

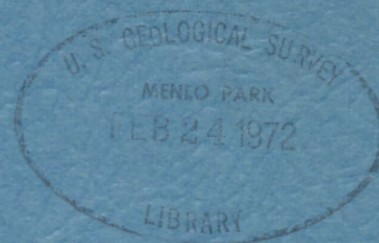
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GEOLOGICAL SURVEY
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ANALYSIS OF SEISMIC NOISE AT THE GEYSERS
GEOHERMAL AREA, CALIFORNIA.

by

H. M. Iyer

Open file report
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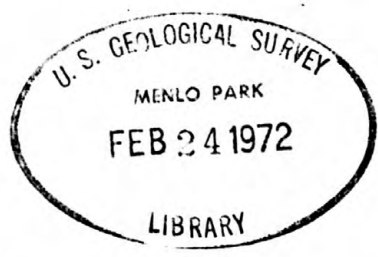
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Analysis of Seismic Noise at The
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Analysis of Seismic Noise at The Geysers Geothermal Area, California

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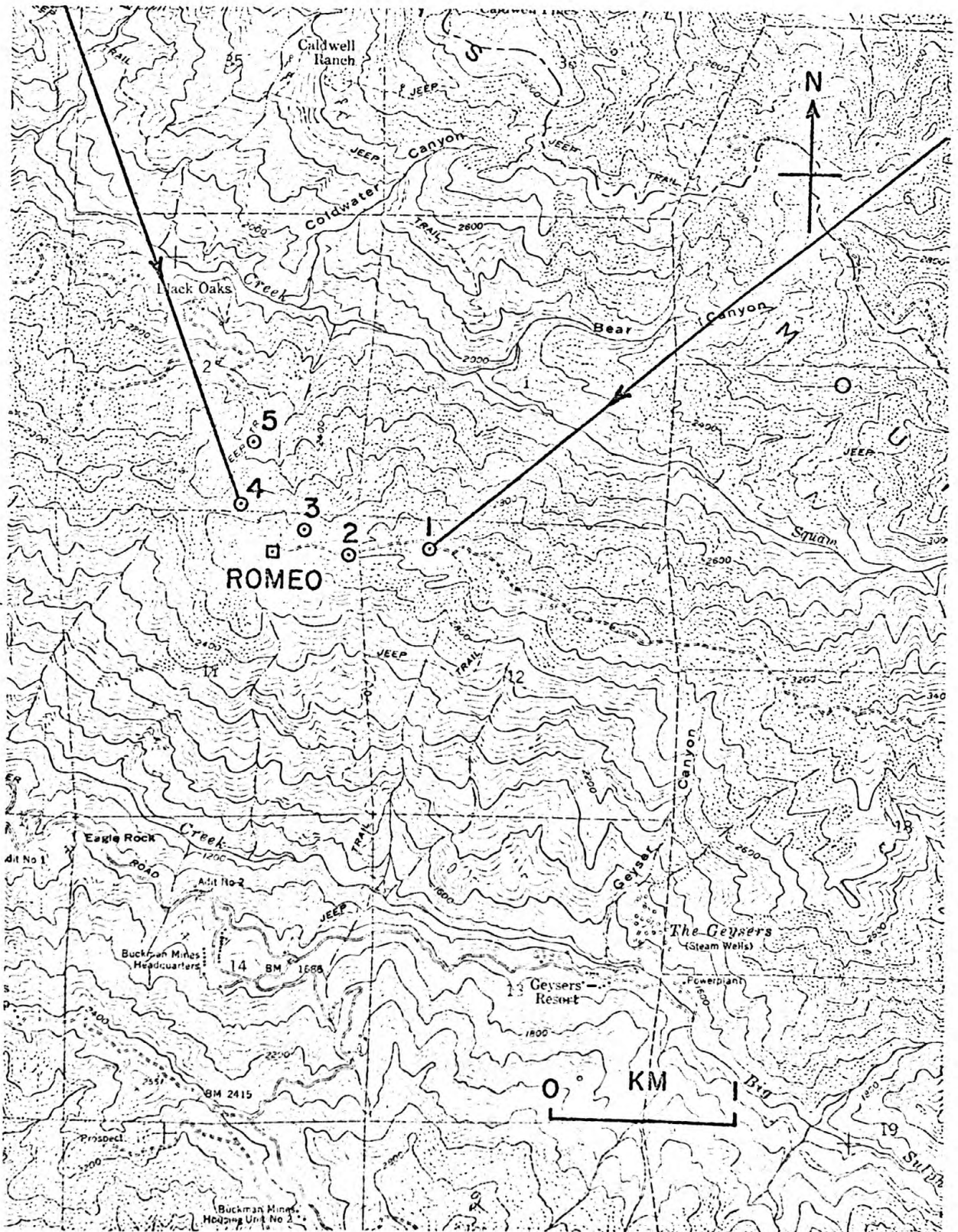
ABSTRACT

The amplitude level and velocity of seismic noise at The Geysers area in California are different from the average pattern of background noise. The predominant peak in the spectrum of noise occurred at about 1 Hz. This noise was highly coherent over a distance of about 1 km, showed episodic bursts of energy, and appeared to come from the general region of major geothermal activity in the region. The predominant noise velocities were in the 4 to 7 km/sec range.

INTRODUCTION

The main purpose of the experiment was to assess the feasibility of measuring the direction of travel and velocity of seismic noise at The Geysers, California. Observations were made using an approximately L-shaped array of five EV-17 (500 ohms) geophones spaced about 0.3 km apart. A description of the seismic system is given by Jackson, Stewart, and Pakiser (1963). At present, only a sample taken around midnight on April 3, 1971, when the wind was practically zero, has been analyzed. Figure 1 shows the location and configuration of the array. We could not achieve a perfect L-shape because of the rugged topography. The topography also limited the aperture of our array to about 1 km.

Figure 1. Location and configuration of the seismic array. Dots within circles indicate instrument positions. Dot within the square is the location of the seismic truck ROMEO. The azimuthal distribution of seismic noise lies within the region bounded by the two lines.



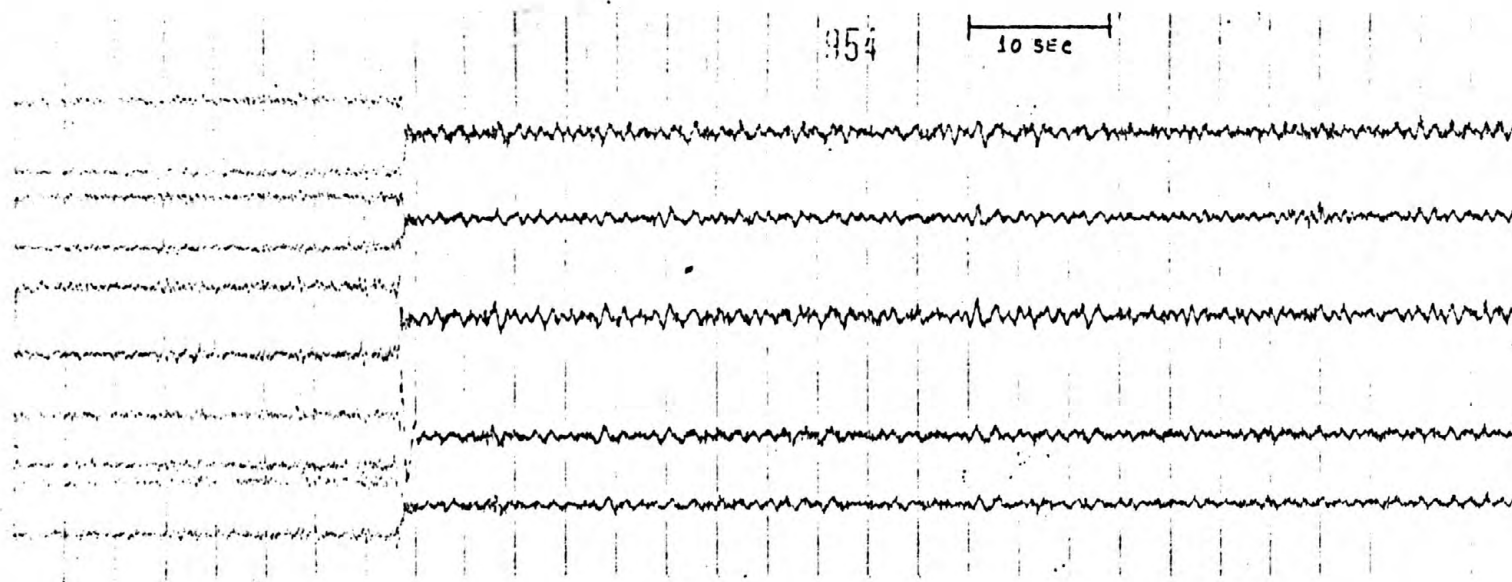


Figure 2. Sample playback of unfiltered noise data. The instrument numbers from top to bottom are in sequence from 1 to 5. The calibration signal of the left has frequency of 10 Hz and r.m.s. amplitude of 6.25 μ v.

