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MEASUREMENT TECHNIQUES, SENSOR, AND DISTANCE-AZIMUTH EFFECTS ON LASA AMPLITUDE ANOMALIES

DECEMBER 9, 1966

REPORT No. LL-3

Prepared for

LINCOLN LABORATORIES
MASSACHUSETTS INSTITUTE of TECHNOLOGY

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FOREWARD

The work documented in this report is part of a study of the amplitude anomalies observed at the Large Aperture Seismic Array (LASA) in Montana. The work was performed by the Applied Research Section, Earth Sciences, a Teledyne Company, 316 Montgomery Street, Alexandria, Virginia, under Lincoln Laboratories Contract No. BB-246.

This report was written by D. E. Frankowski. Assistance was provided by A. L. Kurtz, R. D. Mierley, and P. A. Santiago. Dr. E. F. Chiburis served as a consultant. The project director was Dr. P. W. Broome.

ABSTRACT

The effects of measurement techniques, of sensor used, and of distance-azimuth on computed amplitude anomalies at LASA are discussed.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

1. INTRODUCTION

A seismic P-wave is usually thought of as having a uniform amplitude along the wave front which is attenuated with distance from the source. Thus, one would expect seismometers closely spaced to record the same ground motion amplitudes. Although the Montana Large Aperture Seismic Array is small (200 km) when compared to teleseismic distances ($\Delta > 20^{\circ}$), the recorded P-wave amplitudes are not equal or even near equal for any given event. Ratios between maximum and minimum recorded amplitudes are as high as 9 and 10 to 1 with 5 to 1 ratios commonplace.

Since this factor has a strong bearing on the results of an "amplitude anomaly" calibration, the following ancillary studies were undertaken:

1. The first question to be asked is, "Are the amplitude anomalies a function of the seismometers or of the seismometer location?"

a. If the amplitude anomalies are a function of the seismometers only, it would seem reasonable to expect as much variation within one subarray as that among all subarrays. The amplitudes for the 25 seismometers in each of the 21 subarrays were computed for 10 events which were picked at random. Figures 1 through 10 show these amplitudes plotted on a log scale. It is seen that on the log scale amplitude standard deviation for a subarray is relatively constant over all subarrays and events, and much smaller than the combined LASA amplitude standard deviation. Thus, compared to LASA as

a whole, all the instruments within each subarray record a more constant ground motion. This indicates that the amplitude anomalies are not functions of the instruments alone, but that the subarray locations are a factor.

b. Since the center seismometer from each subarray is to be used in the amplitude anomaly studies, its amplitude is also shown in Figures 1 through 10 for these 10 events. It is seen that the recorded amplitude at each center instrument is very nearly equal to the subarray mean amplitude minus the subarray standard deviation. This indicates that any calculations based on center seismometer amplitudes closely approximates what is taking place between entire subarrays.

2. The second question asked is, "Are the amplitude anomalies a reflection of the measurement techniques?"

There are several methods for converting P-wave analog trace amplitudes to ground motion amplitudes. Some of these are:

a. Measuring the maximum amplitude within the first three or four seconds of signal and correcting for instrument frequency response at each instrument.

b. Measuring the maximum amplitude within the first three or four seconds and correcting for the average frequency across LASA.

c. Measuring the maximum amplitude within the first three or four seconds and not correcting for frequency response (equivalent to assuming the period T = 1.0 sec) .

d. Restricting all measurements to the first half-cycle of the signal.

There are advantages for each method. The first method gives the most accurate ground motion amplitude at each sensor. The second and third methods make ground motion calculations very simple. The fourth method minimizes reverberation effects that may be present in later phases of the signal, but has the disadvantage that it is applicable only to the larger signals.

These four methods were used in calculating amplitude anomalies for five Aleutian Islands events and five Fiji Islands events*. These amplitude anomalies are presented in Figures 11 through 18. It is seen that the average amplitude anomaly curves have similar shapes and variance for the different methods for the same source region. Thus, the anomalies are not a function of measurement techniques. The first method was selected as the measurement technique to be used since it does correct each seismometer for frequency response and results in less variance at each subarray for a given source region than the other techniques. Figures 11 through 18 also show the similarity of the amplitude anomaly curves for peak-to-peak and zero-to-peak amplitudes. Since peak-to-peak measurements tend to reduce observation errors, this method is being used in the amplitude anomaly studies.

3. The third question asked is, "Do the amplitude anomalies vary from source region to source region (distance

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*The method used for calculating amplitude anomalies is presented in the Appendix.

and azimuth)?"

The average amplitude anomalies for the Aleutian Islands and Fiji Islands are shown in Figure 19. It is seen that the average anomalies from these two regions are dissimilar.

2. CONCLUSIONS

The observed amplitude anomalies between subarrays are a function of distance and azimuth to the source and not a reflection of instrument variability or measurement techniques.

APPENDIX

Normalized amplitudes are used to reduce events of different signal levels to a common reference. The normalized amplitude $Y_{I,J}$ for event I and station J is defined as

$$Y_{I,J} = \frac{L_{I,J}}{\text{GEOMEAN}}$$

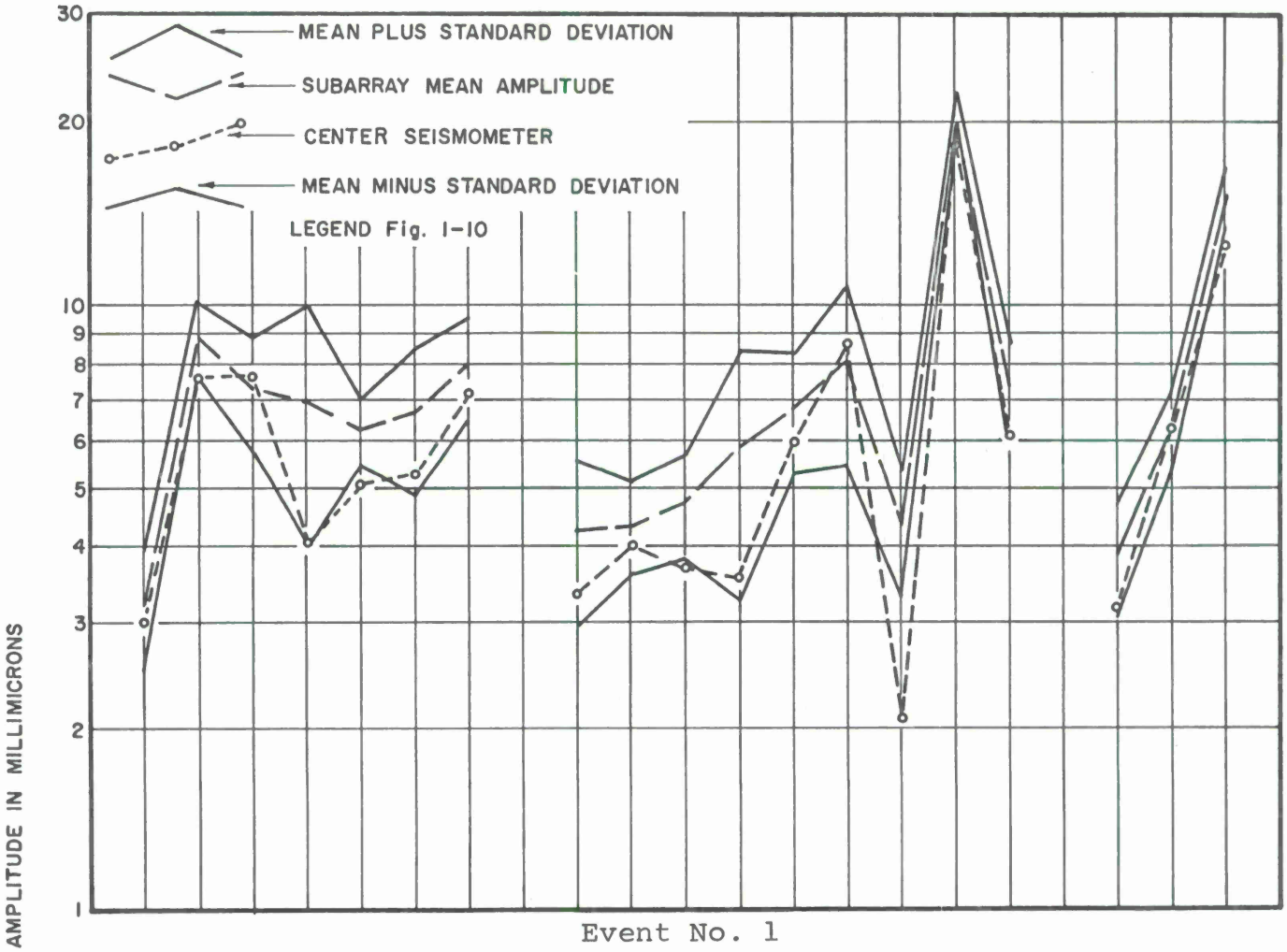
where $L_{I,J}$ is the observed amplitude and GEOMEAN is the geometric mean of the observed amplitudes for event I, or

