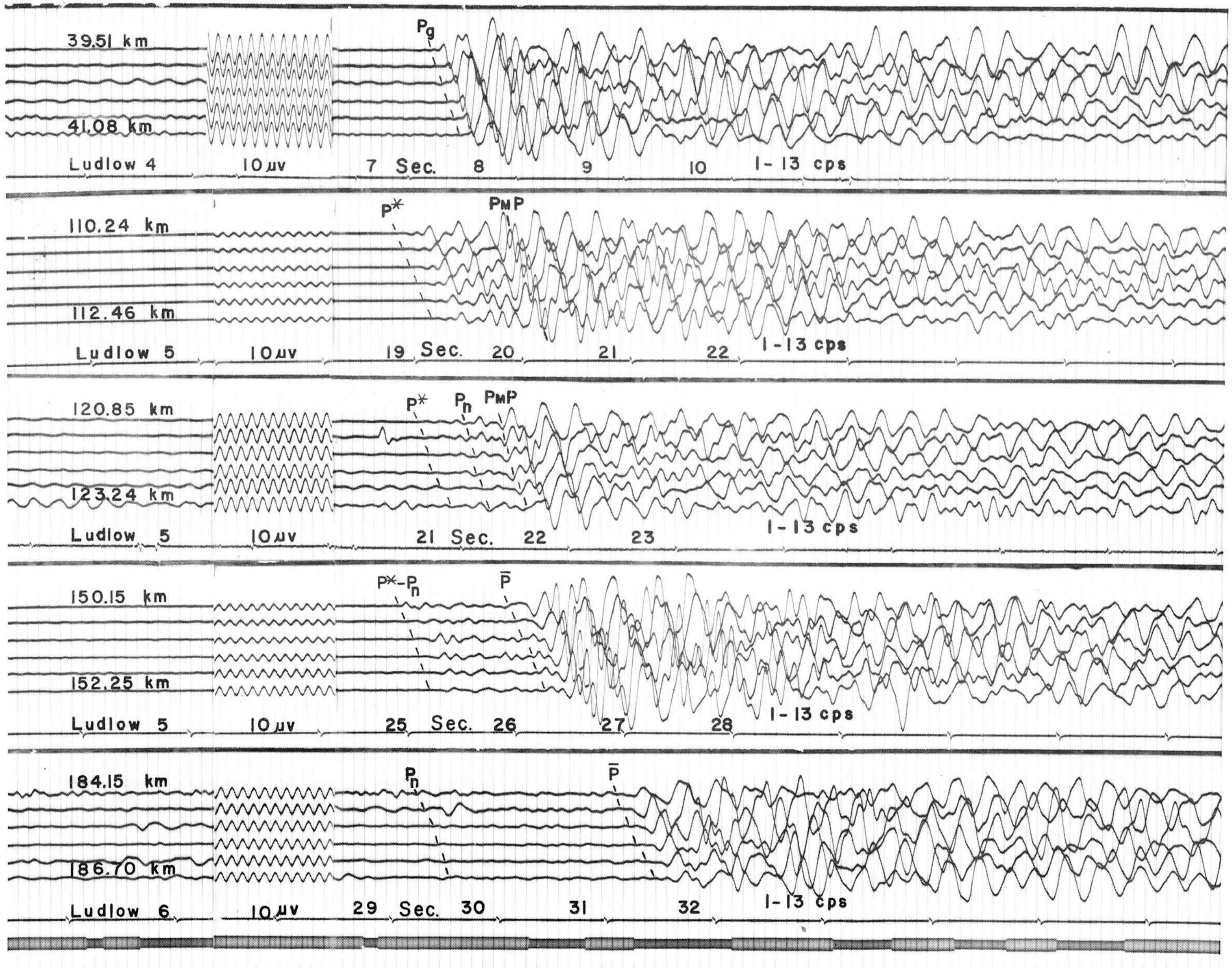

Figure 2.--Selected seismograms from chemical explosions illustrating phases used in interpretation.

