Contractor Report 94-52

A comparison of deep and shallow water ambient noise measurements at selected sites off western Vancouver Island using a multi-element vertical array

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Abstract:

This paper describes ambient noise data recorded at several locations on and near the continental shelf off the west coast of Vancouver Island. The data were obtained in both shallow and deep-water with the Multi Element Vertical Array (MEVA) at various locations during a three year period. These data had not been examined to date; however, given the increased interest in shallow-water acoustic environments, it was considered timely to perform a detailed analysis of the available data. Four sites are examined, two located in deep water (2500-2600 m) just off the continental shelf, and two located in shallow water (400-500 m) on the continental shelf. One deep water site was monitored more or less continually over a four day period, and the data provide a good measure of the temporal variation present in the ambient noise. The analysis includes estimates of the omnidirectional noise level at the four sites as a function of both frequency and water depth (the depth dependency is obtained by examining a time series of the acoustic data recorded for selected individual hydrophones in the MEVA array). Directional estimates of the ambient noise field are also presented. The directional estimates are obtained by beamforming the recorded data over a selected time period and displaying the results in the form of coloured frequency-vs.-elevation angle surfaces.

1. Introduction

Data were collected at four sites off the west coast of Vancouver Island over a three year period by researchers from the Defence Research Establishment Pacific (DREP). The date/time (Pacific Standard Time) of occupation of each site, together with the latitude, longitude, and water depth are listed in Table 1. The sites are also shown on the bathymetry chart in Figure 1.

Table 1. The time, depth, and geographical location of the ambient noise measurements.

Site	Lat. (N)	Lon. (W)	From:	To:	From: (PST)	To: (PST)	Water Depth (m)	Array Depth (m)
1	48°12'	125°53'	19/6/83	19/6/83	08:52	09:00	600	318
2	48°57'	126°45'	9/6/84	12/6/84	18:10	08:30	500	110
3	48°24'	127°31'	5/6/84	8/6/84	00:08	10:20	2600	343
4	48°16'	128°15'	22/4/85	24/4/85	01:50	22:15	2500	333

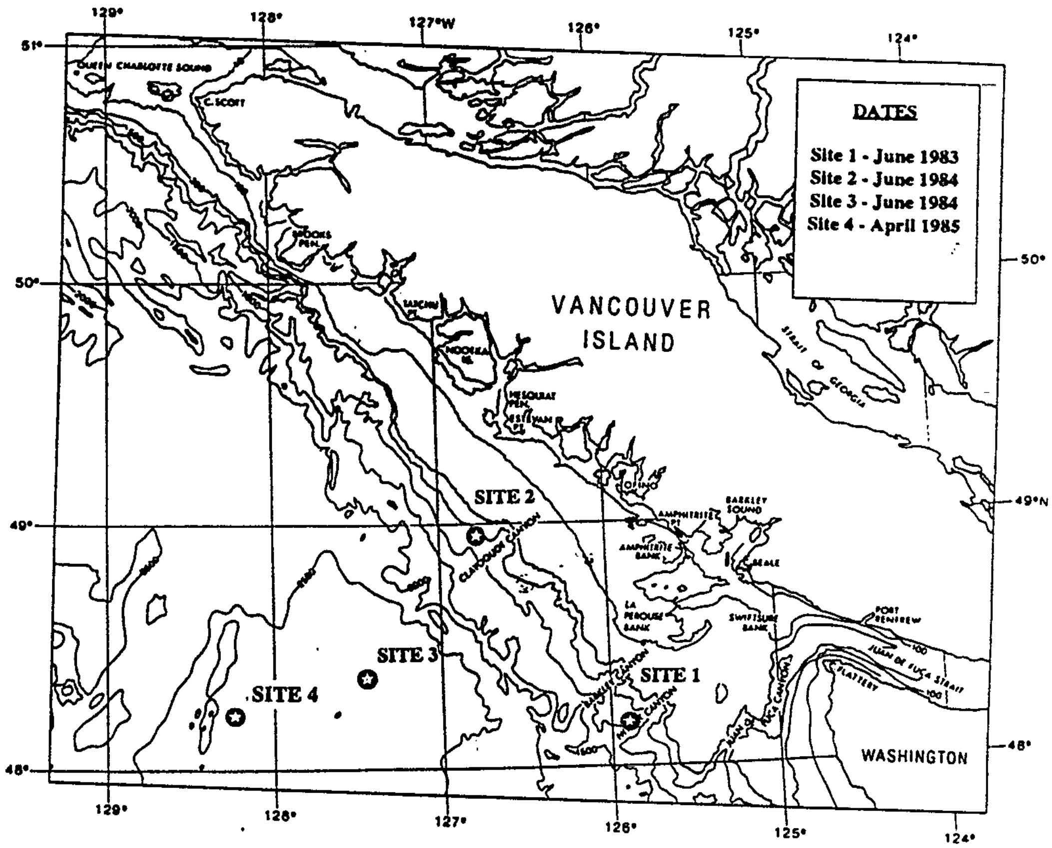

Figure 1. The measurement sites.

These ambient noise data were originally acquired in order to investigate the nature and variability of the vertical ambient noise in areas of interest to the Canadian navy. Recently, it has been of interest to re-examine these data for several reasons, first, in support of a proposal to establish a well-studied and well-understood test-bed site for future ocean based experiments. Second, to make available data which would be of help to Canadian and U.S. researchers involved in the ATOC (Acoustic Tomography for Ocean Climate) program who could use this data to study and select the best possible receiving sites for the potential Canadian receiver. Third, to identify specific data sets which could be used to investigate both the compressional and shear speeds in the bottom sediment using techniques suggested by others (Chapman [1], Buckingham and Jones [2] and Carbone, Deane and Buckingham [3]).

2. *The experimental setup.*

The data were recorded aboard the DREP support ship *CFAV ENDEAVOUR* after being transmitted via an FM data link as indicated in Fig. 2. The vertical line array varied in configuration from year to year, however the number of hydrophones (12) and the data recording format remained essentially unchanged. In 1983 the VLA configuration contained four nested sub-arrays with spacings of 2m, 6m, 18m and 54m. Unfortunately the data received from the deepest phones in this array were subsequently found to be corrupted, and so only data from the first three four-element sub-arrays were

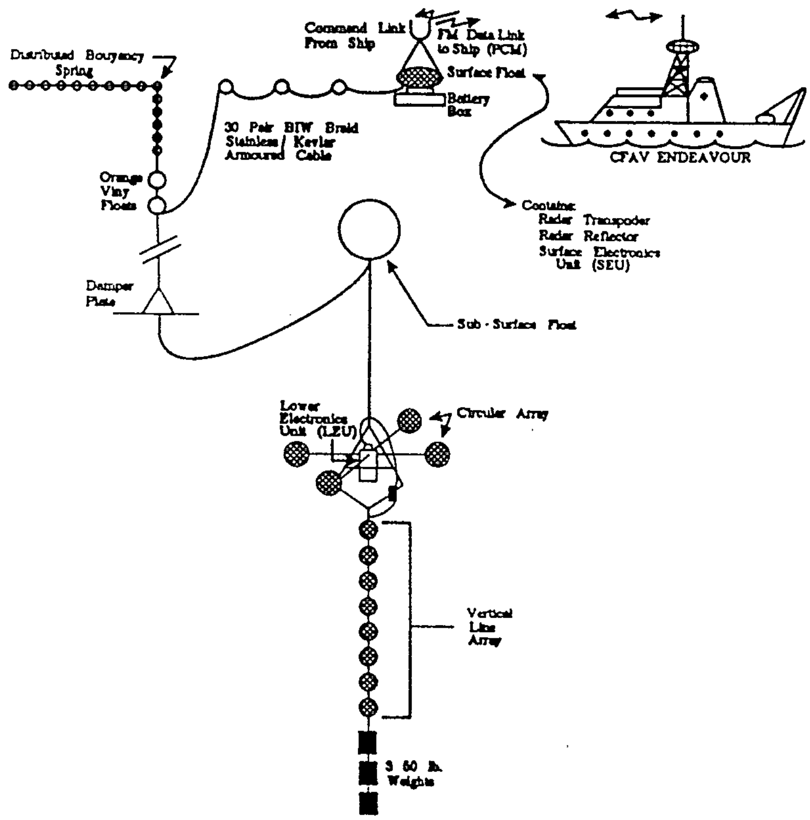

Figure 2. The MEVA system (Note: the vertical line array shown is illustrative only, the actual array configuration was different from year to year as discussed below).

available for further analysis. In 1984 and 1985 the array was configured with two sub-arrays, the first consisting of 8 hydrophones at 6m spacing and the second consisting of 4 hyrophones at 54m spacing. The 6m sub-array in both the 1984 and 1985 data was used to obtain the vertical directionality surfaces shown in this paper.