$$\text{GEOMEAN} = \text{Log}^{-1}\left[\frac{1}{N} \sum_{J=1}^{N} \text{Log } L_{I,J}\right]$$

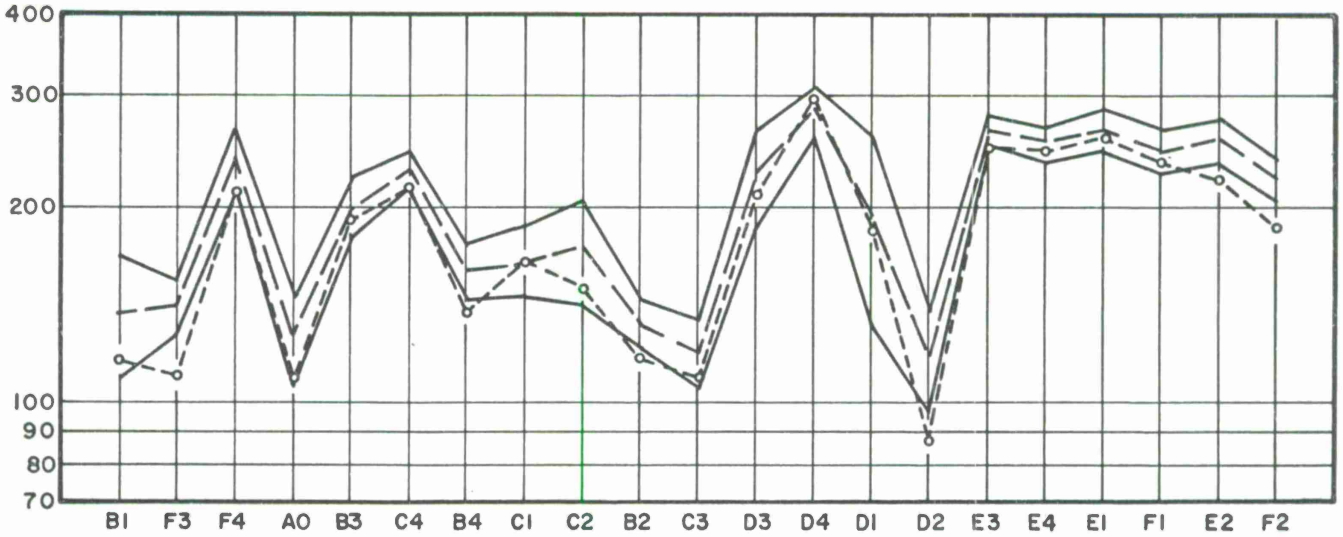
where N is the number of observed amplitudes for event I. The average anomaly for station J is then defined as the geometric mean of the normalized amplitudes, or

$$A_J = \text{Log}^{-1}\left[\frac{1}{N} \sum_{I=1}^{N} \text{Log } Y_{I,J}\right]$$

where N is the number of normalized amplitudes $Y_{I,J}$ for station J.



