UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TECHNICAL LETTER NUMBER 9

CRUSTAL STRUCTURE IN THE WESTERN UNITED STATES: STUDY OF SEISMIC PROPAGATION PATHS AND REGIONAL TRAVELTIMES IN THE CALIFORNIA-NEVADA REGION*

by

J. C. Roller**, W. H. Jackson**, J. F. Cooper***, and B. A. Martina***

February 8, 1963

DENVER, COLORADO

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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Technical Letter
Crustal Studies-9
February 8, 1963

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:

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by

J. C. Roller**, W. H. Jackson**, J. F. Cooper***, and B. A. Martina***

February 8, 1963

This is our annual report on field work and preliminary results for the 1962 field season.

Sincerely,

D J Stuart

D. J. Stuart, Acting Chief
Branch of Crustal Studies

* Work performed under ARPA Order No. 193-62.
** U. S. Geological Survey, Denver, Colorado.
*** United ElectroDynamics, Inc., Pasadena, California.

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IN THE CALIFORNIA-NEVADA REGION

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J. C. Roller*, W. H. Jackson*, J. F. Cooper**,

and B. A. Martina**

1962 Annual Report

Prepared by

United States Geological Survey

Department of the Interior

for

VELA UNIFORM

Advanced Research Projects Agency

Department of Defense

under

ARPA Order No. 193-62

Project Code No. 8100

* U. S. Geological Survey, Denver, Colorado.

** United ElectroDynamics, Inc., Pasadena, California.

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ABSTRACT

The U. S. Geological Survey, with the assistance of United ElectroDynamics, Inc., completed ten weeks of seismic-refraction field work during the summer of 1962 in the southwestern part of the United States. This work was a continuation of a program initiated in 1961 to study traveltimes and seismic propagation paths in the earth's crust and upper mantle in the western United States. A total of 761 seismograms were recorded along 10 profiles from 86 explosions at 18 shotpoints.

Analysis of the data is continuing, but a few conclusions can be made from a preliminary study:

(1) Variations in traveltimes in the Basin and Range province are large but measurable, and perhaps predictable.

* Work performed under ARPA Order No. 193-62.

** U. S. Geological Survey, Denver, Colorado.

*** United ElectroDynamics, Inc., Pasadena, California.

(2) Traveltimes of seismic waves in adjacent geologic provinces are usually significantly different.

(3) The velocity of P_g along all of the profiles recorded in 1962 ranges from 5.0 to 6.5 km/sec, and averages 6.0 km/sec.

(4) The average velocity of P_g in extreme northern Nevada and southern Idaho is 5.6 km/sec, and it is 6.1 km/sec in most of Nevada and California.

(5) The average velocity of P_n is 7.9 km/sec and ranges from 7.85 to 7.95 km/sec on reversed profiles where the true P_n velocity could be computed.

(6) A shallow "intermediate" layer with a velocity of approximately 6.8 km/sec was found in the Snake River Plain.

(7) Refraction arrivals from the mantle (P_n) were recorded in the Sierra Nevada. They indicate that the thickness of the crust in the Sierra Nevada is much greater than that in the Basin and Range province.

(8) Many refinements in field techniques were made during the 1962 field season.

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INTRODUCTION

General -- During September, October, and November, 1961, the U. S. Geological Survey initiated a seismic-refraction survey in California and Nevada to study regional traveltimes and propagation paths of seismic waves in the crust and upper mantle of the earth in the western United States. The immediate objectives of the program were related to the problem of nuclear detection by a network of seismograph stations. During a 12-week's period, 10 shotpoints were established near existing seismograph stations operated by the Air Force Technical Applications Center, California Institute of Technology, and the U. S. Coast and Geodetic Survey, and refraction lines were recorded between these shotpoints. A total of 620 recordings were made from 76 explosions at 10 shotpoints. Results of this work have been presented in previous reports to ARPA.

* Work performed under ARPA Order No. 193-62.

** U. S. Geological Survey, Denver, Colorado.

*** United ElectroDynamics, Inc., Pasadena, California.

The program reported herein is a continuation of the work started in 1961. During the period June 6 to August 9, 1962, a total of 761 recordings were obtained from 86 explosions at 18 shotpoints in California, Nevada, Arizona, Utah, and Idaho (Fig. 1).

The work was accomplished by the Geological Survey and United ElectroDynamics, Inc., according to U. S. Department of the Interior Contract Number 14-08-0001-7634, dated June 29, 1961, modified on May 11, 1962. The 1962 program was sponsored by the Advanced Research Projects Agency of the Department of Defense as a part of the VELA UNIFORM program under ARPA Order No. 193-62, dated January 1, 1962.

Program objectives and approach -- The program was designed to provide a more accurate and detailed knowledge of seismic propagation paths and regional traveltimes in the crust and upper mantle of the earth than previously has been available. This knowledge is essential in calibrating the region to improve the accuracy with which epicenters and focal depths of earthquakes and underground-nuclear explosions can be determined.

Conventional long-offset seismic-refraction methods were used to obtain seismic traveltime data along lines ranging in length from 150 to 400 km. The network of lines was located to supplement information obtained during the 1961 field season and from nuclear explosions at the Nevada Test Site, and to investigate particular phenomena and problems on a regional or local basis, including the nature of first motion and the effects of geologic structure and velocity anisotropy on traveltimes along these paths.

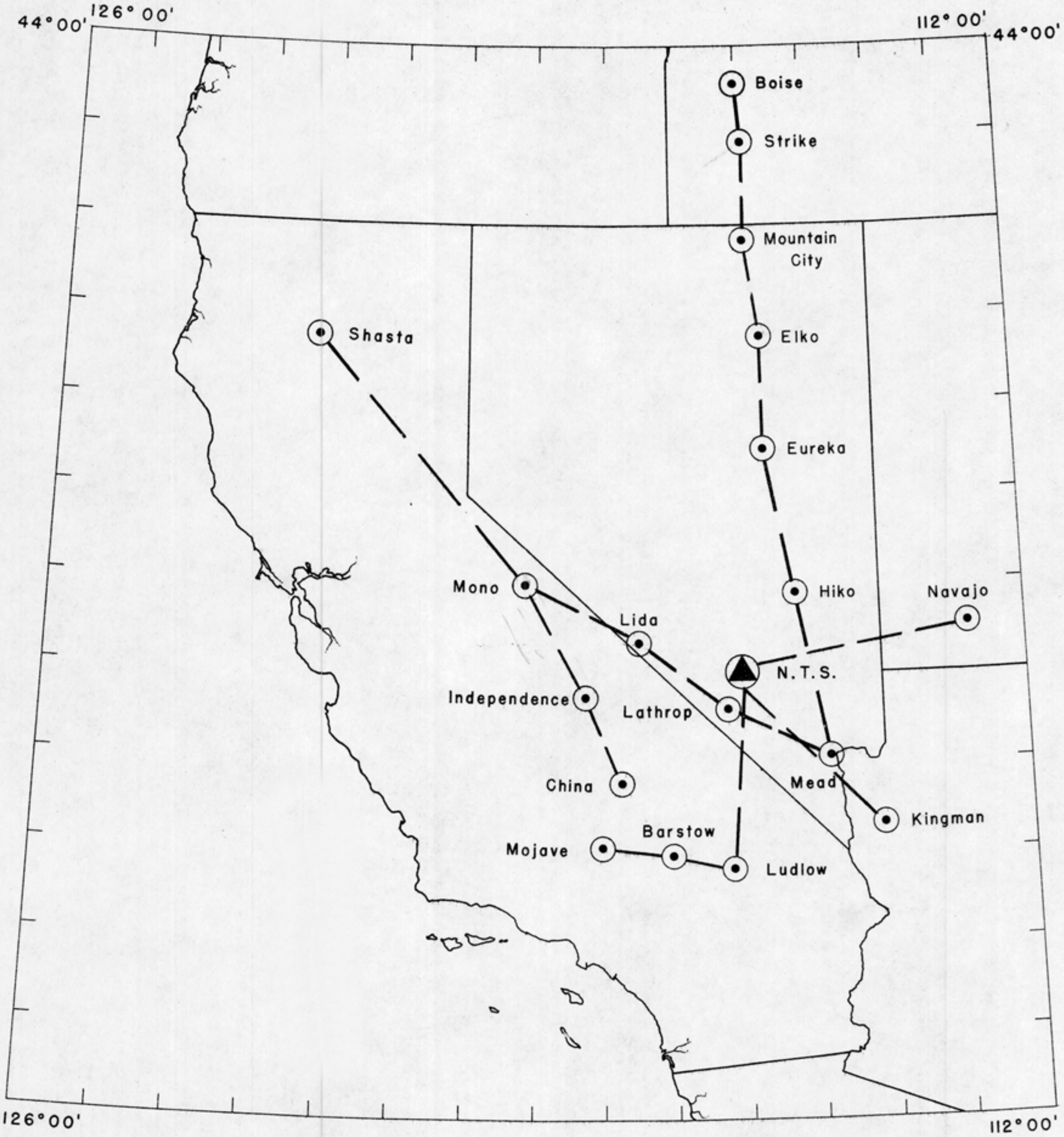

Figure 1.--Shot-point location and seismic profiles.

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Management structure and operational procedures were similar to those followed during the 1961 season (Healy and others, 1962); however, changes were made in the organizational structure to facilitate the handling of data, to provide for a more detailed supervision in field and office personnel, and to expedite maintenance of equipment.

ORGANIZATION AND OPERATIONS

Field operations -- During the 1961 season the recording units were spaced 10 to 20 kilometers apart, and during the 1962 season the recording units were spaced at 10 km or less; near the shotpoints the spacing was reduced to 5 km. The purpose of this change was to aid in the correlation of secondary phases on seismograms.

Along several of the long profiles an intermediate shotpoint was placed near the center of the profile. The purpose of these shotpoints was to provide a more accurate determination of the velocity of P_g, and to provide information on time delays caused by near-surface low-velocity material. The information recorded from the intermediate shotpoints will be used to correct for these near-surface variations in a manner similar to "weathering shots" recorded in conventional seismic-exploration reflection work.

During the 1961 field season the seismograms were collected at a central office in Pasadena, California, for processing. In general, one to two weeks was required before a preliminary evaluation of the data was made. During the 1962 field season a mobile field office was stationed in the general vicinity of the field crews. A courier was employed to collect the data at the end of each day's work and turn it into the office. Here time-distance curves were plotted, and recommendations for additional work, repeat work, changes in charge sizes, etc., were sent to the field supervisor within 24 to 48 hours after the seismograms were recorded. The data were then airmailed to the Denver office for final processing. This system proved to be very effective in controlling the field work and the quality of data. The field office also acted as a general headquarters for telephone communications, personnel and supply problems, and map distribution.

The recording sites were selected and marked by two-man crews prior to the recording-shooting operation on three profiles. These crews checked accessibility of each area, noise level, marked each site with flags, and made a sketch map for the recording-unit operator. Although this system facilitated the operation in many cases, it is questionable whether the cost would justify this manner of site selection on a routine basis. Preselection of recording sites is advantageous in hazardous areas or in regions lacking good map coverage.

Two additional seismic units were used to record very near the shotpoints (less than 10 km). Information obtained by these units will be used to make shot-point time corrections caused by low-velocity material directly below the charge.

Organizational structure -- Again in 1962 the U. S. Geological Survey contracted with United ElectroDynamics, Inc. (UED), to supply various geophysical-contract services to expedite the field work and to accomplish the overall objectives of the program. Services supplied by UED included preliminary scouting of shot-point locations, cooperating with the Geological Survey in efforts to secure shooting permits, a noise-analysis survey and selection of recording sites along 3 lines, and personnel to operate five of the recording systems.

An important task assigned to UED was that of shot-point management and operation. Their responsibilities included drilling shot holes, surveying, renting and operating boats, acquiring explosives, loading and shooting charges, providing insurance coverage, maintaining safety practices at the shotpoints, scheduling shots, cooperating with State and Federal agencies in the evaluation of fish kill, arranging for strong-motion studies on dams, bridges, etc.

The field operation was under the general supervision of either the Chief of the Branch of Crustal Studies, U. S. Geological Survey, or his assistant, one of whom was in the field at all times (Fig. 2). Shooting, drilling, and other shot-point activities were supervised by the Assistant Project Manager (UED); recording and field-data analysis were supervised by Geological Survey personnel. All field activities were coordinated by the Project Manager (UED). He was responsible to the Chief, Branch of Crustal Studies, for the accomplishment of the overall objectives of the field program.

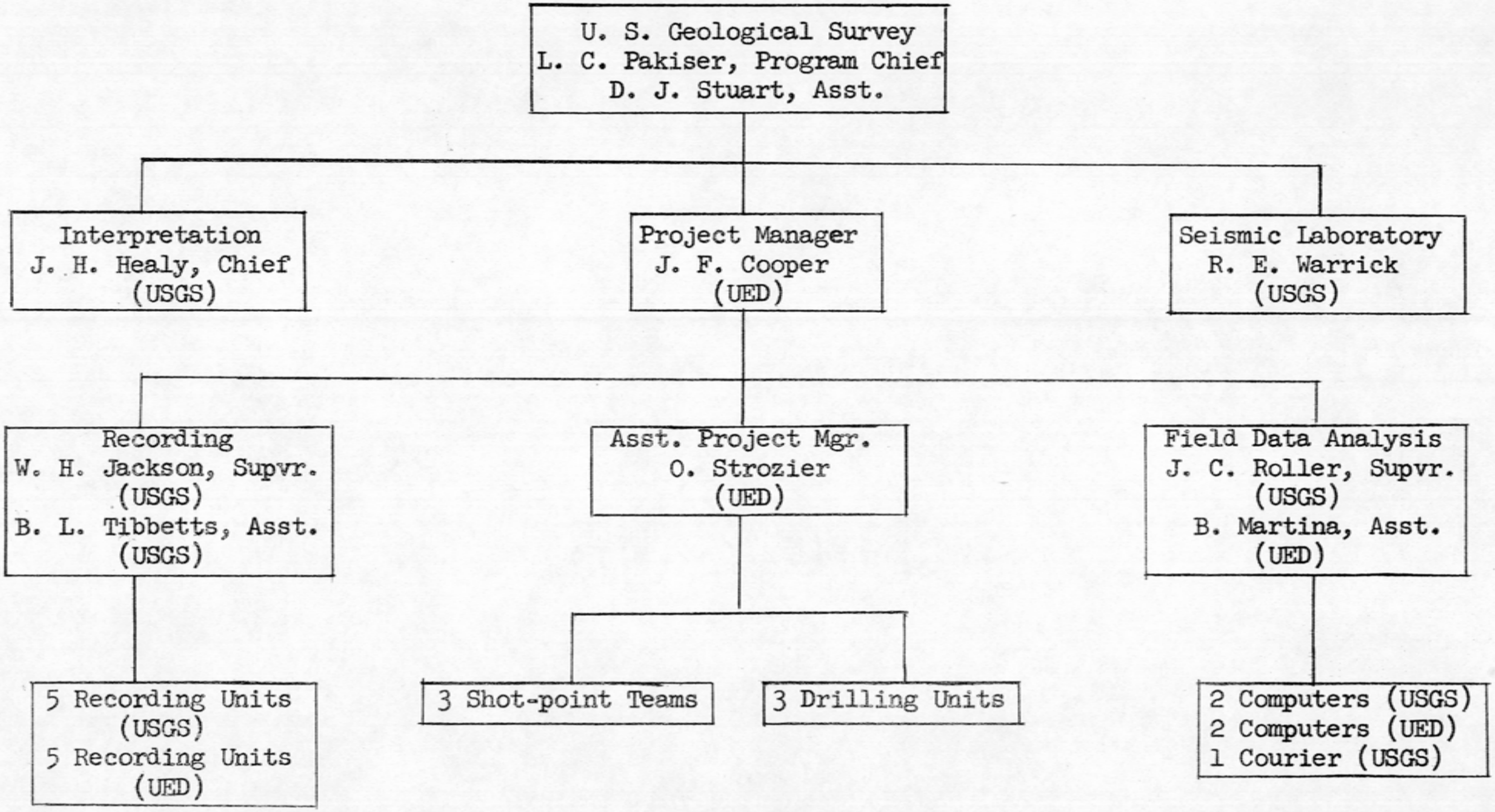


Figure 2.-- Organization chart for field operations and interpretation.

General operational summary -- The network of lines was arranged as shown in Figure 1. Shotpoints were located at the ends and near the centers of the lines at about 150- to 200-kilometer intervals. Charge sizes ranged from 2,000 to 12,000 pounds. Several small charges ranging from 50 to 200 pounds were fired to obtain detailed data near the shotpoints. The following points are particularly significant:

(1) Ten lines of profiling were completed in ten weeks.

(2) Natural bodies of water proved to be superior to drill holes as shotpoints, although the efficiency of several drilled-hole shotpoints was good.

(3) Composition "B," recovered U. S. Army explosive, proved to be completely satisfactory for use in underwater shots.