3. Experimental Results

3.1 Measured Noise Spectra and Omnidirectional Noise Levels:

The data obtained at each measurement site were calibrated and displayed in the form of a waterfall plot shown in Figure 3a (for the 1983 data). This provided both a 'quick look' at the data quality for each of the 12 individual hydrophones in the array and also provided some measure of the spread in the noise intensity as a function of depth. The data for the 'good' phones were then over-plotted (hydrophones VLA1-VLA8 were selected in Figure 3b) to emphasize the inter-channel variability and to provide a method for estimating an average omnidirectional noise level across the array.

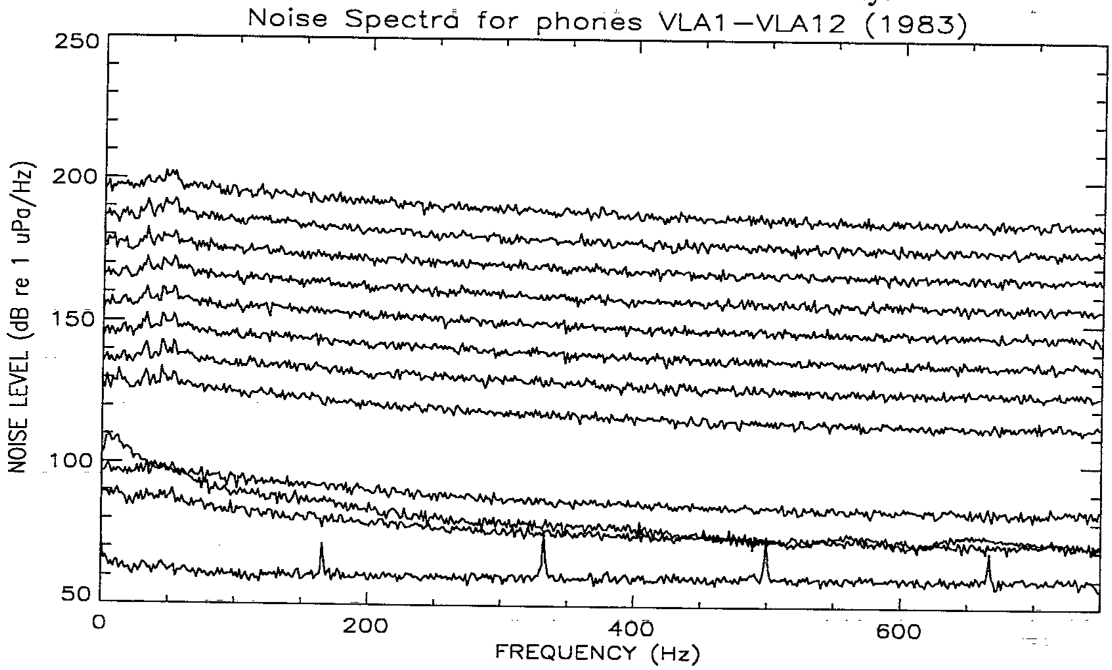

Figure 3a. A plot of the the calibrated noise spectra showing that phones VLA1 to VLA8 (uppermost 8 hydrophones in the array) provide consistent and well-behaved noise spectra and that the last four phones (the deepest, with 54m spacing in the array) do not.

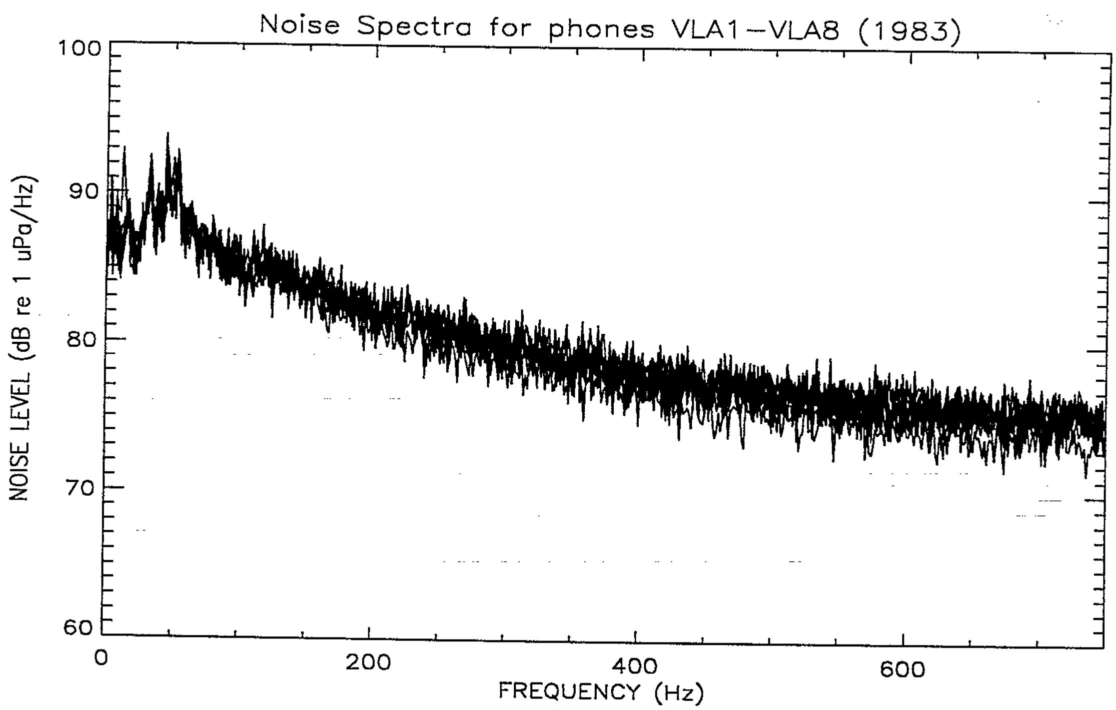

Figure 3b. This plot shows the superimposed calibrated noise spectra for phones VLA1 to VLA8 (uppermost 8 hydrophones in the array). The superposition indicates consistent

results and provides a visual estimate of the variability in the omnidirectional noise level with frequency.

At each site the omnidirectional noise levels at each of the frequencies 50, 100, 200, 400 and 600 Hz were averaged and the results tabulated in Table 2.

Table 2 The omnidirectional noise levels at the principal measurement sites.

	Year	Julian Day	Time (PST)	50 Hz Omni Level (dB)	100 Hz Omni Level (dB)	200 Hz Omni Level (dB)	400 Hz Omni Level (dB)	600 Hz Omni Level (dB)
SITE 1	1983	170	08:55	93	85	82	78	75
SITE 2	1984	161	18:26	93	89	85	80	78
		162	12:45	94	84	76	71	68
		163	14:03	93	86	76	73	70
SITE 3	1984	157	00:09	100	86	79	74	72
		157	09:01	99	88	84	78	75
		157	14:22	97	87	83	79	78
		157	20:17	99	88	82	77	76
		158	02:03	92	88	83	79	77
		158	09:39	94	86	81	76	74
		158	14:09	97	88	85	80	78
		159	02:33	92	88	83	80	79
		159	18:31	92	87	85	80	79
		160	04:36	95	88	83	78	76
		160	10:02	94	89	85	79	77
SITE 4	1985	112	01:58	94	85	78	76	73

3.2. Directional Noise Estimates.

Directional noise estimates were obtained for the four sites covering three different measurement years. These data are shown in Figures 4-9 on the following pages. Each plot shows the relative intensity of the measured noise only and ***not*** an absolute, calibrated intensity level, the absolute calibrated levels can be obtained from Table 2 for the five selected frequencies and are also available in Appendix A in the form of complete spectral plots similar to that shown in Figure 3b above.

3.2.1. Site 1 - June 1983.

One set of data was available for analysis as a result of measurements made on June 19th, 1983. The data were recorded early in the morning (09:00 PST) under calm weather conditions.

Figure 4 shows the vertical arrival structure at the array as determined from the four elements of the 2m sub-array (Fig. 4a), the 6m sub-array (Fig. 4b) and from the 18m sub-array (Fig. 4c). The three figures show the effect of spatial aliasing quite clearly, however the 2m array provides a clear picture of the nature of the ambient noise field and shows that the noise is concentrated symmetrically about the horizontal (90°). The site is relatively shallow, having a bottom depth of around 600m and is located on the continental slope off the mouth of the Strait of Juan de Fuca. The vertical arrival structure of the ambient noise is consistent with results obtained by others **[4-8]** for sites where down-slope enhancement of ship radiated noise is the dominant noise mechanism.

Since this particular data set appears to be free of interference from local shipping, it may prove to be a good candidate for further analysis and could be used to provide an indirect measure of bottom properties in this area (using the well-documented techniques described by other researchers **[1,2]**).