Event No. 1
Figure 1



Event No. 2
Figure 2

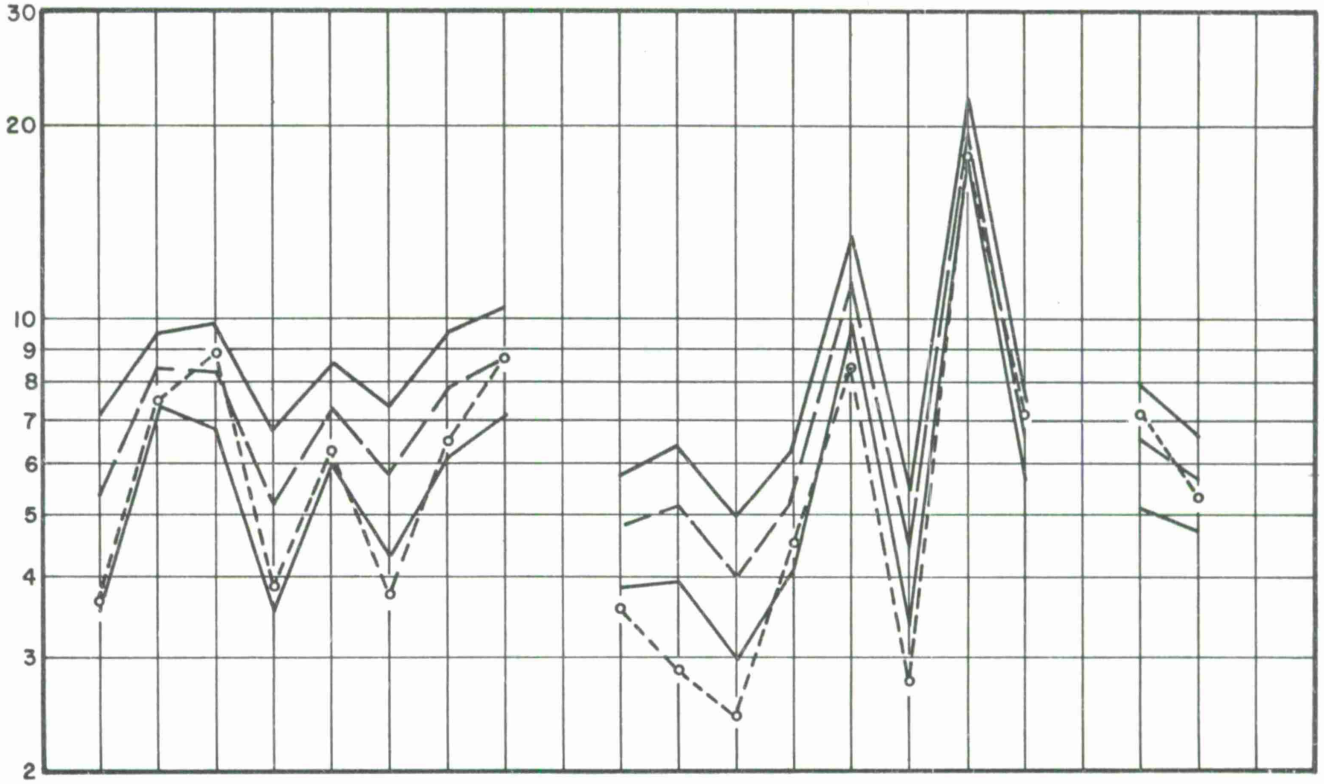


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