

TECHNICAL REPORT VU-66-1

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AIR FORCE TECHNICAL APPLICATIONS CENTER
HEADQUARTERS UNITED STATES AIR FORCE
WASHINGTON DC 20333

LONG RANGE SEISMIC DATA
FROM THE
LAKE SUPERIOR SEISMIC EXPERIMENT
1963-1964

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MAJOR GENERAL J. F. RODENHAUSER, CHIEF


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1963-1964

AFTAC/VELA SEISMOLOGICAL CENTER
TECHNICAL REPORT VU-66-1
PROJECT VELA-UNIFORM
31 MARCH 1966

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ABSTRACT

As part of a planned subcrustal experiment, three series of chemical explosions, ranging in size from 1/8 ton to 10 tons, were detonated on the bottom of Lake Superior during July 1963 and July and October 1964. Although these explosions were intended primarily for stations deployed at fairly close distances, many of them were detected at distances of approximately 500 to 2500 kilometers during routine daily recording operations at a number of mobile Long Range Seismic Measurements van stations, at five experimental seismic observatories, and at several scattered deep-well installations, all operated as part of a VELA-UNIFORM research program under the technical direction of the Air Force Technical Applications Center.

This report summarizes the types of data recorded, presents typical measurements, and discusses some of the resulting conclusions. Travel times of Pn and P, S, Lg, and some unidentified emergent phases were measured. Residuals of Pn and P with reference to a constant velocity of 8.1 kilometers per second are compared with results from the Nevada Test Site and from the GNOME event in New Mexico, confirming a regional difference between eastern and western Pn velocities. Time residuals are also considered in relation to crustal structure under Lake Superior. Amplitudes of Pn and P and S or Lg are shown, and the variation of amplitude with charge is measured for Pn and P and S or Lg for the limits available. Some of the energy considerations related to coupling and signal transmission are discussed, and examples of signals are shown.

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1. Introduction.

a. As of the present writing, three series of chemical explosions have been detonated on the bottom of Lake Superior in a joint research program referred to as the Lake Superior Seismic Experiment. This crustal-upper mantle research effort, carried out by a group of interested governmental and private organizations, is to be described in a volume now in the process of publication by the Carnegie Institution of Washington, and which is to include the material here reported. The present presentation, as an internal AFTAC/VSC technical report, includes only the long range data obtained from the van stations of the Long Range Seismic Measurements (LRSM) program and from five experimental observatories plus a few scattered deep-well installations, all operated as part of the VELA-UNIFORM program under the auspices of the Advanced Research Projects Agency of the Department of Defense, with technical direction by the Air Force Technical Applications Center (AFTAC).

b. The US Coast Guard, in association with the University of Wisconsin-Carnegie Institution of Washington supervisory group, detonated about eight 1-ton shots during July 1963. An additional series of about 40 shots was detonated during July 1964, monitored by the University of Wisconsin. This shot group, principally of 1-ton charges, included some weaker shots of 250, 500, and 1,000 pounds, and tested two types of chemical explosive being compared for efficiency. A third series of 10 shots was detonated in October 1964, under the supervision of the US Geological Survey, Crustal Studies Branch, as part of a

transcontinental measurements program. This shot group included two chemical charges each of 2,000, 4,000, 6,000, 12,000, and 20,000 pounds, one set of which was detonated at a common reference point in the western part of the lake, and the others at several adjacent points previously found to provide good signal strength at a distance.

c. A substantial portion of the shots of each series was recorded at various azimuths and up to distances of more than 2,500 km. The following report presents data on the principal phases recorded, their travel times, and amplitudes, and offers some comment on the travel paths, sub-Lake Superior structural implications, and some of the energy considerations involved.

2. Instrumentation.

a. Instrumentation at each of the LRSM mobile stations consists of 3-component short-period Benioff and 3-component Sprengnether long-period seismographs. Data are recorded on 35mm film and on 1-inch 14-channel magnetic tape. These stations are equipped to record WWV continuously in order to provide accurate time control. Calibration is accomplished at least once a day. Details of the instrumentation and operating procedures for these stations are given in "Routine Operating Instructions," obtainable from Geotech Division, Teledyne Industries, Inc., Dallas, Texas.

b. The five VELA observatories also have both long-period and short-period 3-component instrumentation in addition to their other specialized facilities. Each also maintains a continuously operating array, the

geometry and circuitry being somewhat variable between observatories and from one time period to another. In general, individual instrument traces, summations, and filtered summations are available for various seismometer groupings. Most of the array short-period vertical instruments are of the Johnson-Matheson type.

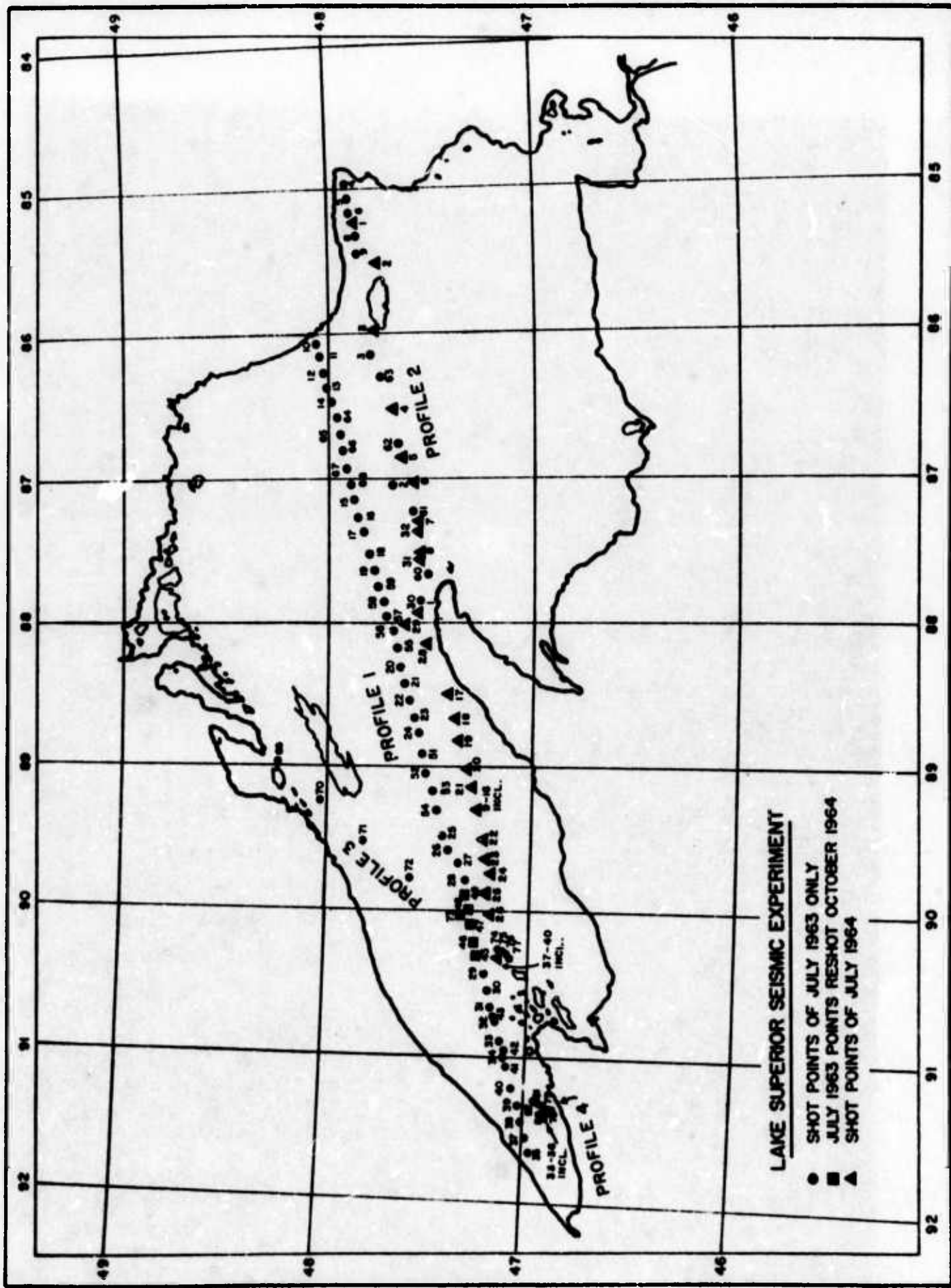
c. Several experimental deep-well short-period installations also received signals. In general, their system characteristics were similar to those of the surface Benioff instruments. Usually the well arrangement included a surface vertical instrument, and a shallow, and a deep vertical instrument, all with similar response characteristics.

d. All of the stations described are operated under the direction of AFTAC as part of the VELA-UNIFORM program, as noted in the introduction.

3. Data and Procedure.

a. Shot positions in Lake Superior are shown on the lake map of Figure 1, and the locations of the recording stations are shown on the United States map of Figure 2. Figure 3 is a chart showing the distribution of signals received from the first or principal shot series, as an example of the coverage obtainable using 1-ton shots at the average magnifications shown.

b. Analysis for this report was restricted to the film recordings, and, since no long-period signals were detected, the emphasis was on the short-period vertical instruments. The horizontal-instrument records were also used where S (or Lg) phase motion was detectable.