DATA

Figure 2 shows a sample playback of the data together with a 6.25 μv (r.m.s.) 10 Hz calibration signal (on the left). Note that the predominant signal is at a frequency of about 1 Hz, that it is highly correlated across the array, and that it has episodic bursts of energy. The peak-to-peak ground-motion associated with the burst is about 30 millimicrons. (Seismic system response of 4.0 volts/inches/second assumed).

Figures 3 and 4 show playbacks of the data (at two speeds) through a band-pass filter of 0.5-3.0 Hz. The highly coherent nature of the noise and the bursts of energy are very obvious in these figures.

A fast playback of the magnetic tape data recorded around midnight on April 3, 1971 was used in the study. The playback speed (which was 2-1/2 times that used in figure 4) enabled timing the coherent peaks and troughs to an accuracy of not less than 1/50 second. A 0.5-3.0 Hz band-pass filter was used in the playback system. Readings of arrival times were made on 101 coherent peaks and troughs, irrespective of whether they formed a burst of energy or not. During the reading, it was quite obvious that several azimuths and velocities were involved in the wave trains. In general, readings belonging to specific wave groups showed similar time differences between instruments.

RESULTS

Wave velocities and azimuths were computed by fitting each set of readings to a plane wave-front using the method of least-squares.

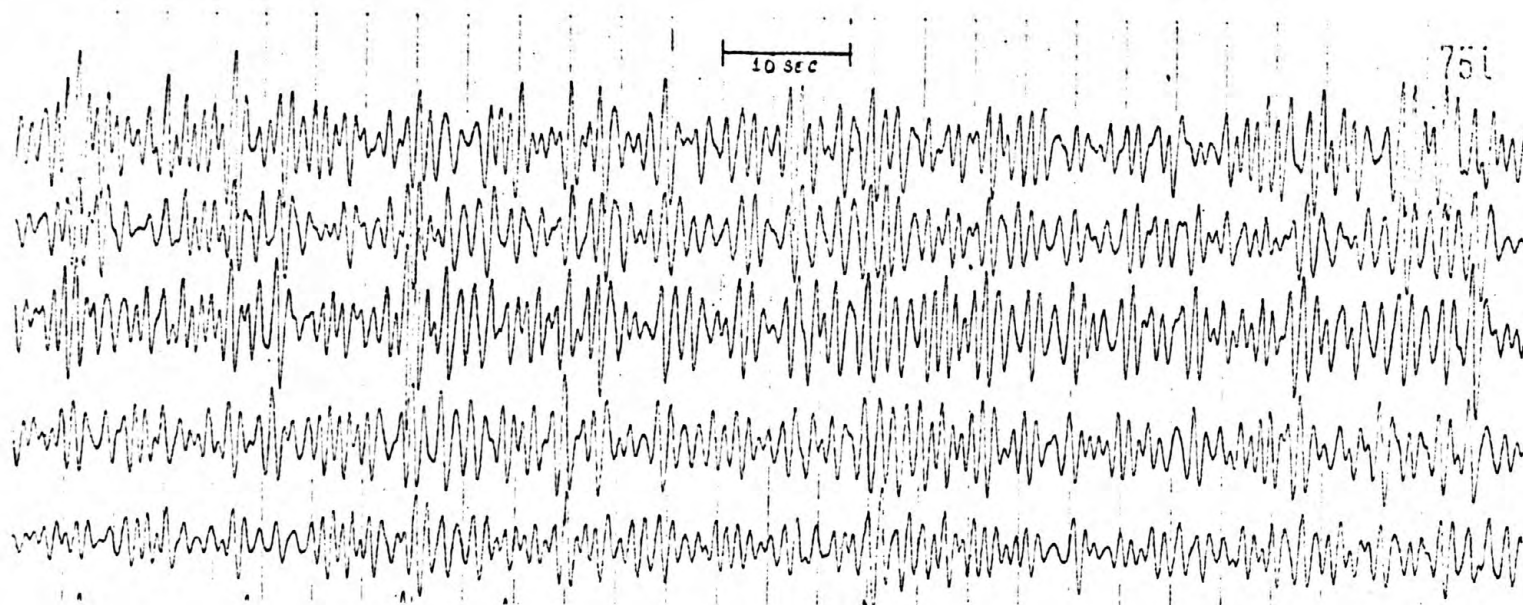


Figure 3. Playback through band-pass filter, 0.5 - 3.0 Hz.