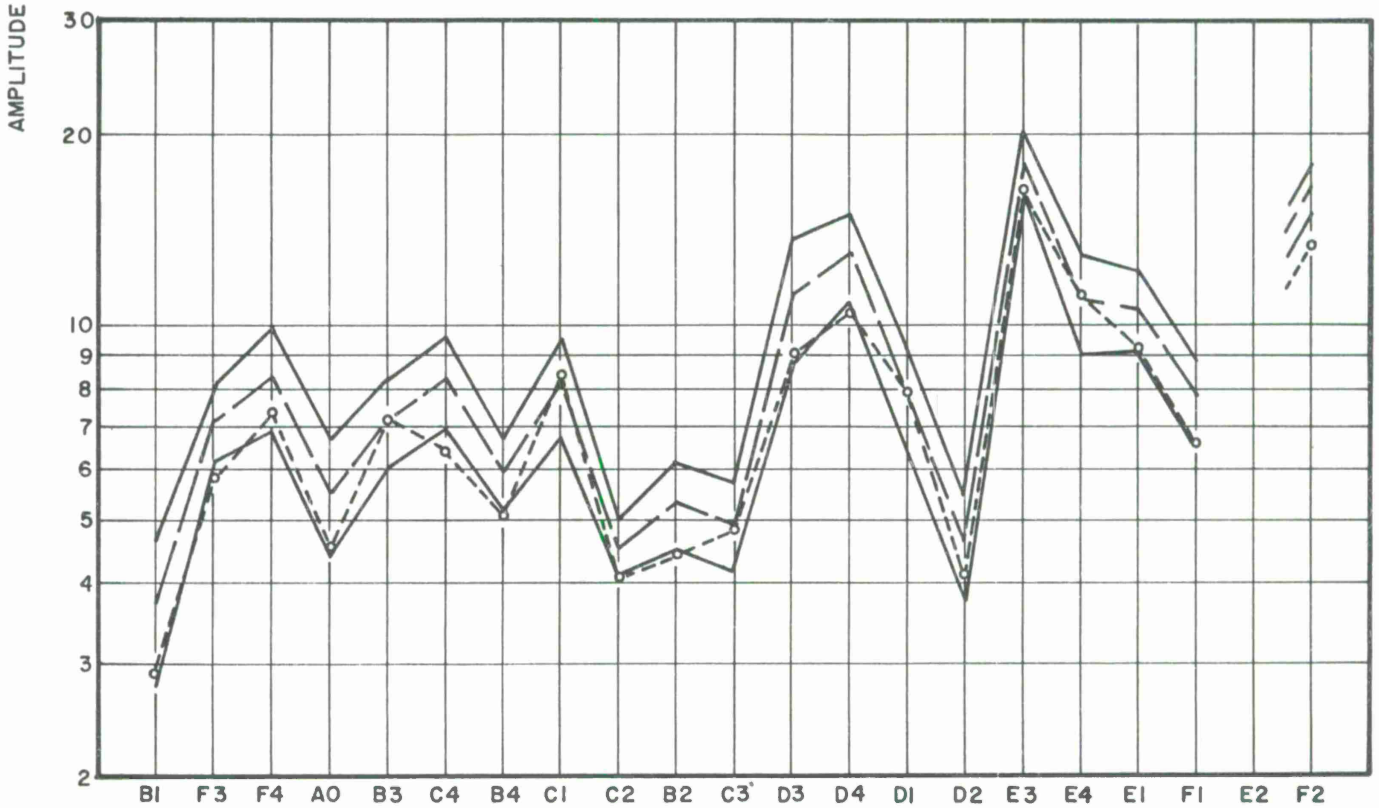
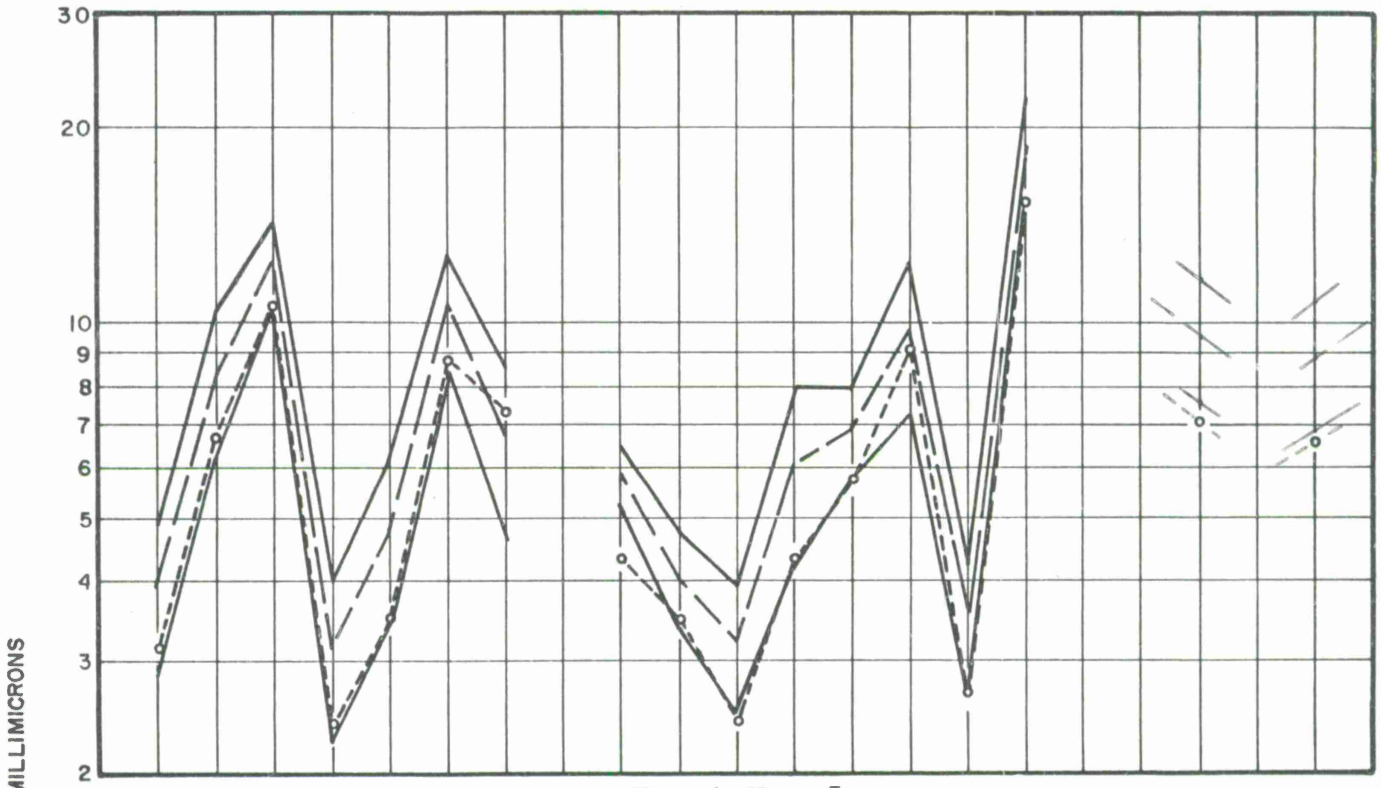
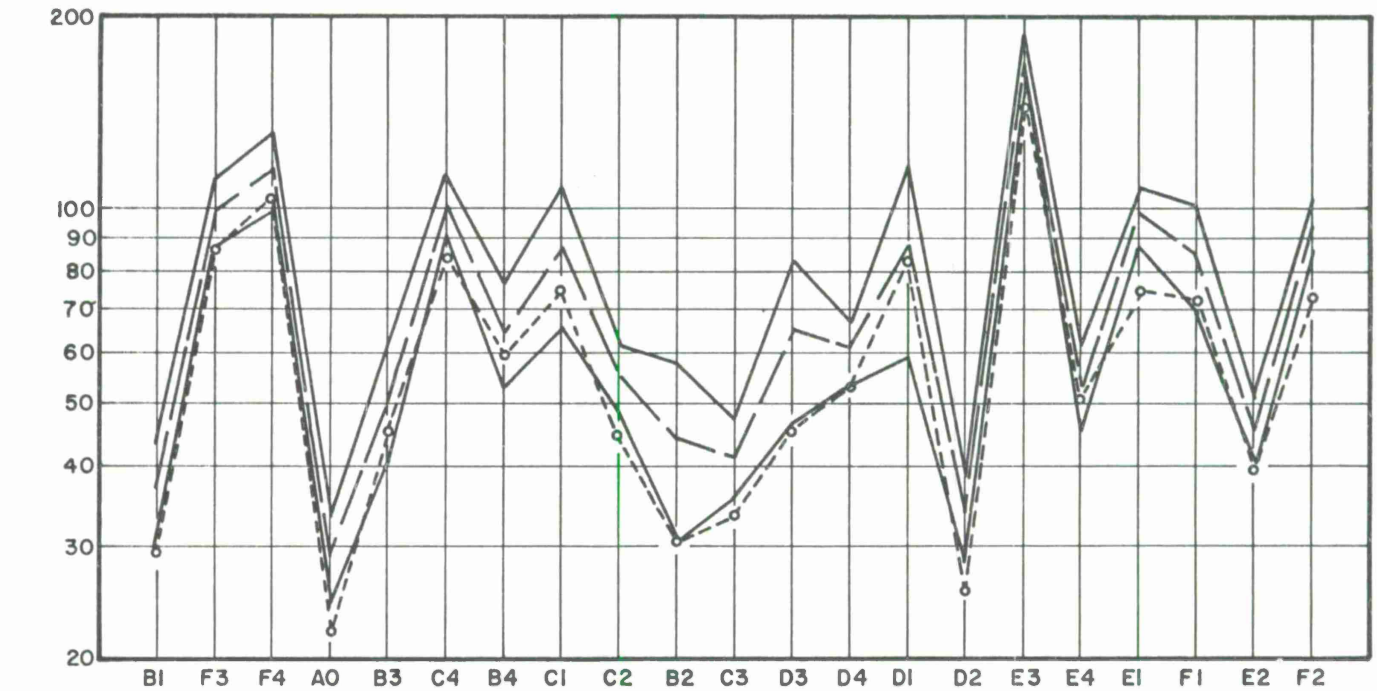
Figure 3