LAKE SUPERIOR SEISMIC EXPERIMENT

- SHOT POINTS OF JULY 1963 ONLY
- JULY 1963 POINTS RESHOT OCTOBER 1964
- ▲ SHOT POINTS OF JULY 1964

Figure 1
AFTAC/VSC

UNITED STATES

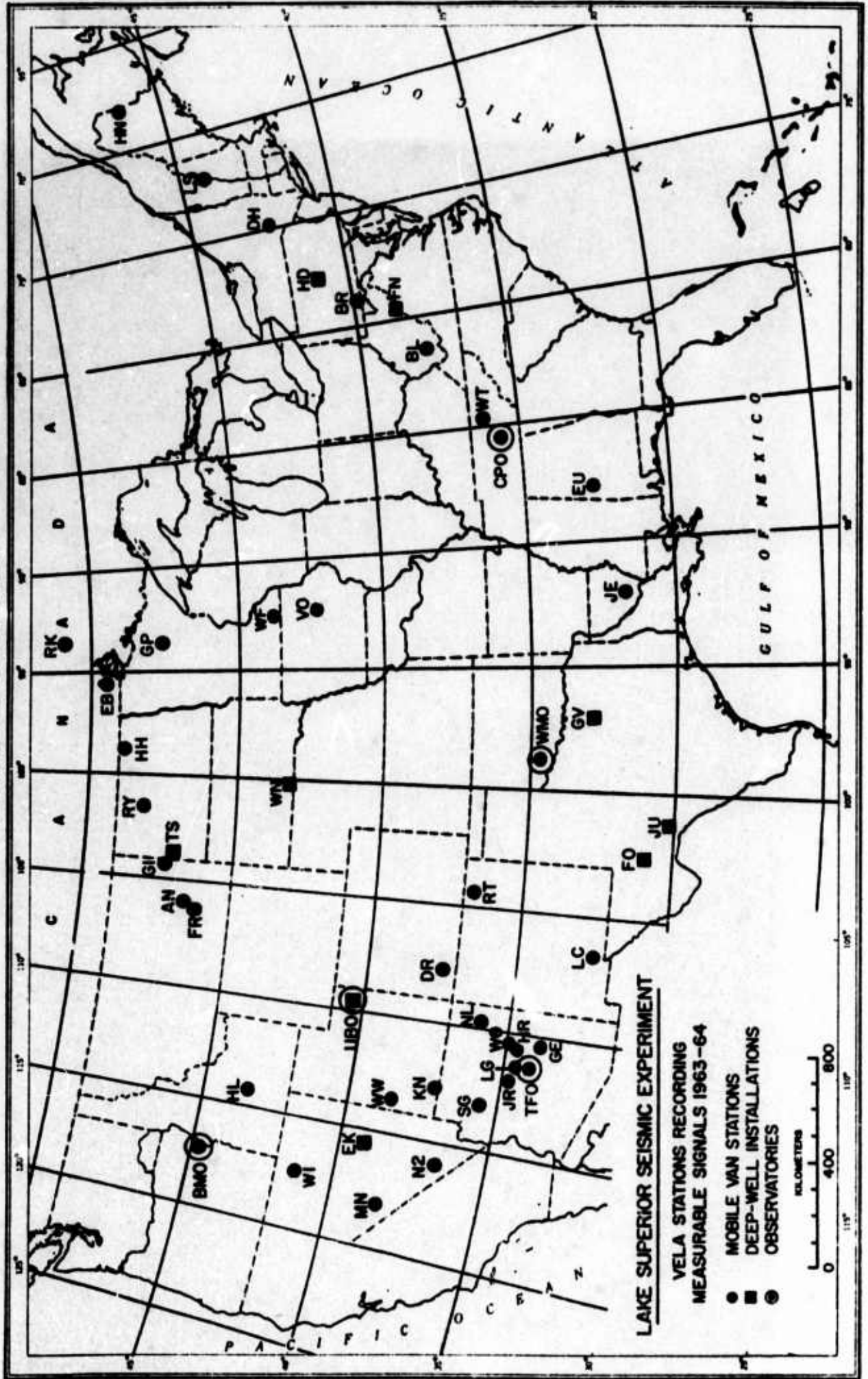
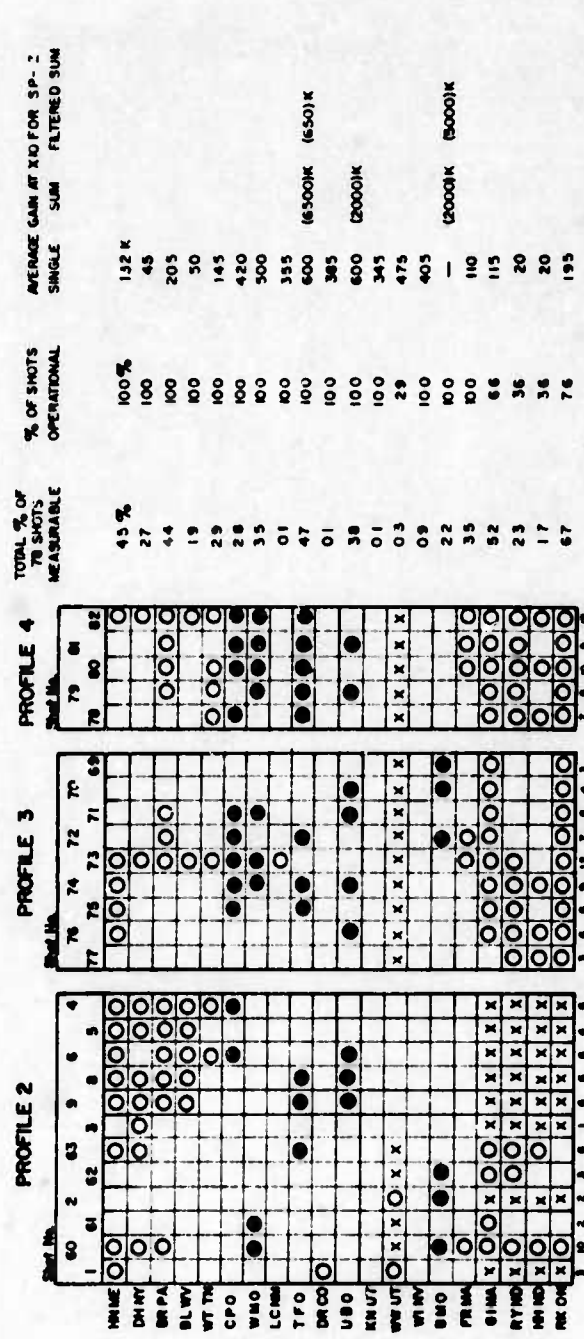
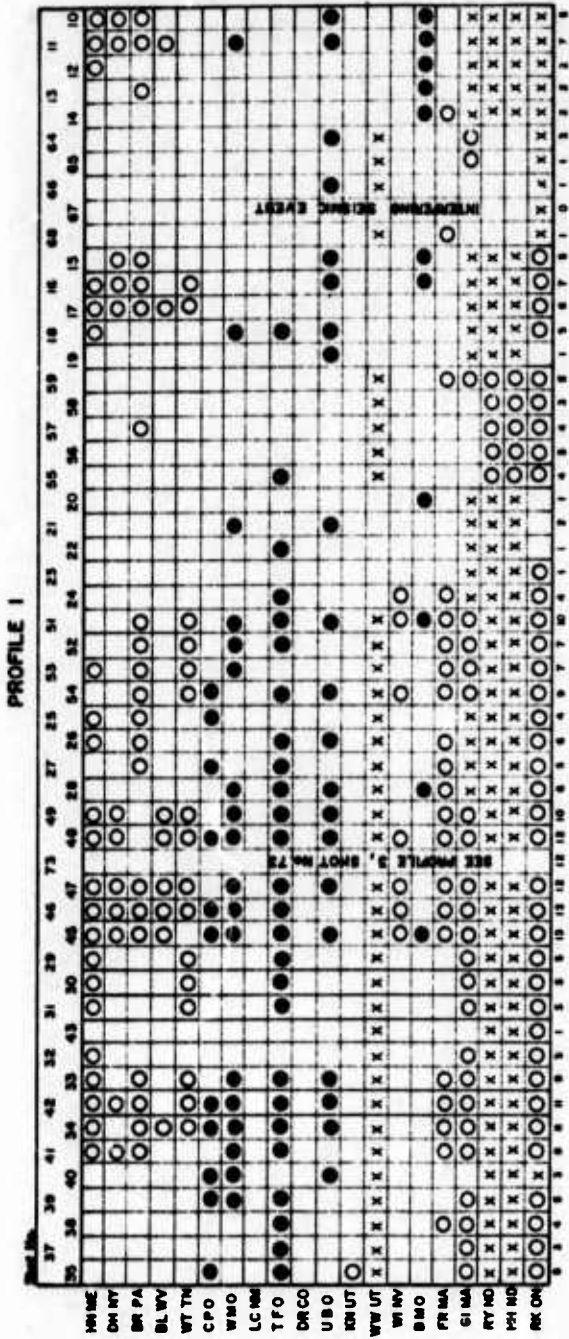


Figure 2
AFTAC/VSC



○ MOBILE STATION
 ● OBSERVATORY
 X INOPERATIVE ON SP-2

SUMMARY OF MEASURABLE SIGNALS JULY 1963
 LAKE SUPERIOR SEISMIC EXPERIMENT
 Figure 3
 AFTAC/VSC

c. The Seismic Data Laboratory¹ digital computer was utilized to provide all required shot-to-station distances, as well as the azimuths shot-to-station and station-to-shot. Predicted arrival times were computed for all signals at all stations, using the Jeffreys-Bullen (J-B) surface travel-time curve. This facilitated record reading and phase identification.

d. Usually the first arrivals for the most distant stations were not easily identifiable above the existing noise background, and so it was fortunate that most of the signals appeared in multiple-trace presentations. At the observatories, the signal alignments were from different single-instrument traces or summations from the array in question. For the mobile stations, a similar signal alignment usually resulted from successive shots at one or more even hourly intervals for the same instrument, the recording rate of one trace-revolution per hour bringing the signals to the same film area for a succession of several shots fired the same Greenwich (Z) day.

4. Analysis and Discussion. Information from the stations described above, which were in routine operation during some time interval within the 1963-64 shot series, is considered in the following under several specific headings:

a. Travel Times.

(1) For the July 1963 explosion program, a composite

¹Operated by the Earth Sciences Division, Teledyne Industries, Inc., under AFTAC direction.

first-arrival tabulation has already been published¹ listing the details of all shot locations and times and the positions of all recording stations that detected measurable signals. Location data for the five VELA observatories and the LRSM mobile stations of interest were included with similar information from other participating groups. The published travel times were also made available on punch cards; and printouts by shot, by distance, and by station are on file.

(2) Travel-time data from the two 10-ton shots of the October 1964 series have also had some informal distribution to government agencies and other organizations and are shown here as a sample presentation (Table I).

(3) These data, including only first arrivals, plus similar data for the remaining shots of July and October 1964, when added to secondary and later arrival data and supplemented with numerous amplitude measurements, comprise a mass of information too large to list here in detail. It is hoped that the following graphs will show the principal features of interest, beginning with the travel times.

(4) For the July 1963 shots, Figure 4 displays the first-arrival residuals with reference to a constant velocity of 8.1 km/sec and includes the J-B surface curve for reference. These data have been separated into five regional geographical zones related to general tectonic structure. It will be seen that signals were received several seconds earlier than J-B arrivals in the three eastern zones and that they

¹"Lake Superior Seismic Experiment: Shots and Travel Times," by Dr. John S. Steinhart. Journal of Geophysical Research, Vol 69, No. 24, Dec 15, 1964, p 5335.