Six seismograms in the distance range 67 to 112 km show a group of strong secondary arrivals which are tentatively identified as reflections from the Mohorovicic discontinuity. This event, P_MP, is shown on the reduced traveltime curve (Fig. 3) between P* and the backward extension of P_n. It is not observed beyond the crossover point of P_g and P*. These events occur earlier than the backward extension of the P_n line, which suggests that the Mohorovicic discontinuity is not a flat surface but changes dip along the profile.

Nevada Test Site (NTS)

The reverse of this profile was made by recording 5 underground nuclear explosions at the Nevada Test Site. Three of these explosions were recorded at 12 locations between NTS and Ludlow, California. The maximum distance between shotpoints at the Test Site was 9.7 km between 3 and 4. Shot numbers 2, 1, 5, and 4 are all within a radius of less than 1 km. Despite the scatter of shotpoints, the traveltimes show a systematic agreement. Seismic waves from Shot 3 were recorded at 5 locations in the distance range 66 to 150 km; 2 was recorded at 6 locations in the distance range 140 to 235 km; 4 and 5 were recorded to distances of 490 km; and 1 was recorded at 5 locations in the distance range 170 to 267 km. Seismograms from the nuclear explosions are of good quality with a high signal-to-noise ratio.

The phase P_g can be identified on 3 seismograms at distances less than 105 km. Beyond 105 km, P_g was not observed as a distinguishable arrival. The phase P_n is observed as a first arrival on 21 seismograms in the distance range from 140 to 490 km.