(4) Super Tovex Gel, a slurry explosive, used only experimentally in 1961, proved to be satisfactory for use in drilled-hole shotpoints.

A statistical summary of the operation is shown in Table 1.

In general, the access and shooting permits were obtained without much difficulty, although the time allotted was inadequate for obtaining all permits prior to the start of the shooting program. As a consequence, the permitting program continued during the normal crustal-recording program, and, on several occasions, necessitated the absence of the Operations Manager and/or the Assistant Operations Manager (engaged in the permitting activities) from immediate supervision of the shooting program.

Table 1 -- Summary of the crustal-recording program

Number of lake shot points	5
Number of drilled-hole shot points	13
Number of production days (including 6 moving and 2 standby)	52
Number of shots (production), including 8 AEC	94
Number of seismograms obtained, including 65 AEC	826
Number of shot-point seismograms obtained	95
Number of miles of profile coverage	1,909
Number of kilometers of subsurface coverage	2,020
Total footage drilled	23,571
Number of holes drilled	145
Number of bits used	67
Drilling mud used (lbs)	31,152
Dynamite used (lbs) Composition B Other	145,240 373,800
Primers used (lbs)	7,773.5
Number of WW boosters used	808
Number of detonators used	3,668
Primacord used (feet)	20,050
Number of vehicles on project	56
Total vehicular miles	530,000

There were no days lost in the scheduled shooting program directly attributable to the lack of a permit for a specific shotpoint, but there were instances in which a more expeditious shooting sequence could have been used had all permits been available.

It is noteworthy that the disadvantage of insufficient time for permitting was largely overcome by the cooperation of the individuals in charge of the agencies through which the permits were obtained (Table 2). Permits for the 18 shotpoints were obtained in less time and at less cost than the permits for the 10 shotpoints used during the 1961 season.

Shotpoint refraction recording -- Near-surface refraction data were obtained in the vicinity of the shot-point locations on the terminal ends of all lines by using two sets of truck-mounted seismic instruments, United Geophysical Corporation Model 1-44 (modified) in conjunction with forty-eight geophones, ElectroTechnical Corporation Model EV 5-4 and EV S-4, having a natural frequency of 7-1/2 cps. Shot-instant reception and two-way voice communications with the shot-point trailer were accomplished with a KAAR Model 245 radio transceiver operating on a frequency of 3253 kc. Twenty-five-trace seismograms were obtained; traces 1 through 24 recorded the refraction data; trace 25 the shot-instant transmission from the shot-point trailer.

Table 2 -- Shot-point permits

Shotpoint	Agency, and/or individual involved
Barstow, Calif.	U. S. Bureau of Land Management Riverside, California
Boise, Ida.	Mr. Robert C. Salter, Acting Director Idaho Department of Fish and Game Boise, Idaho
	Idaho Department of Highways Boise, Idaho
	Col. J. H. Beddow U. S. Corps of Engineers Walla Walla, Washington
	U. S. Bureau of Reclamation Denver, Colorado
Mountain City, Nev.	Mr. R. R. Chambers Mountain City, Nevada
	U. S. Forest Service Humboldt National Forest Mountain City, Nevada
China Lake, Calif.	Dr. Pierre St. Amand U. S. Naval Ordnance Test Station China Lake, California
Elko, Nev.	Mr. Claire Whitlock, District Manager U. S. Bureau of Land Management Elko, Nevada
Eureka, Nev.	Mr. Curtis McVee, District Manager U. S. Bureau of Land Management Ely, Nevada
Hiko, Nev.	U. S. Bureau of Land Management Ely, Nevada
Kingman, Ariz.	U. S. Bureau of Land Management Phoenix, Arizona
Lathrop Wells, Nev.	U. S. Bureau of Land Management Las Vegas, Nevada

Table 2 -- Shot-point permits (Continued)

Shotpoint	Agency, and/or individual involved
Lida Junction, Nev.	U. S. Bureau of Land Management Las Vegas, Nevada
Ludlow, Calif.	U. S. Bureau of Land Management Riverside, California
Lake Mead, Calif.	Mr. Charles A. Richey, Superintendent U. S. National Park Service Boulder City, Nevada
	U. S. Bureau of Reclamation Boulder City, Nevada
	Mr. Wayne Kirch, Chairman Nevada Fish and Game Commission Reno, Nevada
	Arizona Fish and Game Department Phoenix, Arizona
Mojave, Calif.	U. S. Bureau of Land Management Sacramento, California
	California State Fish and Game Commission Sacramento, California
Navajo Lake, Utah	U. S. Forest Service Dixie National Forest Cedar City, Utah
Independence, Calif.	U. S. Forest Service Inyo National Forest Lone Pine, California
	Department of Water and Power City of Los Angeles Independence, California
Shasta Lake, Calif.	Mr. Felix Dashen U. S. Bureau of Reclamation Redding, California
	U. S. Forest Service Shasta-Trinity National Forest Redding, California

Table 2 -- Shot-point permits (Continued)

Shotpoint	Agency, and/or individual involved
Shasta Lake, Calif.	Mr. James Stokes, Director California Department of Fish and Game Redding, California
C. J. Strike Reservoir, Ida.	Mr. H. R. Moore Idaho Power Company Boise, Idaho
	Mr. Robert C. Salter, Acting Director Idaho Department of Fish and Game Boise, Idaho
Nevada Test Site	Lt. Col. Edward G. Halligan Project Operations Officer U. S. Atomic Energy Commission Las Vegas, Nevada
	Mr. W. S. Twenhofel U. S. Geological Survey Denver, Colorado

Explosives -- For the drilled-hole shotpoints, one or a combination of the following explosives was used:

(1) Du Pont's "Nitramon WW," or Nitramex 2H, packaged in metal cylinders without primer wells, which allowed preloading without deterioration, and almost eliminated the possibility of desensitization by water leaks under excessive pressure. The diameters of the cylinders were 4-1/2 inches and 8 inches.

(2) Du Pont's Super Tovex Gel, a slurry-type explosive was used because of the desirable characteristic of completely filling the shot-hole, thereby minimizing the depth of hole required per unit charge.

(3) Du Pont's Pelletol, a granular high-density explosive used especially for filling the space between metal-cylinder encased charges and the hole wall.

(4) Assorted Du Pont primers, boosters, detonators, and primacord, as required. For the lake shots, the following explosives used were:

(a) Du Pont's "Nitramon WW."

(b) A U. S. Army Ordnance surplus explosive "recovered" from obsolete ordnance, termed "Composition B."

(c) Du Pont's primers, boosters, and detonators.

Composition B was used in the majority of the lake shots. The Nitramon WW was the remnant from the 1961 shooting season.

Composition B is classed as a high explosive (Class A). The lot used in this program was composed of:

(1) 59.5 percent RDX.

(2) 39.5 percent TNT.

(3) 1 percent wax.

The explosive force of Composition B is considerably greater than that of straight TNT. Pre-publication reports from the U. S. Coast & Geodetic Survey representative who recorded all of the shots at Lake Mead on instruments installed at Hoover Dam indicate that the amplitude and displacement of energy generated by Composition B is appreciably greater than that of the Nitramon WW.

The Composition B, packaged in tin cubes measuring 9-1/2 inches on each side, was obtained from the Naval Ammunition Depot, Hawthorne, Nevada, and was a portion of the lot made available to the U. S. Department of Interior by the Advanced Research Projects Agency, U. S. Department of Defense. Transportation of the explosives from Hawthorne, Nevada, to the shotpoint locations was arranged with various commercial transport companies by the Du Pont Company.

Shot-point renovation -- Most of the drilled-hole shotpoints required considerable "clean-up" work after the shooting had been completed. In a few holes in which large charges had been fired at relatively shallow depths with inadequate stemming, surface craters 50 or 60 feet in diameter resulted. Charges of 6,000 to 12,000 pounds, when properly stemmed, did not crater although the explosive force cracked the ground and raised mounds which were sometimes 10 to 15 feet in height and 100 feet in diameter.

In such areas of disturbed or damaged surface, heavy equipment such as tractor-blades or bulldozers was used to restore the disturbed zones as nearly as possible to their former condition.

<u>Fish-kill resulting from lake shots</u> -- Table 3 shows the weights of dead game fish collected after large explosive charges had been fired in inland bodies of fresh water. The figures were furnished by the State Fish and Game Departments.

Table 3 -- Fish Kill

Shot Point Location	No. of shots	Total Explosives Used	Fish Kill (Game-Fish)
Lake Mead	9	40,100 lbs.	287.5 lbs.
Shasta Lake	4	21,000 lbs.	57.6 lbs.
Lucky Peak Reservoir	3	12,000 lbs.	119* lbs.
C. J. Strike Reservoir	3	10,000 lbs.	149* lbs.
Total game-fish kill			788-1/2 lbs.

* estimated

TIME-DISTANCE PROFILES

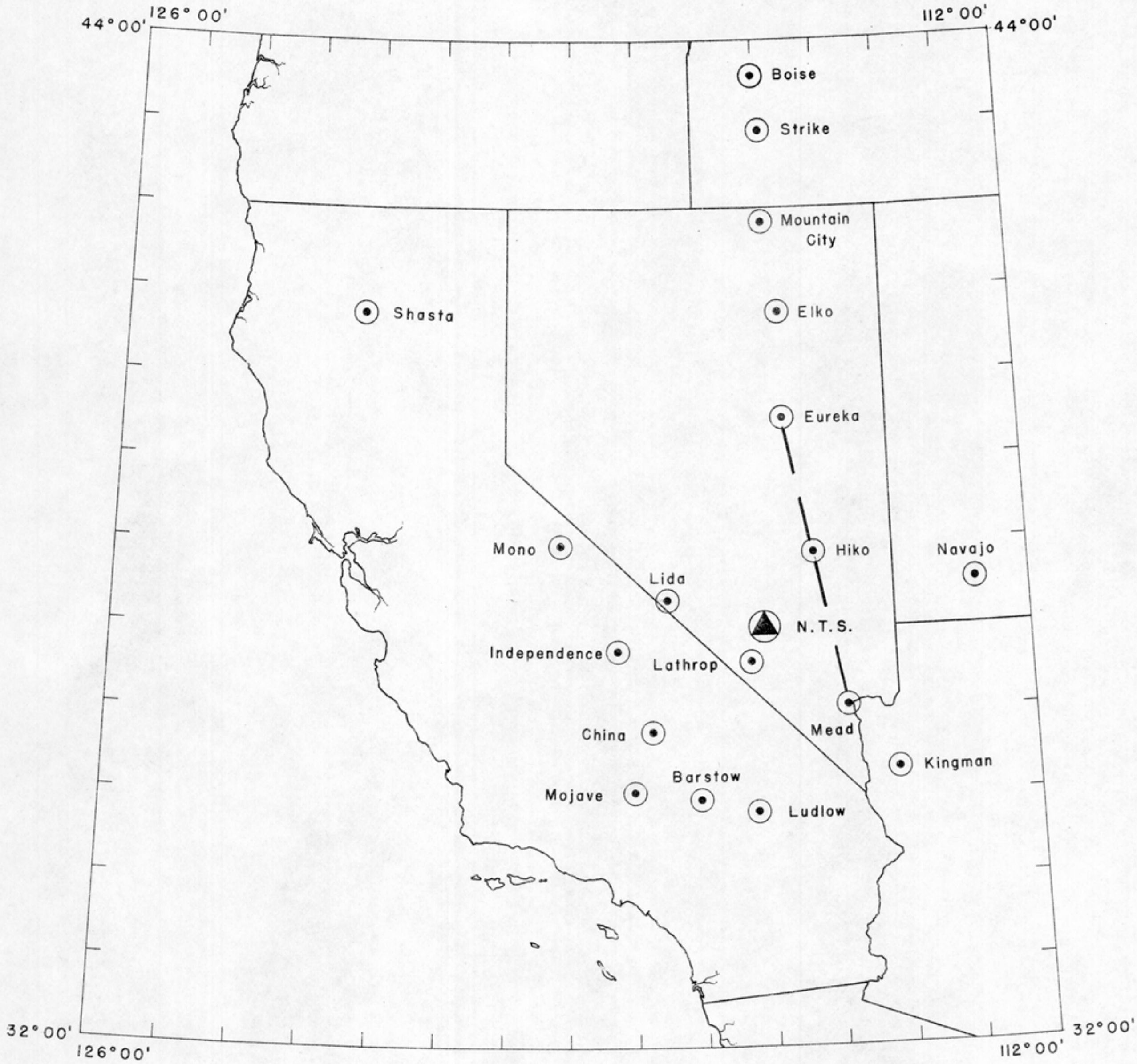
The following sections of this report give the time-distance profiles recorded during the 1962 field season. Only the first arrivals have been used to construct these curves. The seismograms contain many secondary events, such as reflections, secondary refractions, arrivals from shear waves and converted waves; however, no attempt has been made to present these, because the evaluation of secondary arrivals requires considerable time. The grading system of seismograms is the same as that of Healy and others (1962, p. IV-38).

Many seismograms were recorded that are not used in this preliminary summary. In general, only seismograms that show true first arrivals are used. Many of the poorer seismograms will be used in later reports on secondary events. Many of these poorer seismograms can be improved by magnetic playbacks of the magnetic tape using selective filtering.

No attempt has been made to interpret the data in terms of crustal structure in this report.

Profiles between Lake Mead and Eureka -- The profile (Fig. 3) extends 387 km northward from Lake Mead, Nevada, to Eureka, Nevada, with one intermediate shotpoint 205 km north of Lake Mead near Hiko, Nevada. Lake Mead and Eureka are classified as good shotpoints, and Hiko as a fair shotpoint.

Lake Mead to Eureka -- The first arrivals on sixteen recordings plot within ± 0.3 sec of an apparent-velocity line of 6.2 km/sec out to a distance of 180 km from Lake Mead. Eight of these recordings are classified as good, six as fair, and two as poor. Beyond 180 km, eleven recordings plot within ± 0.2 sec of a line that represents an apparent velocity of 7.9 km/sec. Three of these recordings are classified as good, six as fair, and 2 as poor. The probable error in the apparent velocities is not greater than 0.1 km/sec. The quality of the seismograms along this line is higher than the average recorded in the California-Nevada region.



Shot-point location and refraction profile for Figure 3.

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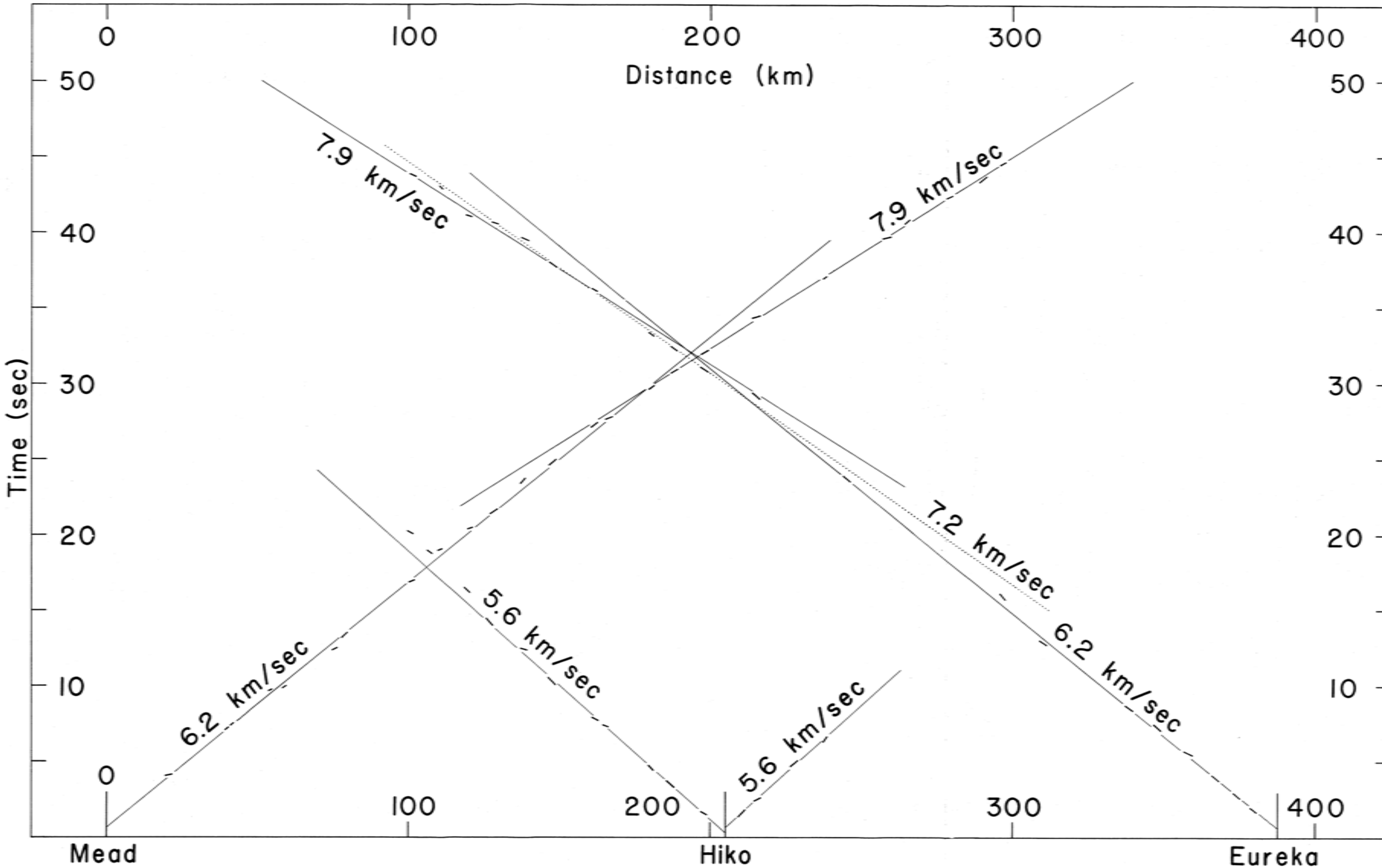


Figure 3, Time—Distance Profile, Mead—Eureka

Eureka to Lake Mead -- An apparent velocity of 6.2 km/sec is defined south of Eureka for a distance of 173 km. The first 50 km of this line is very well defined by six recordings of fair quality that show no appreciable scatter. Beyond 50 km to 173 km first arrivals can be picked on only three recordings, although approximately fifteen recordings were made within this interval. This failure to record first arrivals was partly the result of poor tamping of a shot at Eureka. The records in this interval show many secondary arrivals, however.

