Ground Noise Survey at a Proposed Submarine Test Facility on Lake Travis

by

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INTRODUCTION

We conducted a brief survey of ground noise at a proposed submarine test facility on Lake Travis, northwest of Austin, Texas. The purpose of the survey was to find out the nature and level of the background seismic noise on the bottom of the lake at the site where the proposed submarine test facility would be located. Because of its immediate availability, we used a seismograph designed to acquire seismic data at the ocean floor. The survey was requested by Prof. Thomas Griffy of the Physics Department and Applied Research Laboratory of the University. This report describes the field survey, the data analysis and the results.

FIELD SURVEY

Description of the Site

The site of the survey was within the Lake Travis under-water test facility maintained by the Applied Research Laboratory of the University of Texas at Austin on and off the shore of this artificial lake on Colorado River. It is located at about 30°23'N, 97°54'W, 20 km (12 miles) northwest of downtown Austin, on the Edwards Plateau. As seen on the local map (Fig. 1), the site is very close to the Mansfield Dam with a hydroelectric powerplant. The distance to the powerplant is only about 700 m (2,200 ft).

Two sites were occupied during the survey: one under the water and another on the shore. The under-water site was about 150 m (500 ft) from the shore at a water depth of about 15 m (50 ft). We were told that this site has a rocky bottom, apparently on a ledge, with very thin bottom mud. The on-shore site was about 60 m (200 ft) from the shore and about 2 m (6 ft) above the mean water level of the lake. This site was in an abandoned limestone quarry, and the instrument was placed on thin soil. There were some small trees and bushes in the area, but we chose a site at lease 10 m from any of them to minimize wind-generated noise. The two sites were separated by a distance of about 270 m (900 ft).

Instrumentation

We used an ocean-bottom seismograph (OBS), an instrument designed to acquire seismic data on the ocean floor. It is a self-contained portable instrument that senses the ground motion in three orthogonal directions (vertical and two horizontal), amplifies, filters and digitizes the signals, and records the data on a magnetic tape. The entire instrument is contained in a 17-in diameter glass sphere. A description of this UTIG-designed instrument can be found in a paper by *Nakamura et al.*[1].

Various parameters of the data acquisition used for the survey are as follows:

Sensors:	Mark Product L-10B geophones, 4.5 Hz, 2 horizontal and 1 vertical components
Overall sensitivity:	6.67×10^8 DU/(m/s) [1.50×10^{-9} (m/s)/DU][2]
Instrumental passband:	4.5 - 100 Hz
Sampling interval:	4.032 ms
Recording mode:	Intermittent, 16.45 second recording every 7.5 minutes

The overall frequency response of the instrument is shown in Fig. 2.

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[1] Nakamura, Y., P. L. Donoho, P. H. Roper, and P. M. McPherson, Large-offset seismic surveying using ocean-bottom seismographs and air guns: Instrumentation and field technique. *Geophysics, 52*, 1601-1611, 1987.

[2] DU (digital unit) is the smallest unit of digitization.

Field Experiment

The survey was conducted in two 24+ hour periods separated by a day in the summer of 1987. During the first period, from July 28 to 29, we occupied the under-water site. At about 11 o'clock of the first day, the instrument, mounted on a 4-ft square steel anchor frame, was lowered to the bottom of the lake from a barge with a help of a diver. The diver oriented the instrument in such a way that the first horizontal component pointed towards north and the second horizontal component pointed towards west. The instrument was left there for nearly two days and it recorded the ground noise from 13^h00^m of the first day to 19^h53^m of the following day. On the third day at about 9 o'clock, we pulled up the instrument from the water and removed the data tape for analysis.

During the second period, from July 30 to 31, we occupied the on-shore site. At about 11 o'clock of the first day, we mounted the same instrument on the same anchor frame and set it at the on-shore site maintaining approximately the same instrumental orientation as the one at the other site. We jumped on the frame to embed the spikes, which were welded to the frame, one to two inches in the ground. The instrument was left in the direct sun, although we attempted to make a shade with a piece of aluminum foil covering the sphere. The recording started at 13^h00^m for periodic recordings that were to last more than a day. On the following day, the instrument was removed from the site at around 13^h55^m and was taken back to our laboratory to remove the data tape. It was discovered that this second field environment was not hospitable to the instrument. The high temperature caused the rubber part of the capstan roller on the tape recorder to melt causing a recording difficulty. Judging from the quality of the data on the tape, we estimate that the melting of the rubber part occurred at around 17^h35^m of the first day. We lost the recording of signals at $17^h37^m30^s$. Fortunately, after the rubber part was completely gone, with bare metal acting as a capstan roller, though smaller in diameter, the instrument was able to record data again but at a higher density (slower tape speed). After several attempts, we were able to recover the data from 17^h45^m until after the removal of the instrument from the site.

DATA ANALYSIS AND RESULTS

Since our normal equipment to transfer data from a cartridge (OBS) tape to a 9-track (main-frame computer) tape was on board *R/V Fred H. Moore* operating in the western Pacific and not available to us for this work, we transferred the acquired data to micro-floppy disks and analyzed them mainly on a Macintosh microcomputer. Because of this limitation, we primarily used for the analysis only 1/6 of the acquired data, or 2.74 seconds of data, at each recording segment that occurred every 7.5 minutes. Since most of the time the noise level was fairly steady in the short term (on the order of minutes), this restriction should not have degraded our analysis.

The largest factor that influenced the observed noise level was the operation of the near-by hydroelectric powerplant. We understand that there are two generators in the powerplant, and they were both operating throughout the day except for the following periods during our observation: No generator was in operation from July 29, 00^h00^m through 05^h00^m and July 31, 00^h00^m through 02^h00^m; only one generator was in operation from July 30, 19^h00^m through midnight and July 31, 03^h00^m through 06^h00^m (Fig. 3).

We looked at the total rms noise levels, spectral contents, and particle motions. As expected, the difference in the noise levels between the times when the generators were on and when they were off is very clear. However, there are many subtle variations in the frequency content and the particle motion with time. The remainder of this report describes these results.

Rms Noise Level

We have computed the total rms noise level at each recording throughout the entire observation period. The noise level at the bottom of the lake (Fig. 3, top figure) was very steady. Converting from digital units, shown in the figure, to ground particle velocity, the total rms noise level when the generators were running was generally around 2.0 μm/s for the north-south horizontal motion, 2.5 μm/s for the east-west horizontal motion, and 6 µm/s for the vertical motion. However, there was an early morning period before 6^h40^m when the level of the horizontal components was reduced by about 30% in amplitude (about one half in power) compared to the rest of the time. We were unable to find out what caused this variation. (We were told that the powerplant log indicated that not one but both generators were operational during this period.)