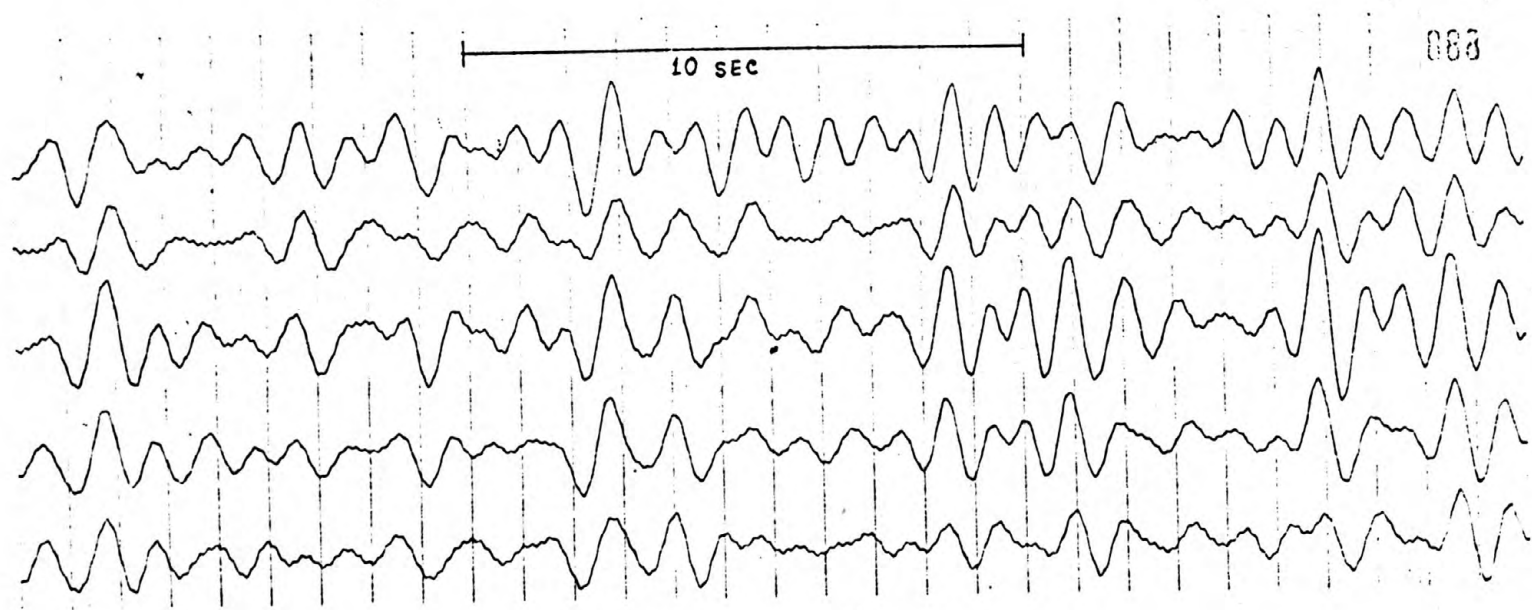
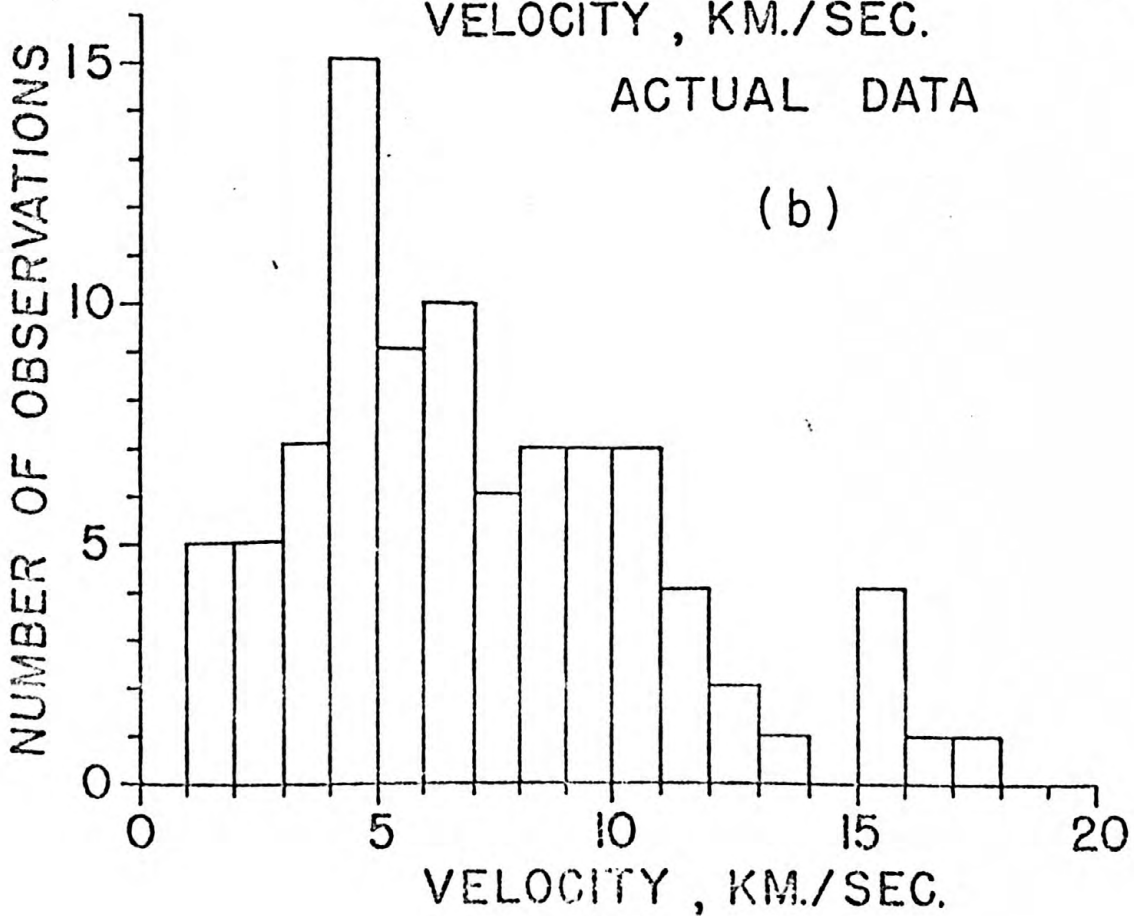
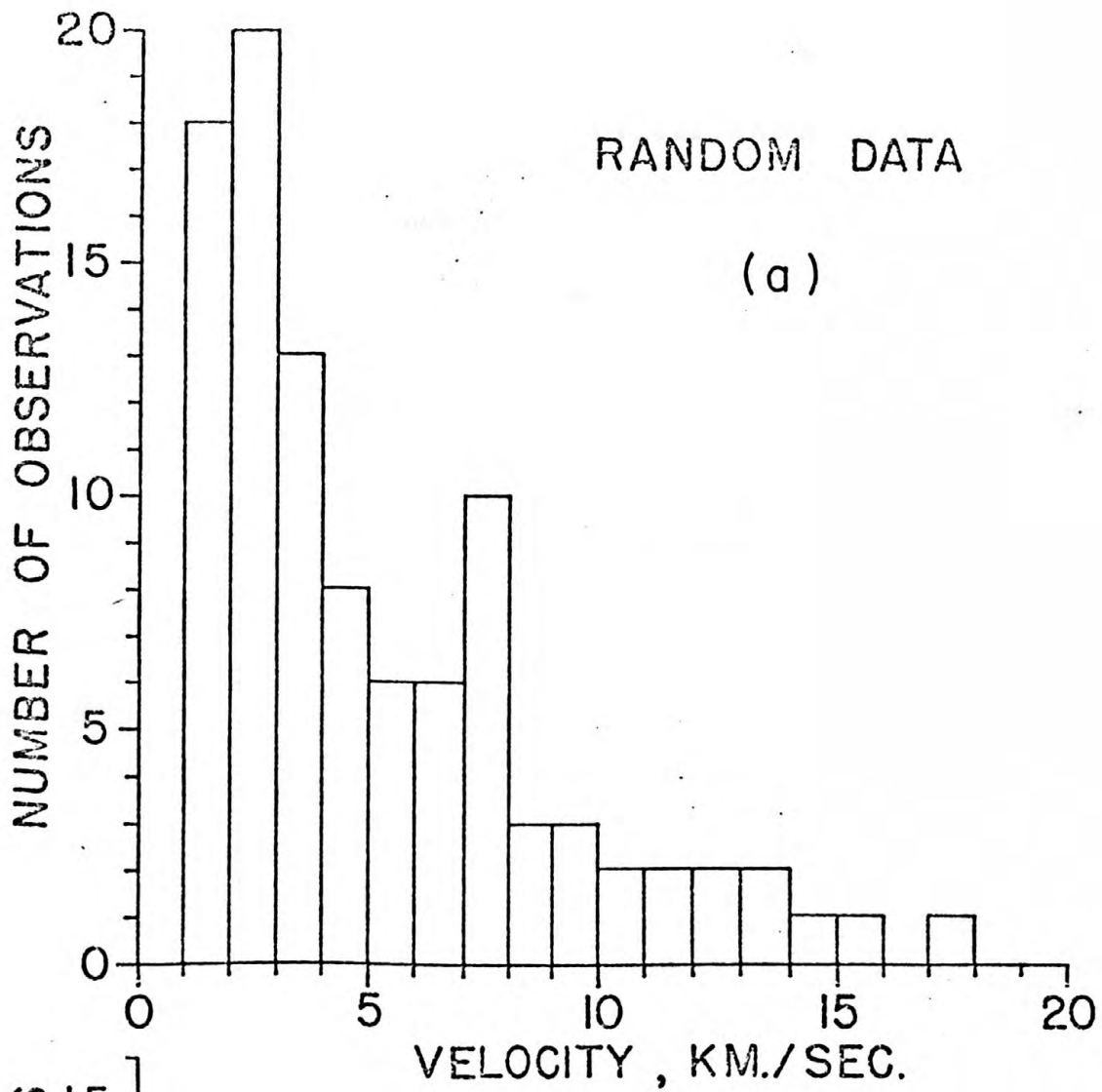


Figure 4. Fast playback through band-pass filter, 0.5 - 3.0 Hz.

Figure 5. Frequency distribution of velocities, (a) using random set of arrival-time data, and (b) using observed arrival-time data.

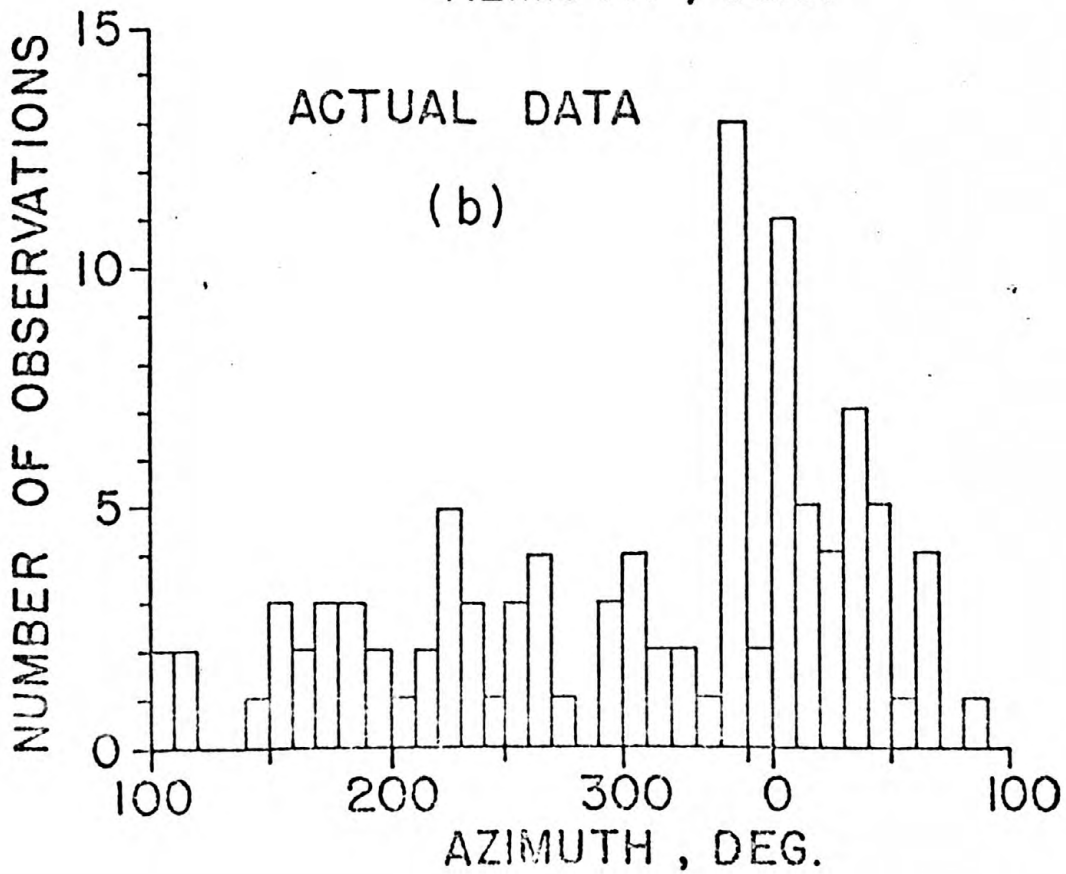
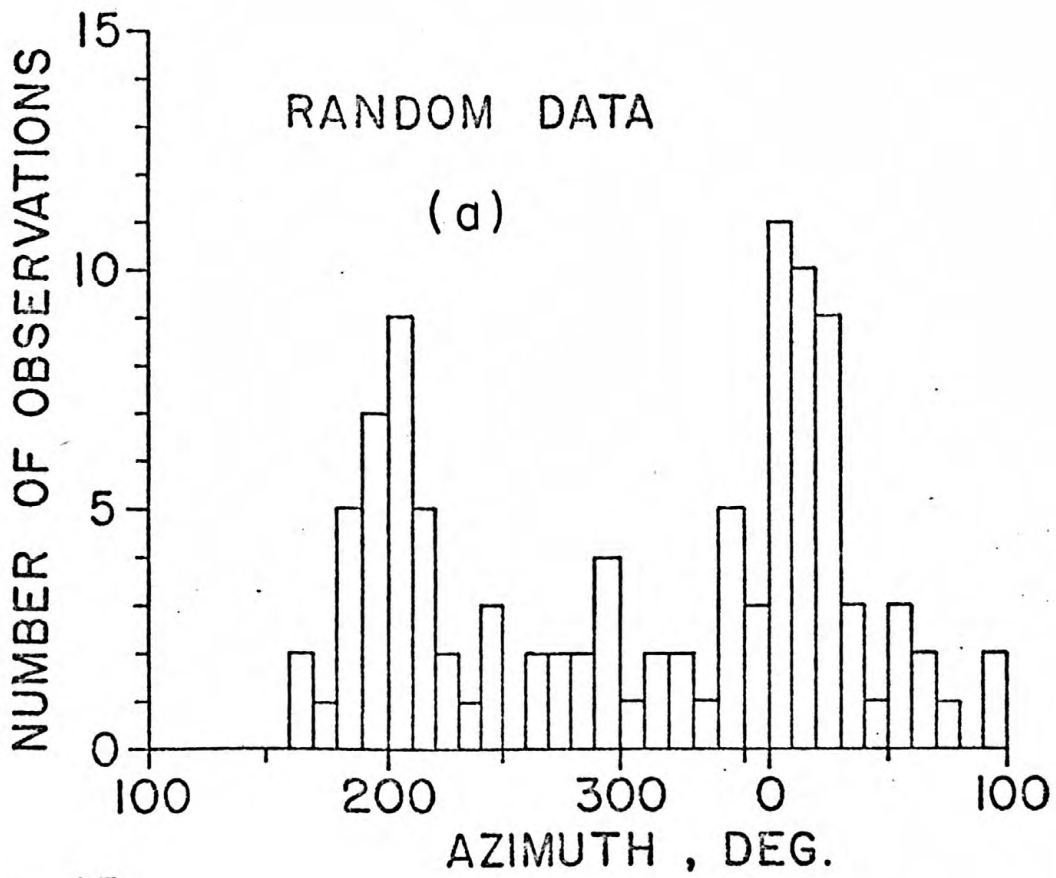