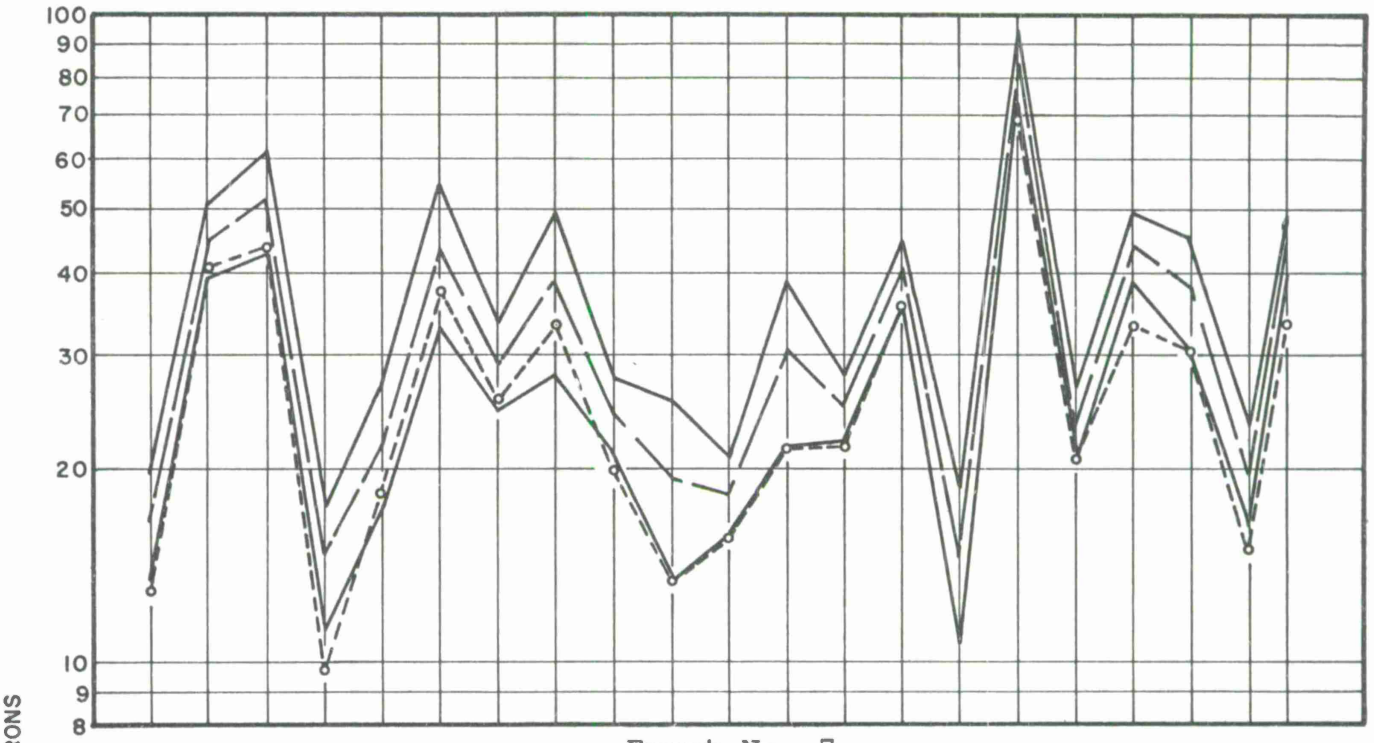
Event No. 4
Figure 4



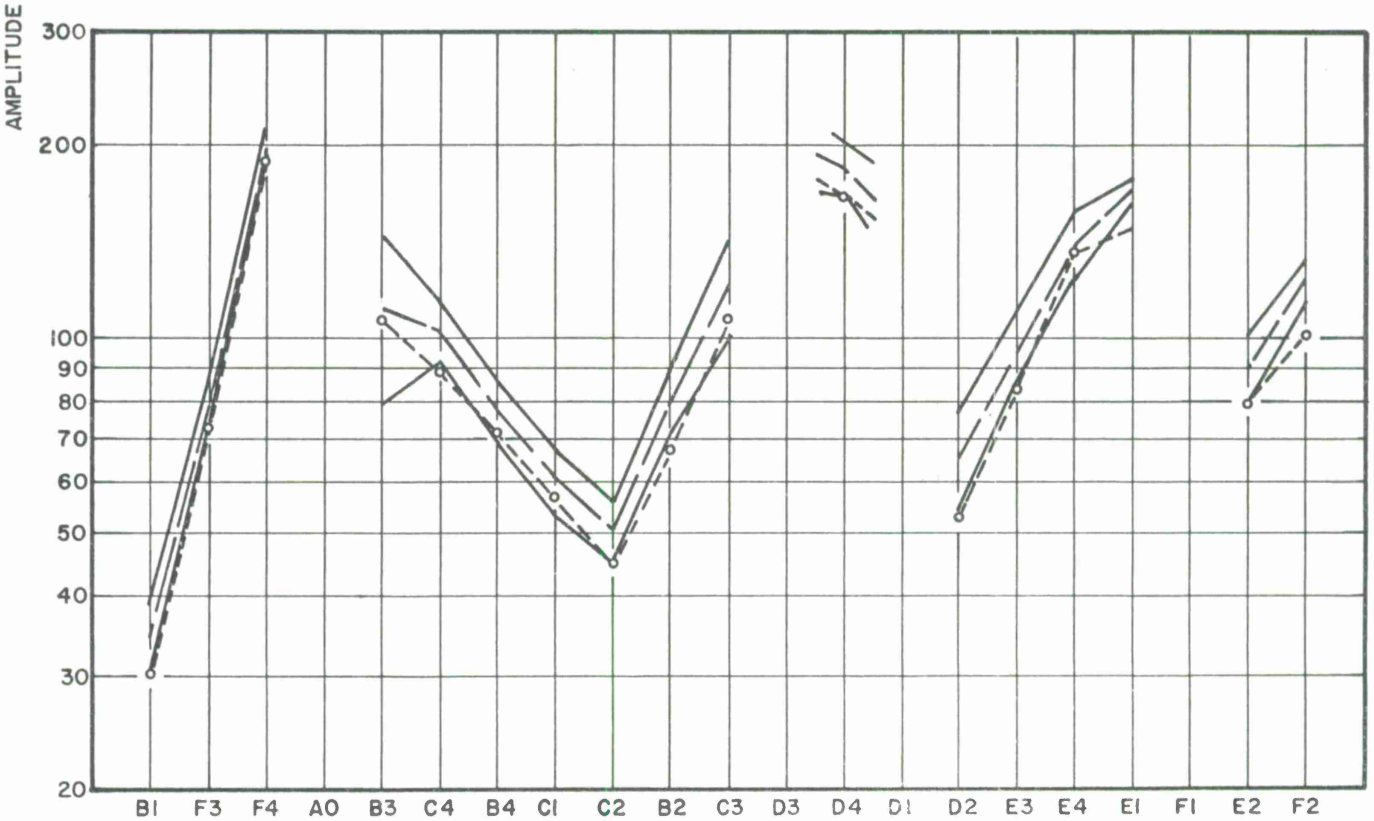
Event No. 5
Figure 5



Event No. 6
Figure 6



Event No. 7
Figure 7