The noise level when the generators were not running was sufficiently low so that the instrumental noise made a significant contribution to the observed noise. By subtracting the instrumental noise power from the measured noise power, we estimate the total rms noise level at the lake bottom when the generators were off to be about 60 nm/s for all three components of ground motion. This was 1.5 to 2 orders of magnitude less than that when the generators were on.

In comparison to the lake-bottom noise level, the noise level on the shore (bottom figure of Fig. 3) when the generators were running was generally lower by a factor of 1/2 to 1/3 in amplitude for the horizontal components and 1/5 to 1/10 in amplitude for the vertical component. There also was a considerable variation in the noise level with time, especially for the vertical component, which changed from about 1.2 µm/s in the afternoon of July 30 to 0.6 µm/s in the morning of July 31, a factor of 2 change in amplitude or 4 in power. The noise level gradually decreased starting at about the time when one of the generators was turned off. This down trend continued even after the three-hour off period. When both of the generators were again turned on at 6 a.m. of the following day, the noise level did increase but did not return to the initial high level of the previous day. The on-shore noise also shows more short-term variations than the lake-bottom noise especially during day time. This suggests that the one-shore site is more susceptible to man(and animal?)-made noise. The several sporadic peaks in noise level may be due to traffic on the near-by road or to people walking close to the instrument.

In contrast, the noise level on the shore when the generators were not running was somewhat higher than at the lake bottom: about 0.3 µm/s for the horizontal components and about 0.1 µm/s for the vertical component after correction for the instrumental noise. Horizontal components show more variations than the vertical component.

The total rms noise level is summarized in Table 1.

Table 1. Summary of observed total rms noise level (unit µm/s)

Site	Generators	Component Horizontal	 Vertical
Lake bottom	On	2.0-2.5	6
	Off	0.06	0.06
Shore	On	0.5-1.5	0.5-1.5
	Off	0.2-0.4	0.1

Spectral Content

We have computed power spectral estimates of all three components in hourly intervals for the entire observation period. The procedure we used was the following: First we selected a block of 2.74 seconds of data (680 samples per component) at every recording period. Most of the time, we selected the second block of each 6-block recording because the first block was contaminated with a low-frequency transient associated with the beginning of each data acquisition. When the second block was not available because of an error in reading the tape, we used the third block. Then we split each of the 680-sample blocks into half, generating two 340-sample sections for each component at each recording. Next we padded each section with zeroes and computed the 512-point FFT. Since there were eight recordings in each interval of one hour, we thus had 16 frequency spectra per hour for each component. In the final step, we averaged all 16 spectra within each hour to obtain hourly spectral estimates. The frequency resolution of the spectra thus calculated is 0.48 Hz.

The computed spectra show vast differences between lake bottom (Fig. 4a) and on-shore (Fig. 4b). On the lake bottom, the most prominent feature is the broad high level between 80 and 115 Hz with a very sharp peak at 93.5 Hz. It is clearly more pronounced on the vertical component than on the horizontal components. Other prominent peaks are a series of peaks from 45 to 53 Hz, mostly on the east-west horizontal component, and a broad peak between 73 and 83 Hz, mostly on the north-south horizontal component. Many other peaks, though smaller in amplitude, were also consistently observed while the generators were running. It is noted, however, that many of the spectral peaks showed significant variations with time.

In contrast to the relatively high frequency nature of the noise on the lake bottom, the noise on the shore (Fig. 4b) was dominated by noise below 32 Hz. The spectral content, however, showed large variations with time. The peak at 31 Hz decreased substantially from the first day to the next. The two peaks between 17 and 25 Hz, which were observed both on the shore and on the lake bottom and even when the generators were not running, showed a peculiar behavior. Their frequencies drifted with time during the observation (Fig. 5): the lower frequency peak migrated from 17.4 Hz to 20.8 Hz, and the higher frequency peak migrated from 21.3 Hz to 24.2 Hz. The occasional spectral peaks near 80 Hz were caused by sporadic noise likely to be due to human activities in the close proximity of the instrument.

Although the relative strength of spectral peaks is quite different between lake bottom and on shore, essentially all of the identified spectral peaks have common frequencies between them (Fig. 5). The most noticeable are the three peaks at 31.0, 62.5 and 93.5 Hz forming a harmonic triplet. Since we suspected that some of these common frequency peaks might represent the resonance of the instrument, we tested the instrumental resonance by tapping the frame-mounted instrument at several places and recording the resulting vibration of the instrument. We found that the frame has a major resonance peak at 101.7 Hz. None of the observed instrumental peaks matched the peaks observed in the field. Thus we conclude that none of the peaks observed during the field noise test is attributable to the instrumental resonance.

Some representative detailed spectra are shown in Fig. 6. When the generators were off, only low-frequency noises (below about 25 Hz at lake bottom and below about 45 Hz on shore) were strong enough to be above the instrumental noise level.

Particle Motion

We computed hourly cross-spectral estimates between pairs of components using the same data set as above, and from these and the power spectral estimates we computed the particle motions at selected spectral peaks. The results (Fig. 7) show a variety of particle motions at different frequencies, some of which are fairly steady, while others show considerable variation with time. Also there are significant differences in particle motions between on-shore and lake-bottom sites. Some examples are:

The 17.9 Hz peak on the lake bottom shows a highly elliptical to nearly rectilinear particle motion with a large tilt of its major axis towards SW, while at a slightly higher frequency of 24.2 Hz the major axis of the elliptical particle motion was tilted towards NW. In contrast, on the shore the particle motion was nearly rectilinear and horizontal at both 17.4 Hz and 24.4 Hz, while the direction of the major axis is NW-SE at 17.4 Hz and NE-SW at 24.4 Hz.

The 31.0 Hz peak on the lake bottom shows nearly circular particle motion in an almost vertical E-W plane with clockwise particle trajectory when viewed from south. In contrast, on shore the particle motion was highly elliptical to nearly rectilinear with a large tilt of the major axis which migrated from NW direction during the first day to EW direction on the second day.

The particle motion at 93.5 Hz on the lake bottom was highly elliptical and nearly vertical, as expected from the behavior of the power spectra. The direction of the slight tilt of its major axis migrated from NW to W during the 30 hour period.

DISCUSSION

The two-day observations on the lake bottom and on the shore at the Lake Travis test facility revealed several properties of the ground noise there. Although a singe-station observation is not sufficient to determine the true nature of the noise because propagation directions and velocities cannot be deduced from the data, some interesting characteristics of the noise can been seen from their frequency contents and particle motions.