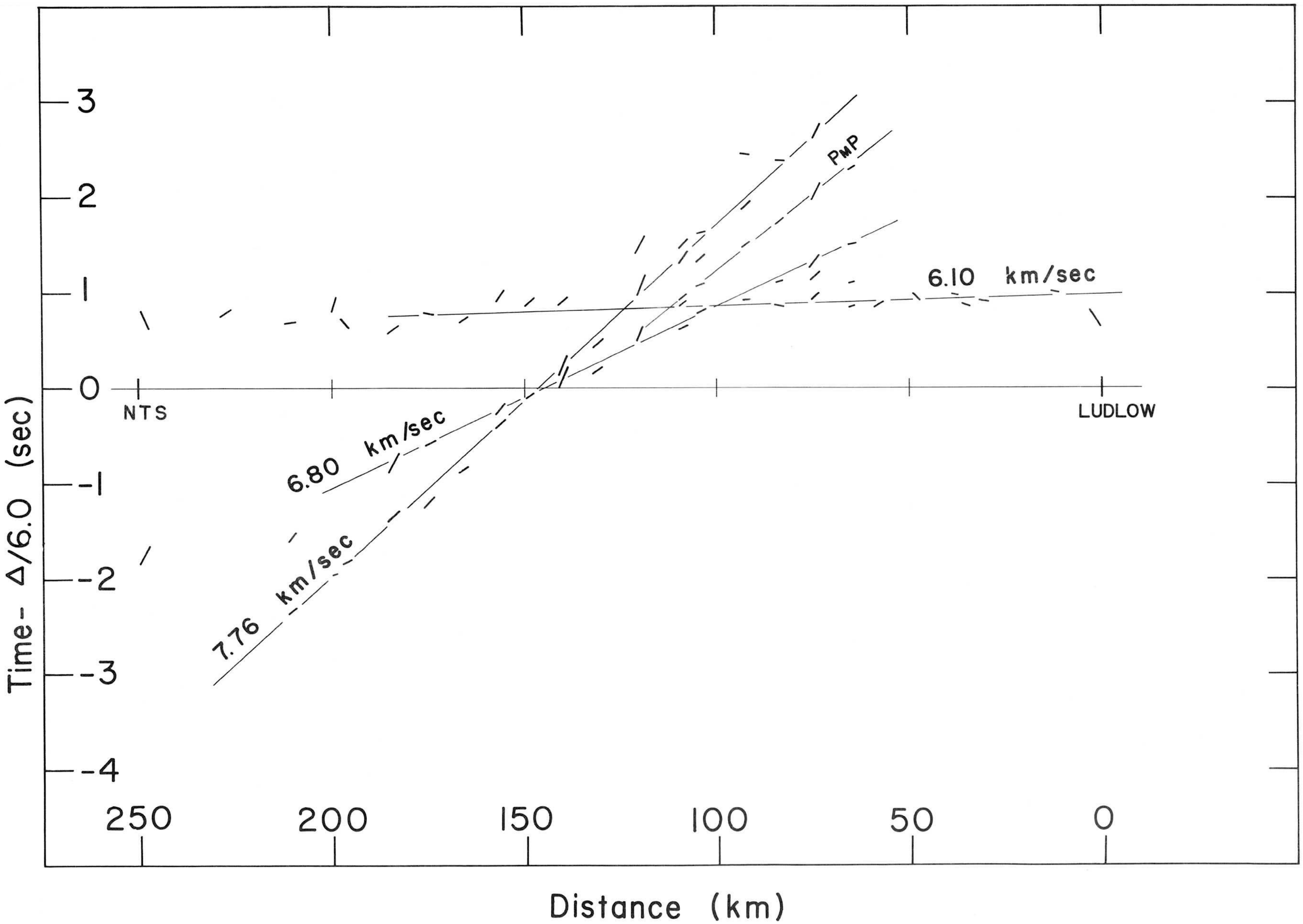

Figure 3.--Reduced travel-time-distance graph Ludlow to NTS.

Several other arrivals are observed on the seismograms recorded from nuclear explosions. The phase P_MP was tentatively identified on 6 seismograms in the distance range from 100 to 175 km. A very large amplitude event which follows an extension of the P_g traveltime line (Fig. 4) by approximately 2 seconds was observed and tentatively identified as $\overline{P}$. Three seismograms recorded in Imperial Valley area have P_n arrivals which are 1.1 sec (I4), 0.6 sec (K5), and 0.6 sec (I5) earlier than an extension of the P_n line. The altitudes of these stations are -30 m, 335 m, and 366 m, respectively. Record I4 was made on alluvium, K5 on Tertiary volcanic rock, and I5 on a Precambrian outcrop. These early arrivals do not seem to be caused entirely by local geology or altitude and may suggest a thinning of the crust in the area of the Salton Trough.

Time of First Arrivals

The first waves from NTS to reach recording locations to a distance of 155 km fit the line $T_1 = 0.74 + \Delta/6.10$. Three positions were recorded in this distance range and the scatter of the arrival is less than 0.1 sec. From 135 km to the P_g-P_n crossover, the true first arrivals on 3 recordings are not distinguishable from the noise. In the distance range 155 to 265 km from NTS, first arrivals fit the line $T_3 = 6.70 + \Delta/8.04$. With the exception of the arrivals on one seismogram, they all fall within 0.1 sec of this line. The exception deviates from the line by less than 0.3 sec. In the distance range 315 km to 490 km, the first arrivals from 8 seismograms fit the line $T_4 = 5.83 + \Delta/7.75$.