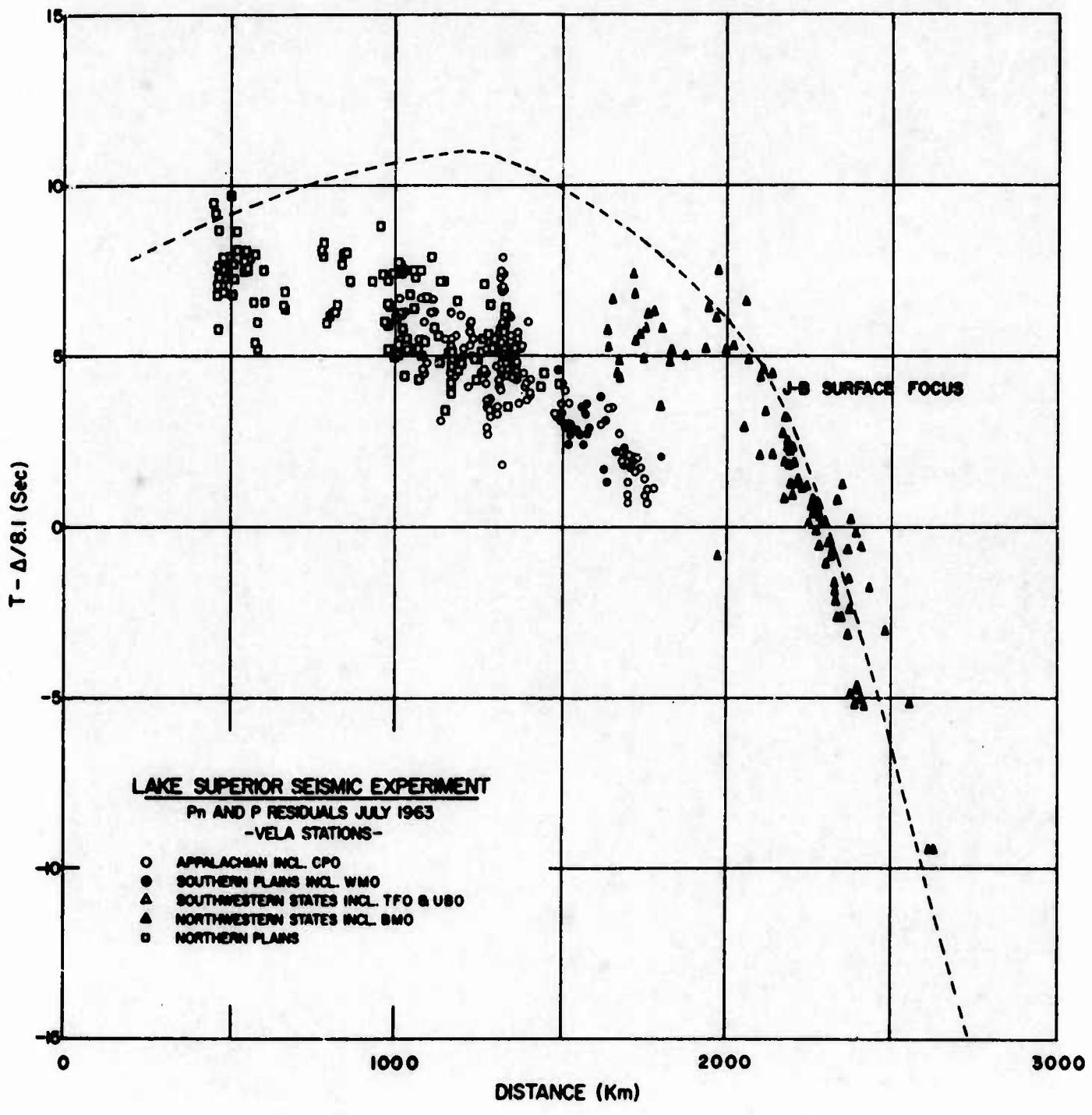


Figure 4
AFTAC/VSC

reverted to a J-B distribution in the northwestern and southwestern zones where at least a part of the path lies west of the Rocky Mountain front. Data from the July and October 1964 shot series are very similar and add statistical support to the distribution shown in Figure 4.

(5) This graph may be contrasted with Figure 5, which is a similar plot for 10 nuclear events detonated underground at the Nevada Test Site. This group of data is more evenly distributed about the J-B curve, though again the signals received in the northern plains tend to be somewhat early.

(6) Figures 4 and 5 may also be compared with Figure 6, which is a reproduction of the corresponding plot for the GNOME (New Mexico) nuclear event, as taken from a published report by Dr. Romney, et al¹.

(7) These three figures indicate a distinct difference between eastern and western travel-time paths. It may also be noted that the differences cease at 2,200 or 2,300 km from the source, suggesting that beyond this distance penetration to a deeper and more uniform travel path has occurred.

(8) The Lake Superior graph, Figure 4, is similar to the eastern section of the GNOME graph, Figure 6, as well as to graphs from SS VILLAGE² and SALMON³ and generally for earthquakes in the eastern United States.

¹ "Travel Times and Amplitudes of Principal Body Phases Recorded from GNOME," Romney, et al, Bulletin of the Seismological Society of America, Vol 52, No. 5, p 1064.

² "Long Range Seismic Measurements, Project 8.4, Seismic Waves from the SS VILLAGE Explosion," Seismic Data Laboratory Report No. 112, Earth Sciences Division, United ElectroDynamics, Inc., 23 November 1964, Figure 3.

³ "Long Range Seismic Measurements, Project 8.4, SALMON," Seismic Data Laboratory Report No. 113, Earth Sciences Division, Teledyne Systems Company, 7 December 1964, Figure 3, p 11. (Teledyne Systems Company taking over United ElectroDynamics, Inc., at about this date)