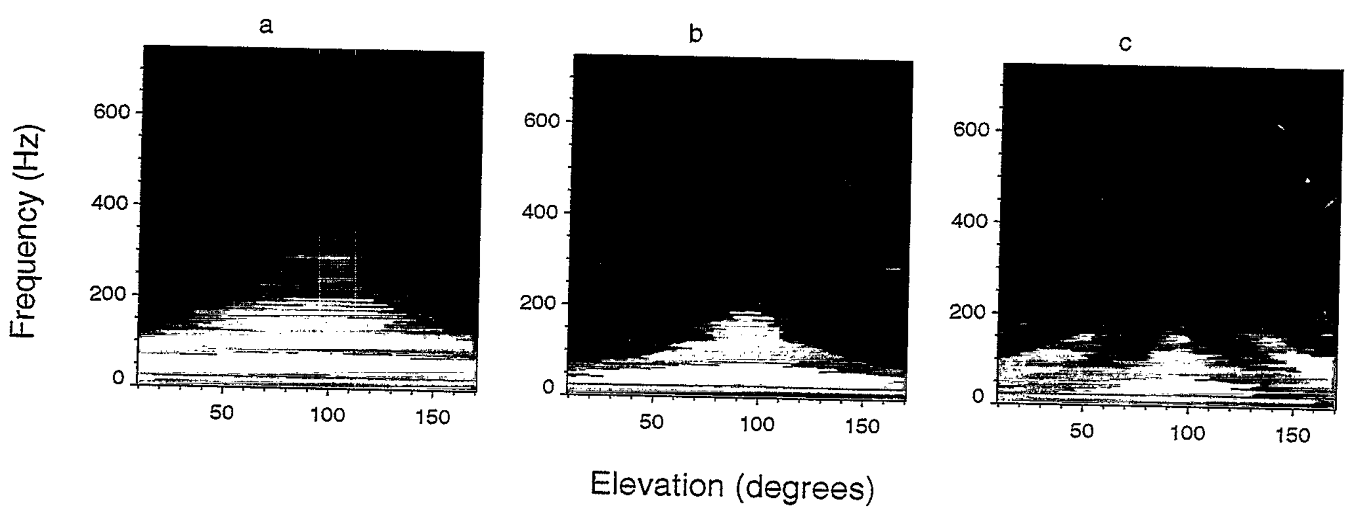

Figure 4a-c. Plots of the vertical ambient noise field as measured with a four-hydrophone vertical array (at 2m, 6m and 18m spacing) for Site 1, June 1983 (up = 0°, down=180°).

3.2.2. Site 2 - June 9th-11th 1984.

Data were recorded over a period of three days on this site. The data for the upper two surfaces in Fig. 5 were recorded in the early evening of June 9th (18:25 and 18:28 PST), the middle surface was recorded at around noon (12:45 PST) on June 10th, and the bottom two surfaces show data recorded in the afternoon (14:03 and 14:06 PST) of June 11th. All of these surfaces show an ambient noise field consistent with that expected from a site where down-slope-enhanced shipping noise is the dominant noise mechanism (*i.e.*, where the noise is concentrated symmetrically about the horizontal axis of the receiving array (90°)). Once again, this data set could provide several good candidates for further analysis in estimating of bottom properties.

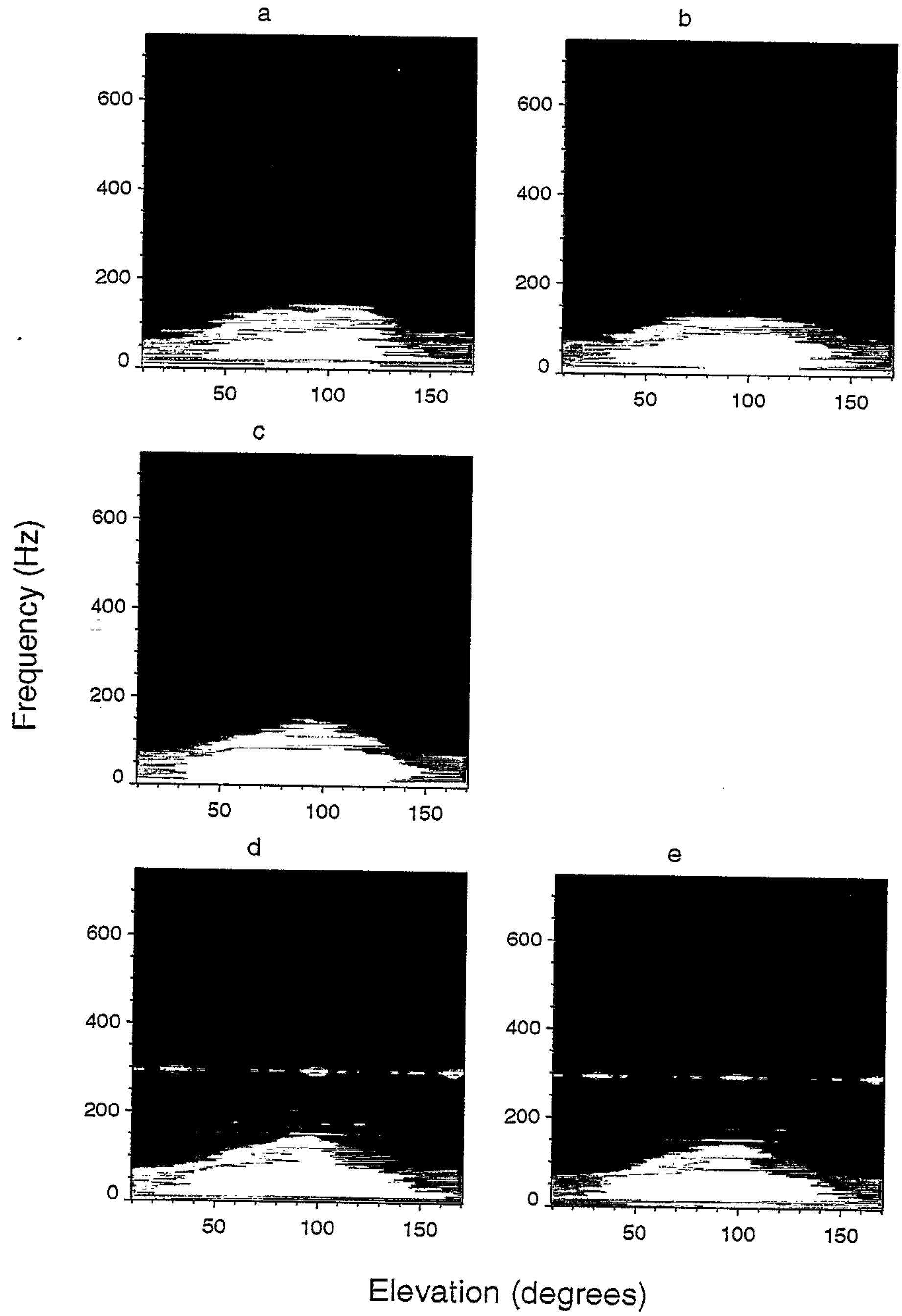

Figure 5a-e. Plots of the vertical ambient noise field as measured with an 8-hydrophone vertical array (6m spacing) at Site 1 during June 9-11, 1984. Figures 5d-e show the presence of an unknown interfering sound source at about 300 Hz.

3.2.3. Site 3 - June 5th-8th 1984.

Data were recorded over a period of three days at this deep water (2600 m) site and the recorded data are discussed separately below:

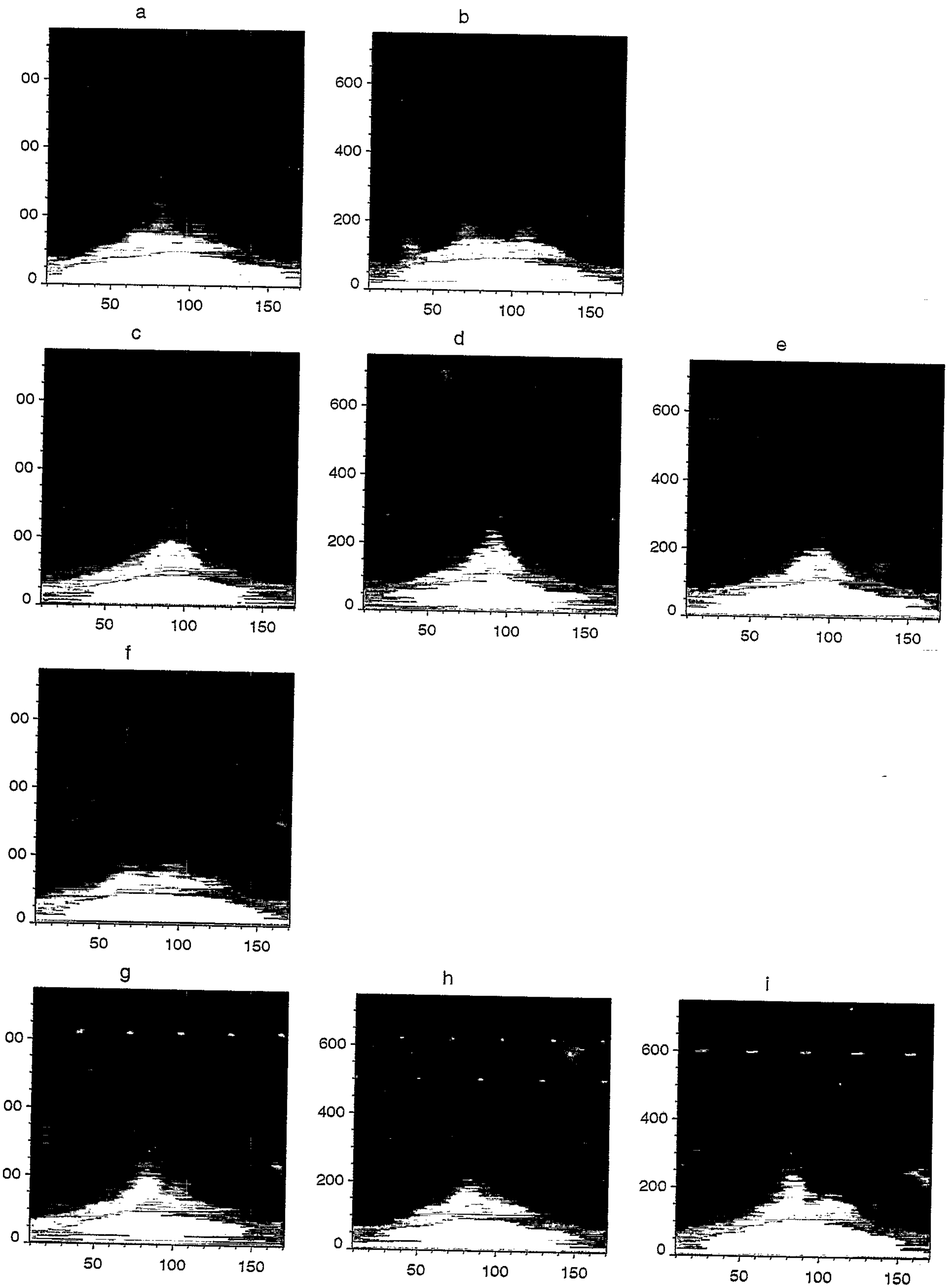

Figure 6a-i. Plots of the vertical ambient noise field as measured with an 8-hydrophone vertical array (6m spacing) at Site 3 on June 5th, 1984.

The bottom two surfaces (Fig. 7e-f) show data recorded in the afternoon (14:09-14:12 PST). This data appears to have contributions which are characteristic of both on-axis arrivals and flat-bottom arrivals. It may well be that these last two vertical arrival structures result from a combination of two distinct noise generation mechanisms.

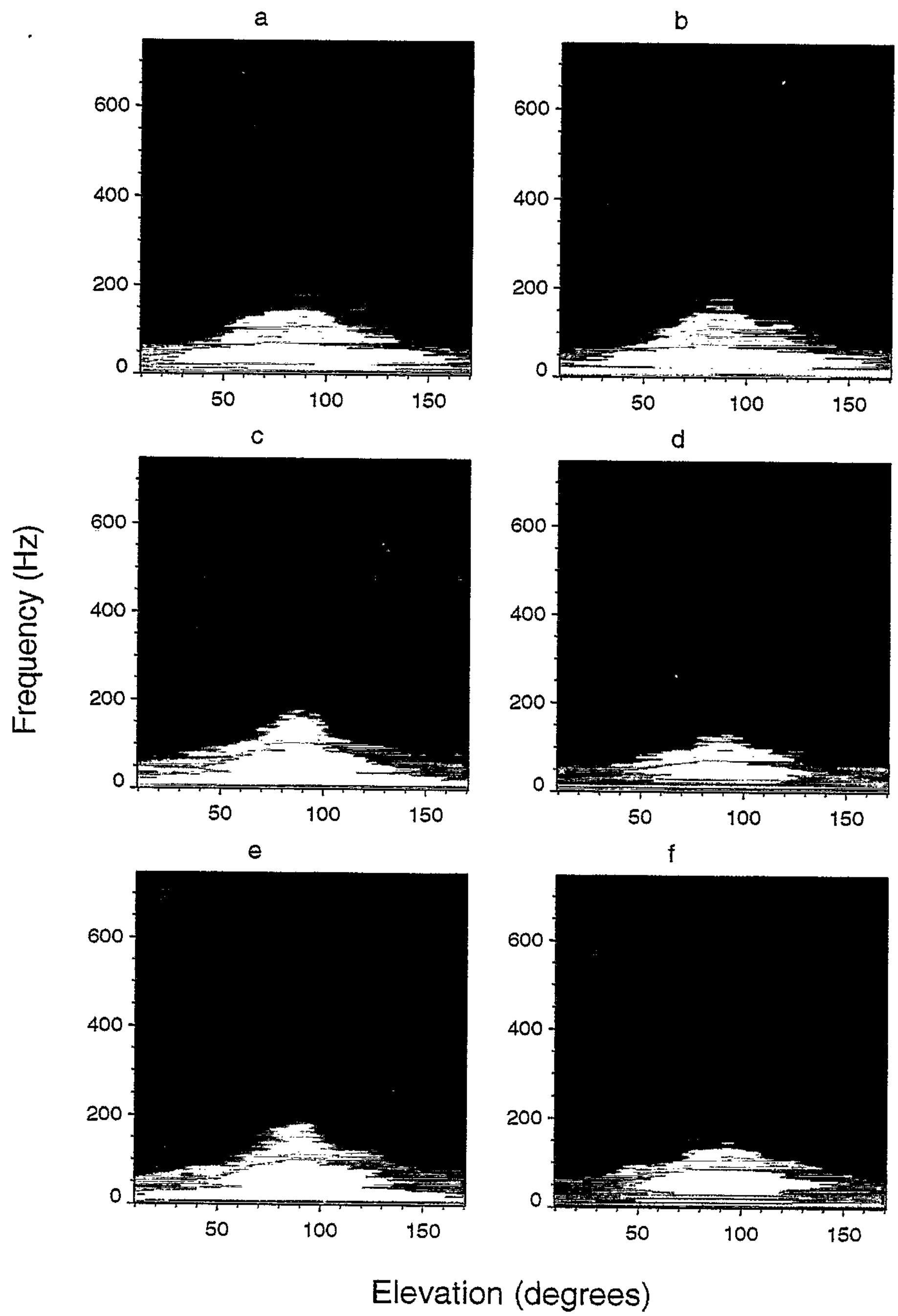

Figure 7a-f. Plots of the vertical ambient noise field as measured with an 8-hydrophone vertical array (6m spacing) at Site 3 on June 6th, 1984.

June 7th,1984 Fig. 8a-c shows selected samples of the ambient noise field data taken in the early morning (02:34 PST) and evening (18:31-18:35 PST) of June 7th. The uppermost surface shows a relatively broad on-axis arrival structure whereas the next two (Fig. 8b-c) show more of a dual arrival structure.