On the lake bottom, the major contribution to the ground noise comes from the noise in a frequency range of 80 to 115 Hz with predominantly vertical particle motion. Within this frequency band, there is a sharp spectral peak at 93.5 (±0.2) Hz. Two of its subharmonics are also observed at 62.5 (±0.2) Hz and 31.0 (±0.2) Hz. These peaks are not related to the instrumental resonance, and disappear when the generators are turned off at the near-by hydroelectric powerplant. Thus they are clearly related to the operation of the powerplant. However, these frequencies are not directly correlated with the rate of revolution of the turbines of the generators, each of which has 14 blades and rotates at a rate of 144 revolutions per minutes, or 2.4 revolutions per second and 'blade frequency' of 33.6 Hz. One might speculate that they may be related to the resonant frequency of the water inlet to the generators.

On the shore, the major contribution comes from noise at lower frequencies. One of the above-mentioned subharmonics at 31.0 Hz is strong there. However, equally dominant are the two spectral peaks between 17.4 Hz and 24.2 Hz. These two peaks are observed even when the generators are off, though at reduced level, and are not at fixed frequencies - they drift with time. We have been unable to explain whey they do this.

Knowing the frequency content of the noise, one can convert the rms noise level of Table 1 in terms of ground displacement from ground velocity. In Table 2, we show rough estimates based on dominant frequencies as given in the table. More precise estimates can be made, if necessary, using the entire spectra. Also when a range of noise level is given in Table 1, we chose a value at mid range.

Table 2. Estimates of rms noise level in terms of ground displacement (unit nm)

Site	Generators	Component Horizontal	 Vertical	Frequency Hz
Lake bottom	On	4	11	90
	Off	0.5	0.5	20
Shore	On	5	5	30
	Off	2.5	0.8	20

The fact that practically all the spectral peaks are common to both in-the-lake and on-the-shore observations suggests that these peaks are source-related. The observed large difference in relative strength and particle motion of each spectral peak at both sites is probably due to the difference in geologic structure, including the water column, in the immediately vicinity of the instrument.

CONCLUSIONS

1. The total rms noise level on the lake bottom in the frequency band of 4.5 Hz to 100 Hz was about 2.0 to 2.5 μm/s in horizontal directions and 6 μm/s in vertical direction when the generators were operating at the powerplant, and about 60 nm/s in all directions when the generators were not operating. The majority of the noise power when the generators were on was at frequencies above 80 Hz with a sharp peak at 93.5±0.2 Hz, while the noise in the 10 to 30 Hz range contributed most when the generators were off.

2. The total rms noise level on the shore in the same frequency band generally varied between about 0.5 μm/s and 1.5 μm/s in all directions when the generators were on, and was about 0.3 μm/s in horizontal

directions and about 0.1 μm/s in vertical direction when the generators were off. The most of the noise power when the generators were on was in the range of 10 to 40 Hz, while the noise in the 10 to 30 Hz range contributed most when the generators were off.

3. Many spectral peaks of common frequency but of vastly different power observed on the lake bottom and on the shore suggest that the observed noise level is highly dependent upon the local structure.

Acknowledgements. We thank Paul Eisman of the Applied Research Laboratory for assisting with the experiment, Randy Rieman of the Lower Colorado River Authority for providing information about the Mansfield Dam generators, and Dr. Thomas A. Davies for offering constructive comments on a draft of the report.

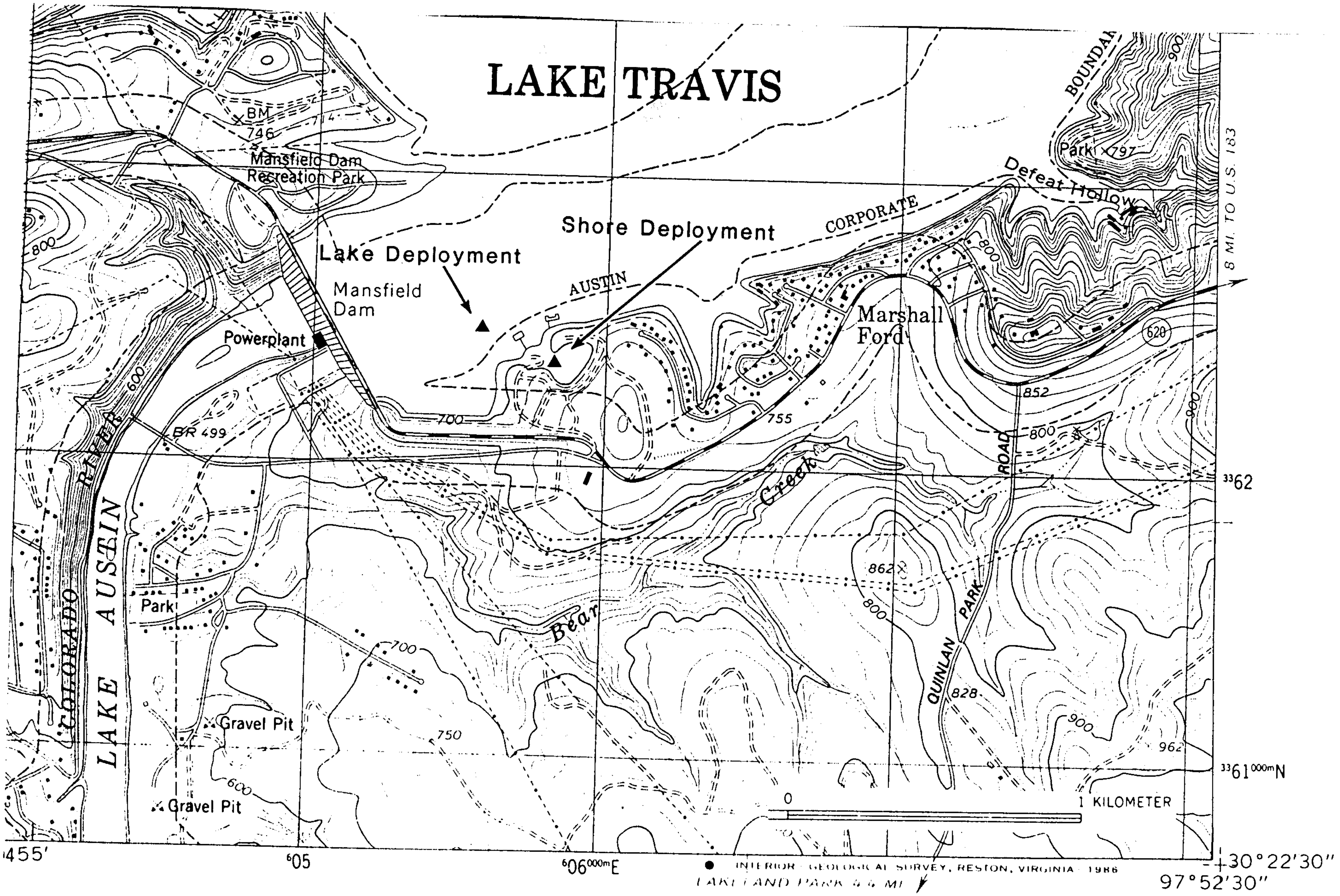


Fig. 1. Map of the survey site. (Based on U.S.G.S. topographic map Mansfield Dam 7.5' quadrangle, 1986.)