The statistical distribution of velocities (fig. 5b) shows that about 35 percent of the values lie in the range of 4 to 7 km/sec. About 45 percent of the azimuths (clockwise from north) lie in the range of 340 to 50 degrees (fig. 6b).

RELIABILITY OF THE RESULTS

The scatter in velocity and azimuth distributions discussed above are caused by the small size and configuration of the array used in this study. However, it can be shown that in spite of the limitations imposed by the array, some confidence can be placed on the observed peaks in the velocity and azimuth distributions. Time differences between instrument #1 and each of the other instruments (τ_{1j}) were computed for the 101 sets of observations. The means and standard deviations of τ_{1j} for each instrument ($j = 2,3,4,5$) were calculated, and with these constraints a random set of 101, τ_{1j} values were generated. Following the same least-squares procedure used in analyzing the real data, velocities and azimuths were computed for the random traveltimes. Their distributions are shown in figures 5a and 6a, respectively. The "random" velocities peak in the range of 1 to 3 km/sec, and the "random" azimuths show two peaks around 200° and 360°, respectively. At first, it may seem strange that random arrival times should give rise to non-random velocity and azimuth distributions, but this is a direct result of the dimensions and geometry of the array. The simplified explanation is as follows: In each set of random data there is a high probability that at least one arrival time will be large enough to predominate and to give a bias towards a low

Figure 6. Frequency distribution of azimuths (counterclockwise from north), (a) using random set of arrival-time data, and (b) using observed arrival-time data.



apparent velocity. Because the large arrival time can be positive or negative, the azimuths are biased towards 0° or 180° . The results given by the real data are significantly different from those given by the random data; hence there is a good probability that the measured velocity of seismic noise at The Geysers is in the 4 to 7 km/sec range and that the waves approach the array from the north. A better index for the reliability of our measurements is in the distribution of time residuals at the five instruments of the array. Residuals are defined as the time difference between the observed arrival times and those predicted by least-squares. They were calculated for each of the instruments using the real data and random data. The frequency distribution of the 101 values at each of the instruments is shown in figures 7 to 11. The distribution of residuals based on the random data set is shown at the top of these figures and that based on real data is shown at the bottom. At all the instruments, the real data set clearly gives a tight distribution of residuals indicating a good least-squares fit. The real-data residuals indicate discrete average-station residuals at each of the instruments. Multiple iteration to obtain better velocity values using these average-station residuals did not show any significant change in the velocity and azimuth values. This again results from the inadequate dimensions of the array in relation to the measured noise wavelength.

INTERPRETATION

The results from this brief study of seismic noise at The Geysers are encouraging, and further study seems warranted. The following

Figure 7. Frequency distribution of residuals at Instrument #1,
(a) using random set of arrival-time data, and (b) using
observed arrival-time data.

INSTRUMENT # 1

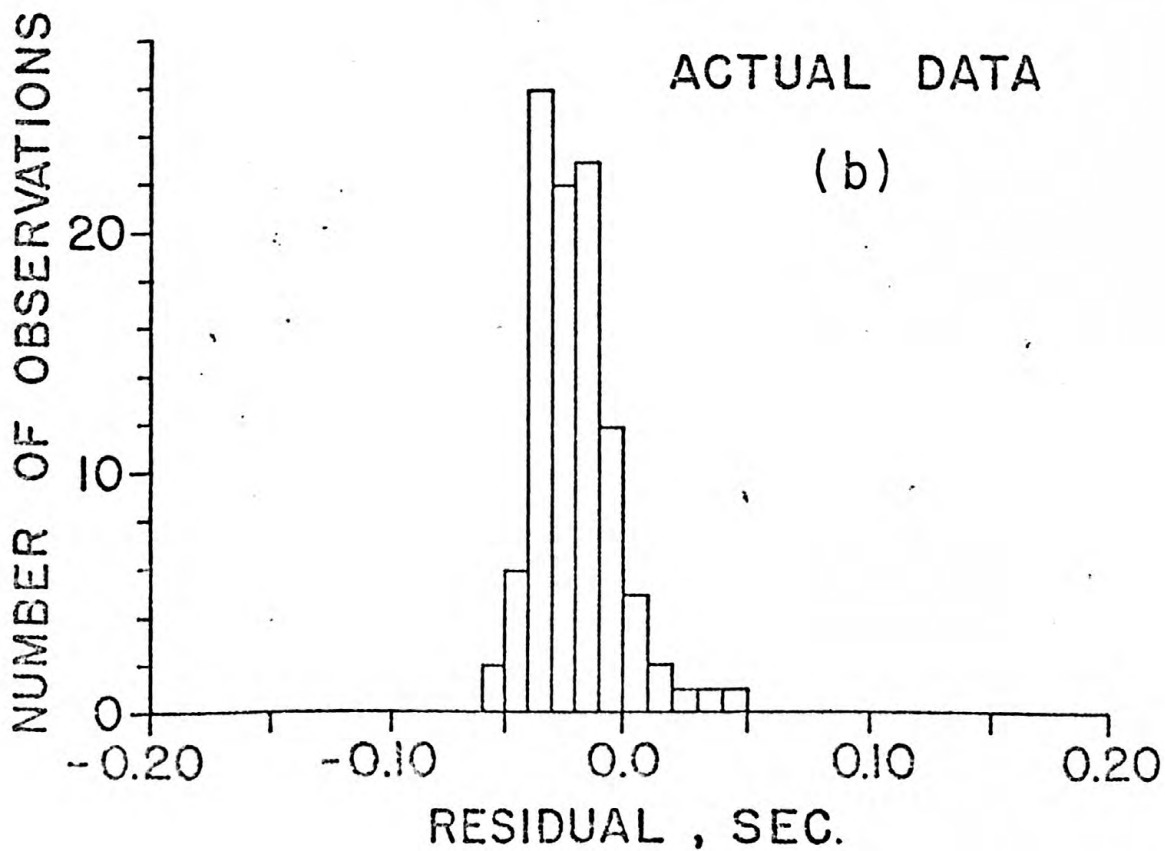
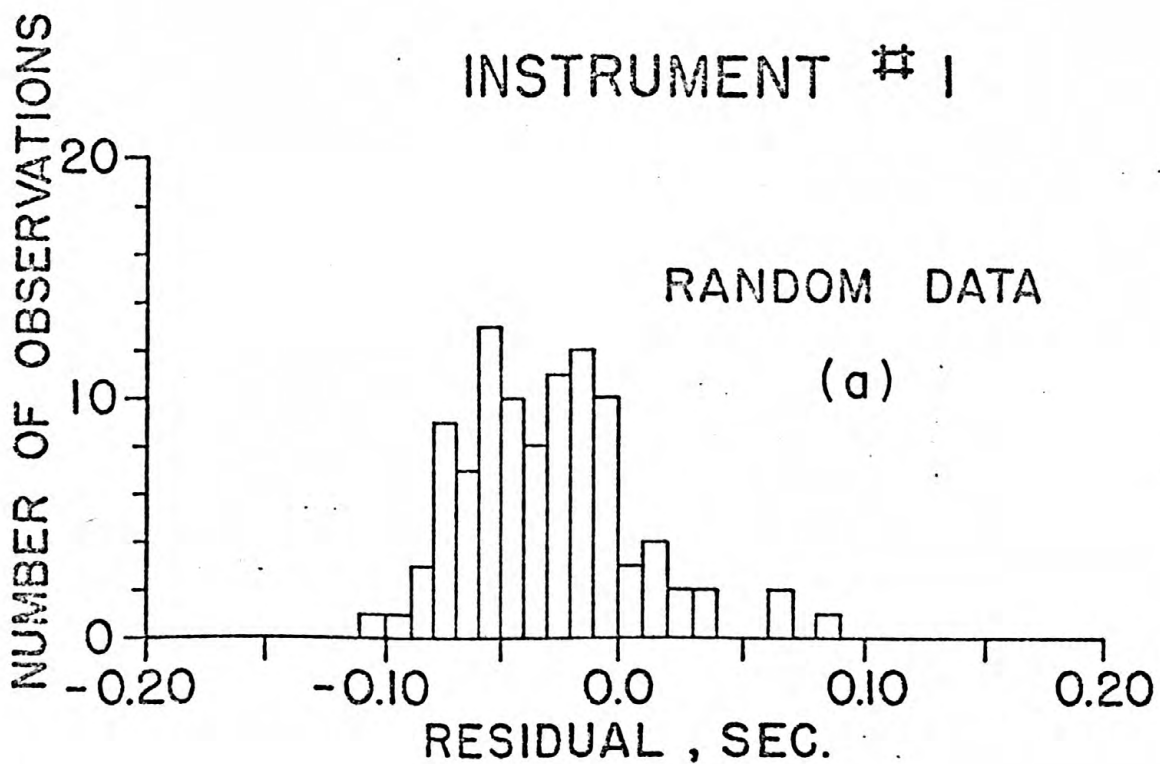