Beyond 173 km, moderately strong first arrivals were recorded on 11 records. Although these arrivals show considerable scatter, they appear to define two apparent velocities, 7.2 km/sec and 7.9 km/sec.

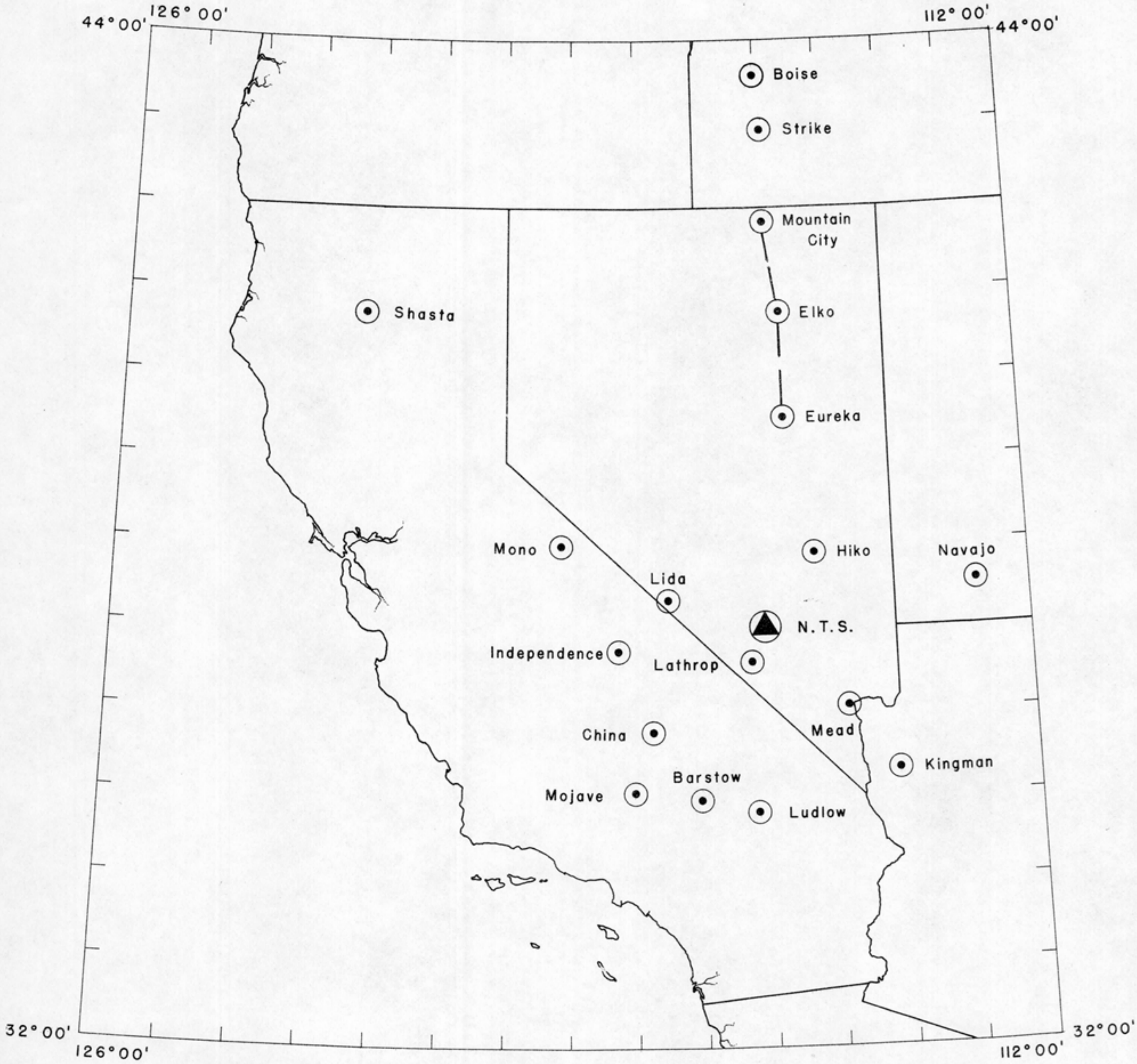
Three fair recordings in the distance range of 173 km to 237 km define an apparent velocity of 7.2 km. A more detailed study will be needed to determine if this is the result to an intermediate crustal layer, or if it is caused by scatter in the data.

Intermediate shotpoint at Hiko -- Four recordings to the north of Hiko (toward Eureka) and 8 recordings to the south of Hiko (toward Lake Mead) define an apparent velocity of 5.6 km/sec. This velocity is significantly lower than the P_g velocities for waves traveling from both Lake Mead and Eureka toward Hiko.

Profiles between Eureka and Mountain City -- This profile (Fig. 4) is an extension of the Lake Mead-Eureka profile. It extends northward 259 km from Eureka, Nevada, to Mountain City, Nevada, with an intermediate shotpoint at Elko. The efficiency of all three of these shotpoints are classified as good.

The profiles from Eureka north and Mountain City south define a "normal" crust for the California-Nevada region, showing a P_g velocity of near 6.0 km/sec and a P_n velocity of 7.9 km with no arrivals of intermediate velocity becoming first arrivals. The profile north from Elko (toward Mountain City) shows a P_g velocity of near 6.0 km/sec for a short distance, and then a velocity of 6.8 km/sec extending at least 300 km from the shotpoint. This line crosses the boundary between the Basin and Range province and the Snake River Plain in the vicinity of Mountain City.

Eureka to Mountain City -- An apparent-velocity line of 5.9 km/sec is well defined from eleven recordings of fair-to-good quality from the shotpoint to a distance of 135 km. The scatter of the data along this section of the profile is small. Most points fall within 0.1 sec of the 5.9-km/sec line. Beyond 135 km, eleven points define a line of 7.9 km/sec. Seven records fall within 0.1 sec of this line, and four recordings plot approximately 0.3 sec later than the 7.9 km/sec line. The recordings along this section of the profile are of poor to fair quality.



Shot-point location and refraction profile for Figure 4.

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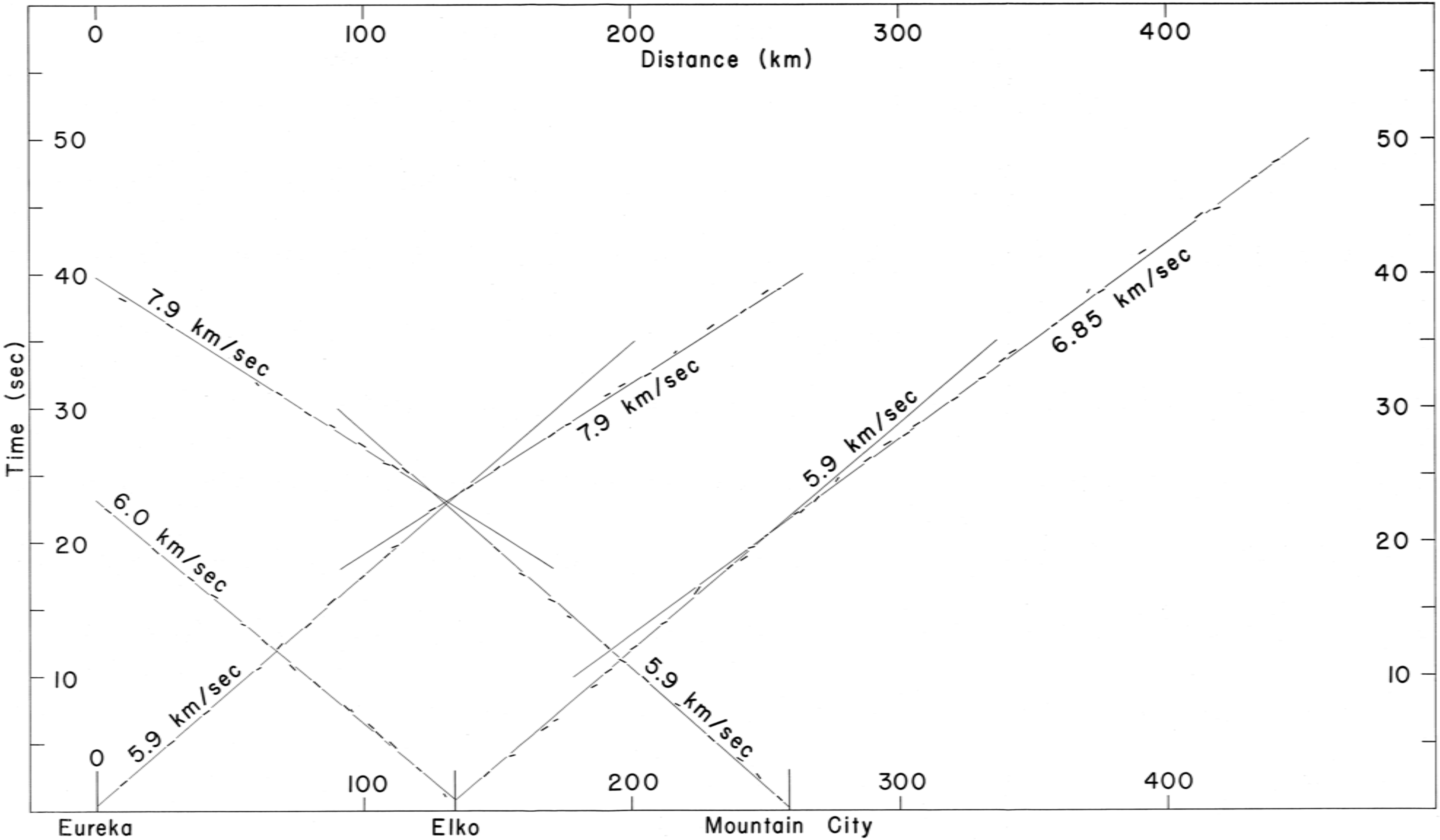


Figure 4, Time—Distance Profile, Eureka—Mountain City

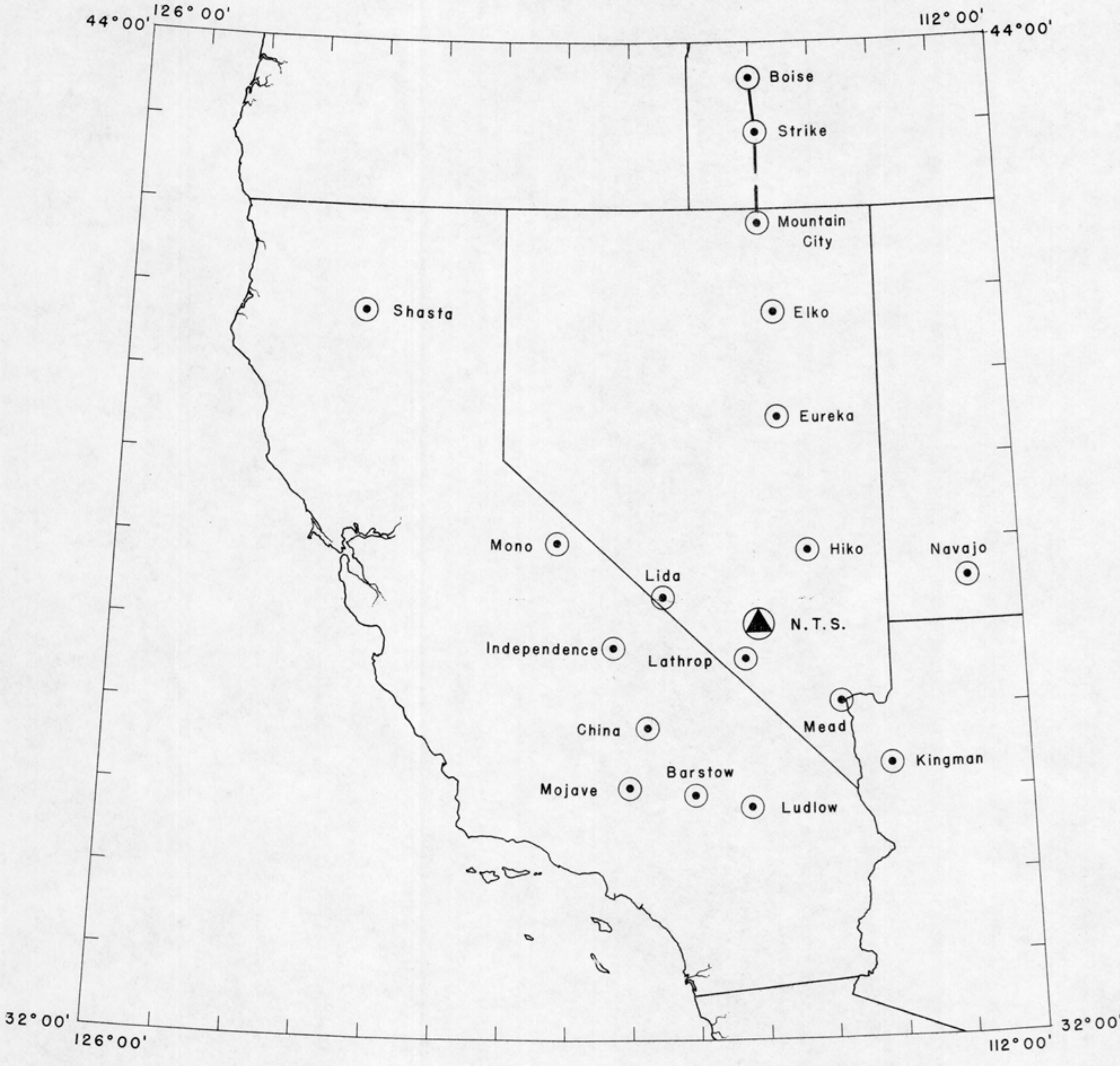
Mountain City to Eureka -- This profile is almost identical to the reversed section (Eureka to Mountain City). The P_g and P_n velocities on the two curves are exactly the same and the cross over distance is 133 km on this profile compared with 135 km on the reversed profile. The P_g line with an apparent velocity of 5.9 km/sec is well defined by 12 recordings of good-to-fair quality, and the P_n line of 7.9 km/sec is well defined with 10 recordings of poor-to-fair quality.

Elko to Eureka -- An apparent P_g velocity of 6.0 km/sec is defined by 15 recordings that show very little scatter. These records are good to fair in quality.

Elko towards Mountain City -- This profile was extended to a total length of 300 km to the north in an attempt to determine if the P_n velocity could be found as a first break.

The profile shows an apparent velocity of 5.9 km/sec for a distance of 125 km that is defined by 13 recordings of good-to-fair quality. Beyond 125 km an apparent velocity of 6.85 km/sec is defined by 18 recordings of poor-to-good quality. The discovery of this large change in the velocity of the earth's crust is one of the major accomplishments of the 1962 field season.

Profiles between Mountain City and Boise -- These profiles (Fig. 5), like the profile from Elko, show a completely different crustal structure from profiles in the Basin and Range province of California and Nevada. The four profiles show near-surface velocities



Shot-point location and refraction profile for Figure 5.