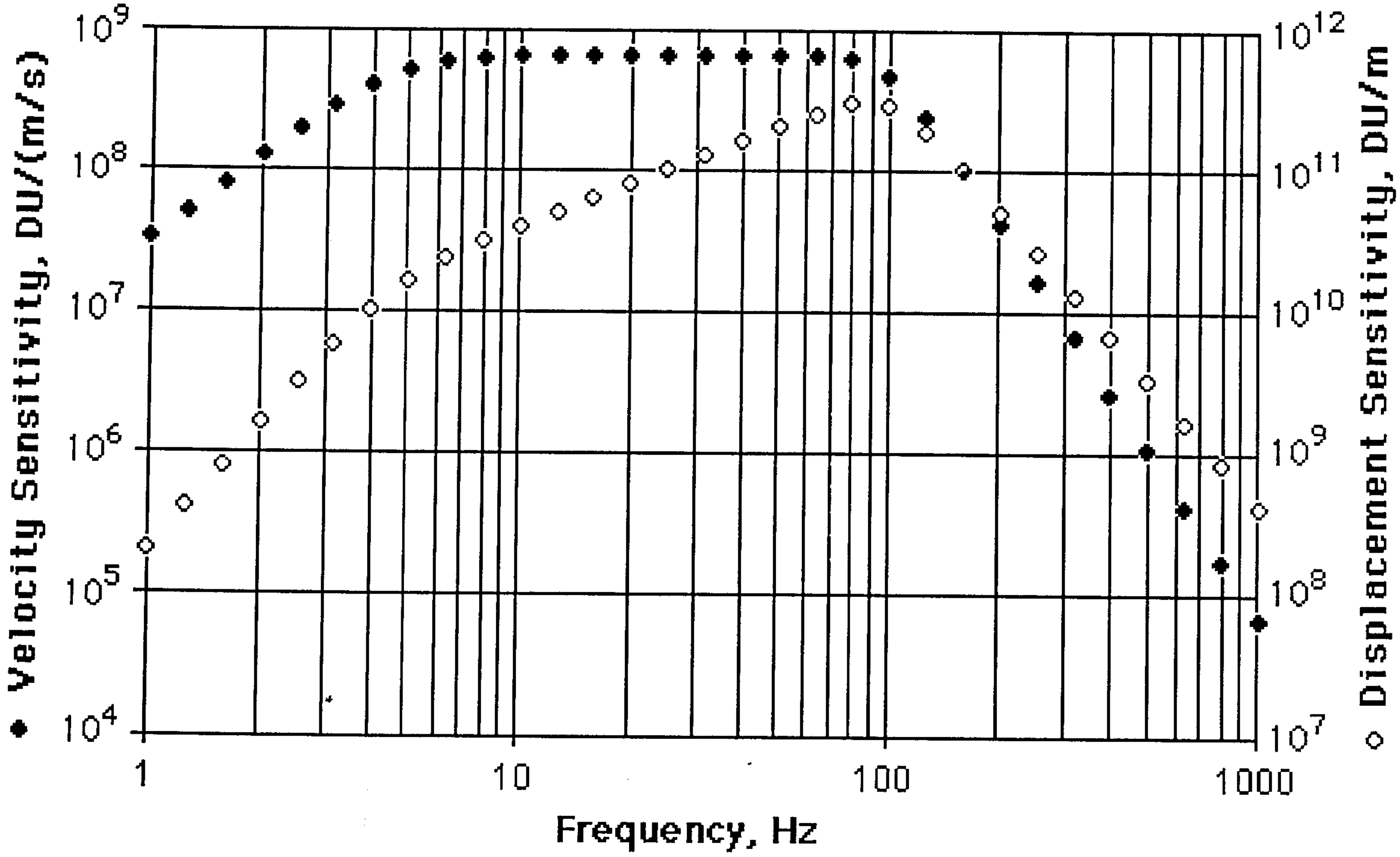
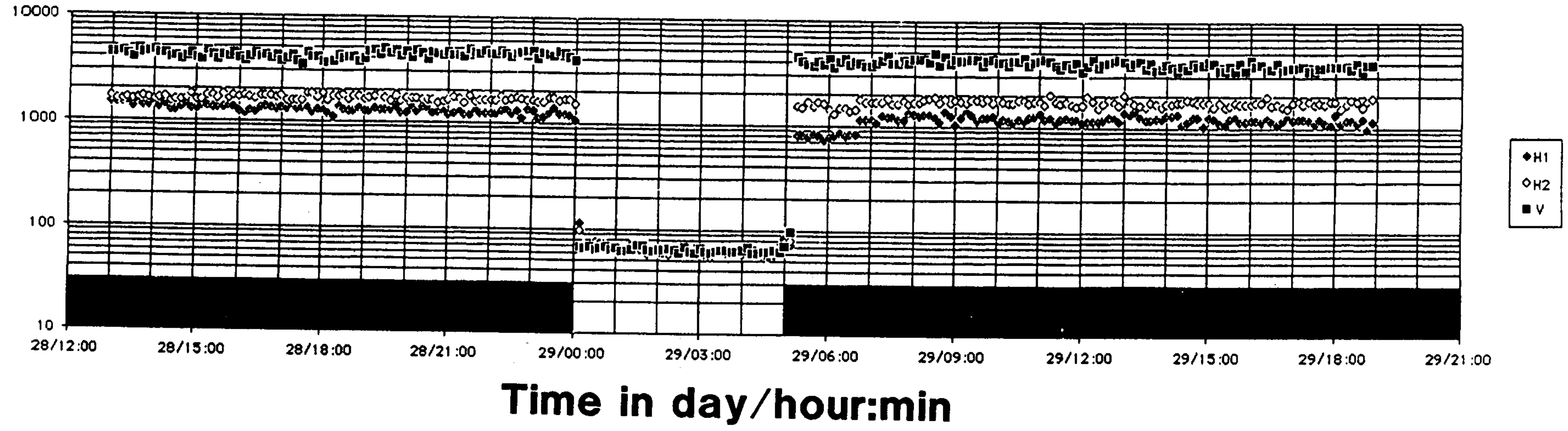


Fig. 2. Overall frequency response of the instrument. Note that the instrument responds to the ground velocity within its passband. The low-frequency roll off at 12 dB/oct in velocity sensitivity below 4.5 Hz is determined by the geophones used, while the high-frequency roll of at 24 dB/oct in velocity sensitivity above 100 Hz is due to the antialiasing filters used.