Figure 8. Frequency distribution of residuals at Instrument #2,
(a) using random set of arrival-time data, and (b) using
observed arrival-time data.

INSTRUMENT # 2

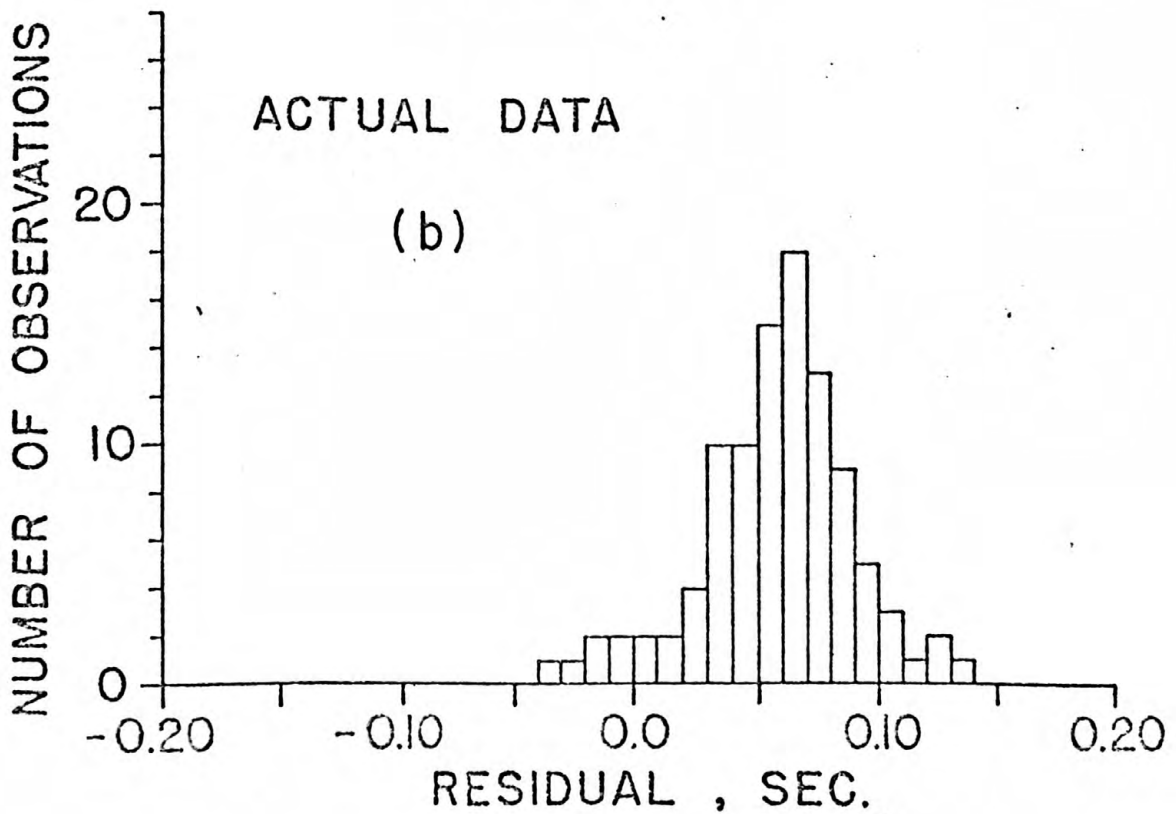
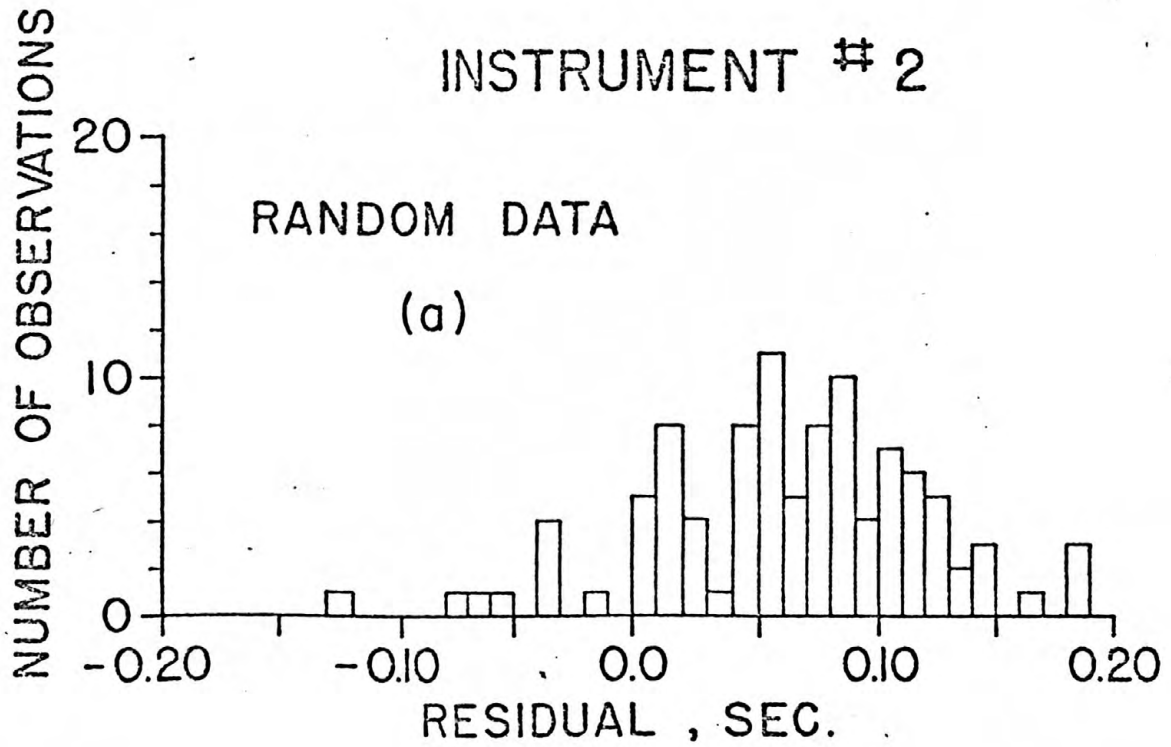


Figure 9. Frequency distribution of residuals at Instrument #3
(a) using random set of arrival-time data, and (b) using
observed arrival-time data.