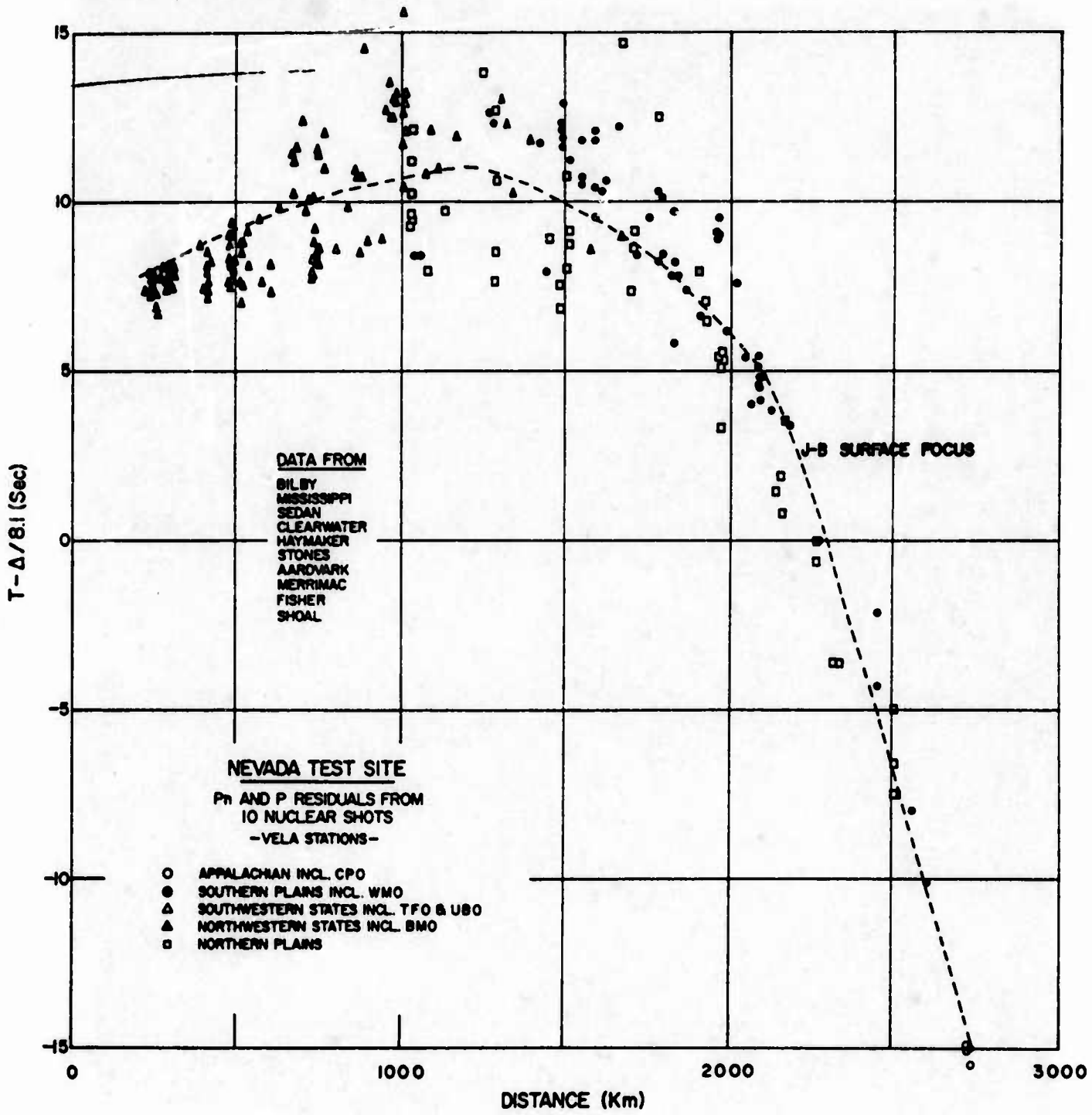


Figure 5
AFTAC/VSC

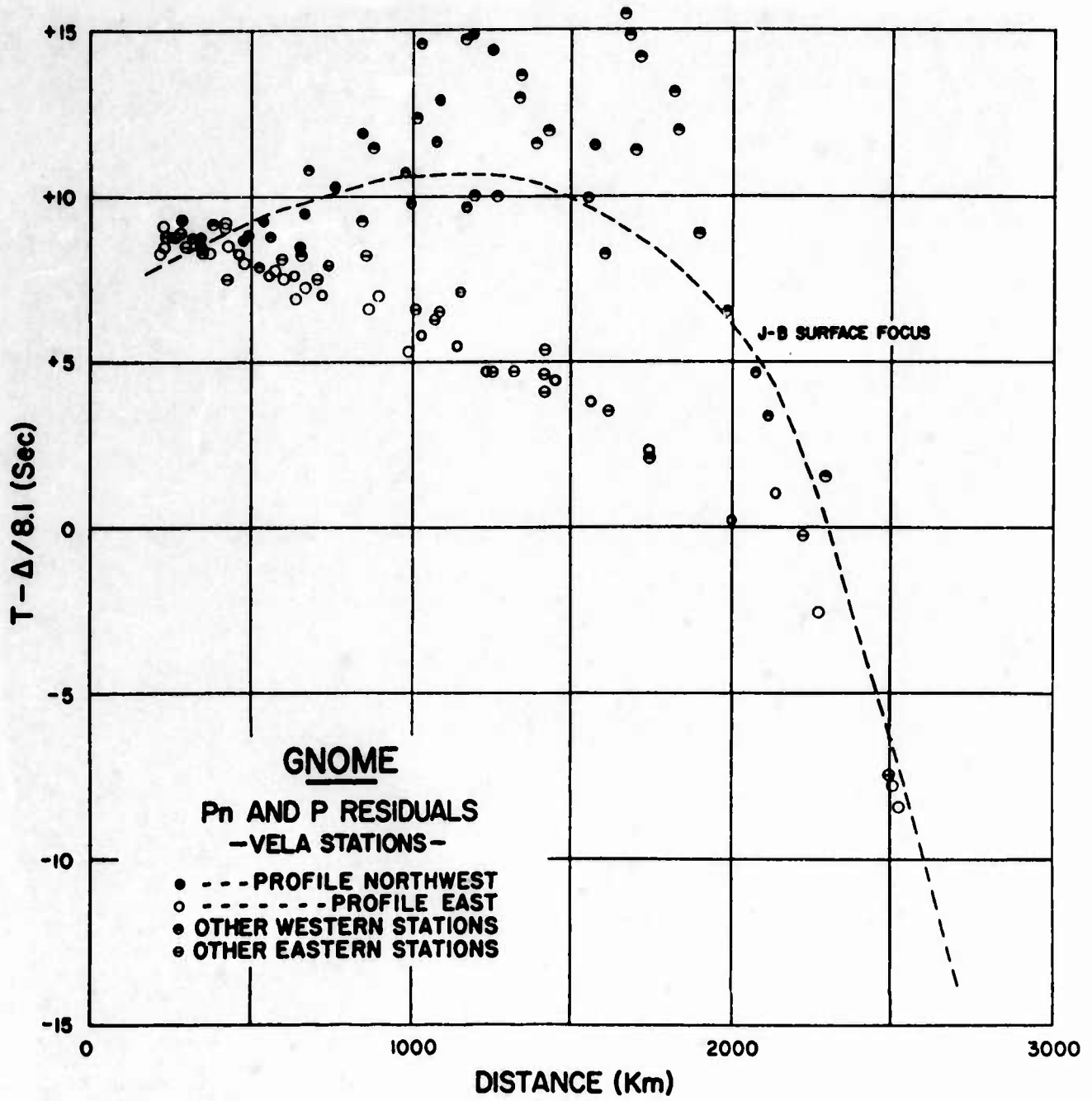


Figure 6
AFTAC/VSC

An average Pn velocity of about 8.4 km/sec is thus suitable for use in the eastern United States and one of about 7.9 km/sec in the western United States.

(9) For individual stations, the variations in travel time from shot points in different parts of Lake Superior could theoretically be utilized to work out details of crustal structure under the lake. Data from other organizations¹ have suggested a possible crustal anomaly under the center of the lake north of the Keweenaw Peninsula. An attempt was made to treat this situation as a 2-layer problem using shot point profiles recorded at more than a dozen stations. Starting with single stations nearly in line with the shot profiles crossing the lake, time profiles were made in terms of residuals from the J-B surface curve. Unfortunately only the profiles based on data from the Tonto Forest Seismological Observatory, Arizona (TFO), and from the Uinta Basin Seismological Observatory, Utah (UBO), showed time differences adequate to suggest a structural anomaly of any size. The best of these, that from TFO (Figure 7), indicates a possible change in average residual of at least 2 seconds somewhere between shot points 27 and 52. By coincidence, this break at shot point 27 is just 2,300 km from TFO, so that there is no assurance that time paths from the western end of the lake can be compared directly with those from the eastern end, if the change of paths suggested at 2,300 km in Figure 4 is borne in mind. Another

¹For example: "An Interpretation of the Lake Superior Experiment First-Arrival Data by the Time Term Method," M. J. Berry and G. F. West, Inst. of Earth Sciences, University of Toronto, Bulletin of the Seismological Society of America, Vol 56, No. 1, p 141.

LAKE SUPERIOR SEISMIC EXPERIMENT

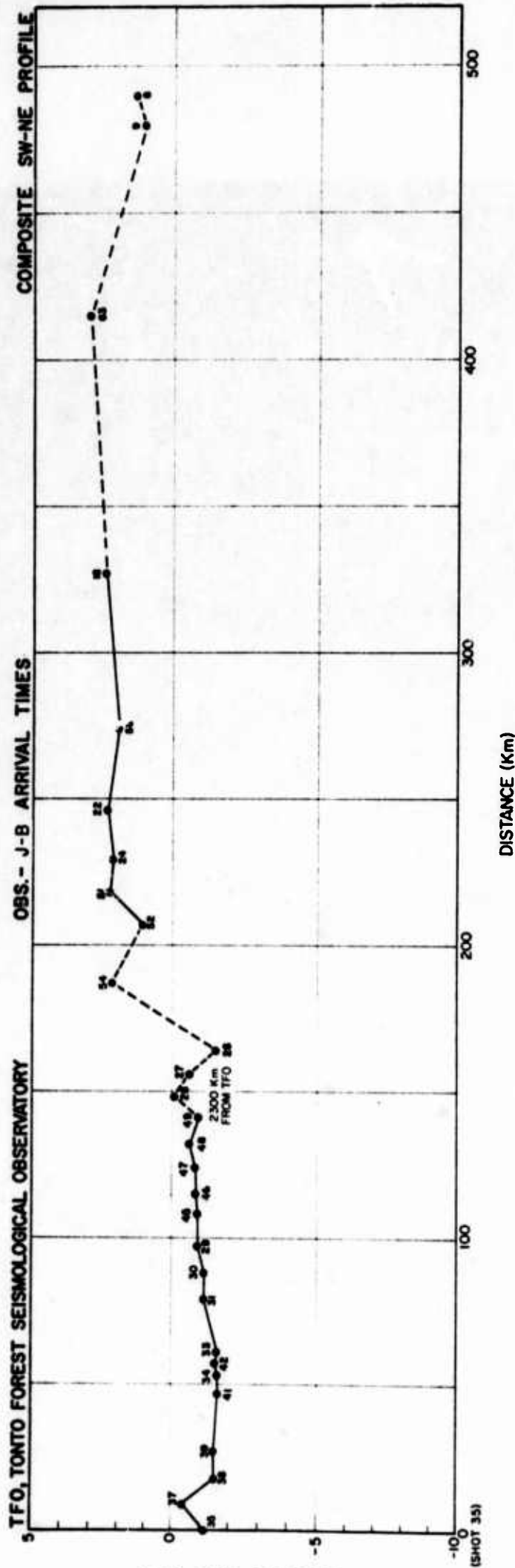
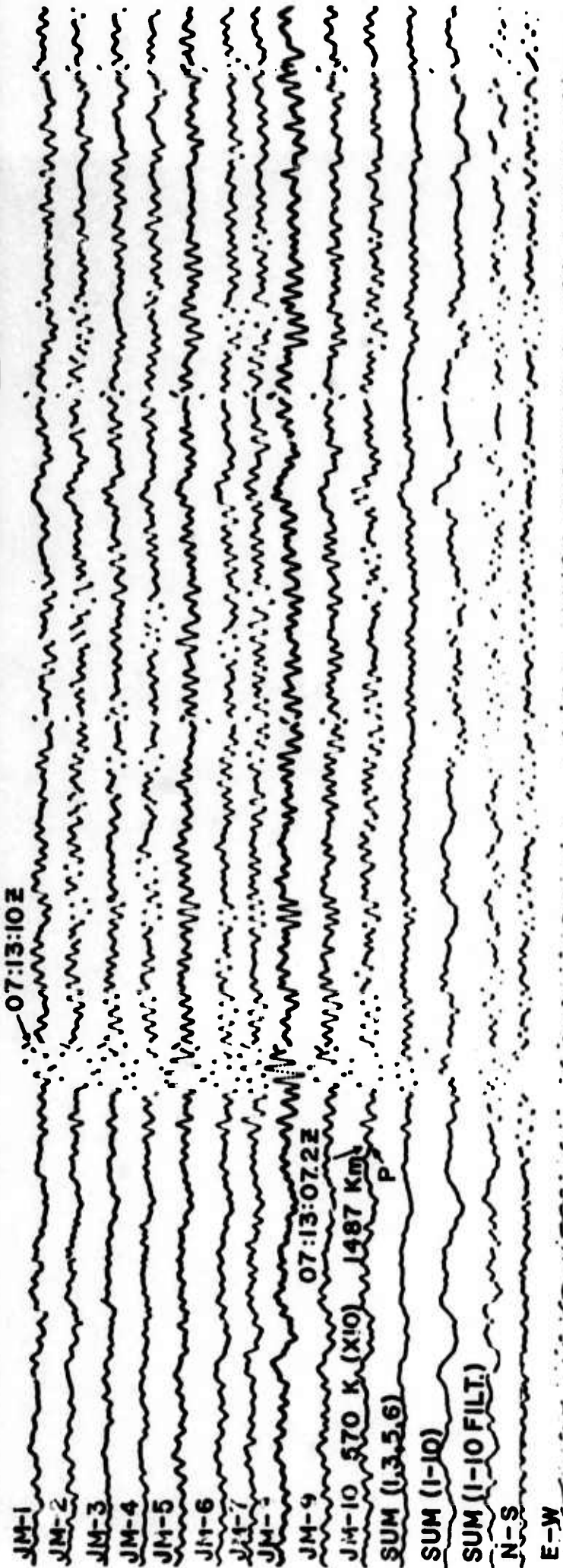


Figure 7
AFTAC/VSC

difficulty with the profile of Figure 7 is that signals from the western end of the lake were in general somewhat stronger than those from the eastern end, so that the identifiable first motion may not be the same phase for the eastern and western shot points. In view of these complications, it is suggested that the data presented here may be more useful in checking structures postulated from other data than in providing structural indications directly. It may further be noted in Figure 7 that only six good readings for the eastern end of the lake showed delayed arrivals as measured from the July 1963 shot series. None of the shots from the July or October 1964 programs add anything to the profile as shown.

(10) In addition to the Pn and P arrivals so far mentioned, some indications of other phases were noted. One of these is illustrated in Figure 8, which shows a recording at the Wichita Mountains Seismological Observatory, Oklahoma (WMO), where a weak P arrival is followed about 2 seconds later by a stronger emergent phase. Evidences of multiple arrivals of this type make it doubtful that some of the weaker arrivals represent true first motion. Another type of phase may be present in Figures 9 and 10, which are recordings at Red Lake, Ontario, and Glendive, Montana. Although these stations are at distances of 475 km and 980 km from the shot points in the same area of the lake, an emergent phase is seen in each recording at about 11 seconds after the first P arrival. It may be that the emergent phases represent SPS paths or something similar.