(a) On Lake Bottom



(b) On Shore

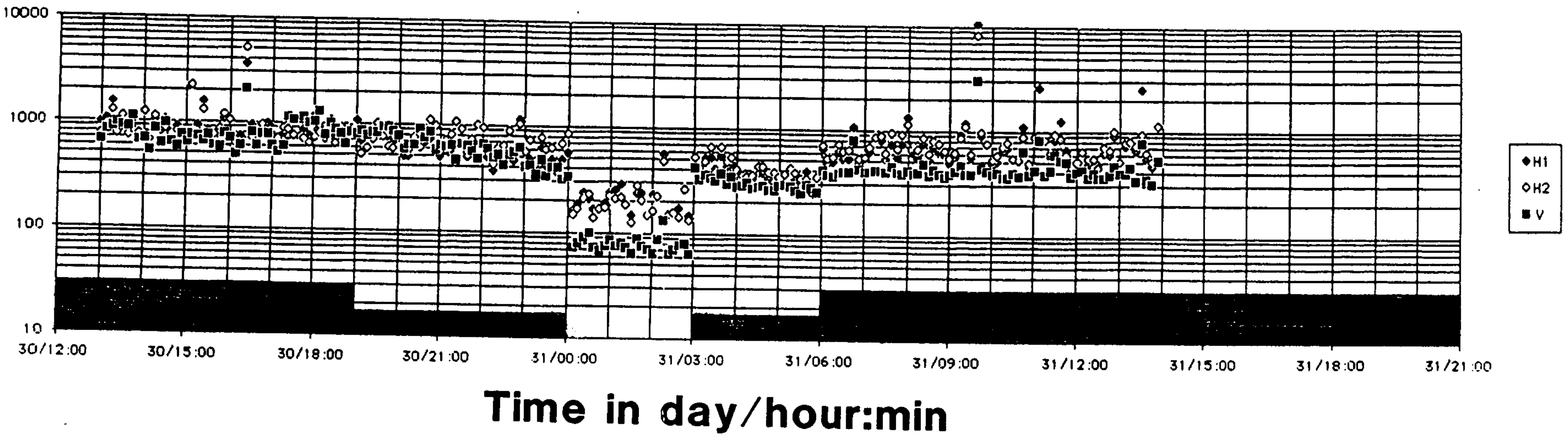


Fig. 3. The variation of the overall rms noise level with time. The rms noise level is in digital units (DU), with 1 DU corresponding to 1.5 nm/s in ground velocity. The height of the bars at the bottom of each diagram indicates whether two, one or no generators were operational at the time.

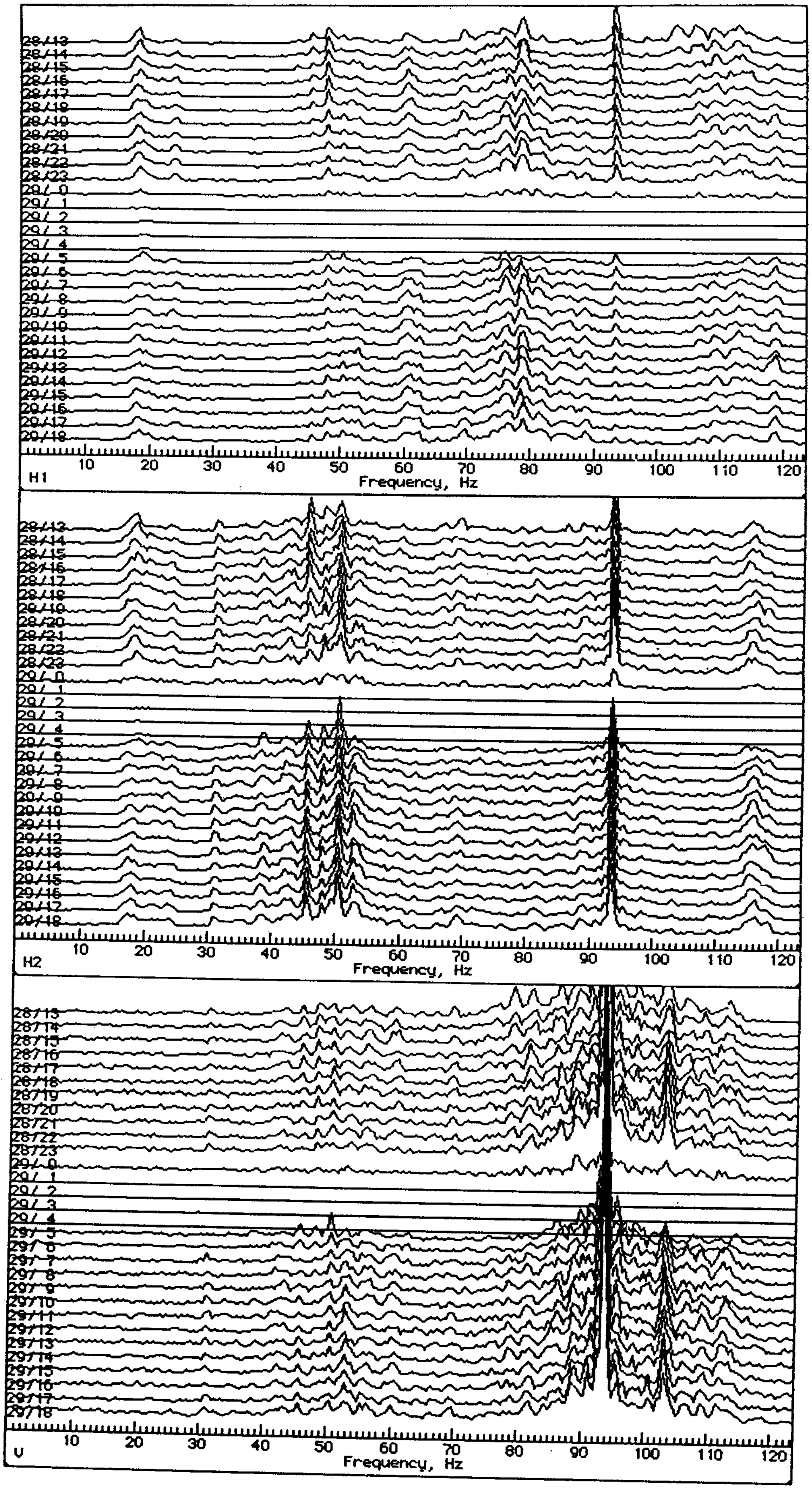


Fig. 4a. Hourly frequency spectra of noise on the lake bottom. The spectra are in an arbitrary linear scale. H1, H2 and V indicate the first and second horizontal components and the vertical component, respectively.