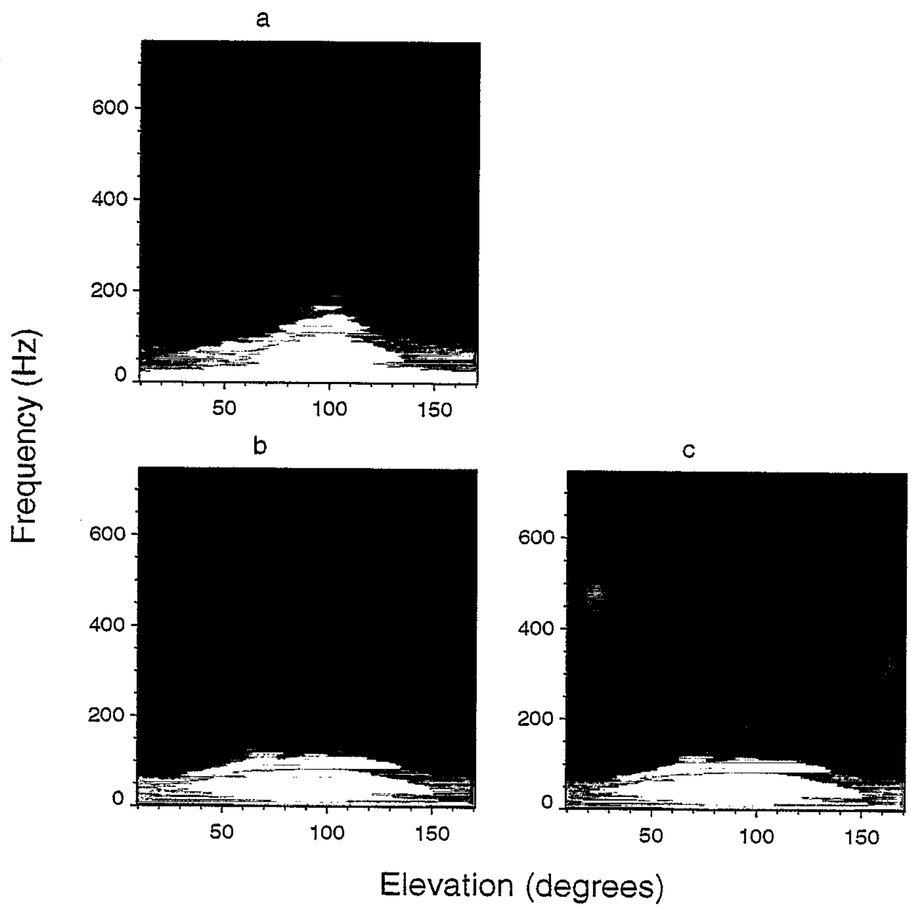

Figure 8a-c. Plots of the vertical ambient noise field as measured with an 8-hydrophone vertical array (6m spacing) at Site 3 on June 7th, 1984.

June 8th,1984

Fig. 9a-c shows selected samples of the ambient noise field data taken in the early morning (04:36 PST) and mid-morning (10:01-10:05 PST) of June 8th. The uppermost surface shows a very strong and quite narrow on-axis arrival structure. This is, again, consistent with a downslope-enhanced noise generation mechanism. It is interesting to note that these results appear to be consistent with the time of day at which increased fishing fleet activity generally takes place. It may well be that in this example, the west coast fishing fleet is playing a dominant role in the generation of ambient noise at this site. The next two (Fig. 9b-c) surfaces show a complex arrival structure which appears to be dominated by individual targets.

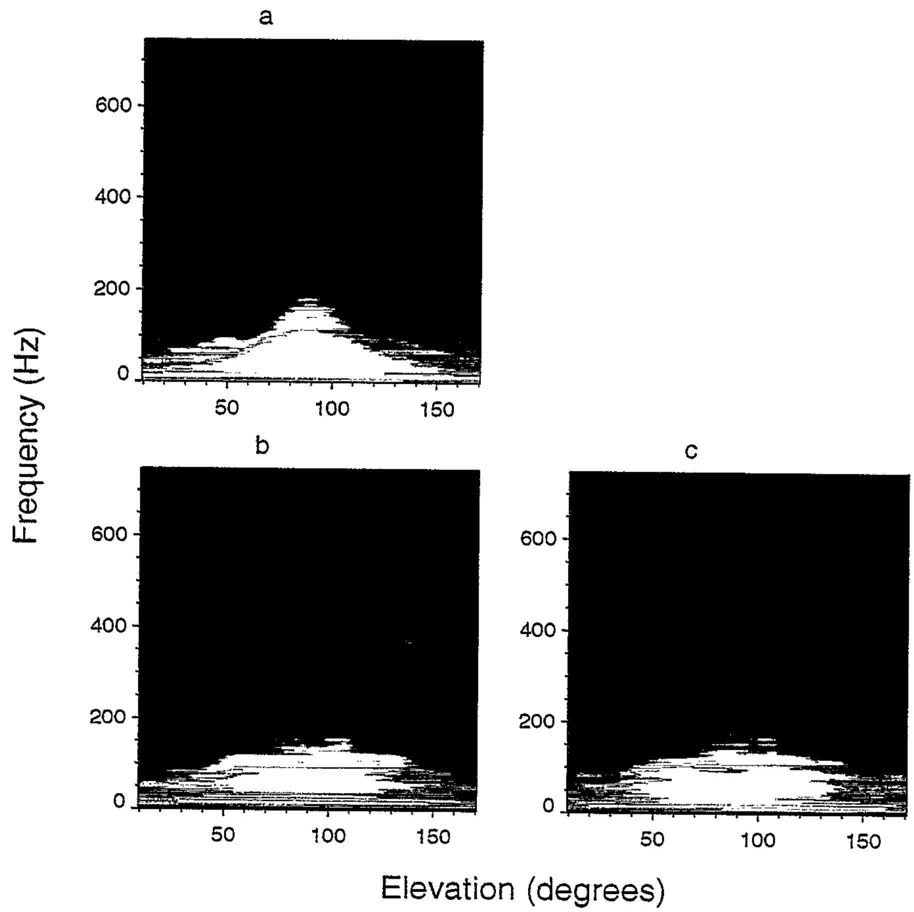

Figure 9a-c. Plots of the vertical ambient noise field as measured with an 8-hydrophone vertical array (6m spacing) at Site 3 on June 8th, 1984.

3.2.4. Site 4 - April 22nd 1985.

Fig. 10a-b shows two samples of the ambient noise field data taken on April 22nd, 1985. This site was located in the deep-water of the Cascadia Basin (2500 m) but about 30 n.mi further offshore than Site 3. The data shown in the two surfaces (Fig. 10a-b) were recorded in the early morning hours (01:58-02:03 PST). Both surfaces show a characteristic on-axis arrival structure. This pattern is characteristic of shipping noise propagated over a down-sloping continental shelf.

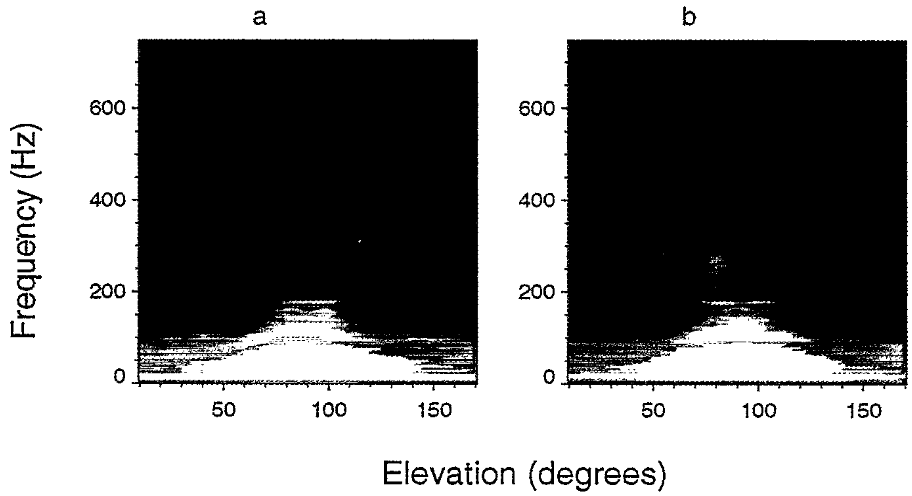

Figure 10a-b. Plots of the vertical ambient noise field as measured with an eight-element vertical array (at 6m spacing) for Site 4, April 22, 1985.

4. Summary and Conclusions

This paper has examined a collection of ambient noise data recorded on a multi-element vertical array over a period of three years and for four different site locations. It was seen that the ambient noise field was extremely variable and complex. The observations at a number of the measurement sites suggest that the ambient noise field may result from two distinct noise generation mechanisms. The first is downslope propagation of shipping noise which results in a single on-axis arrival structure. The second mechanism is offshore shipping noise propagating over the flat-bottomed Cascadia Basin which results in a characteristic dual-arrival structure symmetric about the array axis and having a relative null on the horizontal axis itself. Some of the ambient noise surfaces which were examined in this paper exhibited both characteristics.

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June 5th,1984

Figure 6a-i shows selected samples of the ambient noise field data taken throughout the day on June 5th. The uppermost two surfaces (Fig. 6a-b) were recorded just after midnight (00:08 and 00:10 PST). These two plots show a double arrival structure (*i.e.*, noise distributed symmetrically about the horizontal axis of the vertical array with a relative null at 90°). This pattern is characteristic of shipping noise propagated over a flat ocean bottom **[9]**. No nearby shipping was recorded in the experimental log book at the time these measurements were made, and it is unlikely that this pattern could have resulted from a single interfering ship.

The next three surfaces, (Fig. 6c-e) show data recorded in the early morning of June 5th (09:01-09:08 PST). These plots show strong on-axis arrivals centered tightly around the horizontal axis of the array. These are characteristic of down-slope-enhanced shipping noise. It appears, therefore, that the mechanism for generating the ambient noise has changed in a mere 9 hours time. It may be that at the time these measurements were taken, the coastal fishing fleet had moved out onto the continental shelf off western Vancouver Island and were acting as a loud noise source which was then propagated down the continental shelf and into the sound channel.