TIME WWV



LAKE SUPERIOR SEISMIC EXPERIMENT

SHOT No. 81 30 JULY 63

P ARRIVAL

WMO WICHITA MOUNTAINS SEISMOLOGICAL OBSERVATORY, OKLAHOMA

Figure 8
AFTAC/VSC

02:11:02

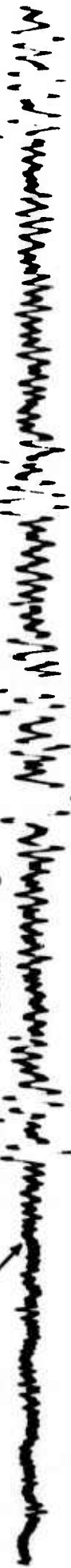
SHOT No. 45 Pn 04:11:06.2Z 468 Km



SHOT No. 46 Pn 05:11:06.1Z 470 Km



SHOT No. 47 Pn 06:11:06.3Z 473 Km



SHOT No. 48 Pn 07:11:06.8Z 475 Km



SHOT No. 49 Pn 08:11:07.4Z 478 Km



NOTE SECONDARY ARRIVALS

LAKE SUPERIOR SEISMIC EXPERIMENT

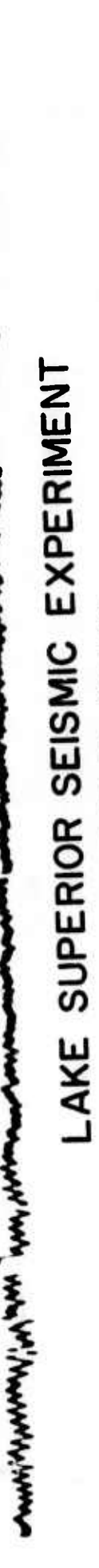
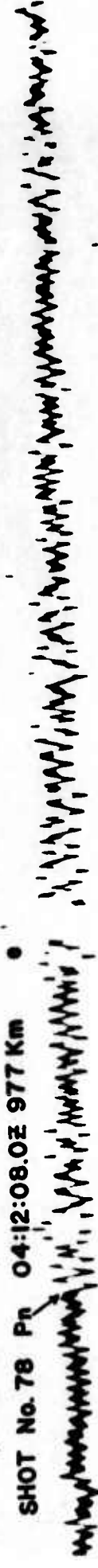
SHOTS OF 17 JULY 63

S-P VERTICAL-165.0 K (X10)

RK ON RED LAKE, ONTARIO

Figure 9
AFTAC/VSC

02:12:10Z



SHOT No. 76 Pn 04:12:08.0Z 977 Km

SHOT No. 79 Pn 05:12:07.5Z 979 Km

SHOT No. 80 Pn 06:12:08.2Z 980 Km

SHOT No. 81 Pn 07:12:07.8Z 981 Km

SHOT No. 82 Pn 08:12:08.2Z 982 Km

NOTE SECONDARY ARRIVALS

LAKE SUPERIOR SEISMIC EXPERIMENT

SHOTS OF 30 JULY 63

S-P VERTICAL - 120.3 K (X10)

(11) Other phase arrivals recorded include S and Lg as indicated by arrival times and component of motion. Examples of these are shown in Figures 11 and 12, again recorded at Red Lake, Ontario, and Glendive, Montana. Figure 13 shows travel time versus distance in kilometers for S and Lg phases recorded from the July and October 1964 shot series. It will be seen that the points tend to lie along the J-B surface S curve, or along the 3.5 km/sec Lg arrival curve.

b. Amplitudes of Pn and P.

(1) Figure 14 is a graph of the amplitudes of Pn and P for the two 10-ton shots of 10 October 1964. These were the strongest shots detonated in any of the three series, and the effects noted are representative of those shown by a large number of readings from many weaker explosions.

(2) Amplitudes in the usual Pn range of approximately 200-1,200 km evidently do not fit an inverse cube rate of decrease, and it is doubtful that any other simple gradient will apply. Stations in the 400-600 km range including Wykoff, Minnesota (WF MN), Red Lake, Ontario (RK ON), and Vinton, Iowa (VO IO), appear relatively low. In the 800-1,300 km range, Ryder, North Dakota (RY ND), and Delhi, New York (DH NY), are on the high side; and other shots suggest that Winner, South Dakota (WN SD), would also be part of this high amplitude group.

(3) It seems unlikely that this amount by which these stations are high or low can be entirely explained in terms of regional amplitude levels, even if it is often noted that WN SD records abnormally high signals (in rather high noise). Thus there remains the possibility that

SHOT 04:11:10Z VERTICAL 165.0 K (X10)

No. 45 P 6
46
47
48
49

SHOT No.	Pn ARRIVAL	DISTANCE Km	SHOT No.	Pn ARRIVAL	DISTANCE Km
45	04:11:06.2Z	468.0	48	07:11:06.8Z	475.3
46	05:11:06.1Z	470.1	49	08:11:07.4Z	478.0
47	06:11:06.3Z	472.6			

SHOT 04:11:10Z HORIZONTAL 160.0 K (X10)

No. 45
46
47
48
49

S.Lg

LAKE SUPERIOR SEISMIC EXPERIMENT

SHOTS OF 21 JULY 63
S & Lg MOTION ON SP VERTICAL AND
SP HORIZONTAL (RADIAL)

RK ON RED LAKE, ONTARIO

Figure 11
AFTAC/VSC

SHOT No. 02:12:10Z VERTICAL 120.3 K (X10)
 78
 79
 80
 81
 82

SHOT No.	Pn ARRIVAL	DISTANCE Km	SHOT No.	Pn ARRIVAL	DISTANCE Km
78	04:12:08.0Z	977.0	81	07:12:07.8Z	981.0
79	05:12:07.5Z	979.0	82	08:12:08.2Z	982.0
80	06:12:08.2Z	980.0			

SHOT No. 02:12:10Z HORIZONTAL 107.2 K (X10)
 78
 79
 80
 81
 82

LAKE SUPERIOR SEISMIC EXPERIMENT

SHOTS OF 30 JULY 63

S & Lg MOTION ON SP VERTICAL AND
 SP HORIZONTAL (RADIAL)