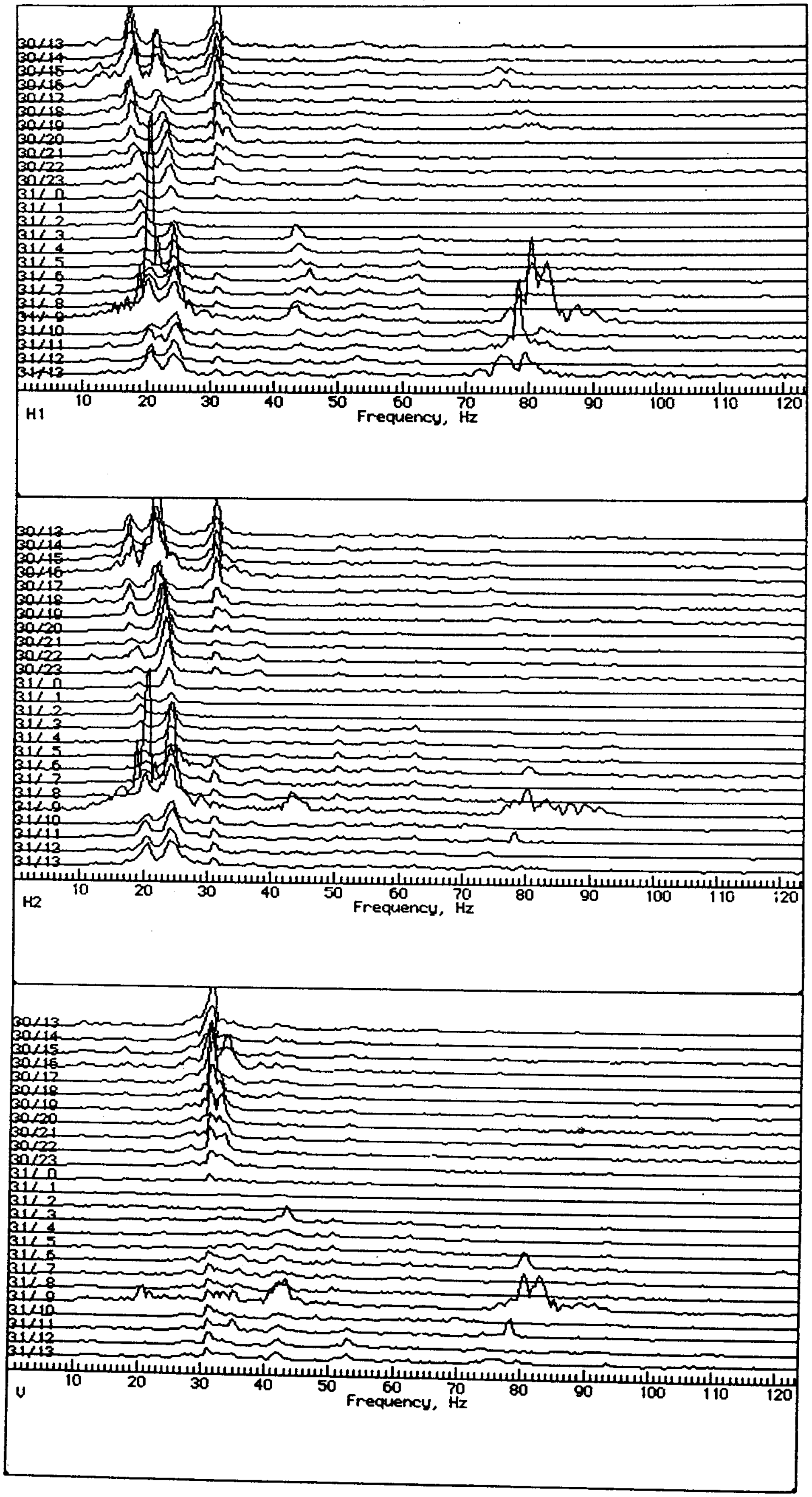
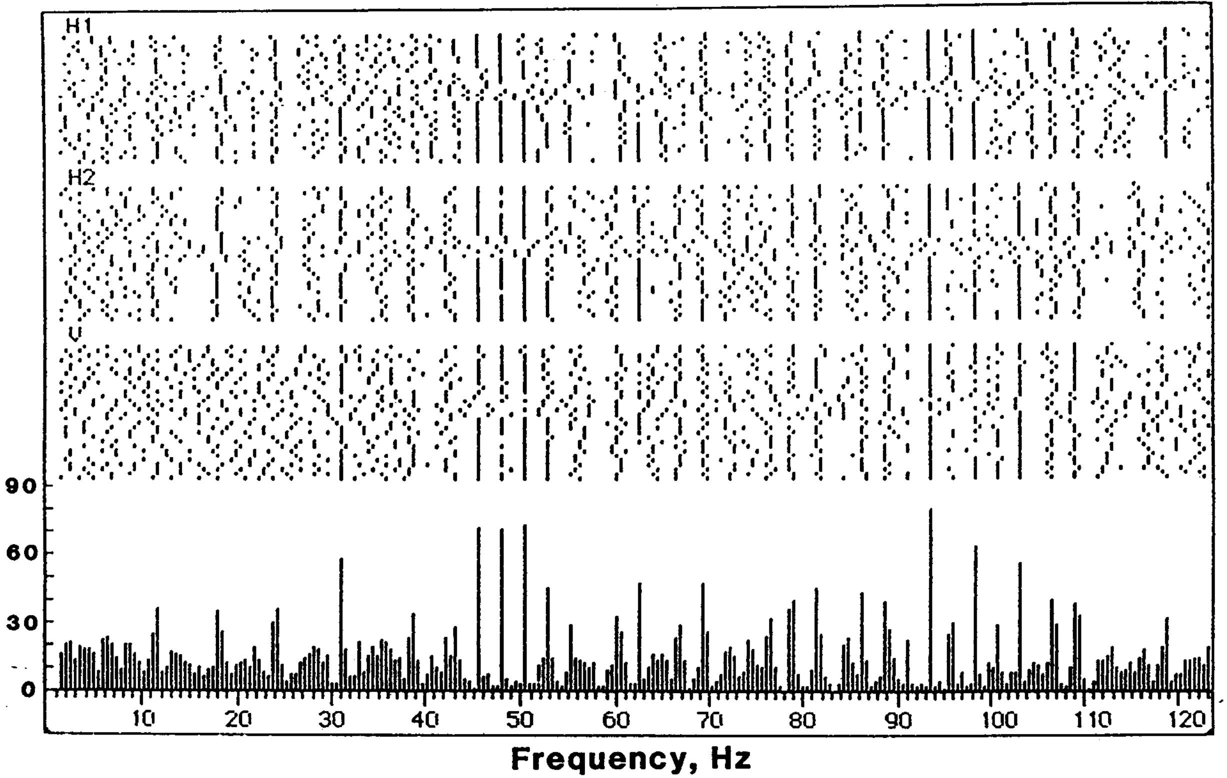


Fig. 4b. Hourly frequency spectra of noise on the shore. See Fig. 4b caption for additional explanations.