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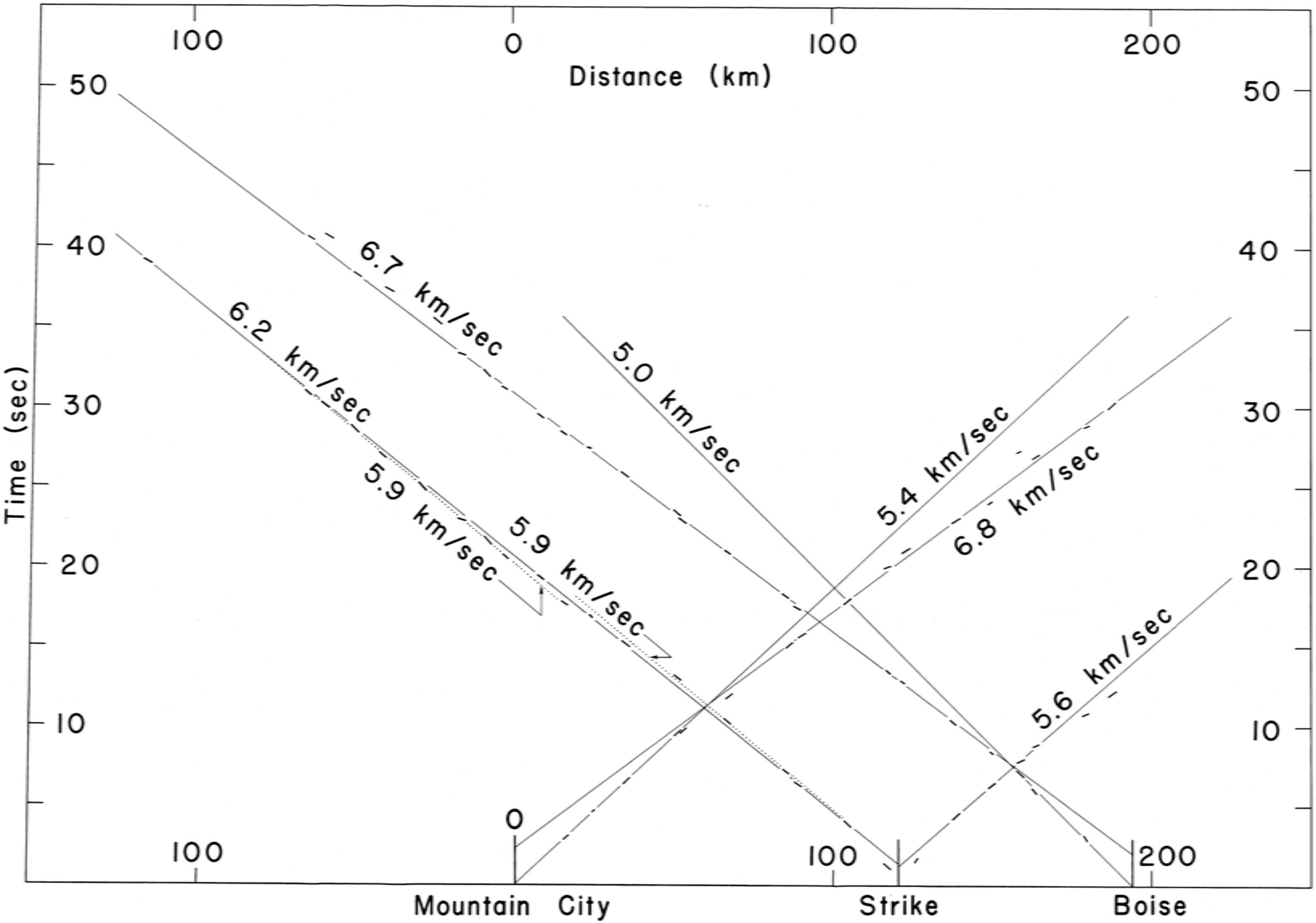

Figure 5, Time—Distance Profile, Mountain City—Boise that range from 5.0 km/sec to 6.2 km/sec, and no P_n velocities, such as the 7.8 to 8.0 km/sec velocity found on all the lines in the Basin and Range province. The thickness of the "intermediate" layer (velocity of 6.8 km/sec) cannot be determined from the data presented in this report; however, the Geological Survey has recorded several nuclear explosions in this region from the Nevada Test Site which should resolve the crustal structure.

Mountain City to Boise -- A near-surface P_g velocity of 5.4 km/sec is defined from the shotpoint for a distance of 60 km by 5 recordings of fair quality. Beyond 60 km to Boise an apparent velocity of 6.8 km/sec is defined by 11 recordings of poor-to-fair quality. The scatter in this data is quite large.

Boise to Mountain City -- Three recordings define an apparent velocity of approximately 5.0 km/sec from the Boise shotpoint south for a distance of 40 km. Beyond 40 km to a distance of 160 km, a 6.7 km/sec line is well defined by 18 recordings that fall within 0.2 sec of this line.

Intermediate shotpoint at C. J. Strike Reservoir -- Four recordings of good quality north of C. J. Strike Reservoir (toward Boise) define a line with an apparent velocity of 5.6 km/sec. Two recordings near Boise fall earlier than this line, indicating a change to a higher velocity.

Eighteen poor-to-good recordings from C. J. Strike Reservoir south, fall close to a line with an apparent velocity of 6.2 km/sec for a distance of 185 km; however, two offset lines, both with a velocity of 5.9 km/sec, fit the data more closely. These data indicate that the structure of the upper crust in this area is complex.

Profiles between Mono Lake and Shasta Lake -- This profile (Fig. 6), which crosses the Sierra Nevada, differs from the California-Nevada area profiles in two significant aspects. First the P_g velocity, which averages 6.4 km/sec, is higher, and secondly, the P_g - P_n cross-over distance is much greater. This indicates a much thicker crust along this profile than the average for the Basin and Range province. The efficiency of the Shasta Lake shotpoint would be classed as good to excellent, and that of the Mono Lake shotpoint as good. No intermediate shotpoints were occupied along this profile.

Shasta Lake to Mono Lake -- Twenty-one recordings define a P_g line with an apparent velocity of 6.5 km/sec out to a distance of 260 km. The scatter in the data to 125 km is small; most of the recordings fall within 0.1 sec of the 6.5 km/sec line. The data along this part of the line are of good quality. Beyond 125 km to the P_g - P_n cross-over at 260 km, the data show much more scatter. These recordings are of poor to fair quality.

From 260 km to 405 km, eight records of poor-to-fair quality define a P_n line with an apparent velocity of 7.9 km/sec. The scatter in the data is very small, with five of the eight recordings falling on the line.

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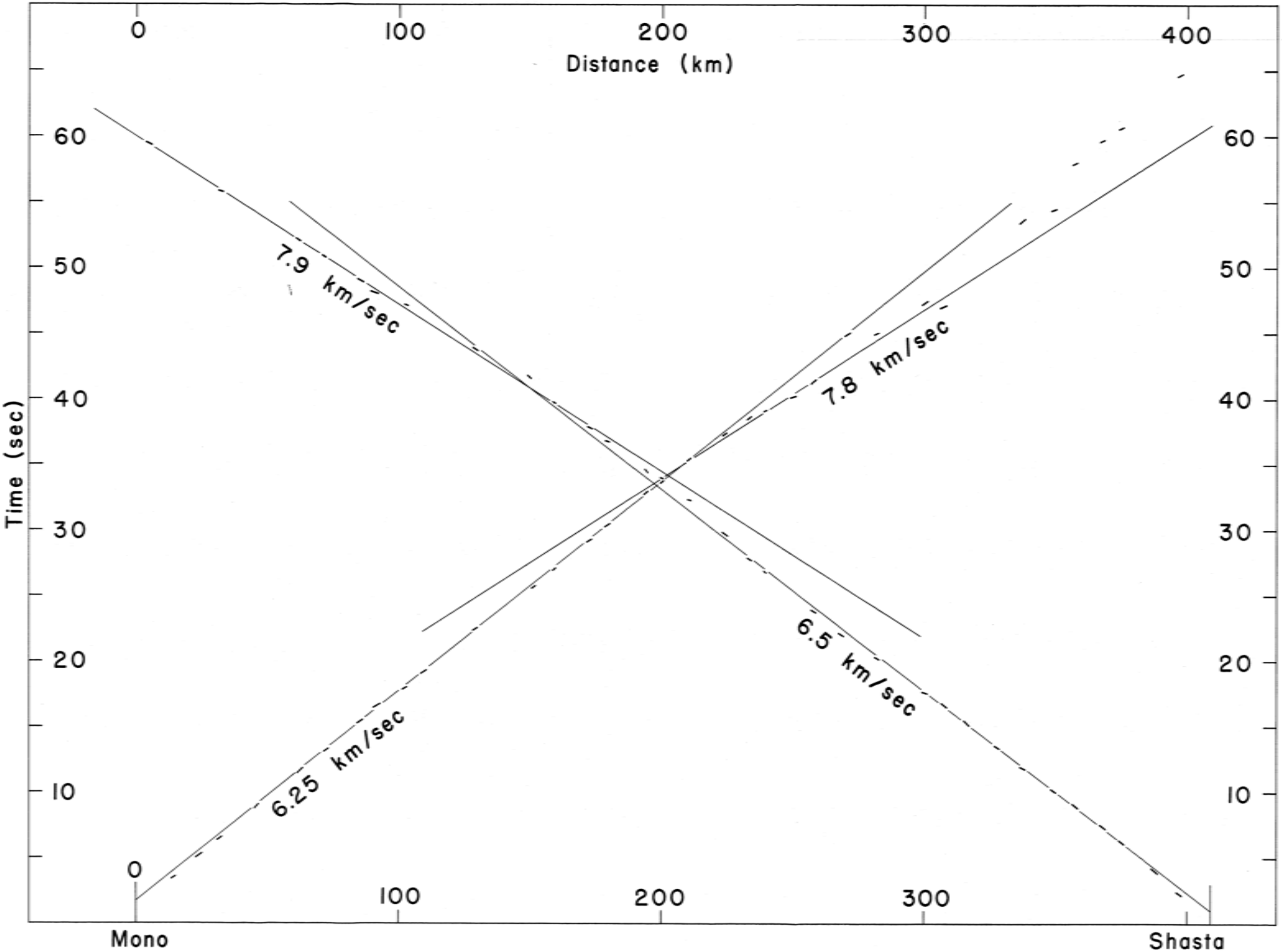


Figure 6, Time—Distance Profile, Mono—Shasta

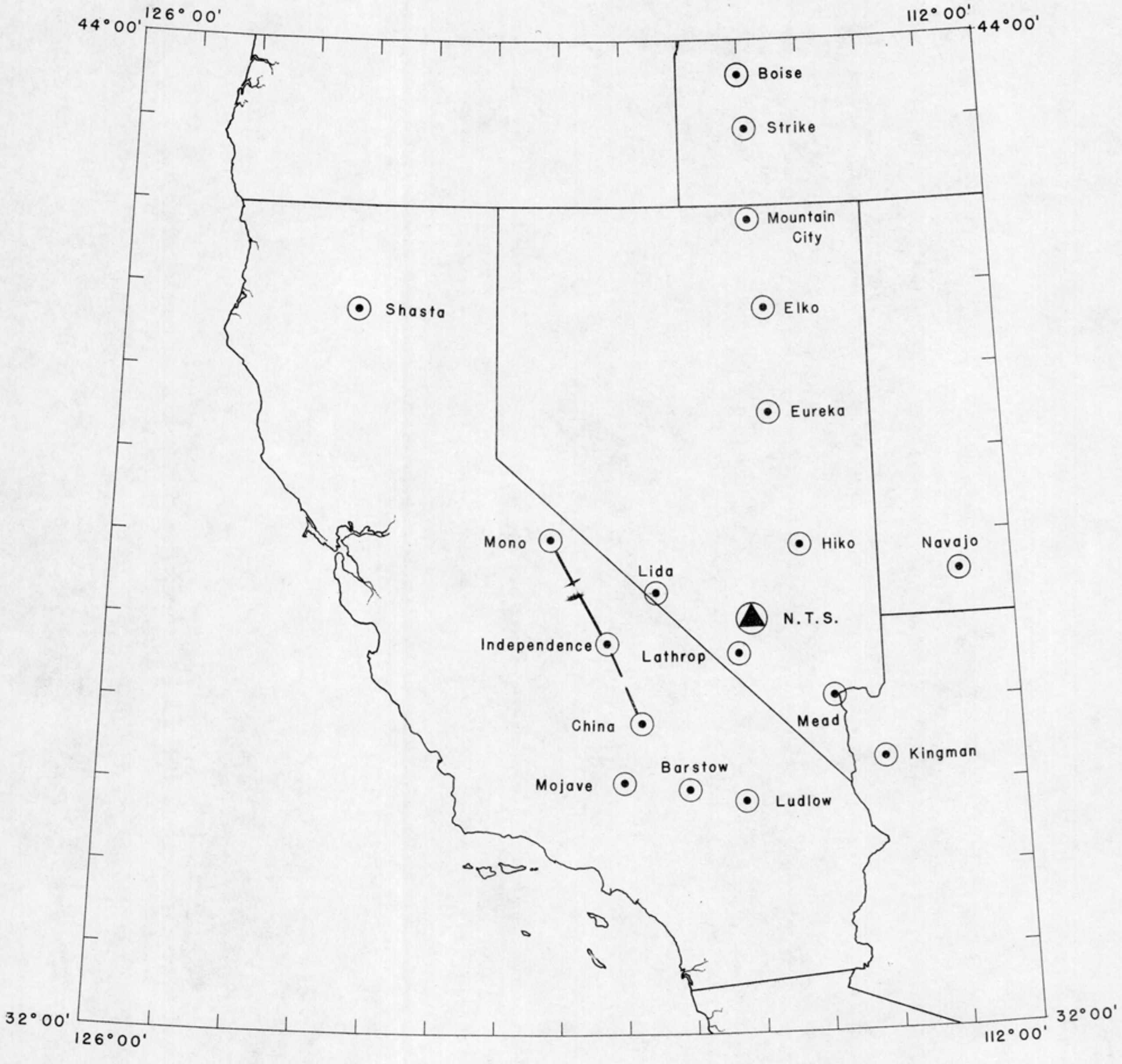
Mono Lake to Shasta Lake -- From the Mono Lake shotpoint for a distance of 200 km an apparent-velocity line of 6.25 km/sec is defined by 17 good-to-fair recordings. The scatter in the data is small, as most recordings fall within 0.2 sec of the line.

Beyond a distance of 200 km, a very poorly defined line is shown with a velocity of 7.8 km/sec. This velocity could be in error because of the large scatter in the data. First arrivals could not be picked on the records beyond 300 km, and the arrivals shown are undoubtedly secondary events. Some improvement of this section of the profile may be obtained by using selective filtering on magnetic playbacks. The measurements made along these profiles constitute a major step in defining the crustal structure beneath the Sierra Nevada.

Profiles between Mono Lake and China Lake -- The highest apparent velocity recorded on this profile (Fig. 7) was 6.1 km/sec. No P_n arrivals were recorded as first breaks. This could be the result of two factors: a thick crust, or poor records.

This line runs parallel to and near the Sierra Nevada: therefore, the crust is expected to be thicker under this profile than the average Basin and Range profile. It is therefore possible that the profiles were not long enough to record P_n as a first arrival.

The efficiency of the China Lake shotpoint was only fair, and the long-range records were generally of poor quality. Although the efficiency of the Mono Lake shotpoint was good, most of the long-range



Shot-point locations and refraction profiles for Figure 7.