INSTRUMENT # 3

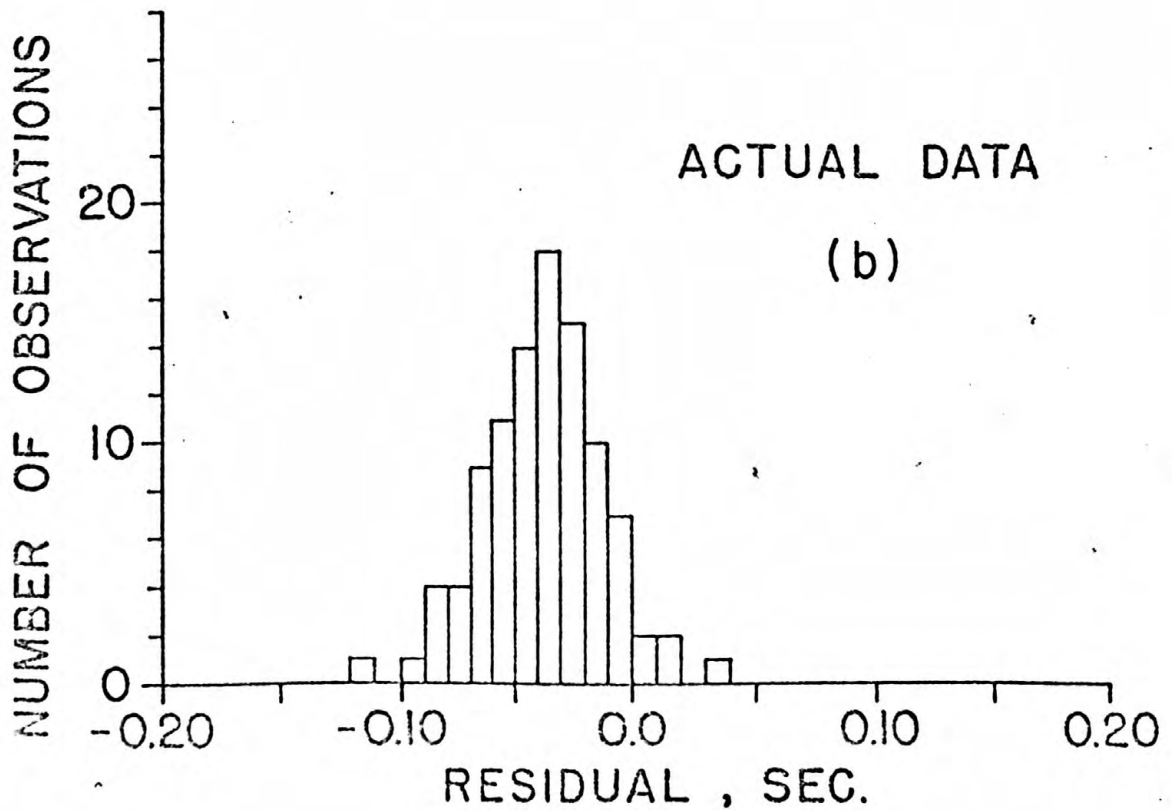
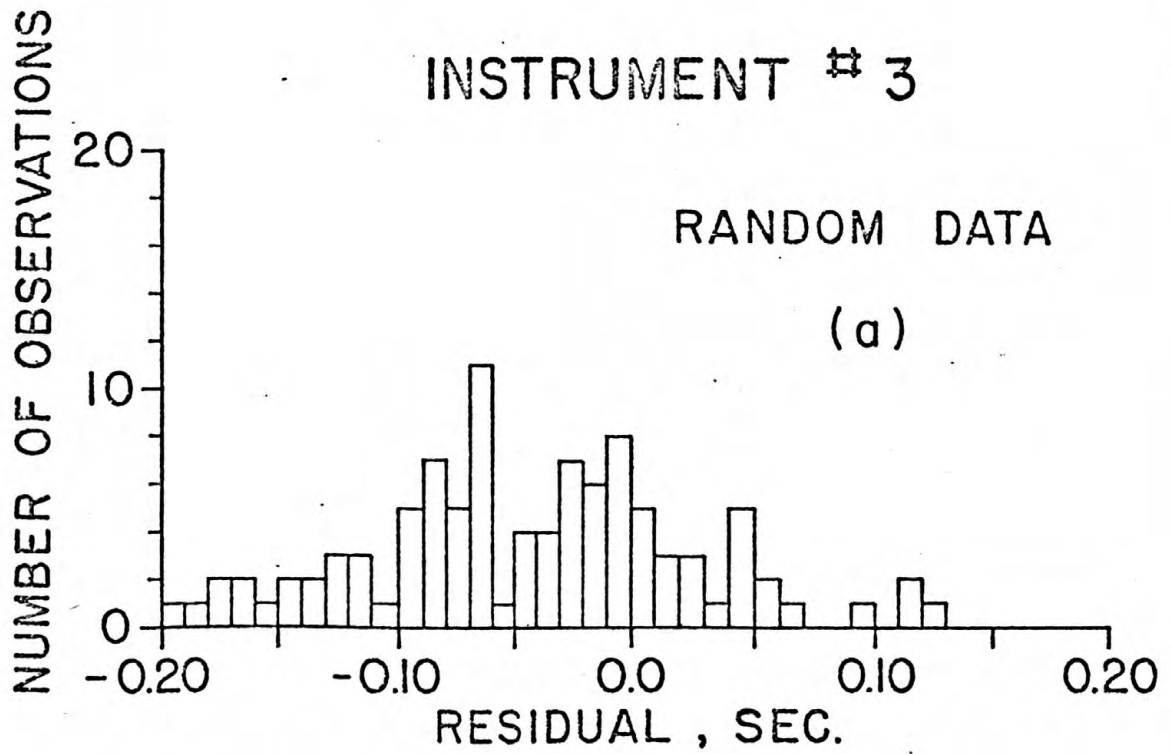


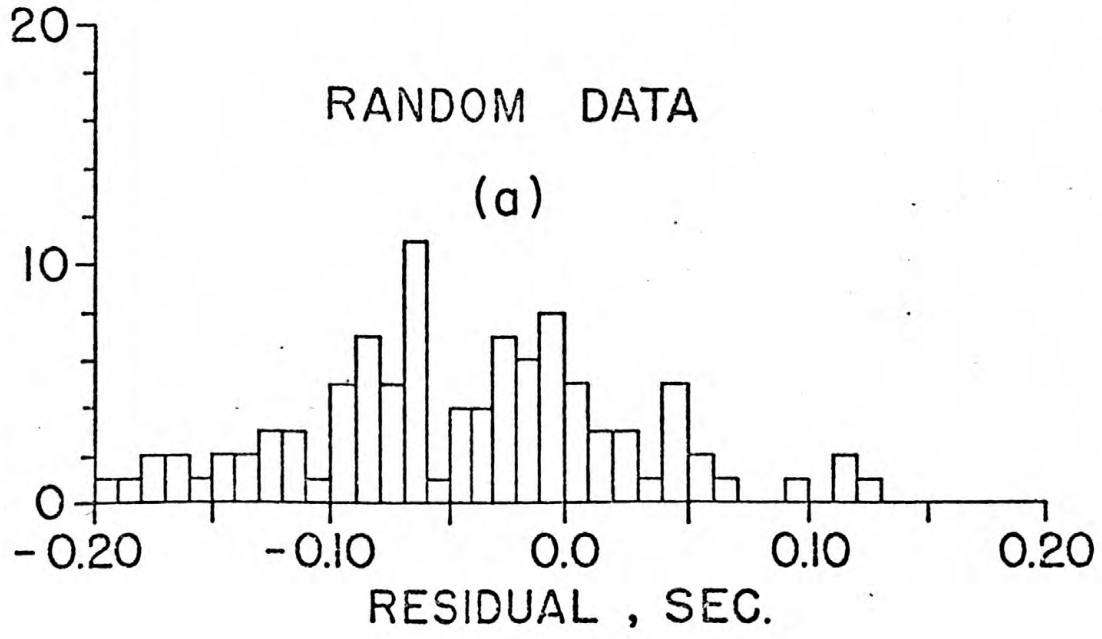
Figure 10. Frequency distribution of residuals at Instrument #4
(a) using random set of arrival-time data, and (b)
using observed arrival-time data.