(a) On Lake Bottom



(b) On Shore

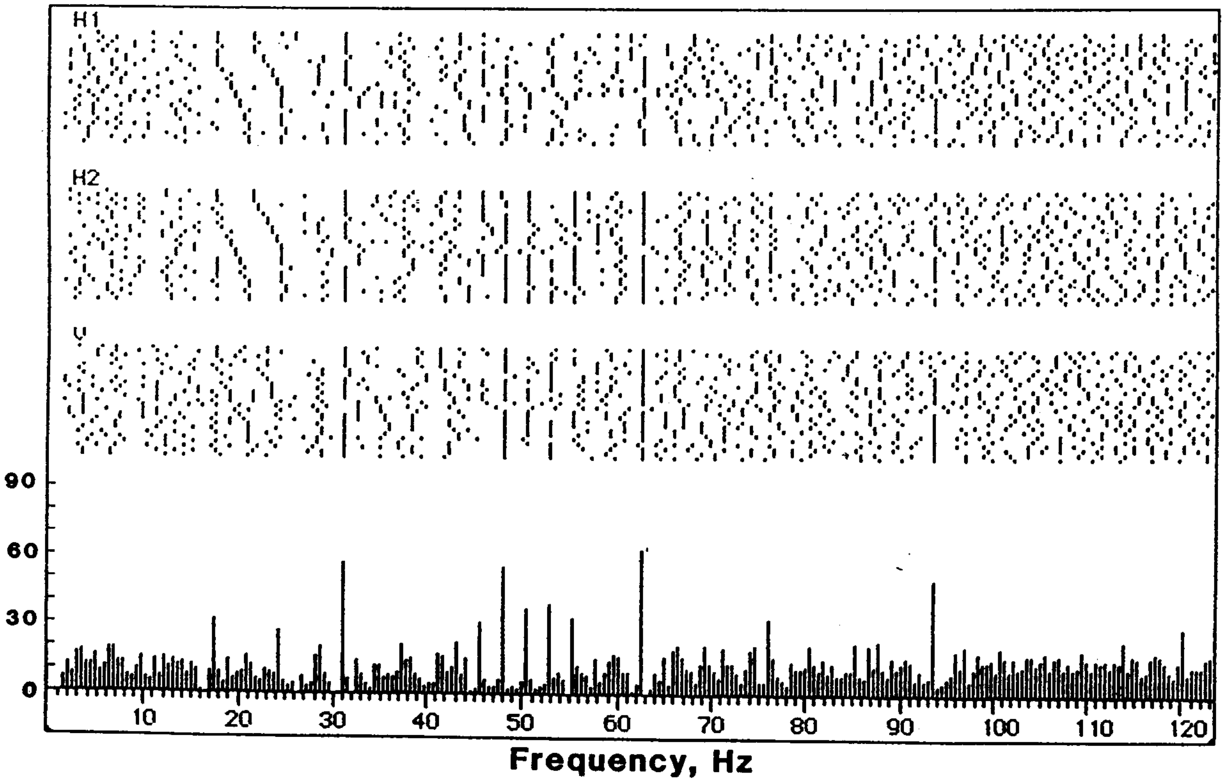


Fig. 5. Observed spectral peaks and their frequency of observation. The top panel is on the lake bottom and the bottom panel is on the shore. On each panel, the top three strips show the locations of spectral peaks in hourly intervals, increasing in time from top to bottom, for the three components as indicated. Each of the spectral peaks is detected as its spectral value exceeds those of the four nearest neighbors in the frequency domain of resolution 0.48 Hz. The histogram shows the frequency of observation of spectral peaks during the survey.