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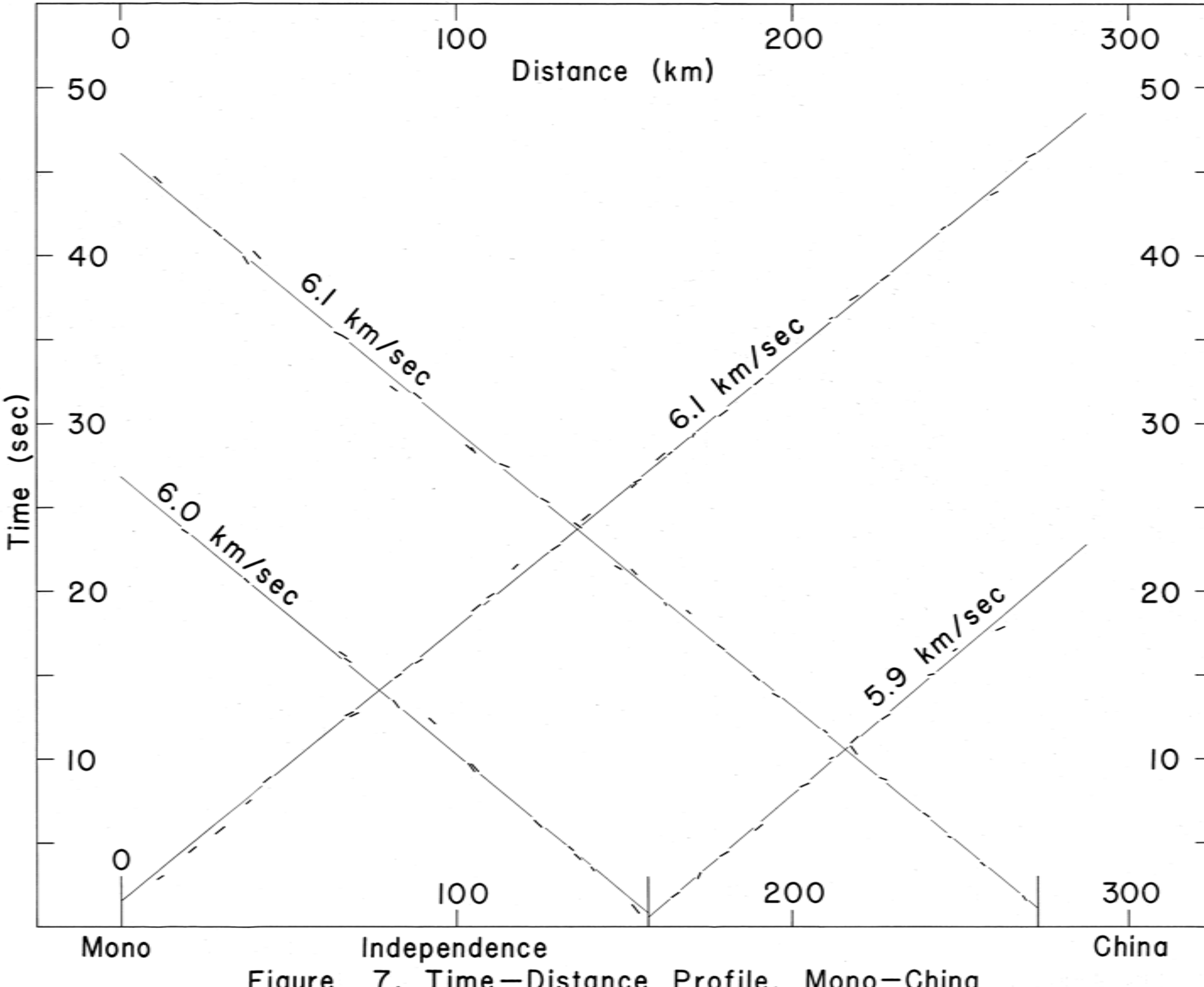
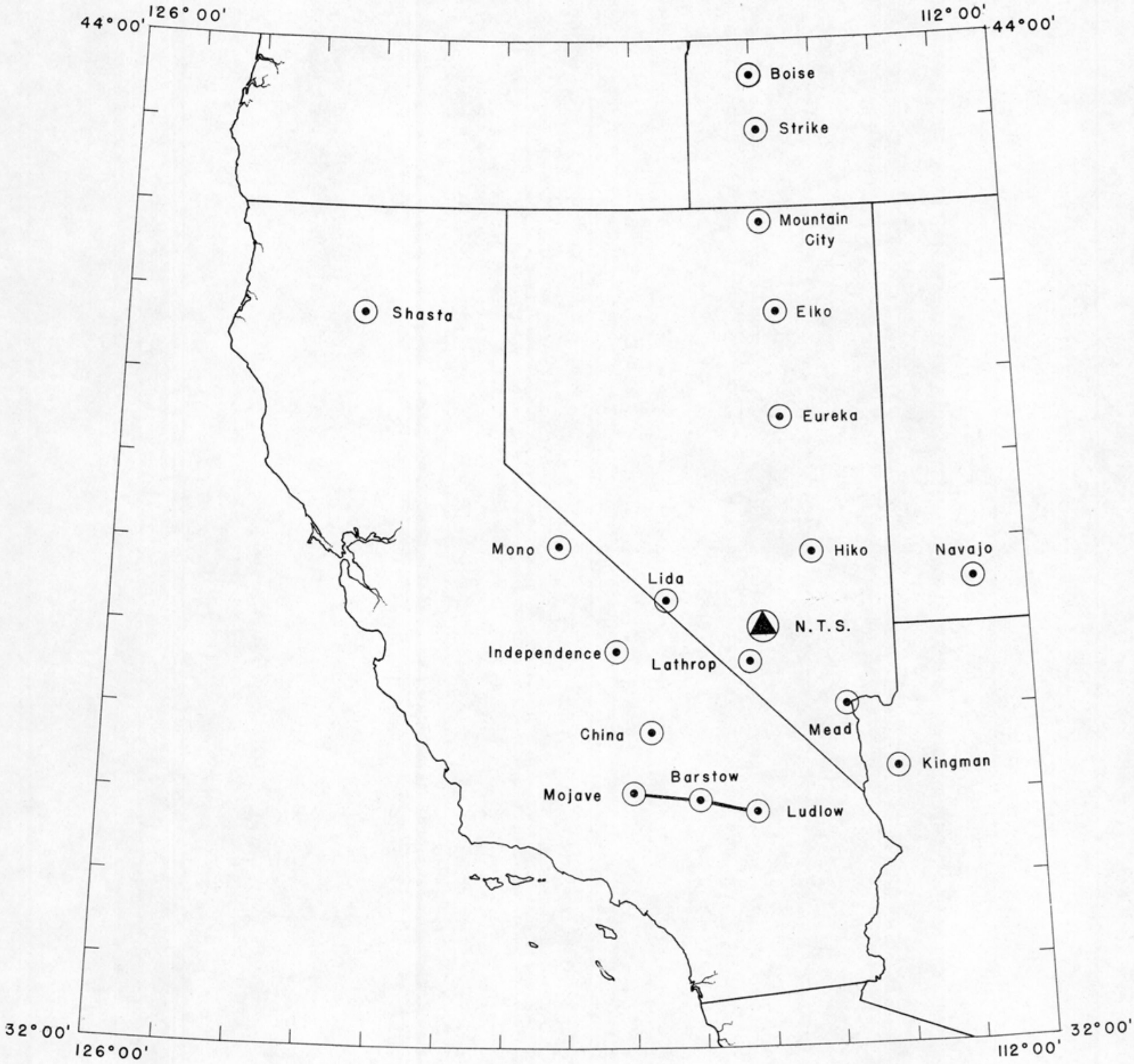


Figure 7, Time—Distance Profile, Mono—China records were recorded in noisy areas. Therefore, it is quite possible that P_n arrivals on these records are present, but are very weak and/or masked in high background noise.

Profiles between Mojave and Ludlow -- These profiles (Fig. 8) in the Mojave block are similar to profiles in the Basin and Range province. The P_g velocities average approximately 6.1 km/sec, and the P_n velocity, although not well defined to the west, appears to be approximately 7.9 km/sec. The high apparent P_n velocity of 8.25 km/sec from Ludlow to the west appears to be an updip velocity which indicates that the Moho under the Mojave Block is dipping downward to the east. The Ludlow shotpoint was very efficient; the efficiency of the intermediate shotpoint at Barstow was fair: and the Mojave shotpoint was poor. The P_n arrivals from Mojave are very weak.

Ludlow to Mojave -- A P_g line with an apparent velocity of 6.15 km/sec is well defined by twelve good recordings from Ludlow. All twelve recordings fall within ± 0.2 seconds of this line. Seven fair to good recordings define a P_n line with an apparent velocity of 8.25 km/sec. Five of these recordings fall within 0.1 seconds of the line.

Mojave to Ludlow -- Twelve poor-to-fair recordings define a P_g line with a velocity of 6.0 km/sec out to a distance of 137 km. Beyond 137 km the first arrivals are very weak, but they do show that a higher velocity is present. The 7.7 km/sec velocity is not



Shot-point locations and refraction profiles for Figure 8.

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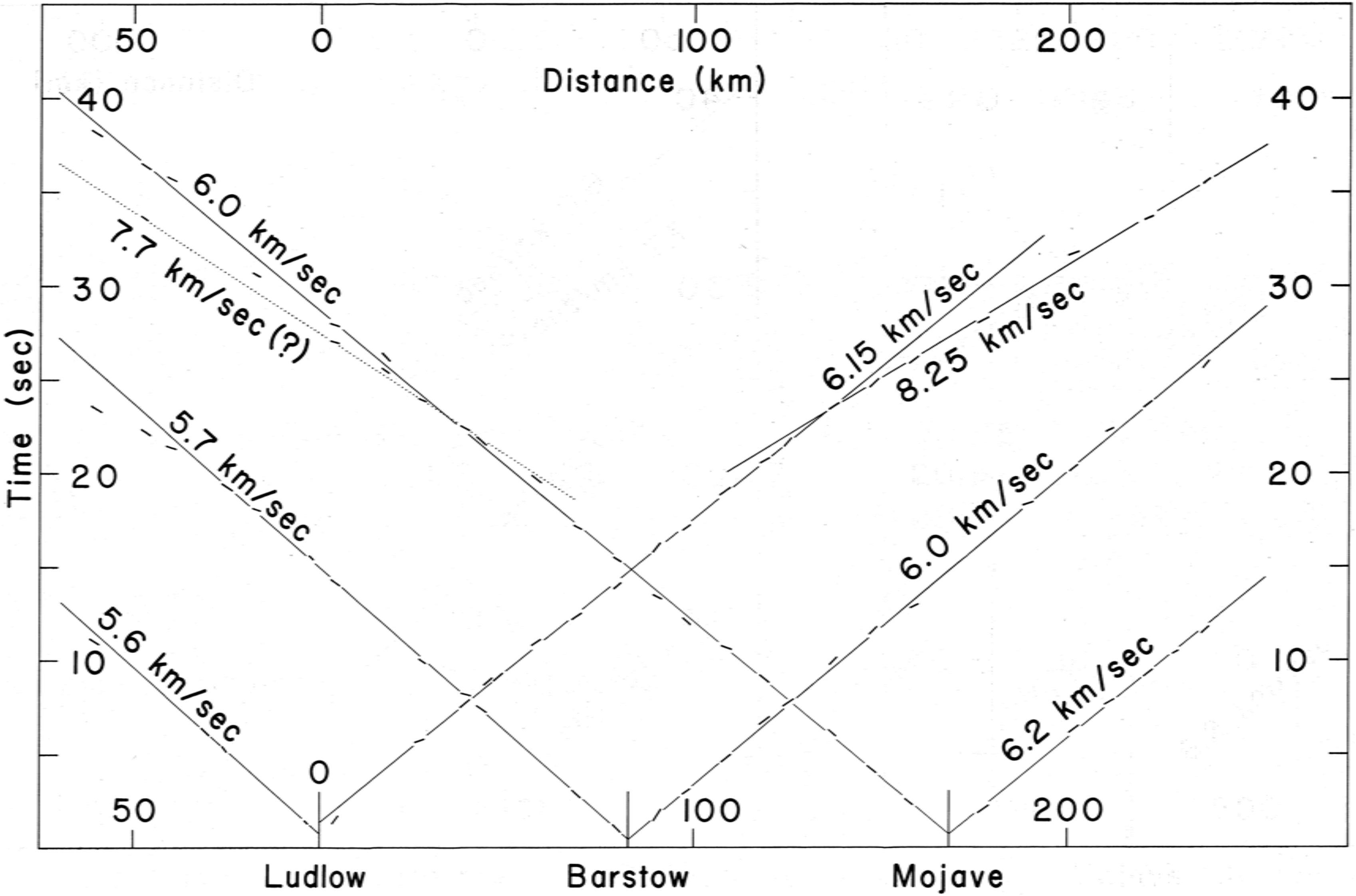


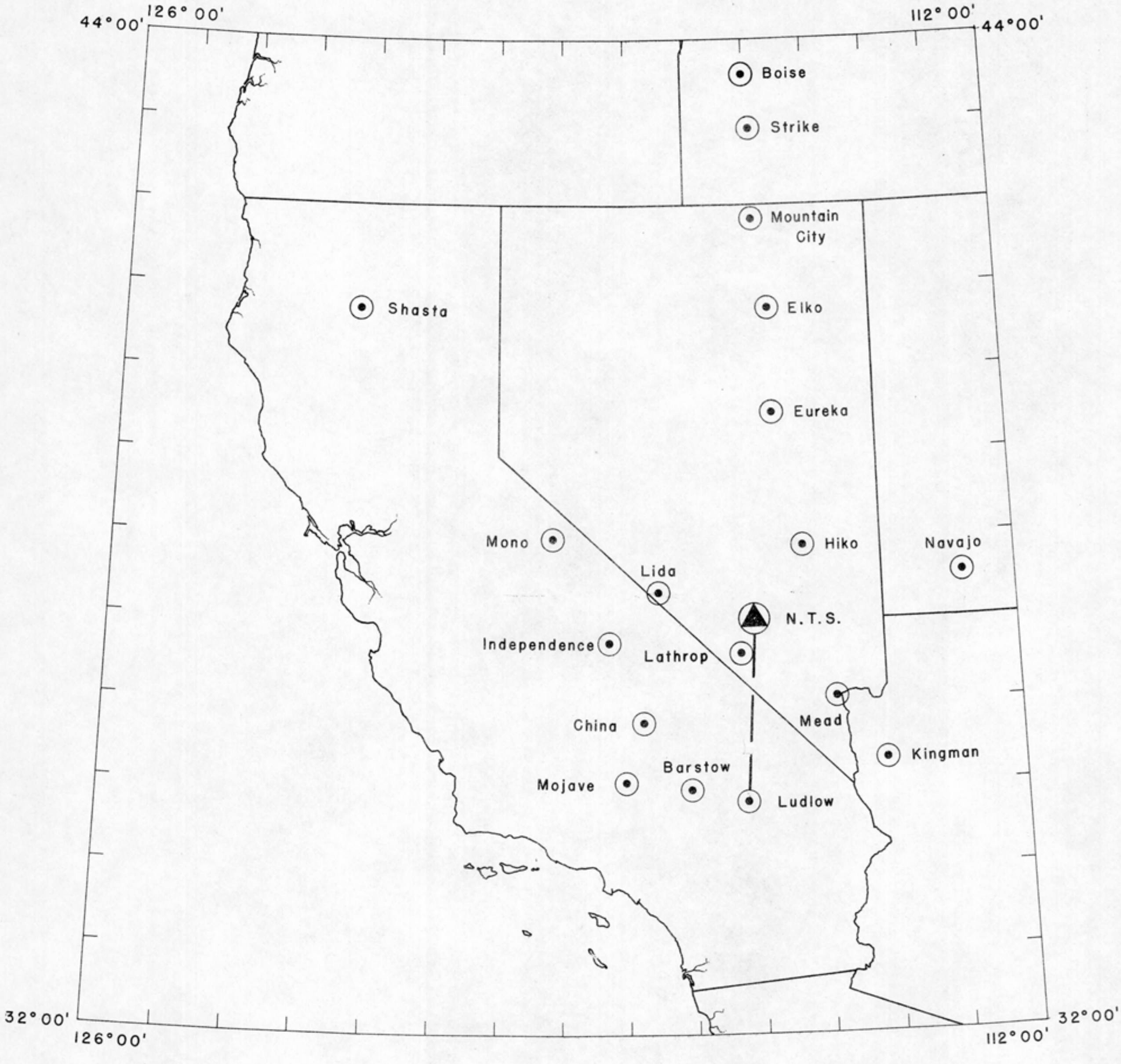
Figure 8, Time—Distance Profile, Ludlow—Mojave well established, and may be changed with a more critical look of the data using selective filtering on playbacks of the magnetic tapes.

Intermediate shotpoint at Barstow -- Twelve fair-to-good recordings show an apparent P_g velocity of 6.0 km/sec towards Mojave, and a fair-to-good recording shows a P_g velocity of 5.9 km/sec towards Ludlow. Three fair recordings beyond Ludlow show that arrivals of higher velocity appear as first breaks, but do not cover a sufficient distance to establish a reliable P_n velocity.

Profile from Ludlow toward the Nevada Test Site -- This profile, extending 215 km north, was recorded in only one direction (Fig. 9). It is being reversed by recording nuclear explosions from NTS.

The P_g velocity of 6.0 km/sec is well defined by thirteen recordings of good quality that show practically no scatter. Beyond 100 km the first arrivals can be fitted to an apparent velocity of 6.8 km/sec over a distance of 50 km. Beyond this, a 7.8 km/sec line fits the data very well. Whether the 6.8 km/sec line is related to an intermediate crustal layer or surface effects will be determined when the reversed section of this profile is completed.

Profiles between Mono Lake and Lake Mead -- This profile (Fig. 10) extends from Mono Lake, California, 438 kilometers southeast to Lake Mead, Nevada, with intermediate shotpoints at Lida Junction and Lathrop Wells, Nevada. Both Mono Lake and Lake Mead are classified as good shotpoints; Lathrop Wells is classified as poor; and Lida Junction as very poor. The profiles from Mono Lake and Lake Mead show typical



Location of shotpoints and refraction profiles for Figure 9.