NUMBER OF OBSERVATIONS

INSTRUMENT # 4

RANDOM DATA

(a)



NUMBER OF OBSERVATIONS

ACTUAL DATA

(b)

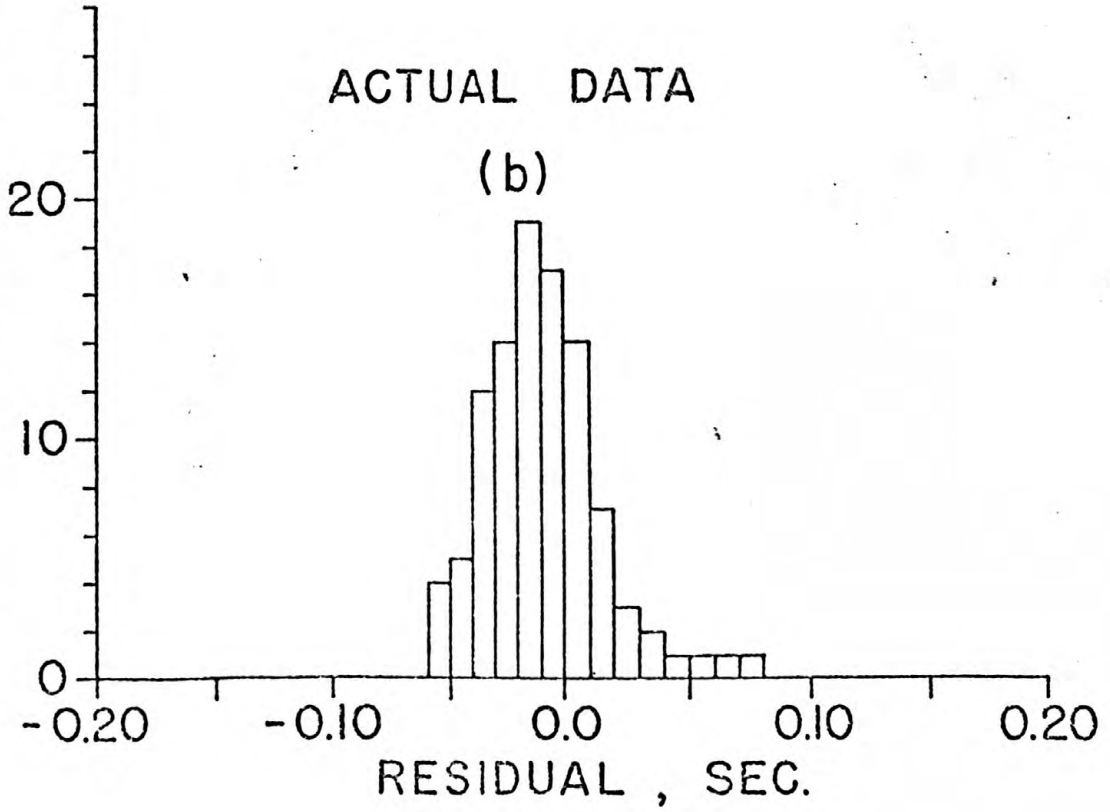
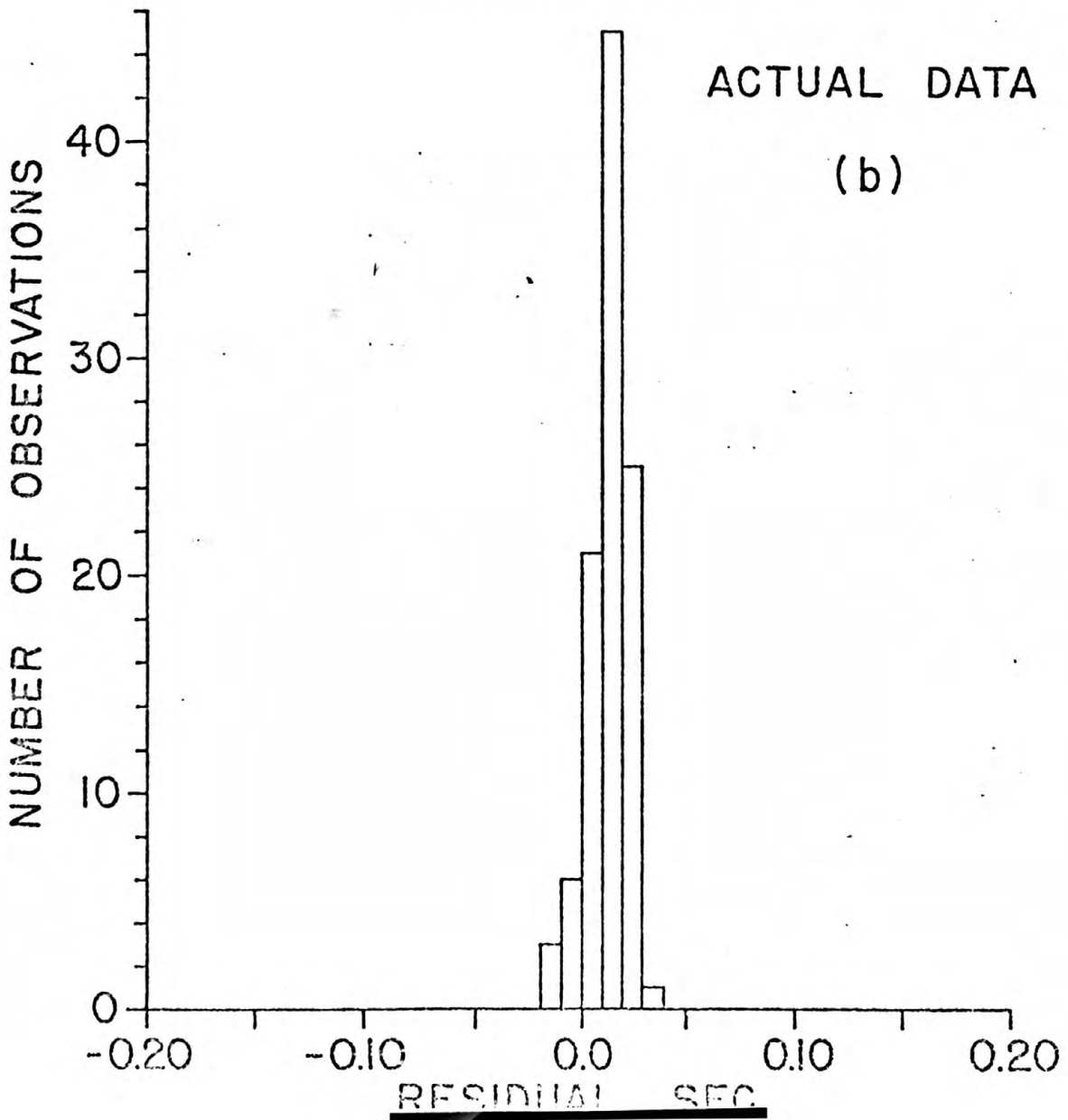
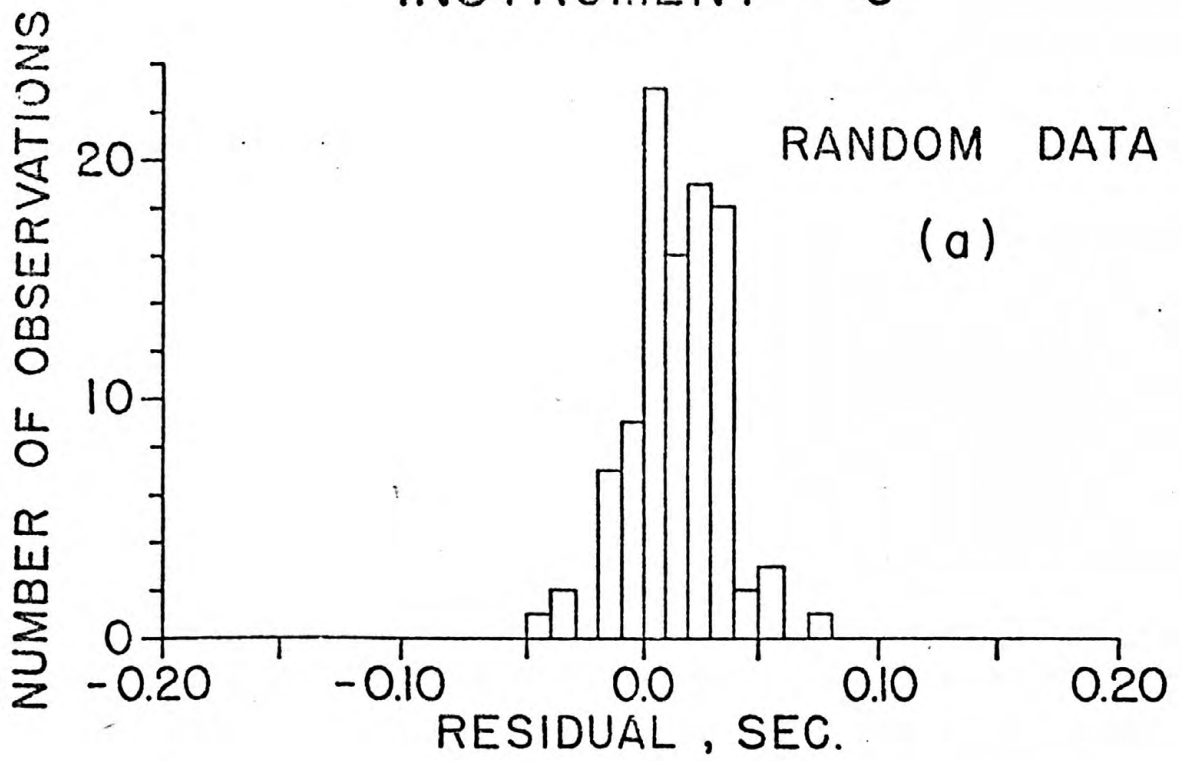


Figure 11. Frequency distribution of residuals at Instrument #5
(a) using random set of arrival-time data, and (b)
using observed arrival-time data.