Event No. 8
Figure 8

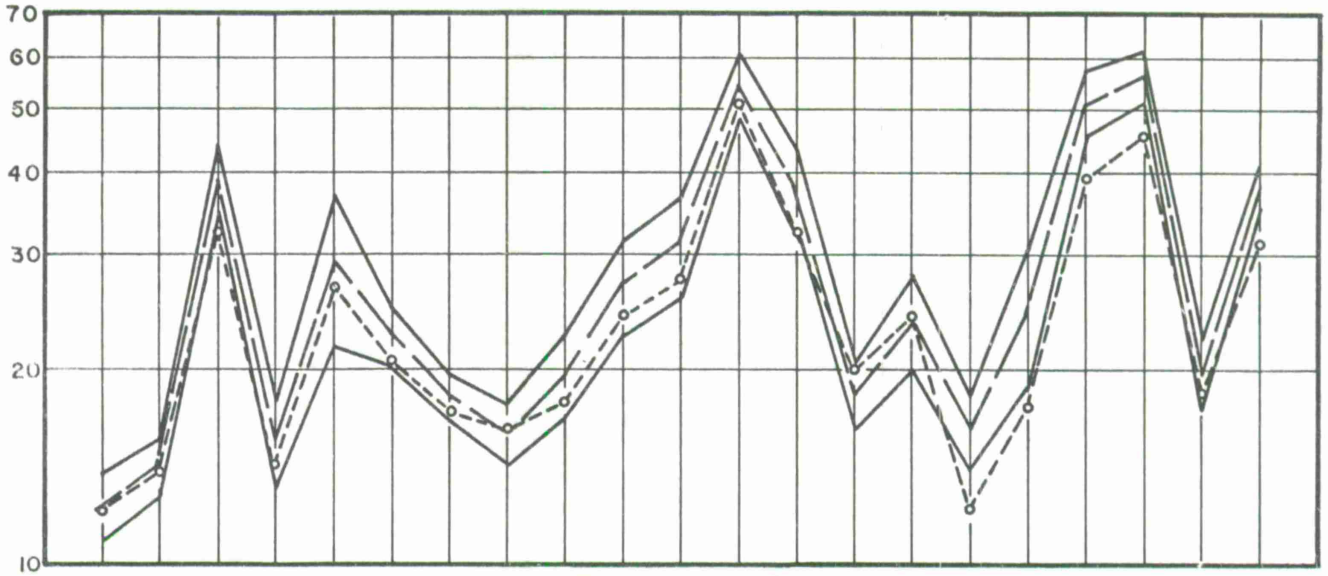


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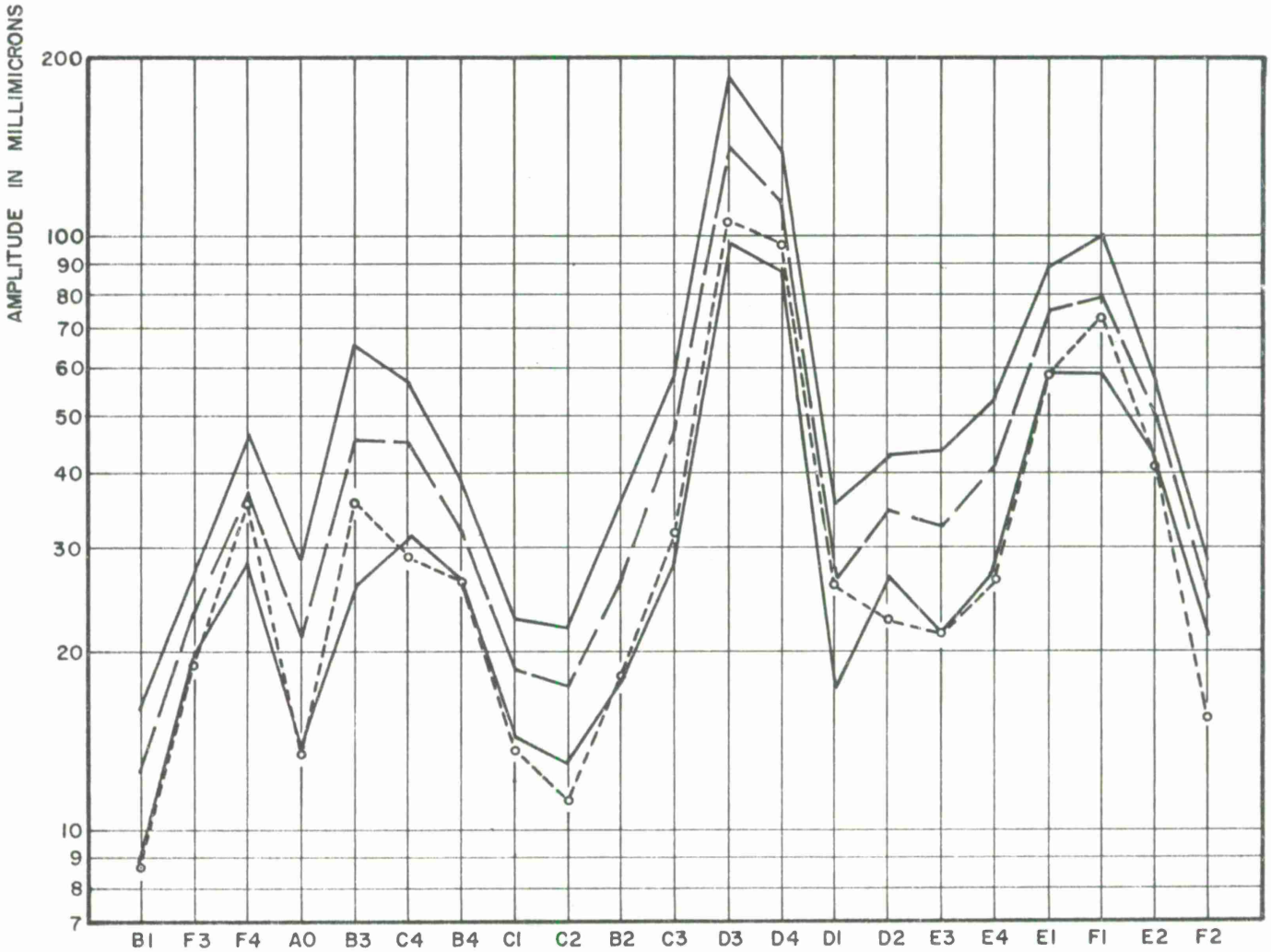
Figure 9