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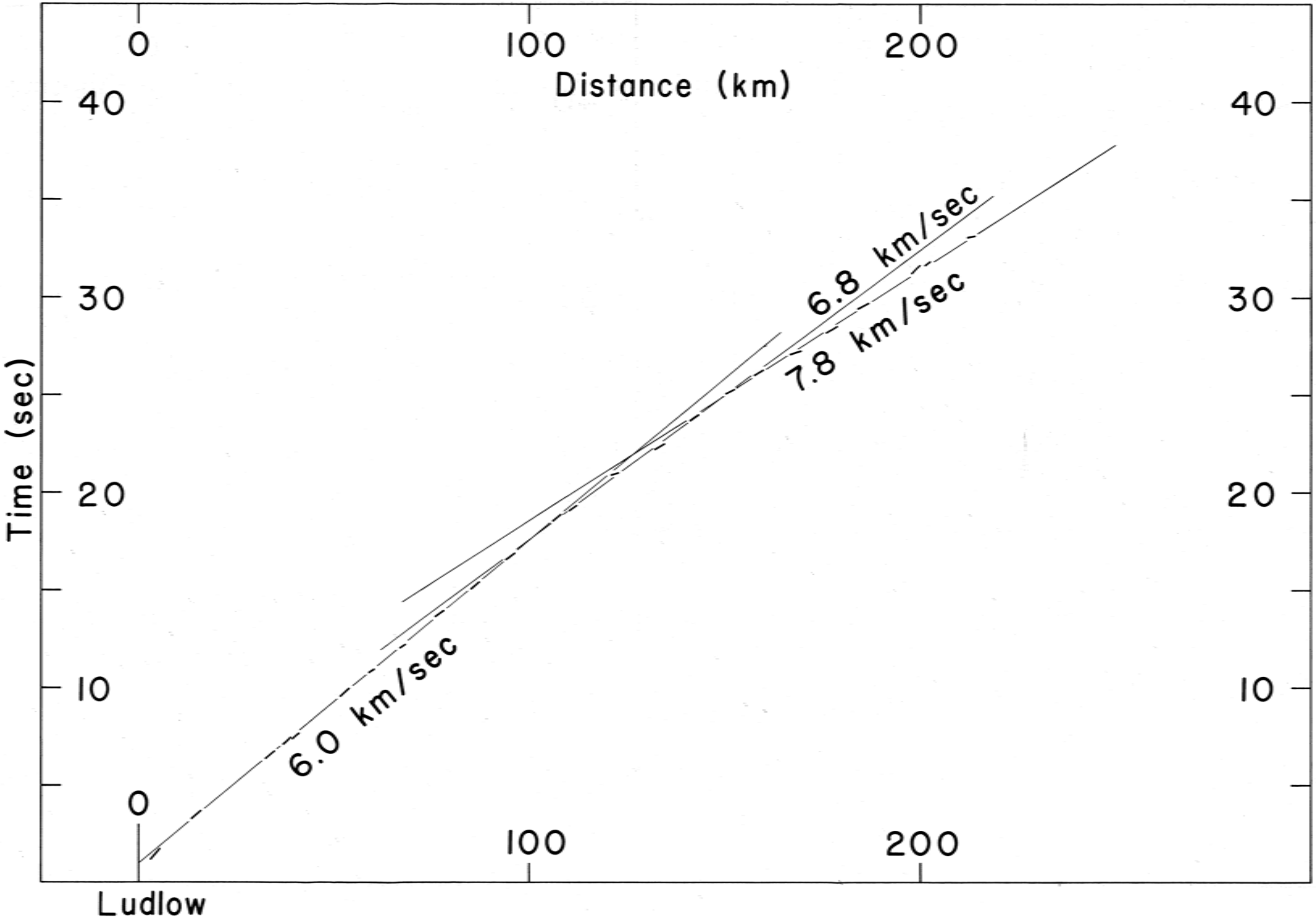
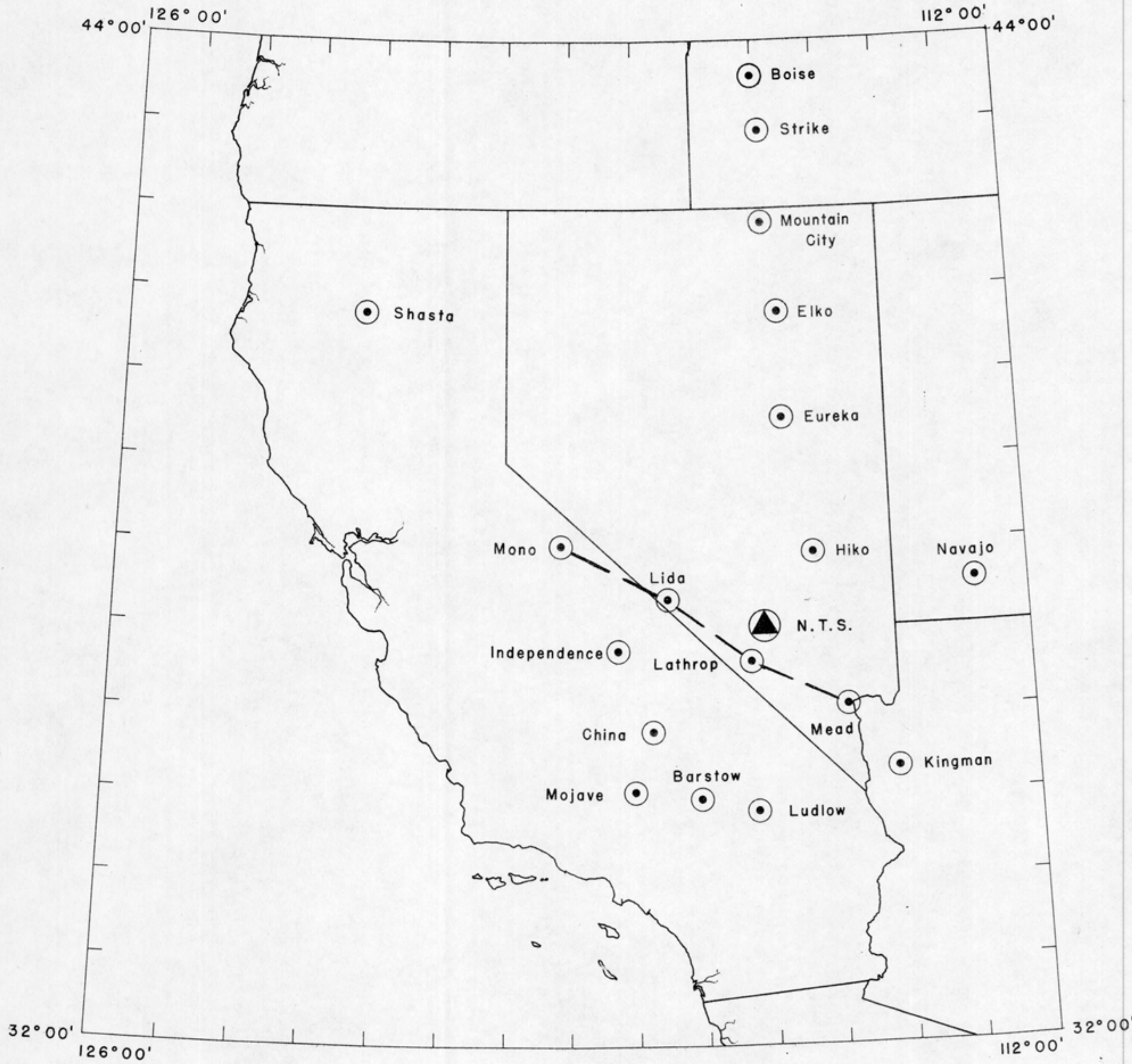


Figure 9, Time—Distance Profile, Ludlow—N.T.S



Location of shotpoints and refraction profile for Figure 10.

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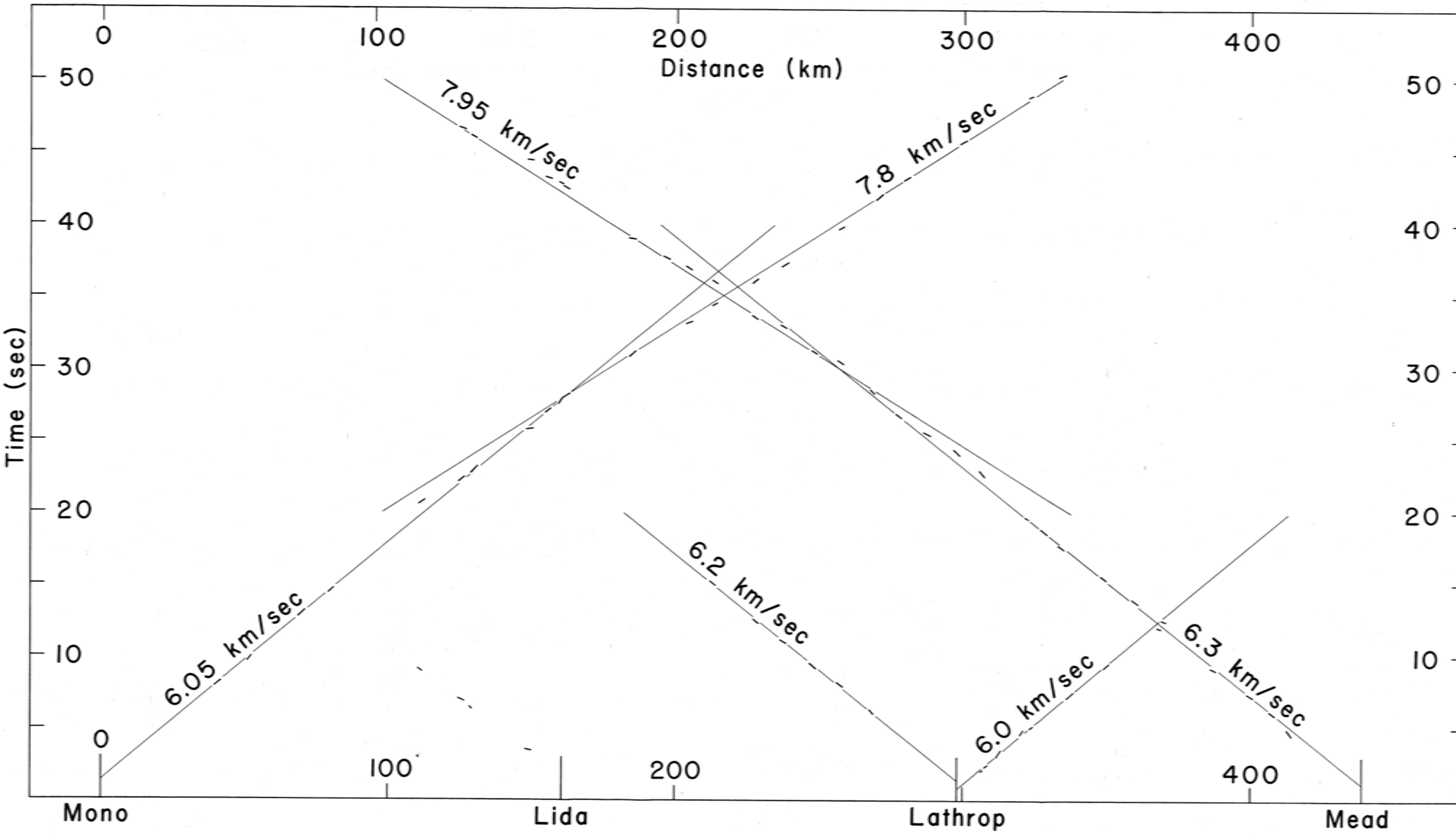


Figure 10, Time-Distance Profile, Mono-Mead

Basin and Range time-distance curves. The recordings from both shotpoints can be fitted with two lines, a P_g velocity slightly over 6 km/sec and a P_n velocity of 7.8 to 7.9 km/sec.

The information gained from the intermediate shotpoints is very limited due to poor shot-point efficiency.

Mono Lake to Lake Mead -- An apparent P_g velocity of 6.05 km/sec is well defined by ten fair-to-good recordings for a distance of 160 km. The scatter shown by these recordings is small; all but one fall within 0.1 second of the line. Beyond 160 km, an apparent P_n velocity of 7.8 km is defined by 12 recordings. Although some scatter is present, 7 of the 12 recordings fall with 0.2 sec of the line and all recordings are within 0.4 second.

Lake Mead to Mono Lake -- A P_g line with an apparent velocity of 6.3 km/sec is defined by 15 recordings for a distance of 180 km. Several of the first arrivals plot later than the line, but these are all from weak and noisy records where the true first arrivals are probably obscured by noise. Beyond 180 km a P_n line with an apparent velocity of 7.95 km/sec is defined by six of twelve arrivals that fall within 0.1 seconds of the line. Most of the delayed arrivals are thought to be secondary, and not true first arrivals.

Intermediate shotpoints -- Most of the recordings from Lida Junction and many from Lathrop Wells were very poor, and the first arrivals could not be determined.

From Lathrop a P_g velocity of 6.0 km/sec is shown towards Lake Mead, and a P_g velocity of 6.2 km/sec towards Mono Lake.

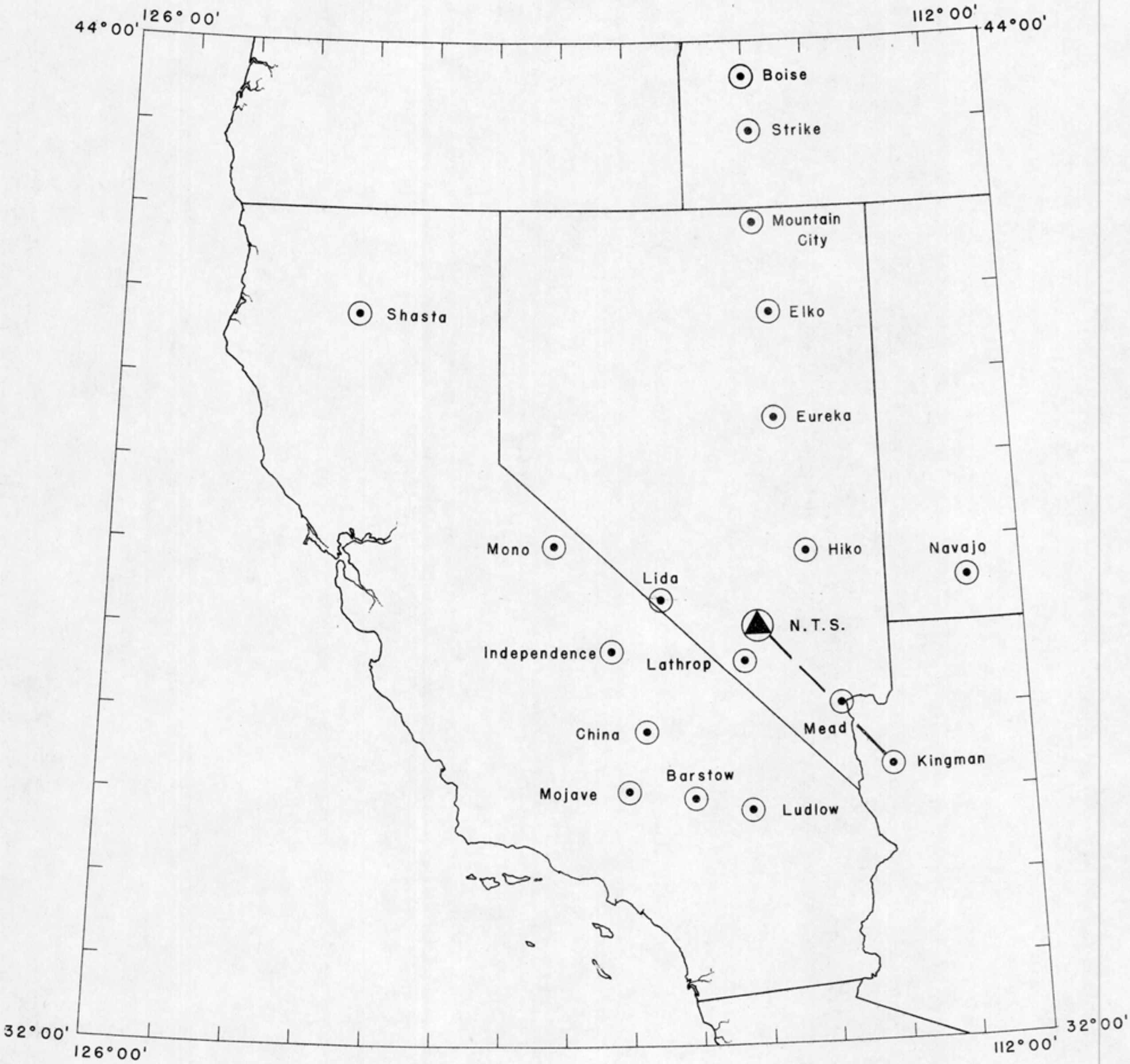
First arrivals could be determined on only four recordings from Lida Junction, and no attempt has been made to assign a velocity to these data.

Profile from Kingman to NTS -- This profile (Fig. 11) extending northwest from Kingman, Arizona, was made to reverse a profile that was made by the Geological Survey in 1958. (Diment, Stewart, and Roller, 1961). The Kingman shotpoint is classified as good; however, several of the long-range records were very poor as they were recorded on the Nevada Test Site and the arrivals were obscured by man-made noise.