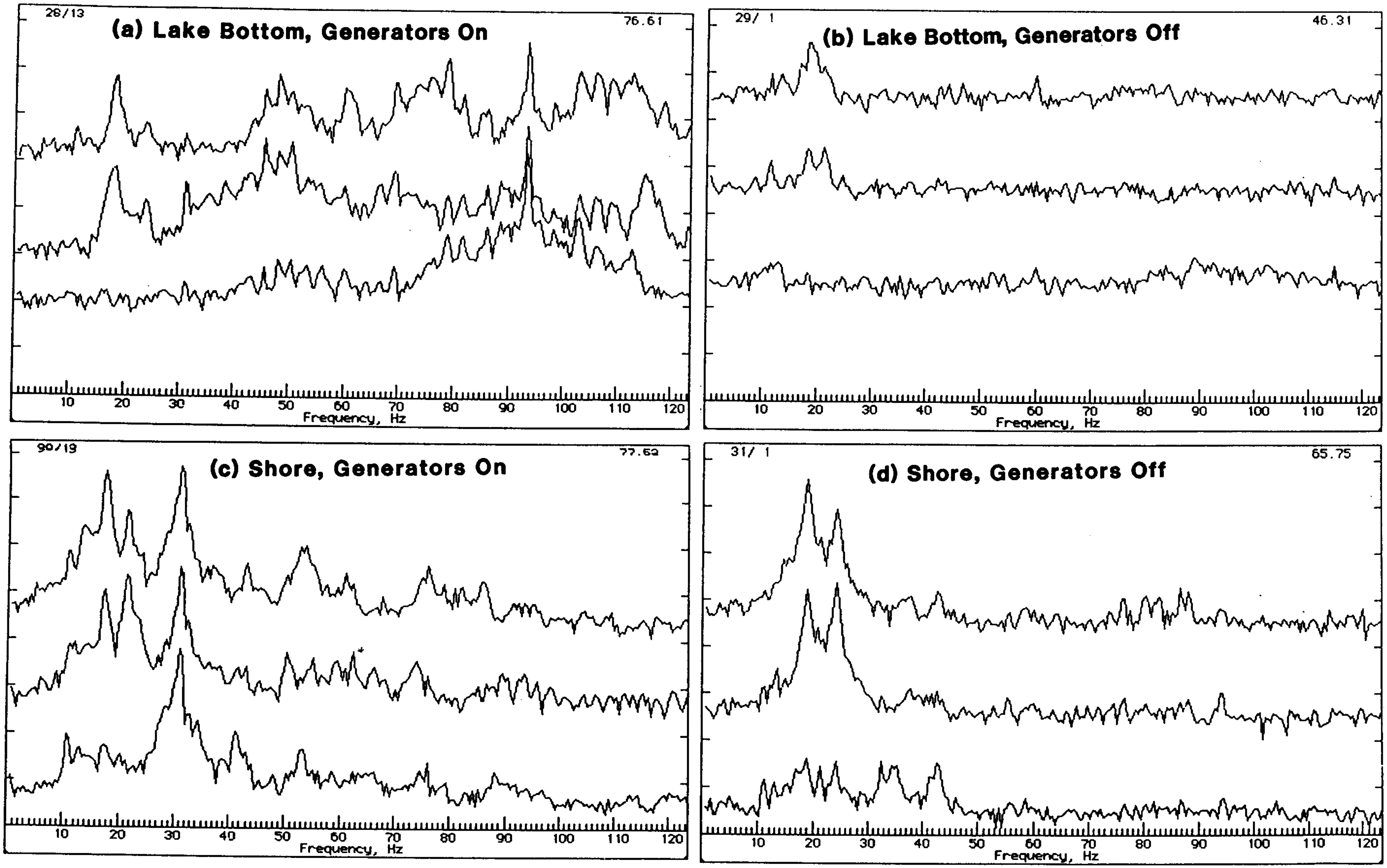


Fig. 6. Frequency spectra averaged over hourly intervals. The vertical scale is in 10 dB intervals. The three spectra in each panel represent, from top to bottom, first horizontal, second horizontal and vertical components, respectively. (a) On the lake bottom, July 28, 13^h-14^h (generators on). (b) On the lake bottom, July 29, 1^h-2^h (generators off). (c) On the shore, July 30, 13^h-14^h (generators on). (d) On the shore, July 31, 1^h-2^h (generators off).

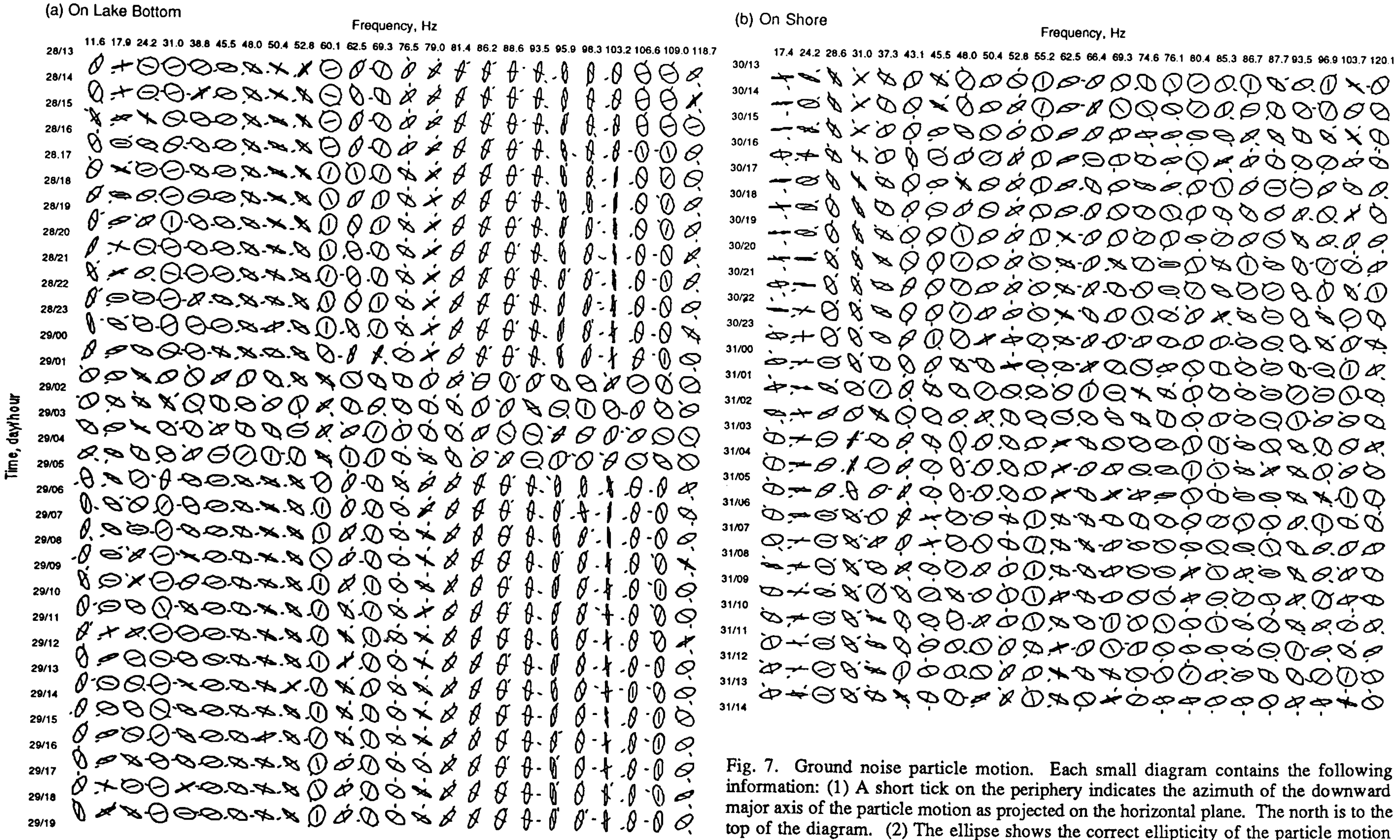


Fig. 7. Ground noise particle motion. Each small diagram contains the following information: (1) A short tick on the periphery indicates the azimuth of the downward major axis of the particle motion as projected on the horizontal plane. The north is to the top of the diagram. (2) The ellipse shows the correct ellipticity of the particle motion with the normalized major axis. (3) The orientation of the ellipse shows the orientation of the downward major axis in a vertical plane (i.e., the tilt of the major axis) as seen from the side where the particle motion is seen moving clockwise. (4) The line through the center has the correct tilt of the plane of the particle motion ellipse. (A horizontal line means that the minor axis is horizontal, while a vertical line means that the particle motion plane is vertical.) The angle of tilt is as seen from the side of the downward major axis.