INSTRUMENT # 5



points may be noted in this connection:

1. The 1 Hz background noise level at The Geysers is rather high, about 30 millimicrons. This is about the maximum noise level for U.S.A. as reported by Haubrich (1967).
2. The most significant clue regarding the peculiarity of the noise is the velocity. It is rather unusual to see the high velocities that we have measured if the noise is of the usual surface wave type associated with water bodies and human activities. For a given apparent velocity of seismic noise the distance and depth of the source can be estimated if the crustal structure in the region is known. It is hard to assign an average apparent velocity for The Geysers noise because the velocity distribution (fig. 5b) shows a wide scatter. However, the three large peaks in the distribution are in the range of 4 to 7 km/sec and to demonstrate the technique for locating the noise source a mean apparent velocity of 5.5 km/sec is assumed. For a model with a velocity of 5.0 km/sec at the surface and a constant positive velocity gradient of 0.2 km/sec per km, in order to obtain an apparent velocity of 5.5 km/sec, the source must lie anywhere along a raypath defined by the arc of a circle (Officer, 1958) described by the following coordinate

(x - horizontal distance from station, z - depth):

x (km):	0.0	5.0	11.0	15.0	20.0	23.0
z (km):	0.0	1.8	2.5	2.3	1.2	0.0

One of the basic principles of ray theory states that for a plane-layered earth the ray bottoms at a depth where the rock velocity

is the same as the measured apparent velocity. Assuming an average apparent velocity of seismic noise of 5.5 km/sec, the maximum depth of the source should not be larger than a few kilometers. This discussion demonstrates that the noise source can be located by measuring apparent velocities using an array of seismometers.

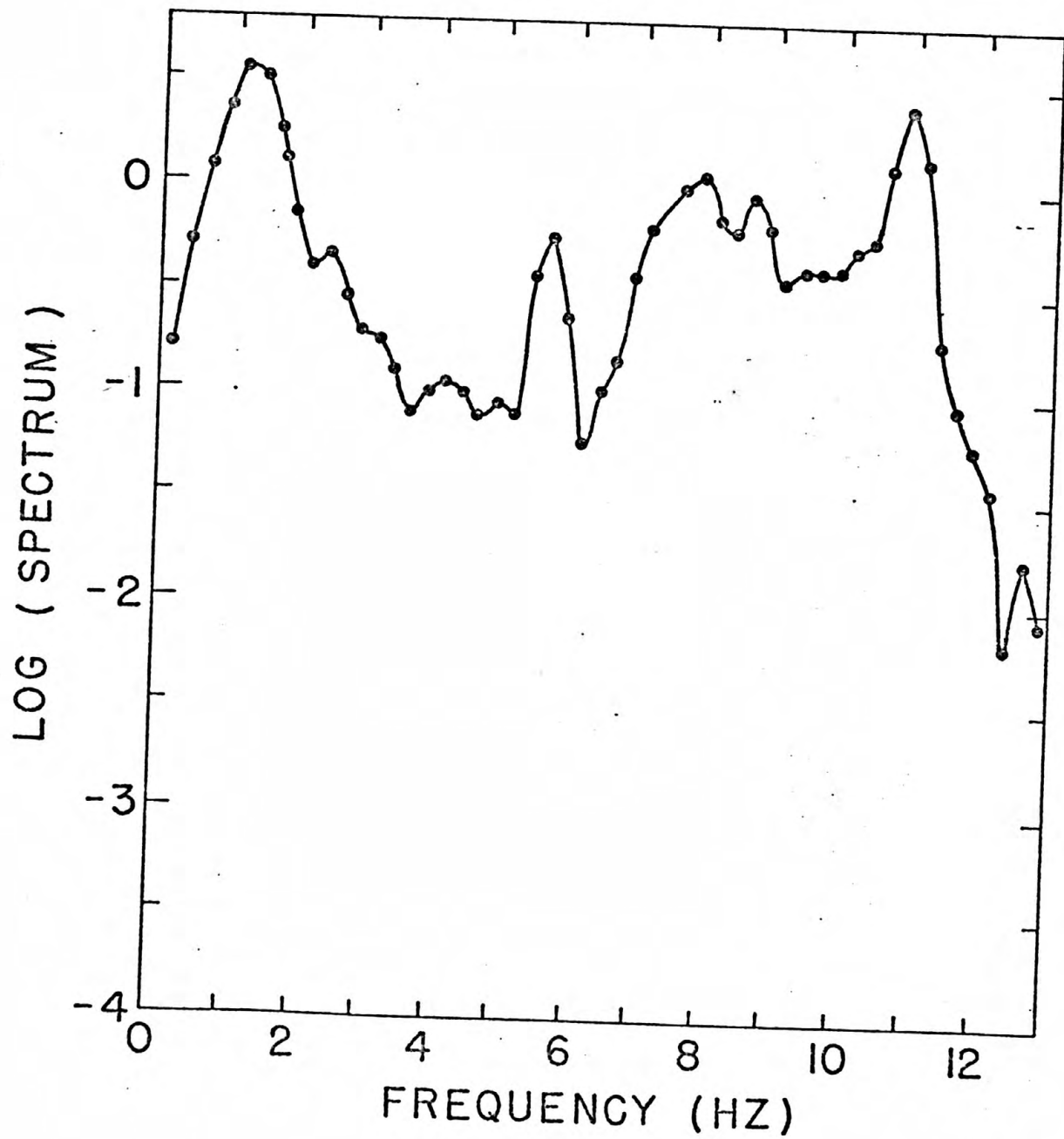
A few local earthquakes and a teleseism were very well recorded by the array. One of the local earthquakes showed a high apparent velocity of 17 km/sec, indicating that it was almost underneath the array. A second earthquake was in the general azimuth range of the noise source and gave an apparent velocity of 4.6 km/sec. The earthquake data demonstrate that the recording and analysis techniques were satisfactory for measuring a wide range of apparent velocities.

Noise spectrum from The Geysers (fig. 12) showed, in addition to the main peak at 1 Hz, significant energy in the band of 5 to 10 Hz. The nature of this noise source is unknown.

In spite of the highly coherent nature of the noise events, the average coherence measured using cross-spectral techniques, involving integration over a long data sample, was low, and the phase difference between the channels was negligible. This shows that the noise consists of a conglomeration of signals with rapidly changing phases and hence does not fit into the ordinary category of "stationary noise."



Figure 12. Power-spectral estimate in logarithmic scale plotted against frequency in Hz. Sample length = 19 sec, sampling interval = 0.0185 sec.



An attempt was made to trace noise peaks in the array through the larger radio telemetry network used for a concurrent microearthquake study (Hamilton and Muffler, 1972), but there was no conclusive indication that they were recorded. The closest station was about 3 km from the array. The telemetry stations were operating at a much lower gain than the array and had a different frequency response, which could explain why noise similar to that recorded by the array was not seen by the telemetry stations.

PROPOSAL FOR FURTHER WORK

Future seismic noise experiment at The Geysers should be designed to locate the noise source and to produce more detailed information on characteristics of geothermal noise.

1. Velocity and azimuth distribution of seismic noise in the geothermal region of The Geysers must be recorded more accurately. An L-shaped array, with 2.5 km arms and instruments spaced at 0.5 km, should give the necessary resolution.
2. The noise energy must be measured at different places in the geothermal area, particularly in the vicinity of steam holes, power plant, and drills, in order to understand the nature of the noise field.
3. It may be useful to measure velocity and azimuth distribution of seismic noise in a non-geothermal area near The Geysers to obtain a reference datum for comparison with the measurements in the geothermal region.
4. If it is demonstrated that the noise field at The Geysers is associated with the geothermal sources and if, as shown in this report, the waves

travel at speeds close to Pg-waves from local earthquakes, an attempt to locate the "hypocenter" of the noise field is required. This experiment can be done by operating three arrays around The Geysers and by pinpointing the noise source.

A two-stage experiment at The Geysers is proposed:

1. Operate one L-shaped array with 2.5 km spread along each arm of the L. Two refraction trucks can be used to give this configuration. While the array is recording, a third truck can make point measurements at different parts of The Geysers region. (This stage was completed during September 1971.)
2. Operate three L-shaped arrays at three different locations around The Geysers. If coherent "noise signals" are recorded at all the arrays, conventional earthquake-location techniques can also be employed to determine the depth of the noise sources.

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