A P_g velocity of 6.0 km/sec is defined by twelve fair-to-good recordings that show very little scatter. Beyond the P_g-P_n crossover at 155 km, seven poor to fair recordings define a P_n line with an apparent velocity of 7.6 km/sec. This velocity is lower than the 7.81 km/sec P_n velocity reported by Diment, Stewart, and Roller (1961) in their previous survey from NTS to Kingman.

Two first arrivals near the crossover fall below the P_g and P_n lines and could represent arrivals from an intermediate crustal layer.

Profile from Navajo Lake to NTS -- This profile (Fig. 12) was an attempt to reverse a profile, extending eastward from the Nevada Test Site through Utah and into Colorado, that was made by the Geological Survey from nuclear explosions. Unfortunately, the efficiency of the Navajo Lake shotpoint was very poor, and no P_n arrivals were recorded. The P_g velocity is well defined as 6.1 km/sec



Location of shotpoints and refraction profiles for Figure 11.

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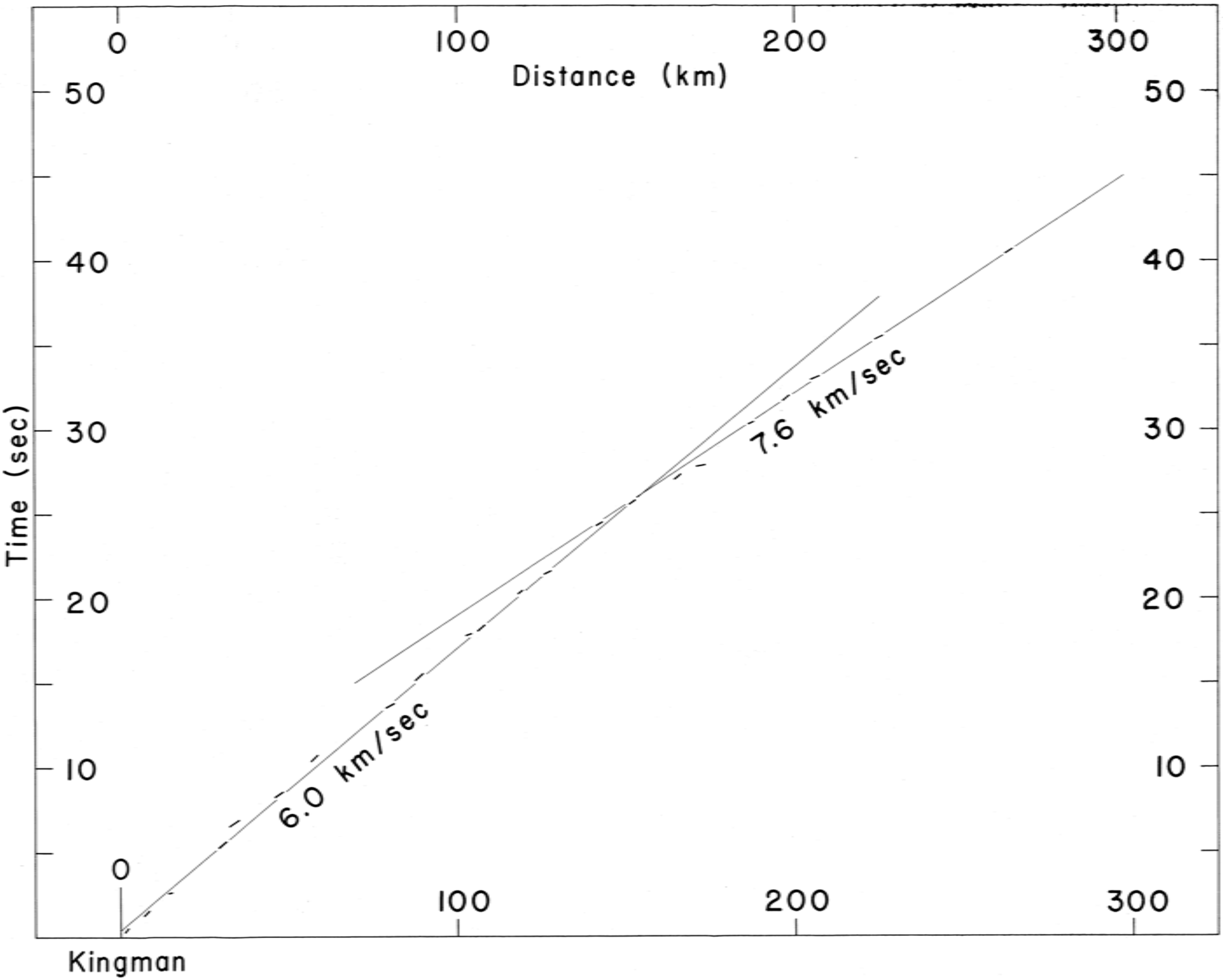
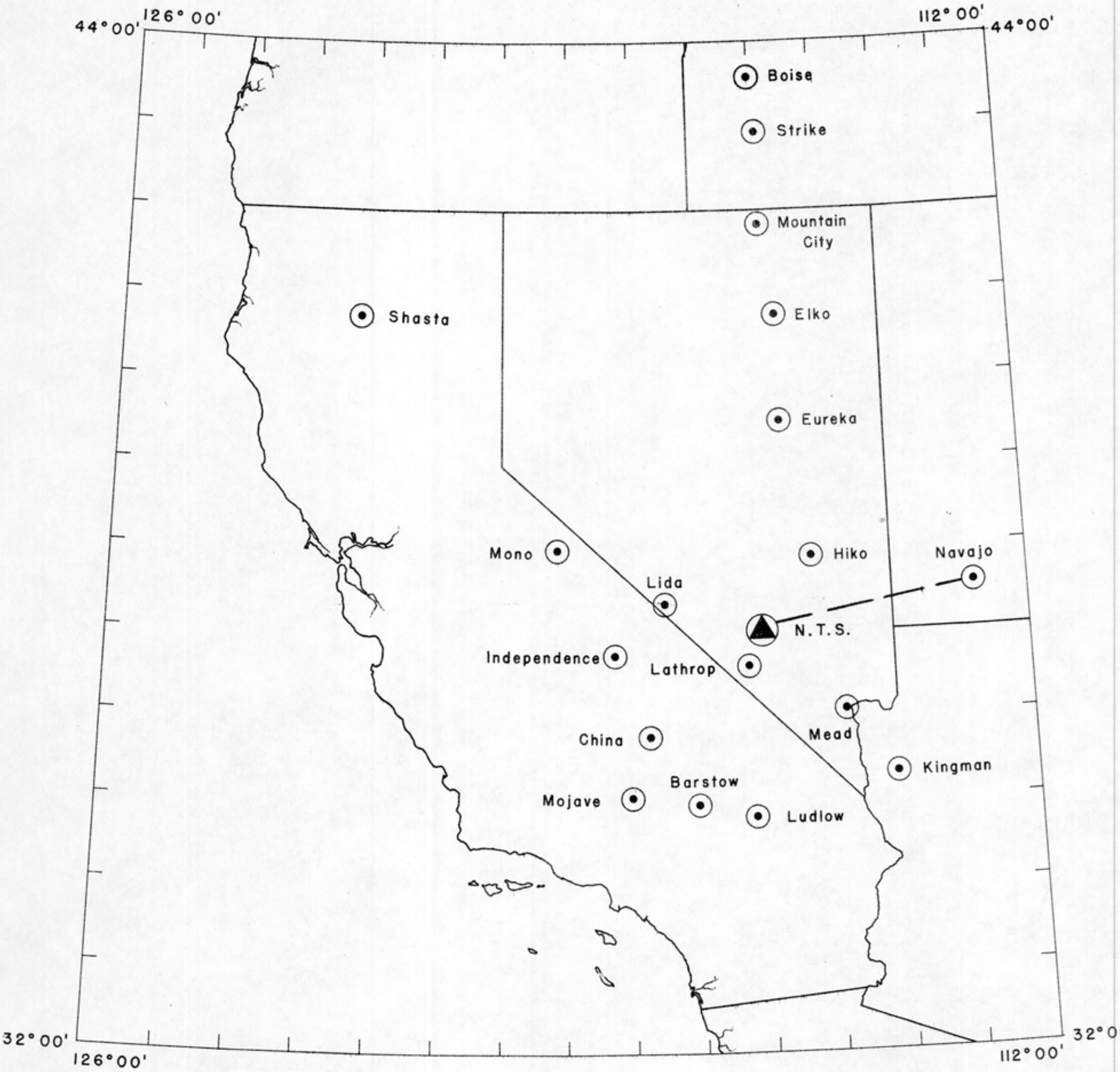


Figure 11, Time—Distance Profile, Kingman—N.T.S.



Location of shotpoints and refraction profiles for Figure 12.

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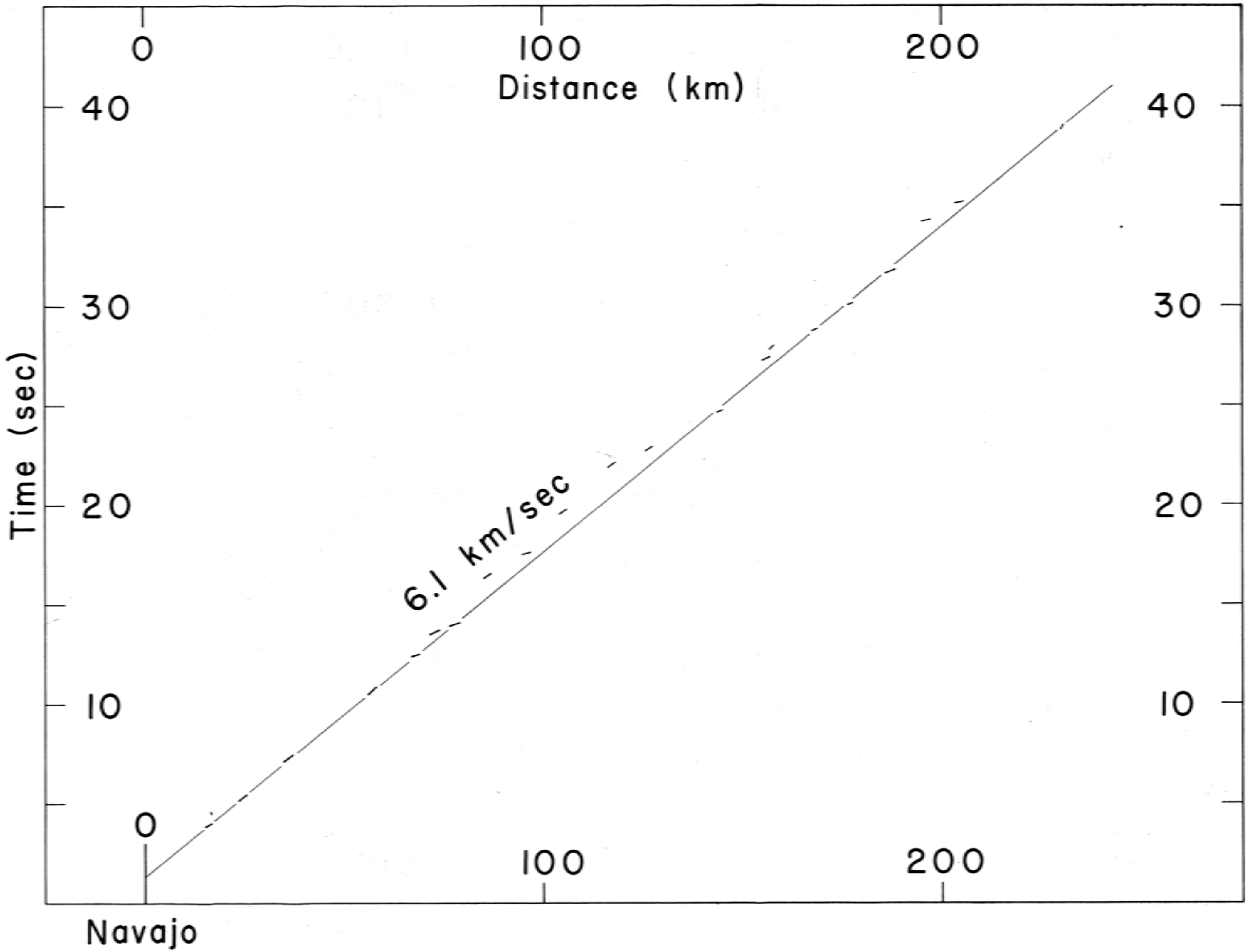

Figure 12, Time—Distance Profile, Navajo—N.T.S.

near the shotpoint. Beyond 75 km, most of the recordings were very poor. The late arrivals shown on the time-distance curve are undoubtedly secondary arrivals. No arrivals can be seen that precede the P_g line.

STATISTICAL PRESENTATION OF DATA

Table 4 summarizes the first arrival times recorded during the 1962 field season at 50-km intervals. The average time is shown with the mean deviation, range of times, and maximum deviation at each distance. The mean deviation increases from 0.28 sec at 50 km to 1.29 sec at 250 km. The maximum deviation increases from 0.6 at 50 km to 2.6 at 250 km. The deviations out to approximately 160 km are mainly caused by the variations in the thickness and velocity of the near-surface material. The large deviations, especially the 2.6-second maximum deviation at 250 km, is caused by the fact that part of the first arrivals at this distance are P_g or intermediate arrivals and part are P_n arrivals.

Table 5 presents the time-distance curves in terms of intercept times and apparent velocities. P_g was recorded on 29 profiles. The value of the apparent P_g velocity ranges from 5.0 km/sec to 6.5 km/sec; however, by disregarding only three profiles (Boise to Mountain City, Mountain City to Boise, and Shasta Lake to Mono Lake) this range can be reduced to 5.6 to 6.3 km/sec. The average value of P_g on all 29 profiles is 5.96 km/sec. The apparent P_g velocities are shown on the map in Figure 13. The P_g velocities in northeastern

Table 4 -- Statistical summary of first arrival data

Profile	Distance in Km							
	50	100	150	200	250	300	350	400
	Time in Seconds							
Ludlow to NTS	9.3	17.6	25.0	31.4				
Navajo to NTS	9.5	17.6	25.8	34.0	42.2			
Mead to Eureka	8.7	16.8	24.9	32.3	38.6	45.0		
Eureka to Mead	8.7	16.8	24.9	32.4	39.2	45.5	50.7	
Hiko to Eureka	9.6							
Hiko to Mead	9.2	18.1	27.0					
Ludlow to Mojave	9.4	17.5	25.1	31.2	37.2			
Mojave to Ludlow	9.0	17.3	25.6	33.9	42.3			
Barstow to Mojave	8.8	17.2	25.5					
Barstow to Ludlow	9.2	18.0	26.9					
Mono to Mead	9.6	17.9	26.2	33.0	39.4	45.8	52.2	
Mead to Mono	9.1	17.0	24.9	32.3	38.6	44.8	51.1	
Lathrop to Mono	9.4	17.4						
Lathrop to Mead	9.1	17.5						
Mono to Shasta	9.7	17.8	25.8	33.7	40.4	46.8	53.3	
Shasta to Mono	8.7	16.4	24.1	31.7	39.4	46.1	52.4	58.8

Table 4 -- Statistical summary of first arrival data (continued)

Profile	Distance in Km							
	50	100	150	200	250	300	350	400
	Time in Seconds							
Mtn City to Boise	9.5	17.3	24.7	32.2				
Boise to Mtn City	9.5	17.0	24.5	32.0	38.8			
Mtn City to Strike	9.5	17.3	24.7					
Strike to Mtn City	9.5	17.6	25.7	33.0	40.7			
Boise to Strike	9.5							
Strike to Boise	10.0							
Eureka to Mtn City	8.9	17.5	25.4	31.7	38.1			
Mtn City to Eureka	9.0	17.9	25.9	32.3	38.6			
Elko to Eureka	9.2	17.5						
Elko to Mtn City	9.2	17.6	25.3	32.6	39.9	47.2		
Kingman to NTS	8.7	17.1	25.4	32.2	38.7	45.3		
Mono to China	9.7	17.8	26.0	34.2	42.3			
China to Mono	9.3	17.6	25.8	34.0	42.3			
Independence to Mono	9.1	17.4	25.6					
Independence to China	9.1	18.0						
Average	9.3	17.5	25.5	32.7	39.8	45.8	51.9	

Table 4 -- Statistical summary of first arrival data (continued)

Profile	Distance in Km							
	50	100	150	200	250	300	350	400
	Time in Seconds							
Mean Deviation	.28	.45	.47	.81	1.29	.55	.84	
Total Range	8.7-10.0	16.4-18.1	24.1-27.0	31.2-34.2	37.2-42.3	44.8-47.2	50.7-53.3	
Maximum Deviation	.60	.9	1.5	1.5	2.6	1.4	1.4	