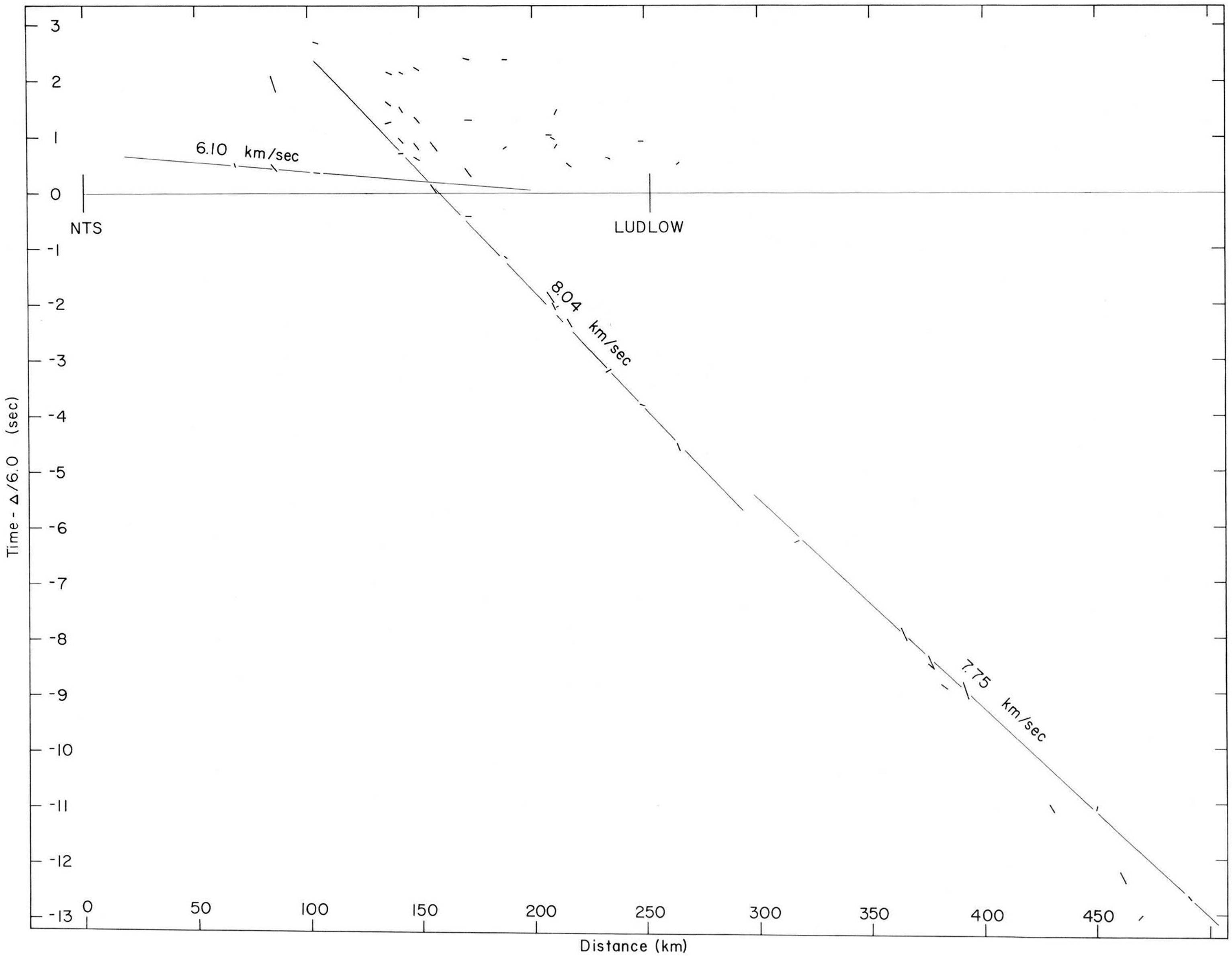

Figure 4.--Reduced travel-time-distance graph NTS to Ludlow.

The first waves from Ludlow shotpoint to reach recording locations to a distance of 95 km fit the line $T_1 = 1.00 + \Delta/6.10$, with a maximum deviation of 0.1 seconds. The first arrivals in the distance range 103 to 152 km fit the line $T_2 = 2.81 + \Delta/6.80$. Again in this range, all the first arrivals fit this line within 0.1 sec. The first arrivals in the distance range 152 to 215 km fit the line $T_3 = 5.48 + \Delta/7.76$. The largest deviation from this line is less than 0.2 sec.

Depth Calculations

Using the zero intercept times and the apparent velocities of only the first arrivals, depth calculations (Table 3) were made for two crustal models (Mota, 1954). Disregarding the evidence for an intermediate layer, the depth to the crust-mantle interface was calculated to be 30 km at NTS and 22 km at Ludlow (Table 3, Model I). The sedimentary deposits at NTS were calculated (assuming a velocity of 2.50 km/sec) to be 1.0 km thick, and at Ludlow they were calculated to be 1.4 km thick. The depth of 30 km in the area of the Nevada Test Site agrees well with other authors. Ryall and Stuart (1963) report the depth to the Mohorovicic discontinuity as 24.3 km. This depth was calculated from an unreversed profile extending eastward from the Nevada Test Site using a one-layer crust. Diment, Stewart, and Roller (1961) report a depth, using a one-layer crustal model, of 28 km to the Mohorovicic discontinuity from recordings southeast of the Nevada Test Site. Pakiser and Hill (1963) report a one-layer crustal thickness of 28 km along an unreversed profile north of the Nevada Test Site.