GI MA GLENDIVE, MONTANA

Figure 12
 AFTAC/VSC

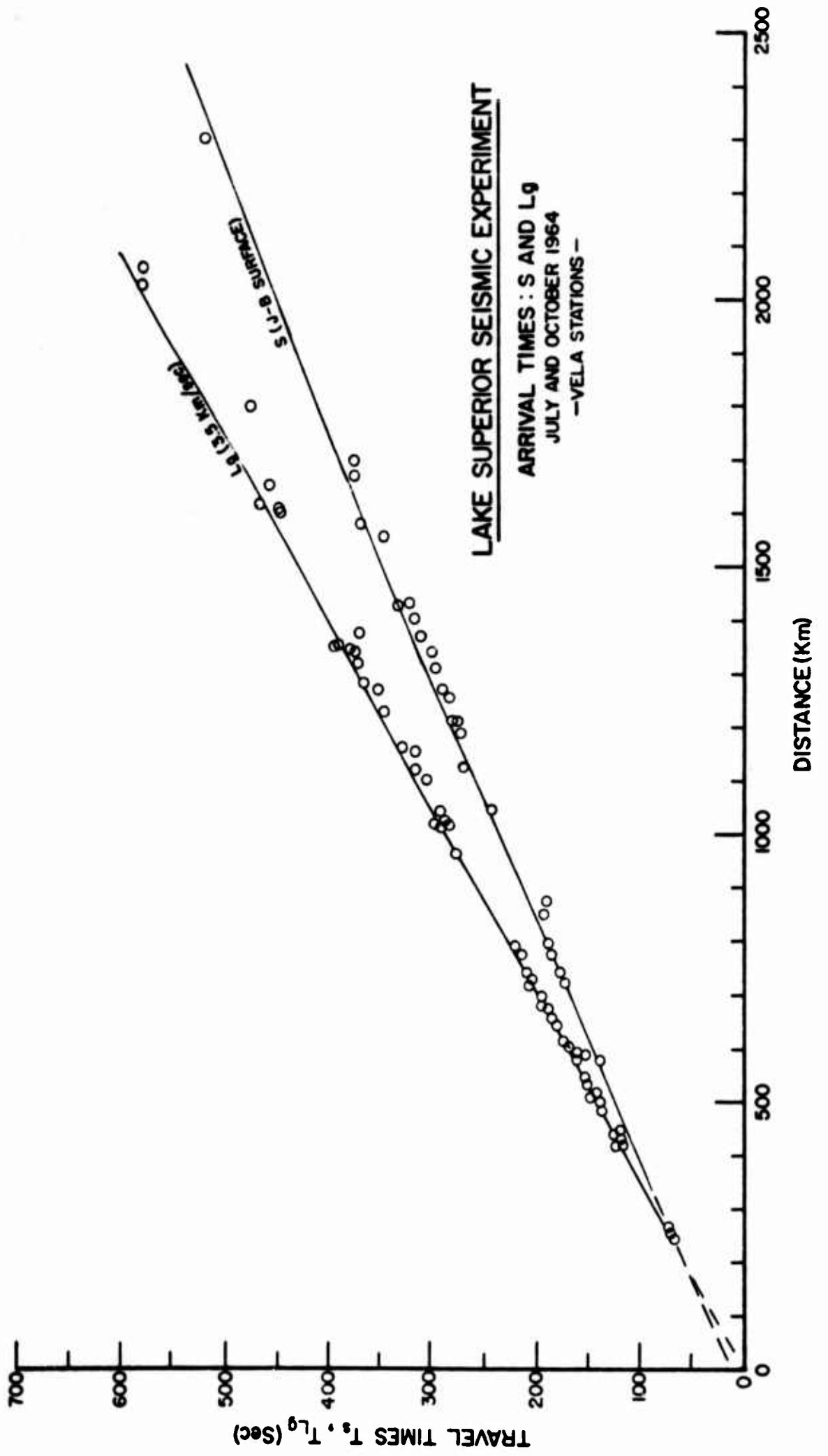


Figure 13
AFTAC/VSC

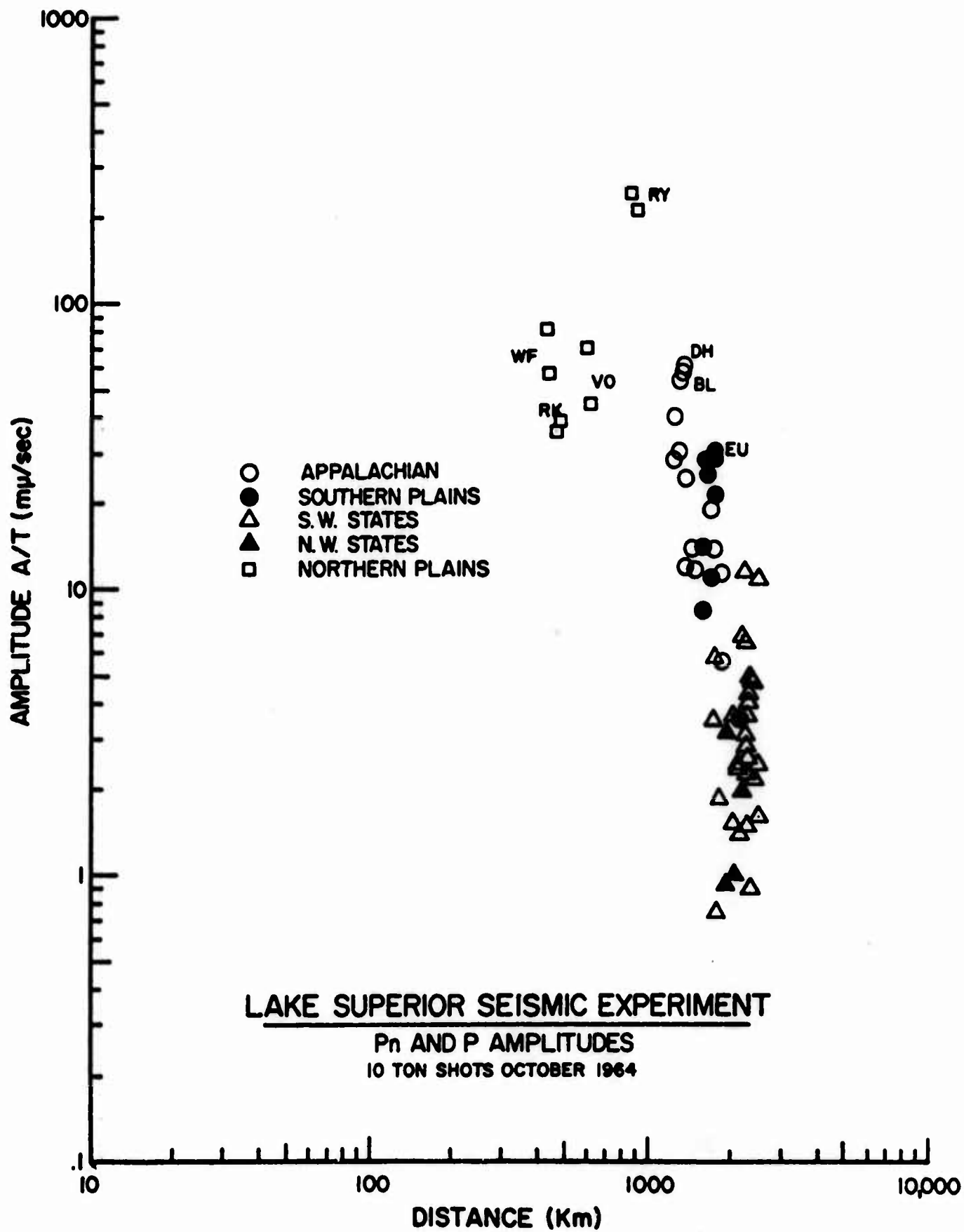


Figure 14
AFTAC/VSC

in the 200-1,300 km range there is some change in the nature of the paths of first-arrival signals because of complexities in the underlying layers. Our data beyond 1,300 km do not carry to a sufficient distance (2,600 km) to establish a well defined rate or rates of variation.

(4) The effect of explosive charge size on Pn and P amplitudes is shown in Figure 15. For several individual stations receiving signals from shots of more than one charge size, a composite plot is presented showing trends within the range from 250 lbs (1/8 ton) to 20,000 lbs (10 tons) of dynamite equivalent. Although there is not much continuity of data, it appears that a slope of approximately 1 is indicated, which is to say that the amplitude is directly proportional to the size of charge within the limits shown.

c. Amplitudes of S or Lg.

(1) As was indicated in the earlier discussion of travel times, Figure 13 gives evidence that both S and Lg signals were recorded at a number of stations. Owing to the emergent character of the signal maxima, only a few of the amplitude readings associated with these phases are definitely correlated to one or the other of these two types of motion. Four cases in which the readings could be clearly identified as to type of motion showed an average of 1.7 as the ratio of Lg and S amplitudes for the same events, as recorded on the same instrument component. The bulk of the recorded amplitudes were simply labeled (S or Lg) in the various graphs plotted.

(2) Figure 16 shows the (S or Lg) amplitudes for the two 10-ton shots previously discussed. The points show relatively little scatter,

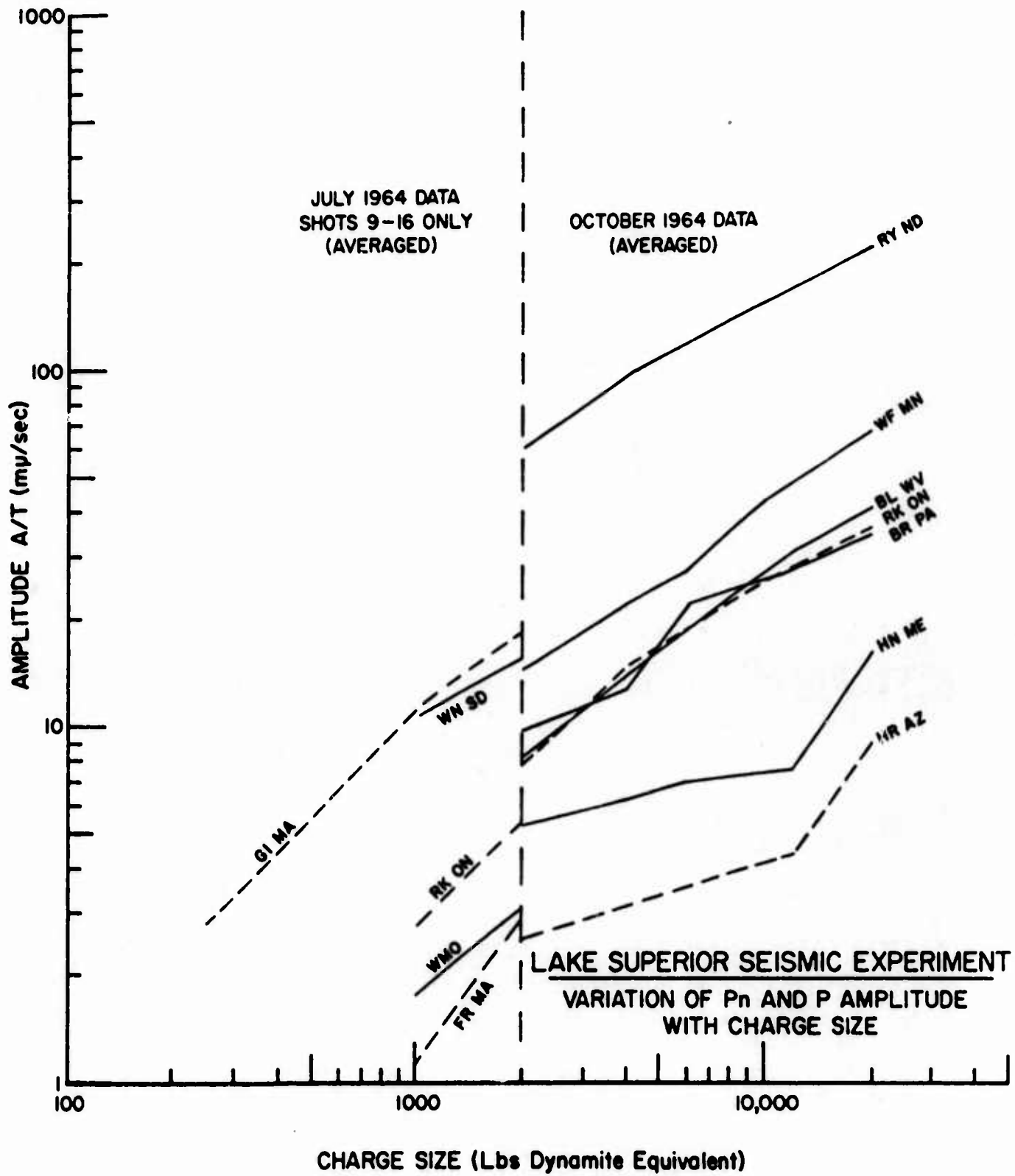


Figure 15
AFTAC/VSC

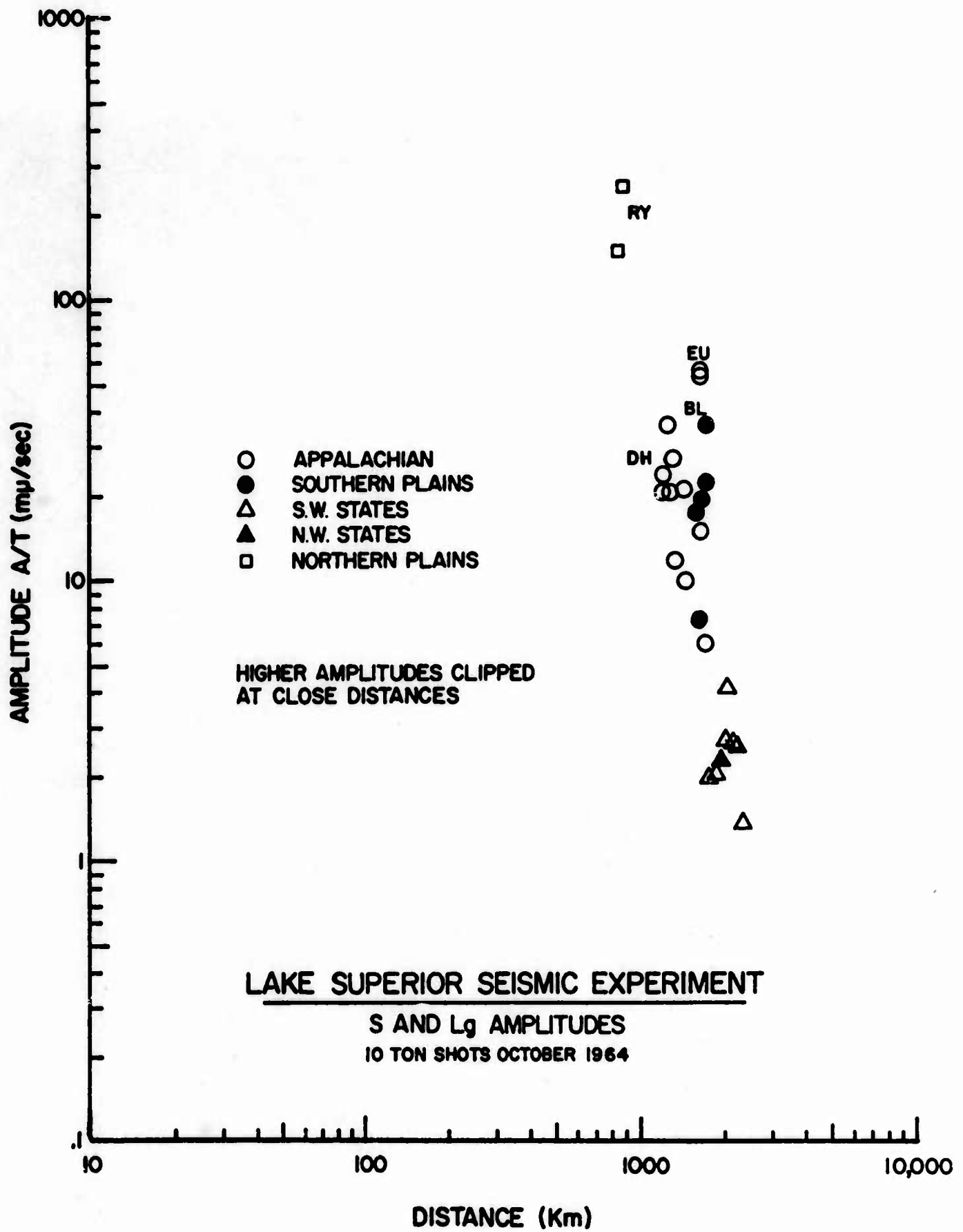


Figure 16
AFTAC/VSC

but no attempt is made to show a gradient in view of the uncertainty as to phase, as to regional signal level, and as to details of the transmission paths involved. Again the data shown is representative of a large number of readings from many weaker explosions.