Event No. 10
Figure 10

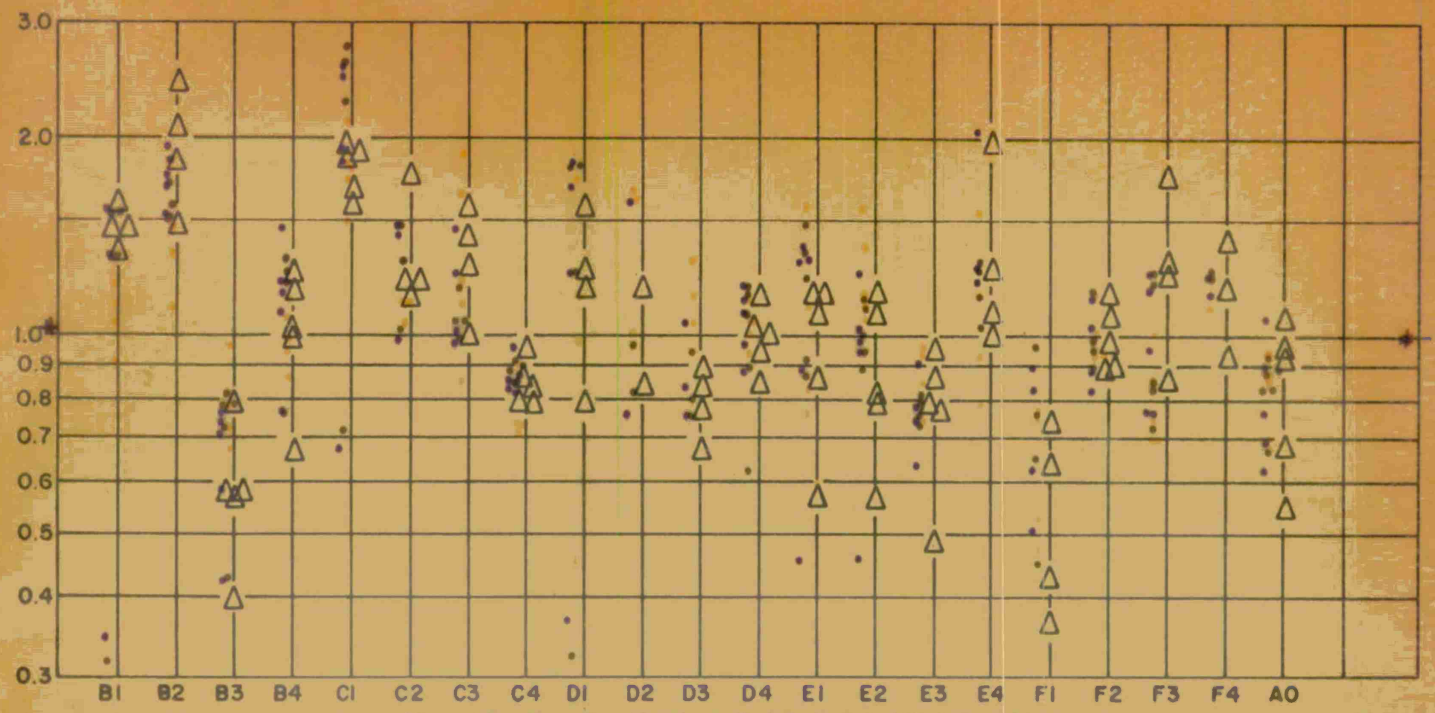


Figure 14b. Near Is., Aleutians, Peak-to-Peak Amplitude Anomalies

Using Measured Period of Individual Seismometers

Figure 13b. Near Is., Aleutians, Peak-to-Peak Amplitude Anomalies

Using Mean of Observed Periods for Each Event

Figure 12b. Near Is., Aleutians, Peak-to-Peak Amplitude Anomalies

Using an Assumed Period of 1.0 Seconds

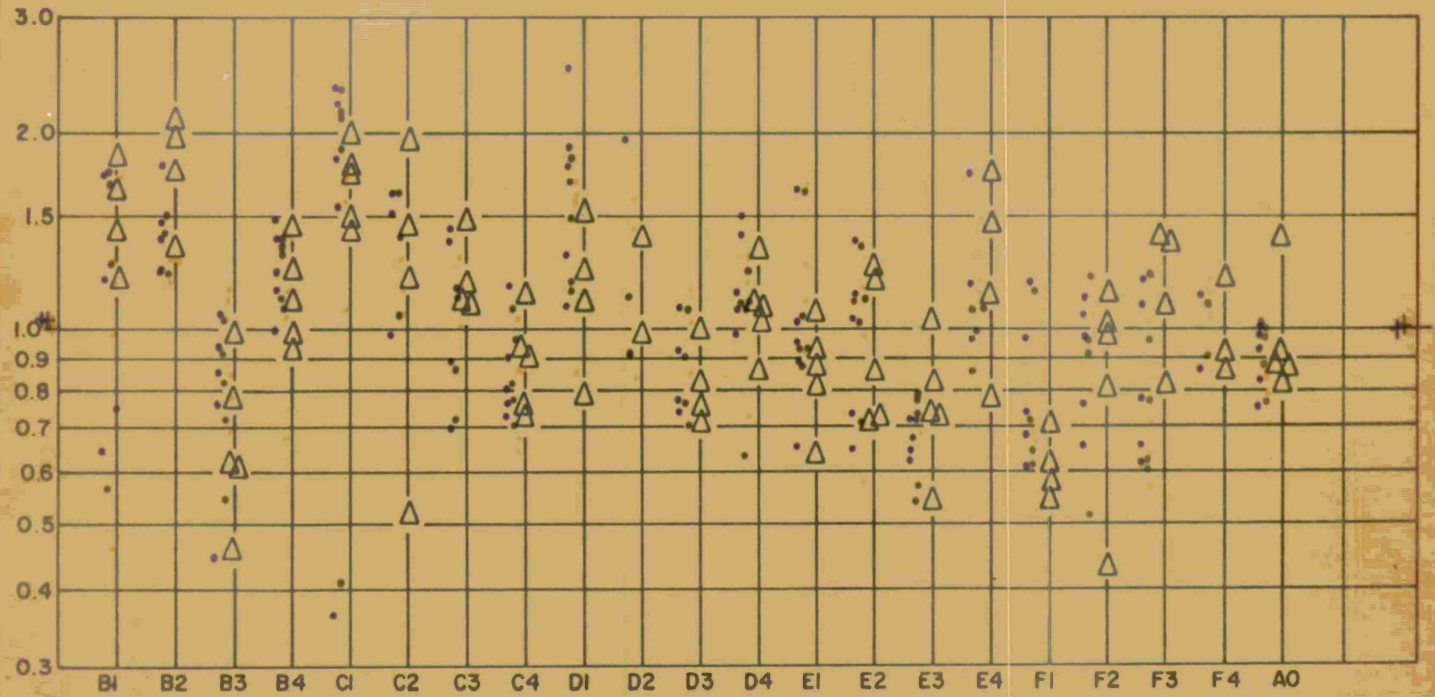


Figure 14a. Near Is., Aleutians, Zero-to-Peak Amplitude Anomalies

Using Measured Period of Individual Seismometers

Figure 13a. Near Is., Aleutians, Zero-to-Peak Amplitude Anomalies

Using Mean of Observed Periods for Each Event

Figure 12a. Near Is., Aleutians, Zero-to-Peak Amplitude Anomalies

Using an Assumed Period of 1.0 Seconds

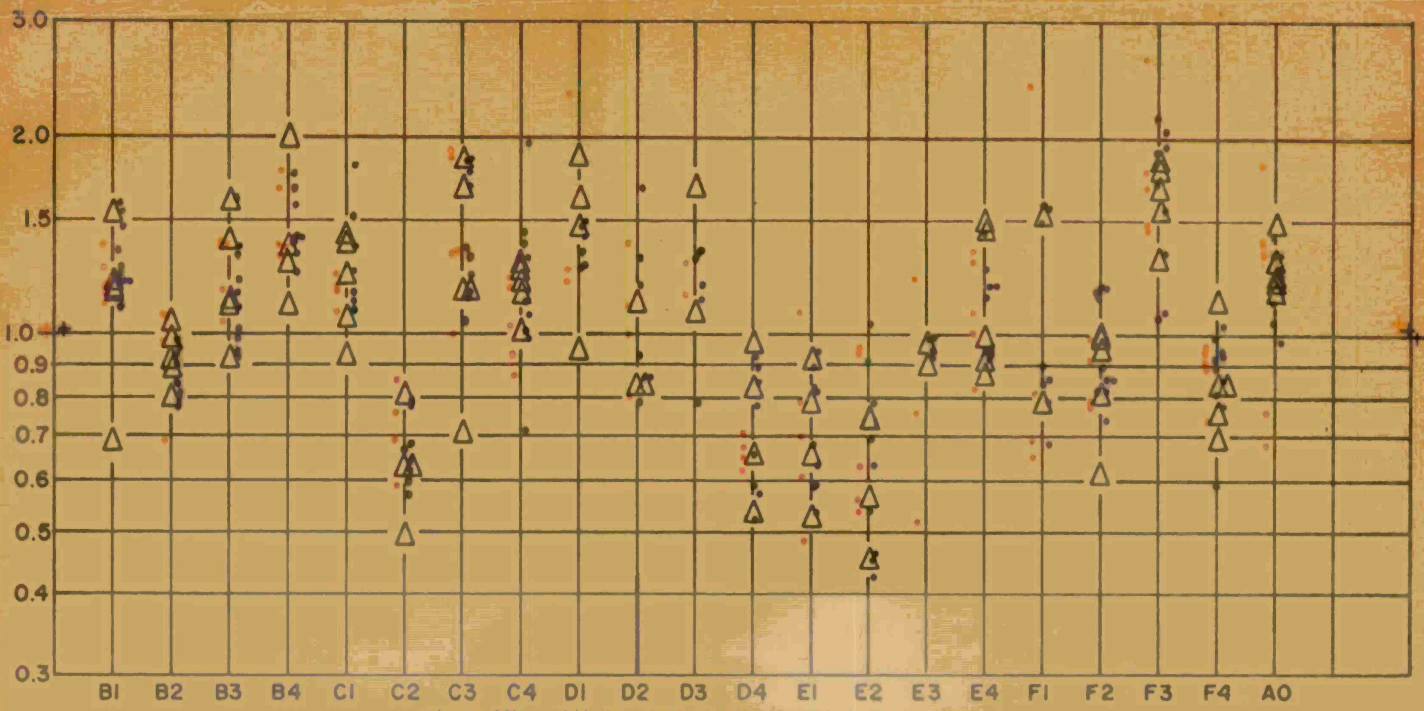


Figure 18b. Fiji Is., Peak-to-Peak Amplitude Anomalies Using Measured Period of Individual Seismometers