Table 3.--Computed Crustal Models

Model I

Layer	From Ludlow Velocity (km/sec)	From Ludlow Thickness (km)	From Nevada Test Site Velocity (km/sec)	From Nevada Test Site Thickness (km)
H_0	2.50	1.4	2.50	1.0
H_1	6.10	21	6.10	29
H_2	7.76	- -	8.04	- -
Total depth to Mohorovicic discontinuity		22		30

Model II

Layer	From Ludlow Velocity (km/sec)	From Ludlow Thickness (km)	From Nevada Test Site Velocity (km/sec)	From Nevada Test Site Thickness (km)
H_0	2.50	1.4	2.50	1.0
H_1	6.10	13	6.10	13 (assumed)
H_2	6.80	13	6.80 (assumed)	20
H_3	7.76	- -	8.04	- -
Total depth to Mohorovicic discontinuity		27		34

Model I was computed to show the extent of agreement. The preferred model using the strong evidence for an intermediate layer is shown in Model II and Figure 5 (Table 3). A depth to the Mohorovicic discontinuity of 27 km was calculated at Ludlow by using a two-layer crust and assuming that the apparent velocity of 6.8 km/sec recorded from Ludlow is the true velocity of the intermediate layer. If we assume that the thickness of the upper layer in the crust is the same at NTS as it is at Ludlow, a depth to the Mohorovicic discontinuity of 34 km can be calculated at NTS. This would make the thickness of the intermediate layer 13 km at Ludlow and 20 km at NTS. The total depth at NTS was calculated on the assumption of constant dip on the upper-mantle surface.

By using the reflected events identified as P_MP, the depth of the reflecting surface was computed to be approximately 23 km immediately north of Ludlow. This suggests that this event is a reflection from an irregular surface on the upper mantle.

The 3 early arrivals on nuclear recordings near the Salton Sea are approximately 0.6 sec earlier than an extension of the P_n line. If we assume that all of this time difference is due to thinning of the crust and not to velocity changes, the depth to the Mohorovicic discontinuity would be 7 km shallower near the Salton Sea than at Ludlow, or about 20 km.