(3) The variation of (S or Lg) amplitude with size of charge is shown in Figure 17. Again, several stations receiving signals from shots of more than one charge size are included, with lines connecting amplitudes received at a particular station from several sizes of shot. A composite effect again suggests that the amplitude is directly proportional to the size of explosive charge within the given limits.

d. Energy Considerations.

(1) Some comment should be made on the general question of how relatively small chemical explosions in Lake Superior managed to generate quite large signals to considerable distances. One shot of 1/8-ton size produced a measurable signal at Glendive, Montana (GI MA), at a distance of 1,128 km. A 1-ton shot was received at Seligman, Arizona (SG AZ), at a distance of 2,678 km. These somewhat unexpected results were in contrast to experience with explosion programs in the western United States and with quarry recordings further east.

(2) It seems likely that the signal strength is a combination of good coupling, signal augmentation, favorable instrument response, and efficient subcrustal energy transmission. Explosions in water or wet porous rock materials generally exhibit good coupling of the explosion to the ground. The present shot series, detonated on the lake bottom in

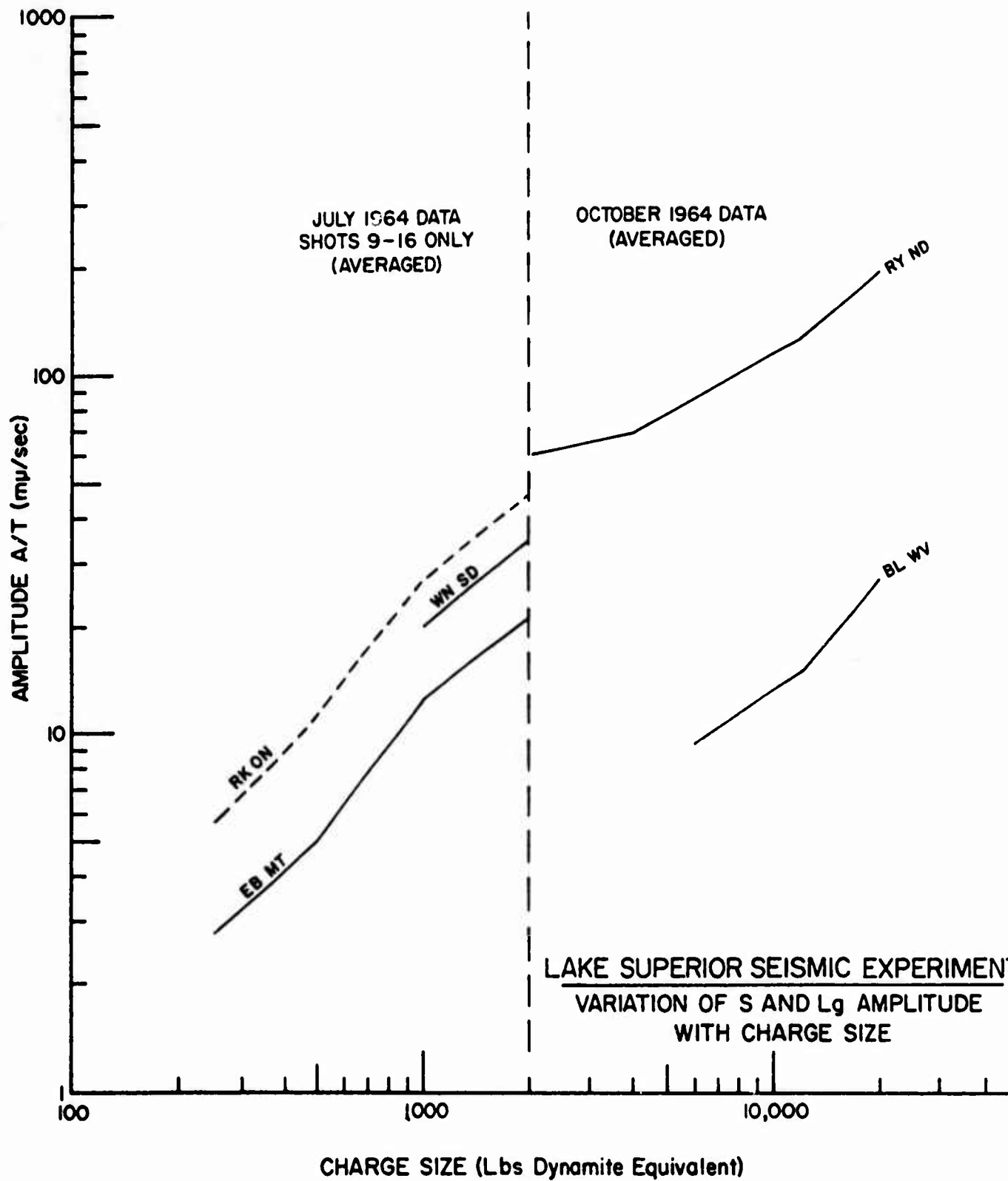


Figure
AFTAC/VS

depths as great as several hundred feet, were well coupled. Beyond this, it is usual for chemical explosions in water to be followed by oscillatory gas pocket pulses which carry considerable energy after the initial shock wave. Where the first gas bubble pulse collapses against the bottom, the oscillatory sequence is interrupted and additional seismic energy may be developed close behind the initial explosion shock wave within a time interval depending mainly on charge size and depth of water.

(3) The two 10-ton events yield computed magnitudes of approximately 3.7 in the western United States at teleseismic distances, a value that would appear anomalous without consideration of the water environment of the foci. As is indicated in the paper by D. E. Weston¹, explosions in water, if recorded in appropriate frequency ranges, may yield indicated magnitudes far above those for similar explosions in solid elastic media. The data for CHASE III², Lake Superior, and small high-explosive shots in water are all quantitatively consistent with the paper cited.

(4) Magnitude estimates of the 10-ton shots in the eastern United States range as high as 6.3 when the computations are conducted according to the procedures followed by VELA reports and the Coast and Geodetic Survey. These procedures are invalid for the eastern United States, owing to the fact that the dependence of A/T on epicenter distance generally shows very nearly a $1/r^2$ dependence from 150 to 2,200 km in this region. This conclusion can be confirmed either by a study of explosions (SS VILLAGE, GNOME, and SALMON) or of earthquakes of the eastern

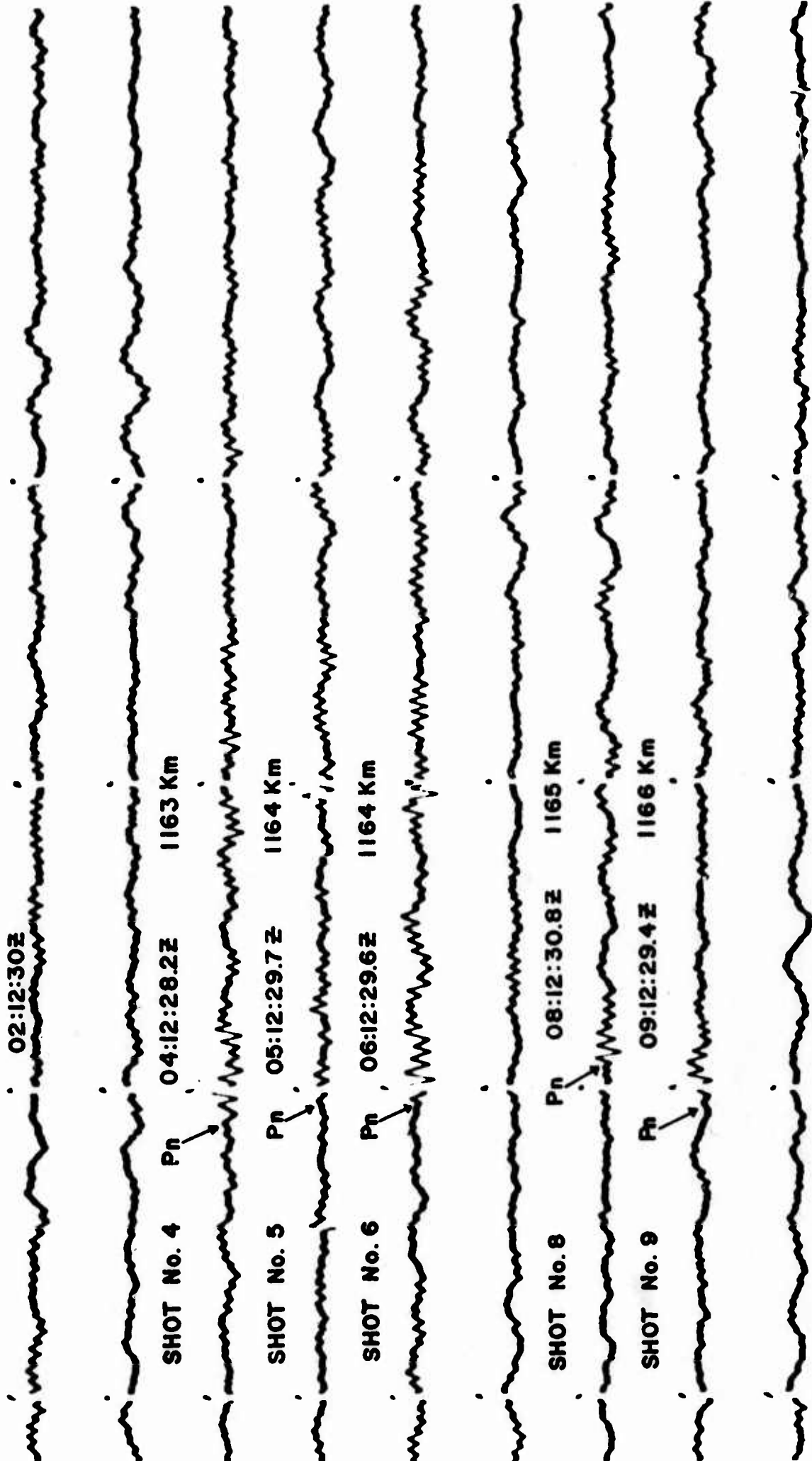
¹ "The Low Frequency Scaling Laws and Source Levels for Underground Explosions and Other Disturbances," Geophysical Journal of Royal Astronomical Society, Vol 3, pp 191-202 (1960).