The next surface (Fig. 6f) shows data recorded in the early afternoon (14:22 PST). This plot shows evidence of a single strong interfering source, and in fact the log book reported a radar contact at a range of 5 nm from the array during these measurements. The underlying ambient noise field is suggestive of the double arrival structure.

The final three surfaces (Fig. 6g-i) show data recorded in the evening (20:18-20:25 PST). The log book reports no radar contacts nearby, although there is clear evidence of one interferer in the ambient noise surfaces. The underlying ambient noise appears to be weakly dual in nature.

June 6th,1984 Fig. 7a-f shows selected samples of the ambient noise field data taken throughout the day on June 6th. The uppermost two surfaces (Fig. 7a-b) were recorded in the early morning hours (02:07-02:11 PST). These plots show a rather complex arrival structure which shows quite strong on-axis arrivals, individual interfering sources and some weak indication of the dual arrival structure.

The middle two surfaces (Fig. 7c-d) show data recorded in the morning (09:38-09:40 PST), and here once again the arrival structure indicates that the noise is predominantly on-axis. Other noise sources are present in this data and are likely due to seismic exploration in the area at the time the measurements were made.

[4] V.C. Anderson, "Variation of the vertical directionality of noise with depth in the North Pacific", J. Acoust. Soc. Am. **66**, 1446-1452 (1979)

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Appendix A

Additional Omnidirectional Noise Level Plots:

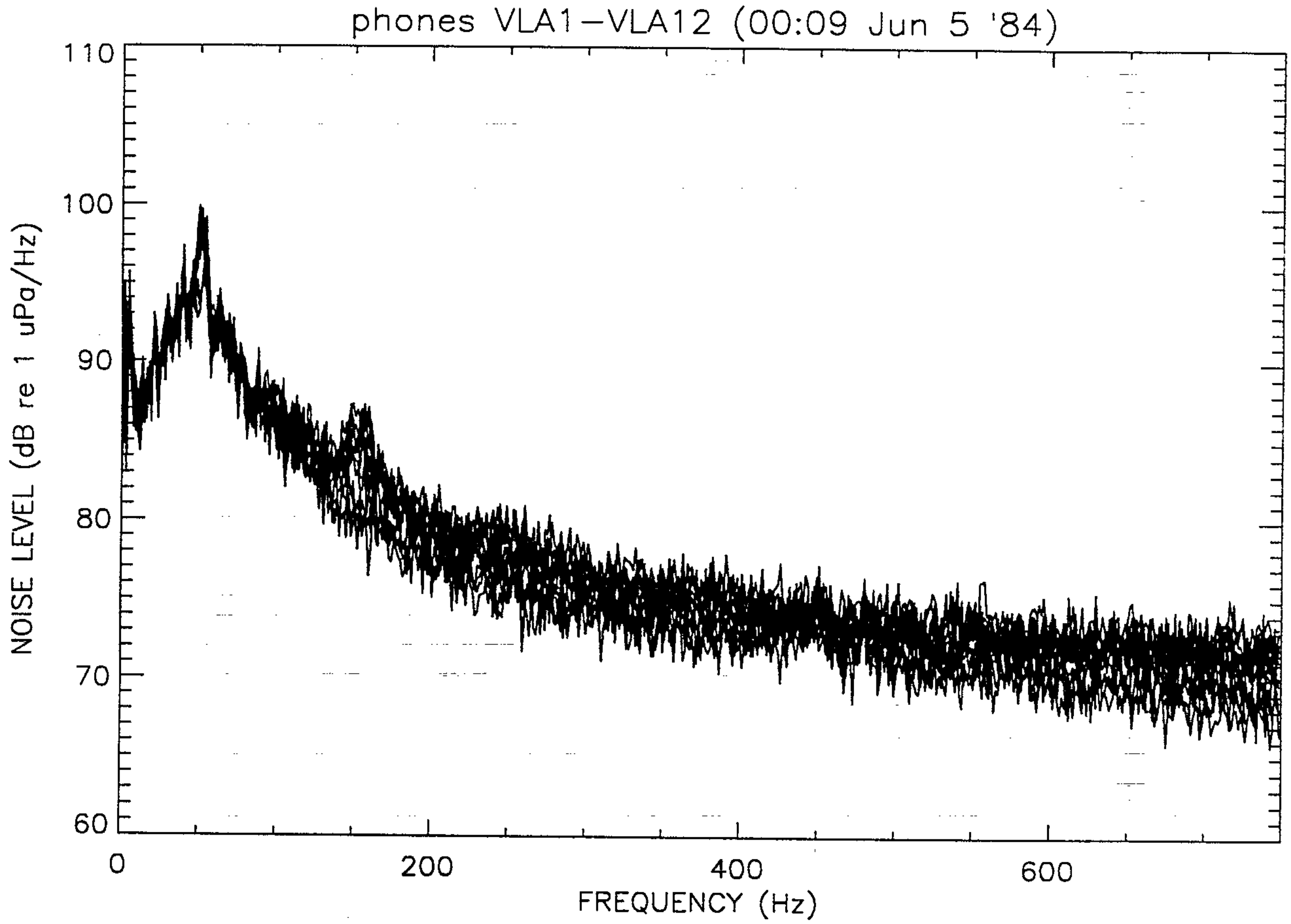

Figure A1. The omnidirectional noise level plot for Site 3. The data was recorded at 00:09 PST on June 5th, 1984. The estimated omnidirectional levels at 50, 100, 200, 400 and 600 Hz are 100, 86, 79, 74 and 72 dB respectively (See Table 2).

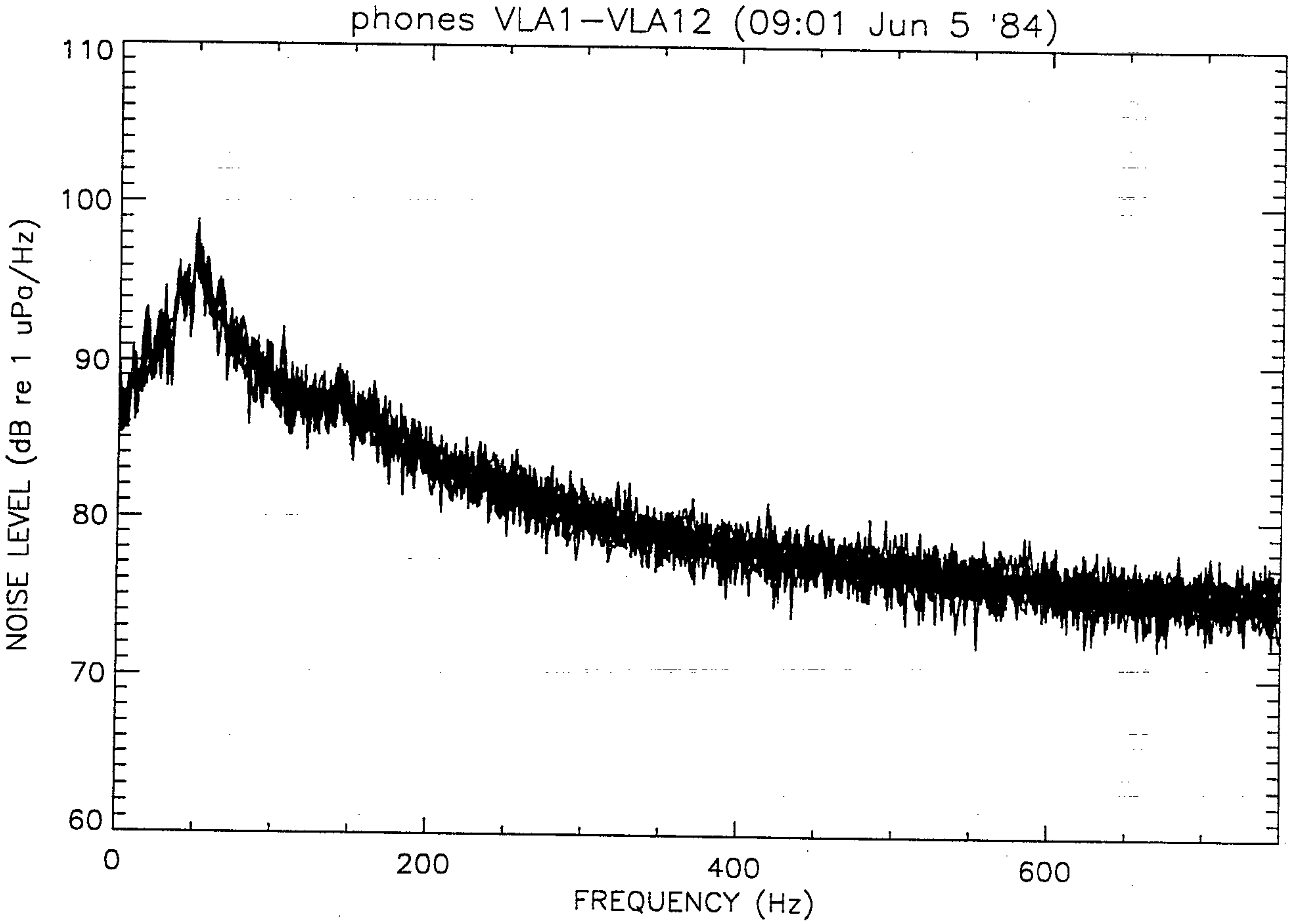

Figure A2. The omnidirectional noise level plot for Site 3. The data was recorded at 09:01 PST on June 5th, 1984. The estimated omnidirectional levels at 50, 100, 200, 400 and 600 Hz are 99, 88, 84, 78 and 75 dB respectively (See Table 2).