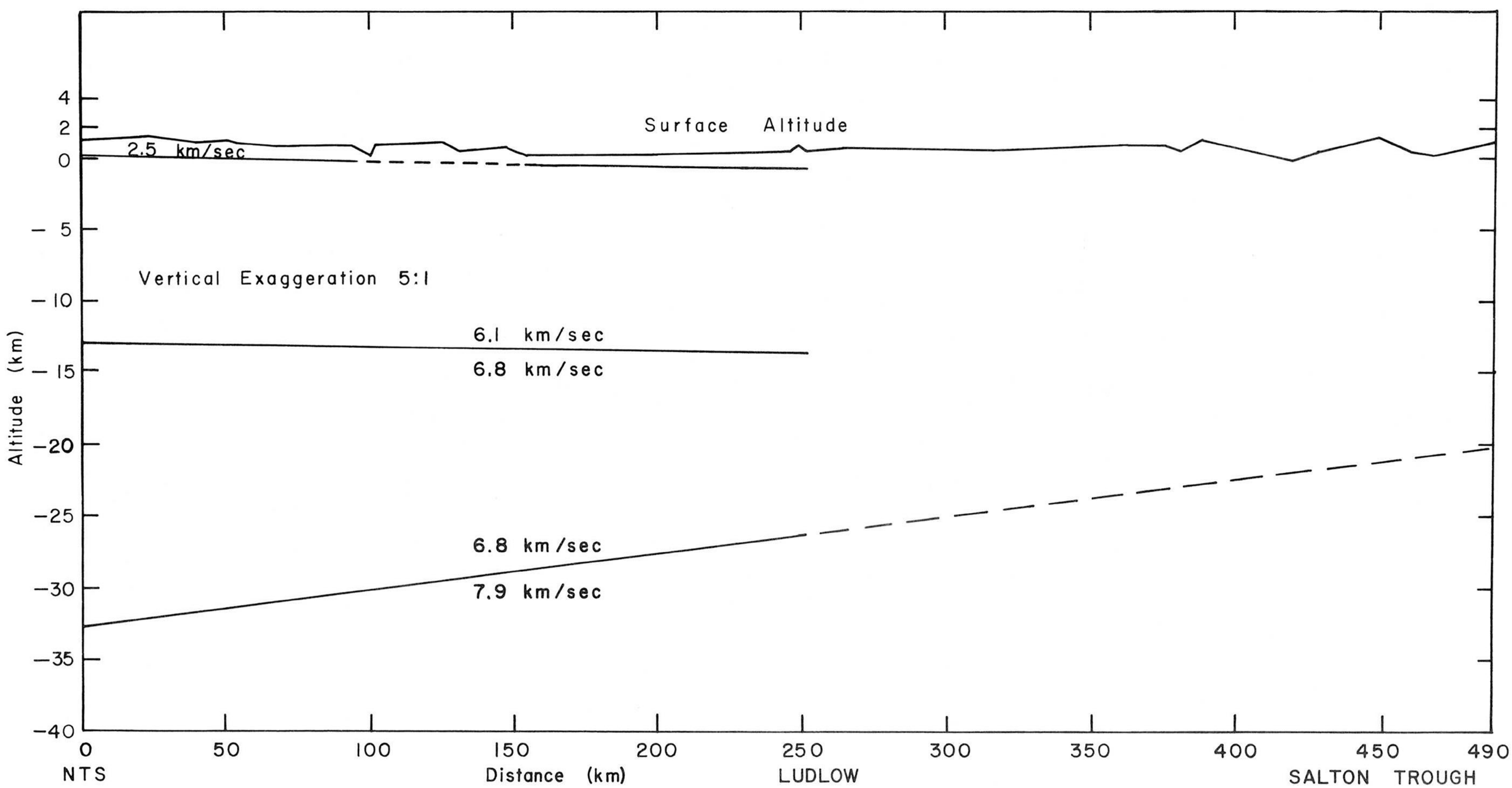

Figure 5.--Interpreted crustal model.

Amplitudes

Because of the difficulty of observing the first upward compressional motion on seismograms at large distances, amplitudes were scaled from the first trough to the second peak (Fig. 6). A charge size of 4,000 lbs was used to normalize the amplitudes, on the assumption that a linear function exists between charge size and amplitude. The amplitudes of the reverse profile from NTS are not plotted. Only relative amplitudes will be discussed for this half of the profile. The phase P_g attenuates very rapidly to a distance of 110 km from the Ludlow shotpoint. Beyond this distance P_g arrivals cannot be positively identified. On 7 seismograms large-amplitude events identified as reflections from the Mohorovicic discontinuity occur as secondary arrivals in the distance range 67 to 121 km.

The phase P* appears as a secondary arrival from 65 to 105 km and as a first arrival from 110 to 155 km; it has approximately the same attenuation with distance as P_g (Fig. 6).

The phase P_n is weak appearing as a first arrival at 150 km and disappearing into the noise at 215 km. The largest amplitude arrivals in the distance range 140 to 250 km are identified as $\overline{P}$.

Amplitudes from the nuclear explosions are very much like those observed from the Ludlow shotpoint. The phase P_g drops off very rapidly with distance and is not distinguishable from the noise at 135 km. Large-amplitude events arriving at a time appropriate for reflections from the Mohorovicic discontinuity are observed on 6 recordings in the distance range 105 to 170 km.