Figure 17b. Fiji Is., Peak-to-Peak Amplitude Anomalies Using Mean of Observed Periods for Each Event

Figure 16b. Fiji Is., Peak-to-Peak Amplitude Anomalies Using an Assumed Period of 1.0 Seconds

Figure 15b. Fiji Is., Peak-to-Peak Amplitude Anomalies Using First Cycle Observations

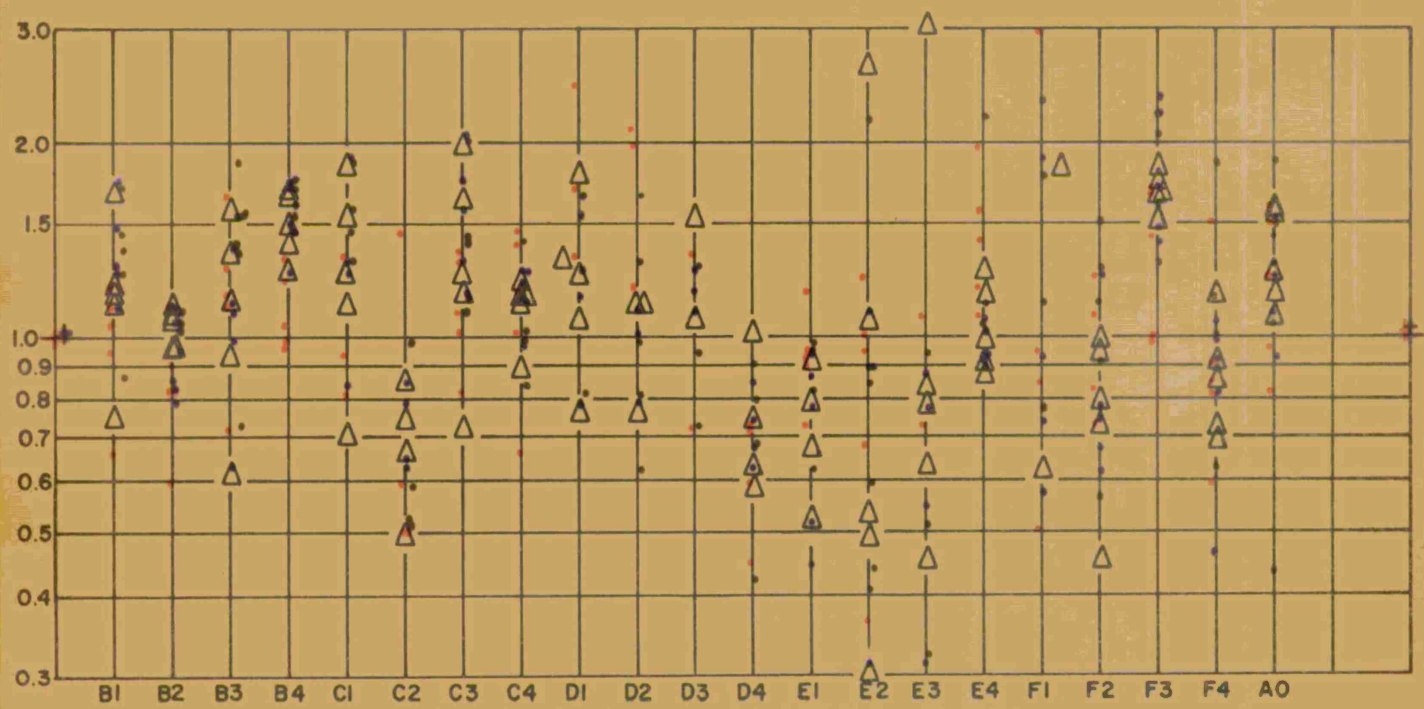


Figure 18a. Fiji Is., Zero-to-Peak Amplitude Anomalies Using Measured Period of Individual Seismometers

Figure 17a. Fiji Is., Zero-to-Peak Amplitude Anomalies Using Mean of Observed Periods for Each Event

Figure 16a. Fiji Is., Zero-to-Peak Amplitude Anomalies Using an Assumed Period of 1.0 Seconds

Figure 15a. Fiji Is., Zero-to-Peak Amplitude Anomalies Using First Cycle Observations

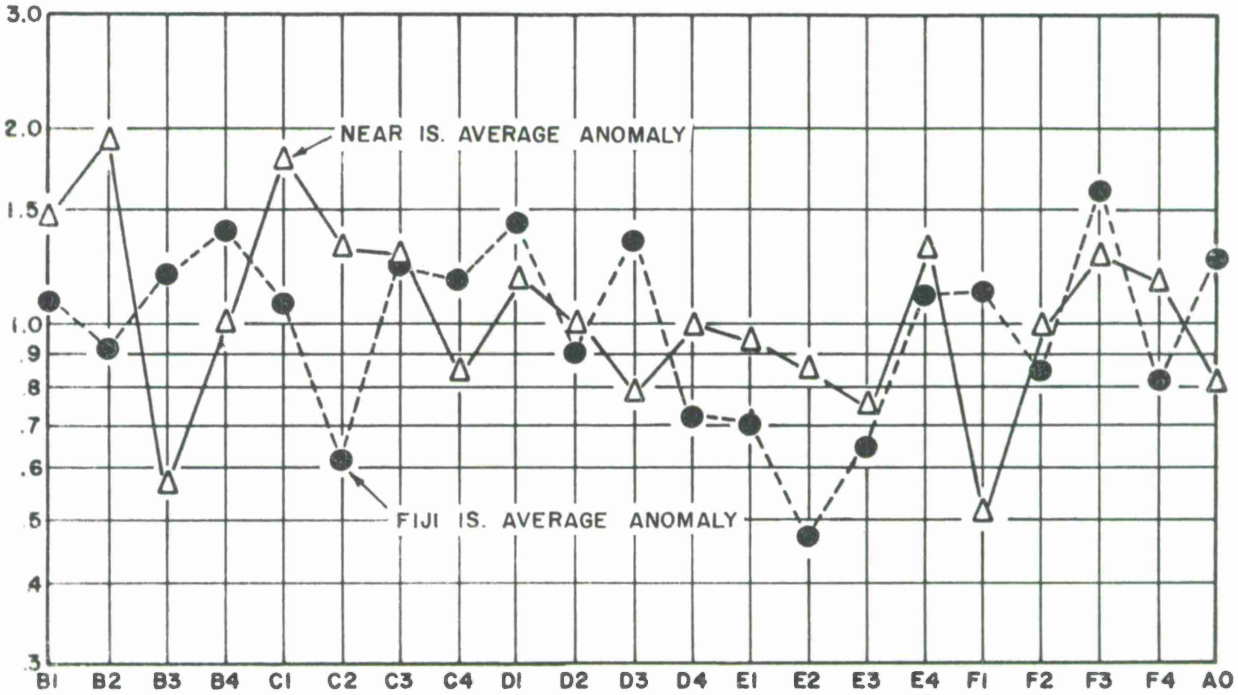


Figure 19. Average Amplitude Anomaly Curves for Near Is., Aleutians and Fiji Is. Events

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13. ABSTRACT

The effects of measurement techniques, of sensor used, and of distance-azimuth on computed amplitude anomalies at LASA are discussed.

14. KEY WORDS

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