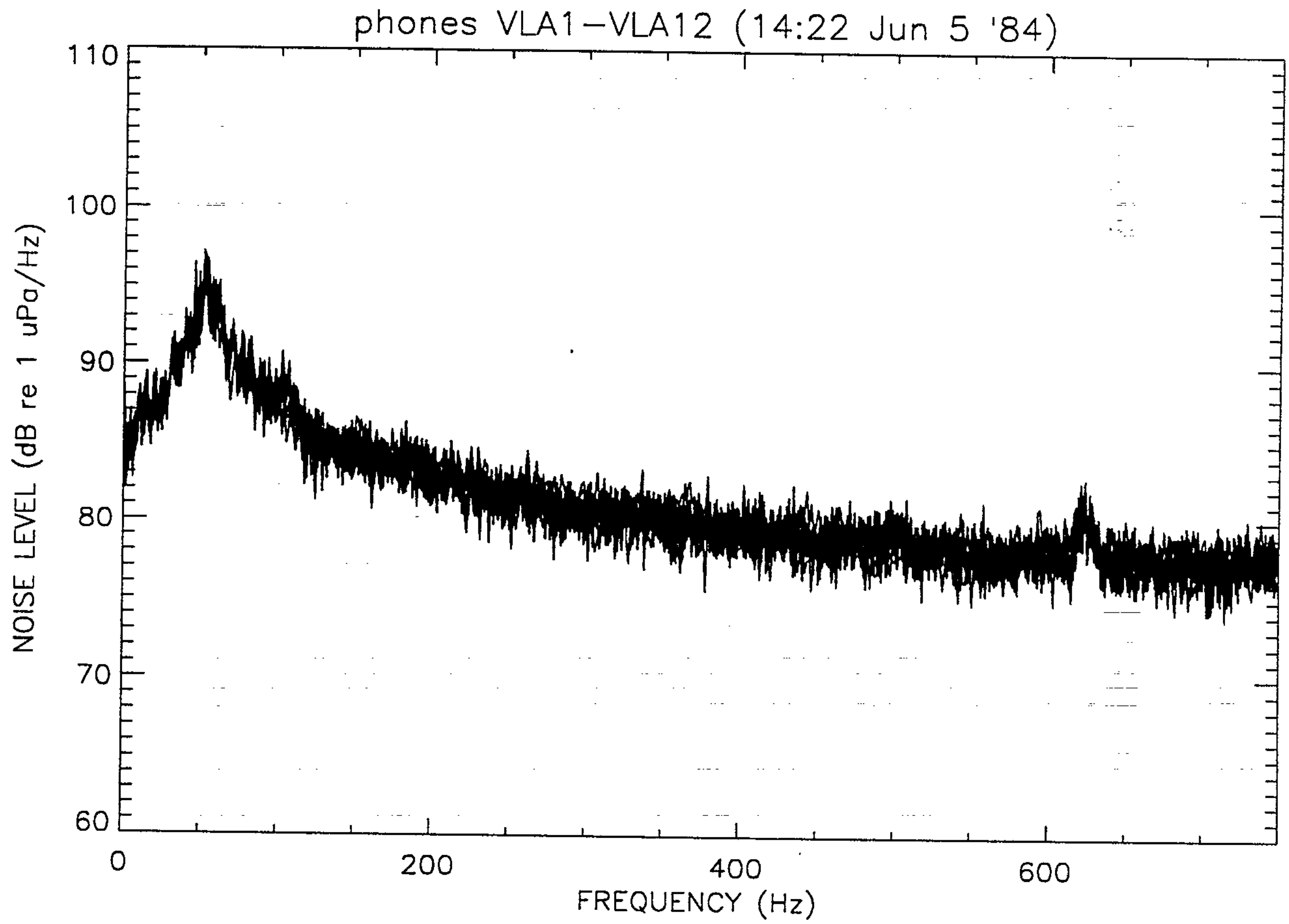

Figure A3. The omnidirectional noise level plot for Site 3. The data was recorded at 14:22 PST on June 5th, 1984. The estimated omnidirectional levels at 50, 100, 200, 400 and 600 Hz are 97, 87, 83, 79 and 78 dB respectively (See Table 2).

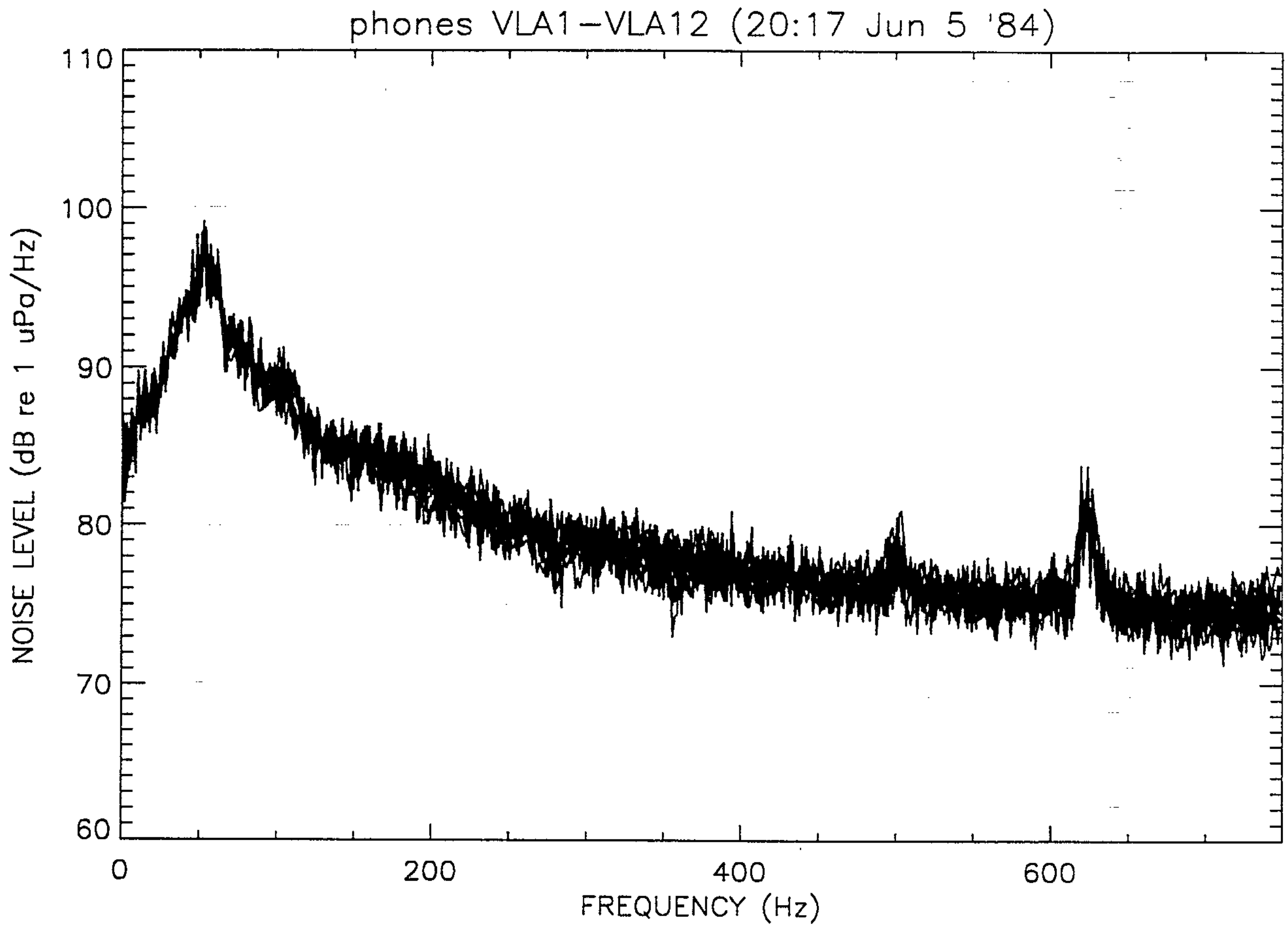

Figure A4. The omnidirectional noise level plot for Site 3. The data was recorded at 20:17 PST on June 5th, 1984. The estimated omnidirectional levels at 50, 100, 200, 400 and 600 Hz are 99, 88, 82, 77 and 76 dB respectively (See Table 2).