² "Long Range Seismic Measurements, Project 8.4, CHASE III," Seismic Data Laboratory Report No. 124, Earth Sciences Division, Teledyne, Inc. (Formerly Teledyne Systems Company).

United States. When a scheme of magnitude predictions based on a study of events of the eastern United States is used, the 10-ton Lake Superior shots appear to be of magnitude 4.3, 0.7 above the value found at teleseismic distances. This discrepancy has yet to be explained, such a discrepancy between teleseismic and closer magnitude values not having been found for SS VILLAGE, CHASE III, GNOME, SALMON, or earthquakes of the eastern United States. It is in some manner related to the Lake Superior shot environment (explosions on bottom?).

e. Sample Signals. Several additional sample recordings are shown in Figures 18 through 22. The first three of these illustrate signals received at some of the eastern stations. Figure 21 shows a routine recording at TFO from a 1-ton lake shot. This may be contrasted with Figure 22, which is a recording of a 10-ton shot on the TFO northeast-southwest linear array. It may be seen on this illustration that there is a signal stepout of 1.2 sec for a linear distance of 10.5 km, so that the apparent arrival velocity of the P wave is 8.8 km/sec for a distance of 2,304 km at the array center. This is within the velocity range expected for this distance.

5. Conclusion. It may be said in general that the shot programs described have produced a large quantity of regional seismic information. Since the procedure is relatively simple and inexpensive it is likely that further programs will be developed. It appears that carefully planned projects using suitable station distribution and at least 5-ton charges might develop much additional useful information and that the utilization of other bodies of water might considerably extend existing geographical coverage.



LAKE SUPERIOR SEISMIC EXPERIMENT

SHOTS OF 10 JULY 63
S-P VERTICAL—52.6 K (X10)

BL WV BECKLEY, WEST VIRGINIA

Figure 18
AFTAC/VSC

01:12:50Z

SHOT No. 45

P

04:12:50.9Z

1340 Km

SHOT No. 46

P

05:12:50.0Z

1334 Km

SHOT No. 47

P

06:12:50.0Z

1327 Km

SHOT No. 48

P

07:12:48.7Z

1320 Km

SHOT No. 49

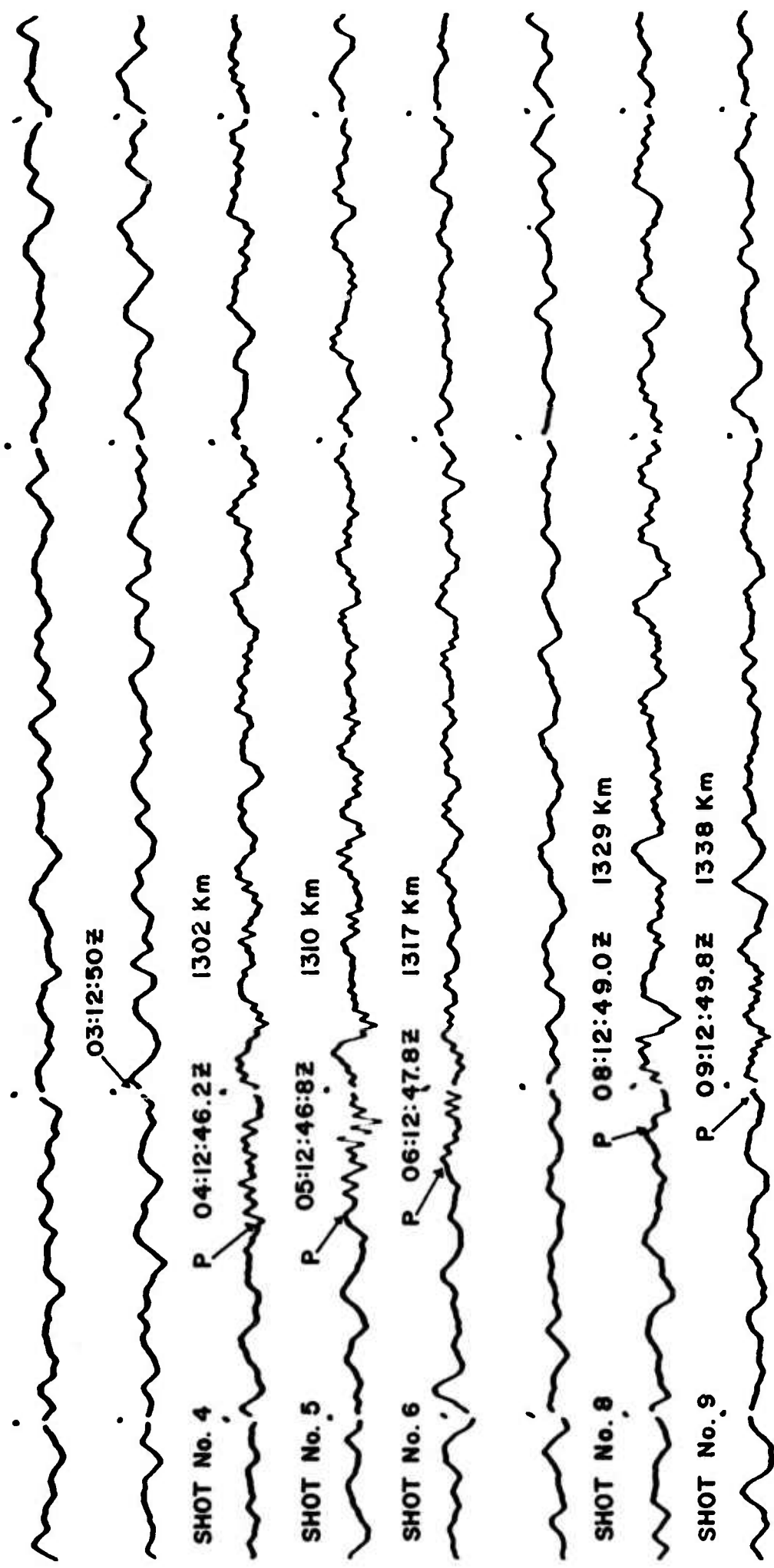
P

08:12:48.2Z

1313 Km

LAKE SUPERIOR SEISMIC EXPERIMENT

SHOTS OF 21 JULY 63



LAKE SUPERIOR SEISMIC EXPERIMENT

SHOTS OF 10 JULY 63

S-P VERTICAL—145.0 K (X10)

TIME

09:14:30Z

E-W

N-S

JM-1

JM-5

JM-11

JM-17

JM-23 6.47 K (X10)

JM-29

JM-2

JM-10

JM-15

JM-20

JM-25

SUM (1-31)

R 09:14:35.0Z

2216 Km

1 TON

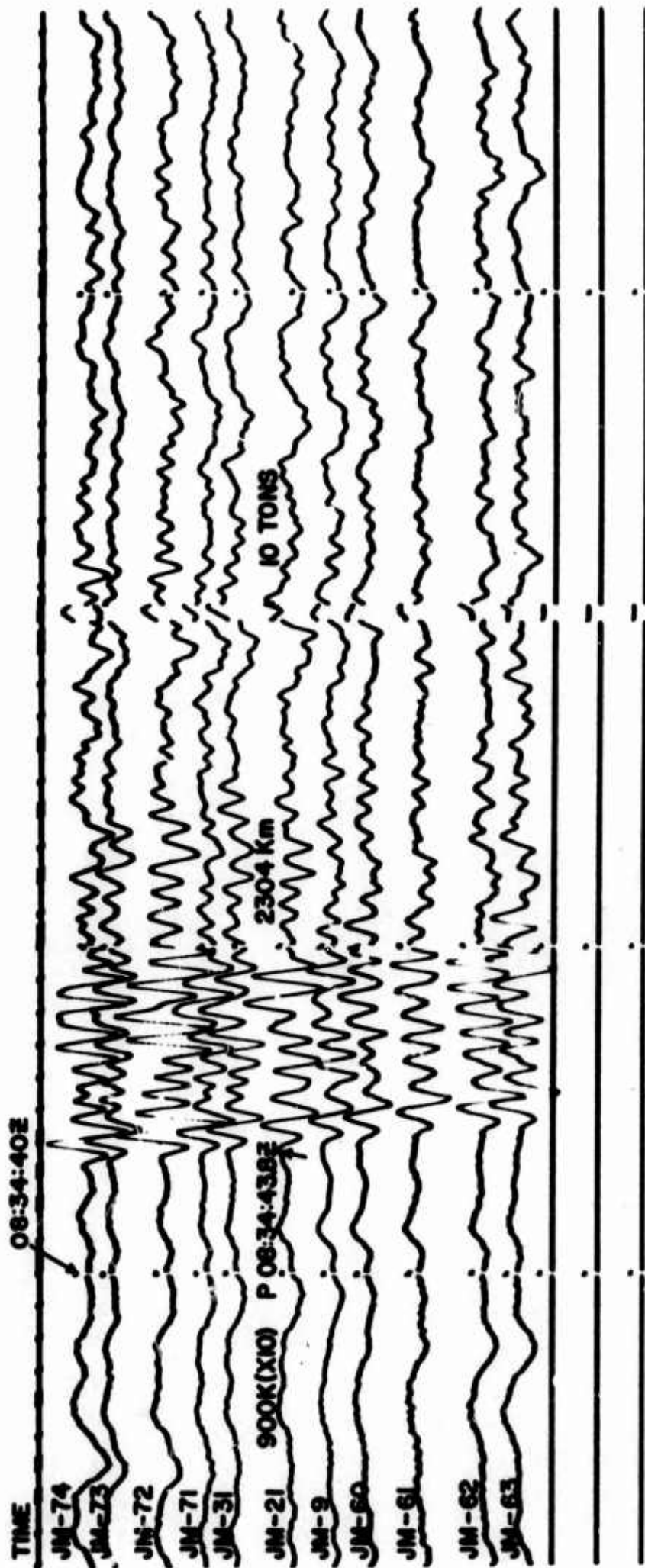
WWV

LAKE SUPERIOR SEISMIC EXPERIMENT

SHOT No. 34

17 JULY 63

08 35



WWV

LAKE SUPERIOR SEISMIC EXPERIMENT

SHOT No. 49 A 10 OCTOBER 64

P ARRIVAL