Table 5 -- Time-distance data in terms of intercept times

Profile	P_g sec	Intermediate	P_n sec
Eureka to Mountain City	$0.3 + \Delta/5.9$		$5.5 + \Delta/7.9$
Mountain City to Eureka	$0.2 + \Delta/5.9$		$6.9 + \Delta/7.9$
Elko to Mountain City	$0.8 + \Delta/5.9$	$3.5 + \Delta/6.85$	No velocity higher than 6.85 recorded as first breaks.
Mono to Shasta	$1.7 + \Delta/6.25$		$8.3 + \Delta/7.8$
Shasta to Mono	$1.0 + \Delta/6.5$		$8.0 + \Delta/7.9$
Kingman to NTS	$0.4 + \Delta/6.0$		$5.9 + \Delta/7.6$
Mono to Mead	$1.3 + \Delta/6.05$		$7.4 + \Delta/7.8$
Mead to Mono	$1.2 + \Delta/6.3$		$7.4 + \Delta/7.95$
Ludlow to NTS	$1.0 + \Delta/6.3$		$5.7 + \Delta/7.8$
Ludlow to Mojave	$1.4 + \Delta/6.15$		$6.9 + \Delta/8.25$
Mojave to Ludlow	$0.7 + \Delta/6.0$		$5.6 + \Delta/7.7$
Barstow to Ludlow	$0.5 + \Delta/5.7$	Higher velocity recorded but not enough points to establish a velocity.	
Navajo to NTS	$1.3 + \Delta/6.1$	No higher velocity determined due to weak arrivals.	
Mead to Eureka	$0.6 + \Delta/6.2$		$7.1 + \Delta/7.9$
Eureka to Mead	$0.7 + \Delta/6.2$	$4.7 + \Delta/7.2$ (Determined from only 3 points)	$7.7 + \Delta/7.9$
Mono to China	$1.5 + \Delta/6.1$	No higher velocity recorded.	
China to Mono	$1.1 + \Delta/6.1$	Do.	
Mountain City to Boise	$0.1 + \Delta/5.4$	$2.6 + \Delta/6.8$	
Boise to Mountain City	$0.0 + \Delta/5.0$	$2.1 + \Delta/6.7$	

Table 5 -- Time-distance data in terms of intercept times (continued)

Profile	P_g sec	Intermediate	P_n sec
(The following profiles are from intermediate shotpoints and the profiles were not intended to be long enough to record arrivals other than P_g)			
Elko to Eureka	$0.9 + \Delta/6.0$		
Lathrop to Mead	$0.8 + \Delta/6.0$		
Lathrop to Mono	$1.4 + \Delta/6.2$		
Lida to Mono	Not sufficient number of points to verify velocity		
Barstow to Mojave	$0.5 + \Delta/6.0$		
Hiko to Mead	$0.3 + \Delta/5.6$		
Hiko to Eureka	$0.6 + \Delta/5.6$		
Independence to Mono	$0.8 + \Delta/6.0$		
Independence to China	$0.6 + \Delta/5.9$		
Strike to Mountain City	$1.6 + \Delta/5.9$		
Strike to Boise	$1.3 + \Delta/5.6$		

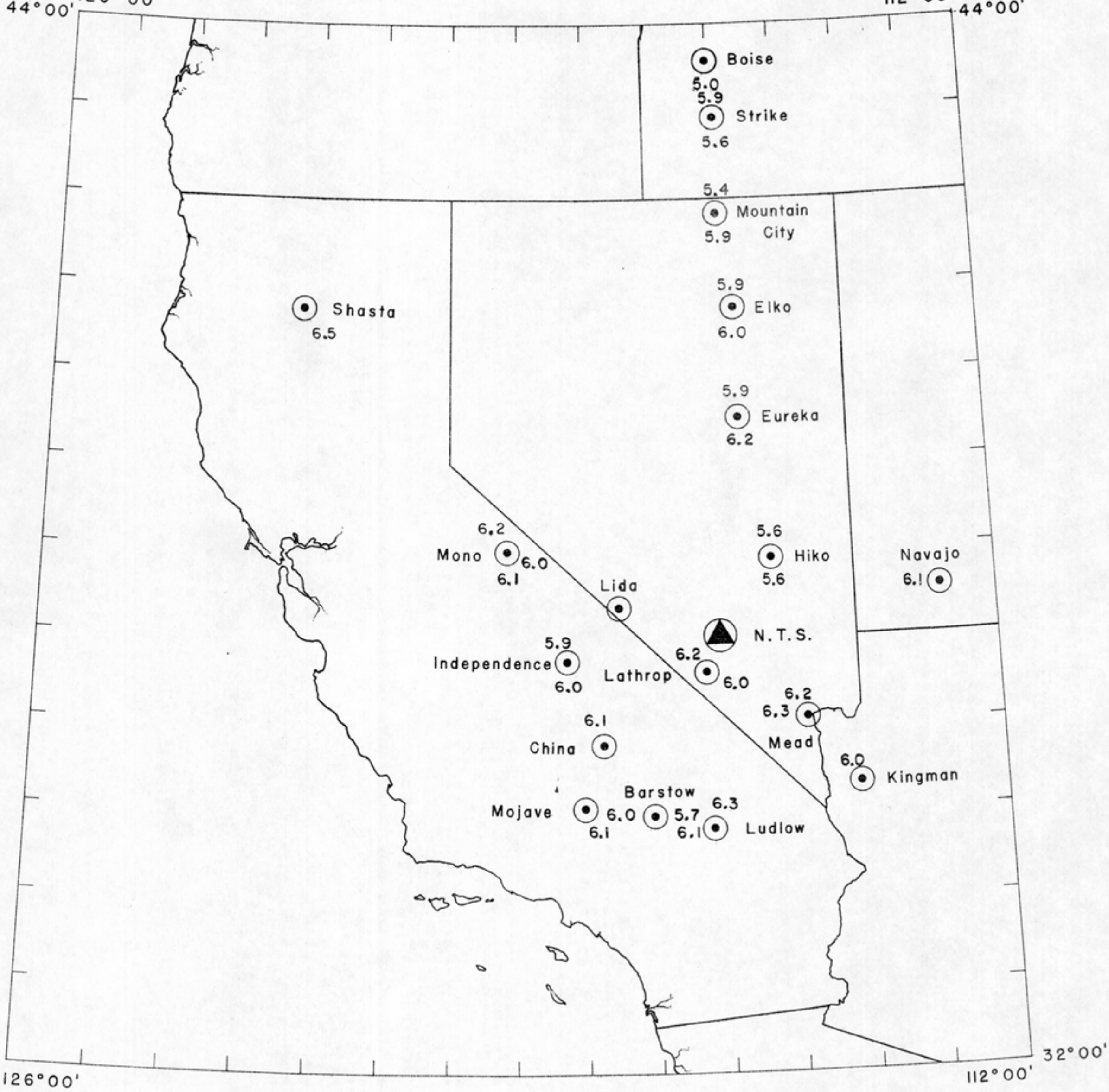

Figure 13 -- P_g velocities recorded during the 1962 field season.

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Nevada and interior Idaho from the Hiko shotpoint north to Boise average 5.6 km/sec, and the P_g velocities for the rest of Nevada and California area average 6.1.

P_n was recorded on twelve profiles. The value of P_n apparent velocity ranges from 7.6 to 8.25. The 8.25 apparent velocity is from Ludlow to Mojave; although it is not well defined, the apparent velocity from Mojave to Ludlow is approximately 7.7 km/sec, which would give a true velocity of about 7.95 km/sec. Therefore, disregarding this high velocity, the range in P_n velocities is 7.6 km/sec to 7.95 km/sec. The average P_n velocity for all twelve profiles is 7.87 km/sec.

By using only the profiles that have been reversed, and computing the true P_n velocity, the values range only from 7.85 to 7.95 km/sec and average 7.90 km/sec. The variation in the velocity of P_n in this area is smaller than the variation in the velocity of P_g.

MAJOR ACCOMPLISHMENTS

Below are the major objectives that were satisfied by the 1962 field season.

1. Seismograms were recorded along 10 profiles in the western part of the United States.
2. Enough data has now been obtained to make a very good start on a crustal and mantle velocity map of a large area.
3. It has been demonstrated that variations in arrival times of seismic energy over a large area are sufficiently large

to require detailed knowledge of crustal structure for a seismic-detection system based on location of seismic events.

4. It has demonstrated that the configuration of the crust and the arrival times of seismic energy can vary by a large amount over a relatively short distance. Two examples of this are the difference between the Basin and Range province and the Snake River Plain, and also the difference in the Basin and Range province and the Sierra Nevada.
5. From the data collected on the Mono Lake-Shasta Lake line, the depth of the root of the Sierra Nevada can now be computed.
6. Many refinements in crustal studies field procedures and data-processing methods have been made.

LITERATURE CITED

Healy, J. H., Cooper, J. F., Eaton, J. P., Forbes, C. B., Frankovitch C. J., Pakiser, L. C., Roller, J. C., and Stewart, S. W., Crustal Structure in Western United States, Part IV, Study of Seismic Propagation Paths and Regional Traveltimes in the California-Nevada Region: U. S. Geological Survey Annual Report to ARPA.

Diment, W. H., Stewart, S. W., and Roller, J. C., Crustal Structure from NTS to Kingman: Journal of Geophys. Res., Vol. 66, No. 1, January 1961.

APPENDIX A -- DRILLING

General -- The shot-hole drilling was initiated by three two-man teams (driller and helper), using truck-mounted Mayhew 1000 rotary drills. Each drill was accompanied by a water truck with a 1000-gallon capacity, and a 1/2-ton pickup truck for transportation of personnel and supplies.

Thirteen shot-point locations required drill holes:

(1) Lida, near Lida Junction, Nevada

(2) Lathrop, near Lathrop Wells, Nevada

(3) Kingman, near Kingman, Arizona

(4) Navajo Lake, near Cedar City, Utah

(5) Hiko, near Hiko, Nevada

(6) Eureka, in Newark Valley near Eureka, Nevada

(7) Elko, near Elko, Nevada

(8) Mountain City, near Mountain City, Nevada

(9) China Lake, on the Naval Ordnance Test Station, China Lake, California

(10) Independence, near Independence, California

(11) Mojave, near Mojave, California

(12) Barstow, near Barstow, California

(13) Ludlow, near Ludlow, California

Drilling Conditions -- The majority of the drill-holes were difficult to drill. In the early stages of the drilling program, the difficulties encountered at the Lida Junction and Lathrop Wells shotpoints made obvious the inadequacies of the Mayhew 1000 drill. Arrangements were made to replace two of the drills with larger, heavier drill units. Under normal shot-hole drilling conditions, the depth of hole and hole diameter required, pose no problem for the Mayhew 1000 drill. However, the requirements of 6-1/2-inch and 11-inch hole diameters, in most instances drilled into extremely hard and/or bouldery formations, pointed out the following inadequacies of the drill:

(1) Insufficient pump pressure to remove cuttings adequately at depth of 100 feet or more.

(2) Insufficient pull-down for an adequate rate of production.

(3) A general weakness of draw-works.

(4) A lack of air compressors for combination air-water drilling.

One Mayhew 1000 drill unit was retained for the drilling of the intermediate shotpoints, which required approximately one-half the number of holes usually needed for shotpoints at the terminal ends of the measured lines. The performance of this unit proved to be completely satisfactory in drilling the 6-1/2-inch diameter holes.

Drilling conditions for the particularly difficult shotpoints were as follows:

(1) Kingman -- Extremely hard, metamorphosed granitic rocks were encountered at 60 feet below the overlying, unconsolidated, bouldery, clastic material. The initial drilling with a Mayhew 1000 was slow, often done at a rate of no more than 6 inches per hour, and

the drill-bit consumption was prohibitive. On one occasion the drill stem "twisted off," resulting in the loss of two lengths of drill collar, drill bit, sub-joint, and 105 feet of drill stem, none of which was recovered.

(2) Lida Junction and Lathrop Wells -- Drilling 6-1/2-inch holes through 100 to 200 feet of unconsolidated, bouldery (volcanic), clastic material was especially difficult. Not only was the rate of production decreased because of the hardness of the boulders, but also the string of drill stem often became stuck in the hole because of the loose material falling in behind the bit and drill collars. On one occasion, attempts to loosen the drill stem resulted in breakdown of the drill draw-works, but no equipment was lost in the hole.

(3) Navajo Lake -- The rate of drilling 11-inch holes through limestone was adequate, although on several occasions "loss of circulation" in solution cavities necessitated moving onto a new drill site. Some loss in hole depth, after drilling, was caused by the caving of the loose to moderately-indurated sands underlying the limestone.

(4) Mountain City -- The granitic mass east of Mountain City, Nevada, proved to be a difficult drilling medium. Because of the urgency in obtaining drill holes and the probability of easier drilling conditions, the shot-point location was moved to the south, into a water-saturated fault zone. Drilling 11-inch holes in the wet fault gouge was relatively easy. The rate of production ranged from 100 to 200 feet an hour.

(5) Independence -- Drilling 6-1/2-inch holes, 240 feet deep, in the bouldery talus formation on the east flank of the Sierra Nevada mountains proved to be extremely difficult for the Mayhew 1000 drill. On one occasion, as the hole was being "washed out" prior to charge-loading, the hole collapsed above the drill collars. Ineffectual attempts were made to recover the string of drill stem by "shooting off" the drill bit by means of small charges lowered into the hollow drill stem. Drill bit, sub-joint, drill collars and 105 feet of drill stem were lost in the hole. One of the larger drill units was brought in to complete the drilling of the shot holes.

(6) Mojave and Barstow -- In both areas, hard crystalline formations were encountered at 35 feet below the surface. At the Mojave shotpoint the hard formation was a coarse-grained granite, overlain by 20 to 25 feet of decomposed granite. Air-drilling to 120 feet was accomplished by the larger, heavier drill unit with relative ease. At Barstow, the hard formation was a highly-metamorphosed granitic rock, encountered at 40 feet, overlain by unconsolidated clastic material composed mainly of variable-sized granite and volcanic boulders. The Mayhew 1000 drilled 6-1/2-inch holes satisfactorily, although slowly, with high-density and high-viscosity drilling fluid. A larger rig capable of drilling 11-inch holes was brought in to expedite necessary hole production.

The drilling media at the other five drill-hole shotpoints were largely unconsolidated sands and gravels with several intercalated clay stringers. At these locations there were no drilling difficulties other than that of maintaining "hole-wall cake" to prevent hole loss due to ravelling and caving.

Local water tables were encountered at the Eureka, Elko, and Ludlow shotpoints and the drill holes were bottomed in the water-saturated sands and gravels.

APPENDIX B -- SHOTPOINT REFRACTION PROFILES

Ninety-five short refraction spreads were recorded at eleven terminal shotpoints for the purpose of determining correction data for reducing observed long-range refraction times to a common datum.

The number of spreads recorded by the United Geophysical Company recording units for each shot-point location varied from a single spread at Kingman to fourteen spreads at Mono Lake, largely dependent on the number of shots required at each shotpoint to carry out the main project.

Profiles with sparse spread coverage were supplemented with the data, from regular recording units located near the respective shotpoint. Because traveltimes through the overburden near the shot-point locations were of primary importance, most of the spreads were laid out as close to the shot-point site as practicable. The remainder of the spreads were spaced about four, seven, and ten kilometers from the shotpoints to give an approximate indication of the basement contact.

The results are believed to be generally satisfactory and seem to fulfill the objectives of the survey. Large differences in formation velocities and total section thicknesses were found. The extreme values for near-surface velocity were observed at the Ludlow shotpoint (1,400 m/s or lower) and at the Boise shotpoint (3,700 m/s). The thinnest sedimentary cover was measured at the Mountain City shotpoint site (220 m) and the thickest at the Navajo shot-point location (2,910 m).

The first arrivals were reduced to datum for each trace by adding the difference in elevation between the shotpoint and datum plane and between geophone and datum plane and dividing the sum by the correctional velocity.

Table 6 lists, for each shotpoint, the velocities of the basement and overlying material, the mean sea level of the reference datum, the datum to basement thickness in both time and depth.

Table 6 -- Velocity data at the shotpoints

Shotpoint	V_o (m/s)	$V_{intermediate}$ (m/s)	$V_{basement}$ (m/s)	Reference Datum (meters MSL)	Tc Corrected Time-Datum to Basement	Depth to Basement (below datum) (meters)
Boise	3700	3700	5750	870	0.095	350
Mountain City	2850	2850	6000	1800	0.056	160
China	1500?	2350 3500	6000	600	0.614	1760
Eureka	1900	1900	6000	1740	0.308	585
Kingman	3500	3500	6100	1150	0.040	140
Ludlow	1400?	2700 3100	6000?	360	0.450	1180
Mead	2800	2800	6000	300	0.232	650
Mojave	3200	4200	6000	730	0.264	1060
Mono	2120	4000	6000	1940	0.560	1600
Navajo	3450	3450	5800?	2850	0.826	2800
Shasta	2000	2000	6000	1150	0.345	690