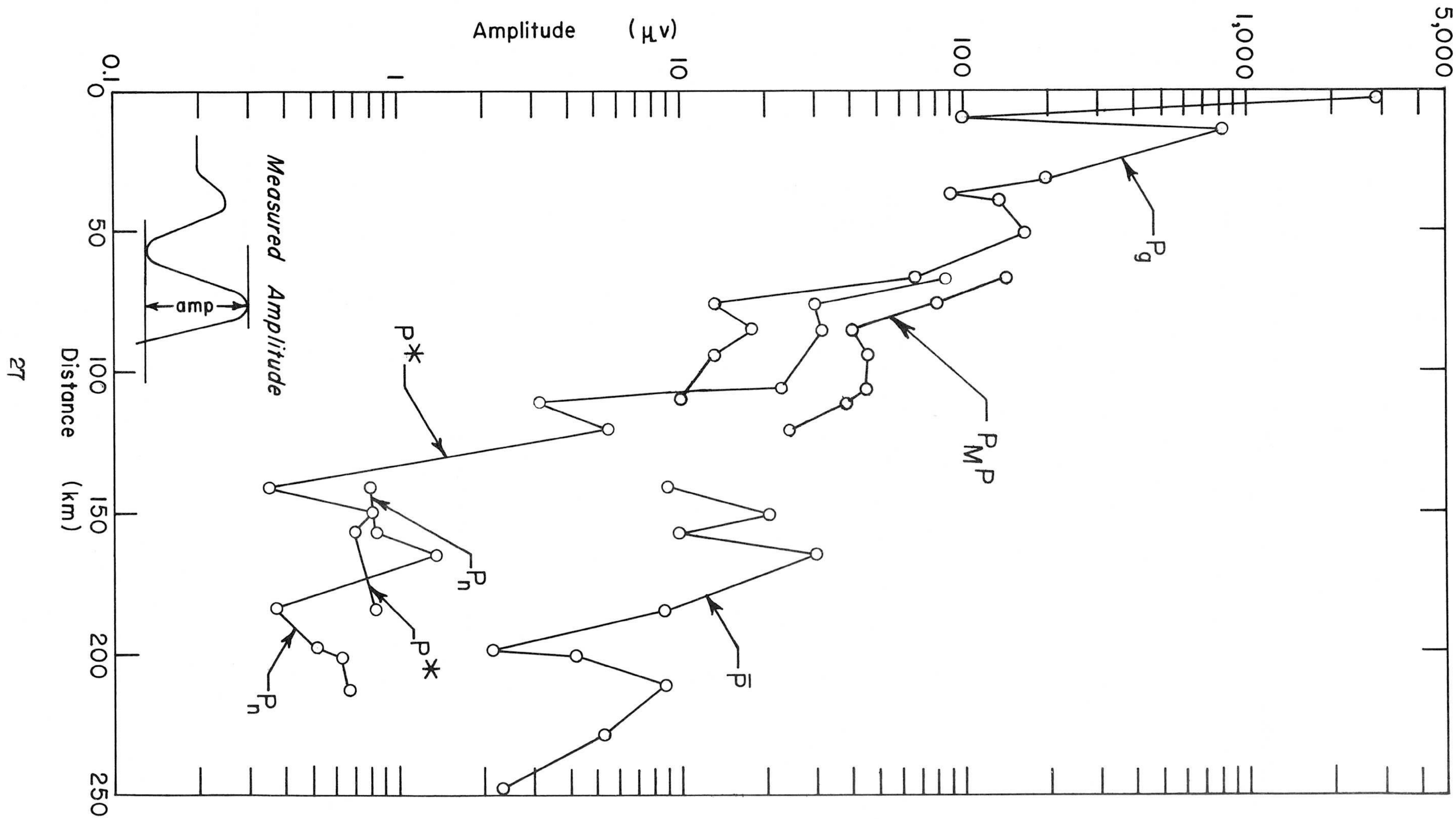

Figure 6.--Graph showing phase amplitude vs. distance from Ludlow chemical explosions.

A very large amplitude event is observed on 5 seismograms in the distance range 135 to 190 km. This event has approximately 3 times the amplitude of P_MP and has the largest amplitude on the seismogram. It has not yet been identified.

Conclusions

A P_g velocity of 6.10 km/sec was recorded from both directions. The velocity of P_n from Ludlow to NTS is 7.76 km/sec and the reverse is 8.04 km/sec. A dip of 1.7° in the Mohorovicic discontinuity would account for this difference in the apparent velocities.

Using a one-way refraction profile from Ludlow southward, the velocity of P_n decreases to 7.75 km/sec. This would indicate that the Mohorovicic discontinuity begins to flatten out at a distance of 315 km south of NTS. An intermediate-layer velocity of 6.80 km/sec was determined from first arrivals from the Ludlow shotpoint. No evidence for an intermediate layer was observed from the NTS; however, the separation between recording locations from NTS may have been too great to establish the presence of an intermediate layer.

The thickness of the crust is computed to be 27 and 34 km at Ludlow and NTS, respectively. Evidence was found that indicates the crust may be as thin as 20 km in the Salton Sea area.

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