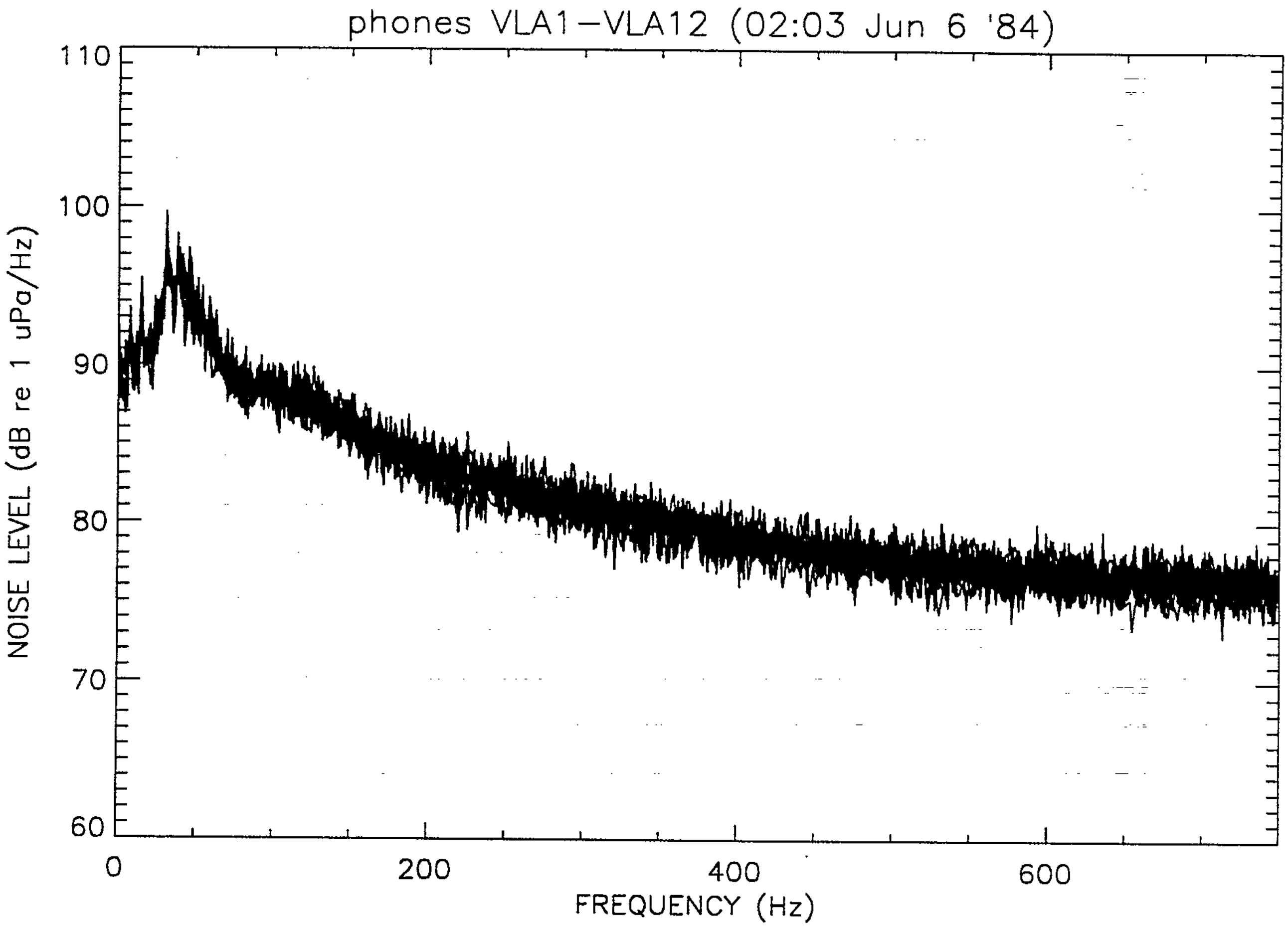

Figure A5. The omnidirectional noise level plot for Site 3. The data was recorded at 02:03 PST on June 6th, 1984. The estimated omnidirectional levels at 50, 100, 200, 400 and 600 Hz are 92, 88, 83, 79 and 77 dB respectively (See Table 2).

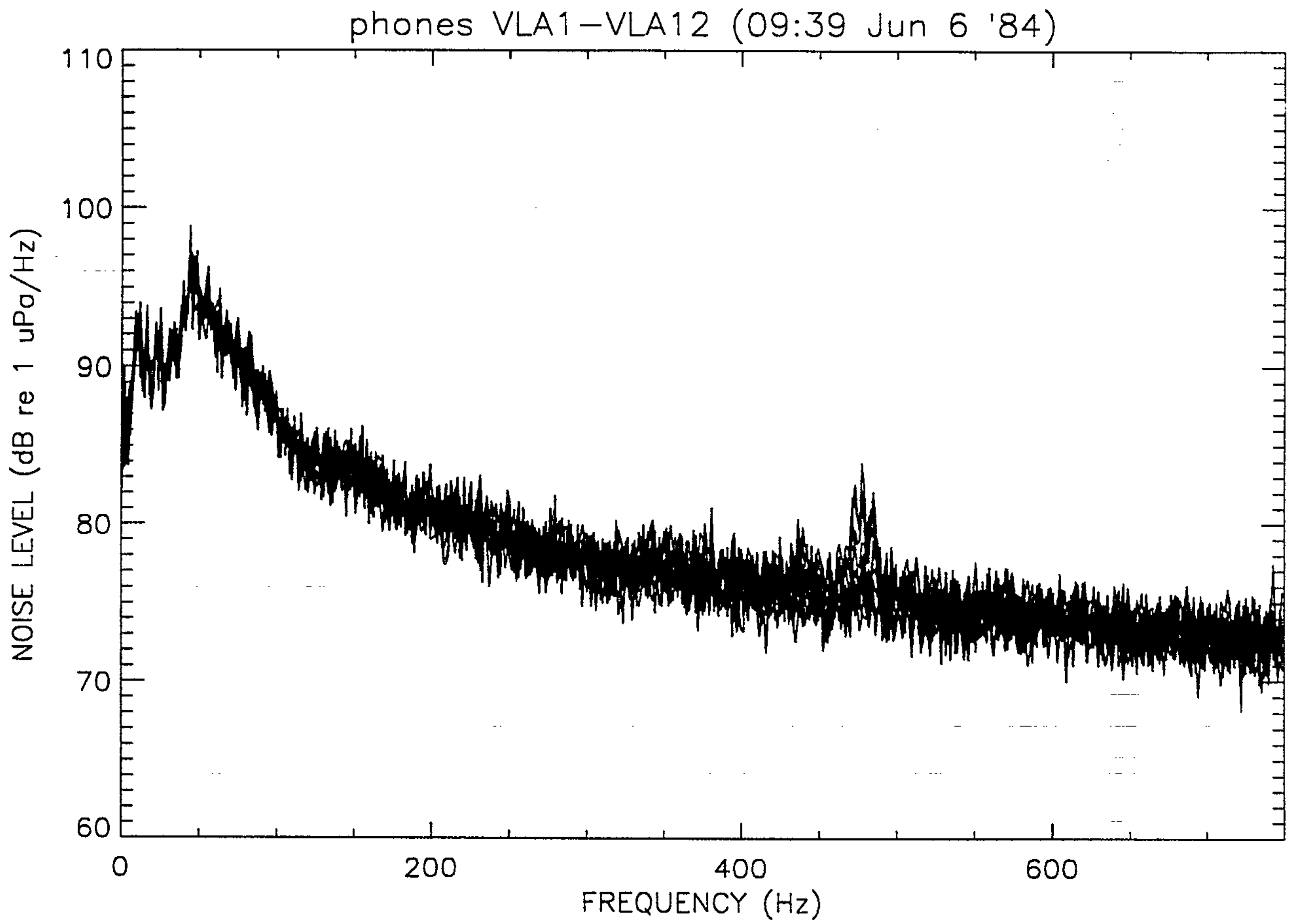

Figure A6. The omnidirectional noise level plot for Site 3. The data was recorded at 09:39 PST on June 6th, 1984. The estimated omnidirectional levels at 50, 100, 200, 400 and 600 Hz are 92, 88, 83, 79 and 77 dB respectively (See Table 2).

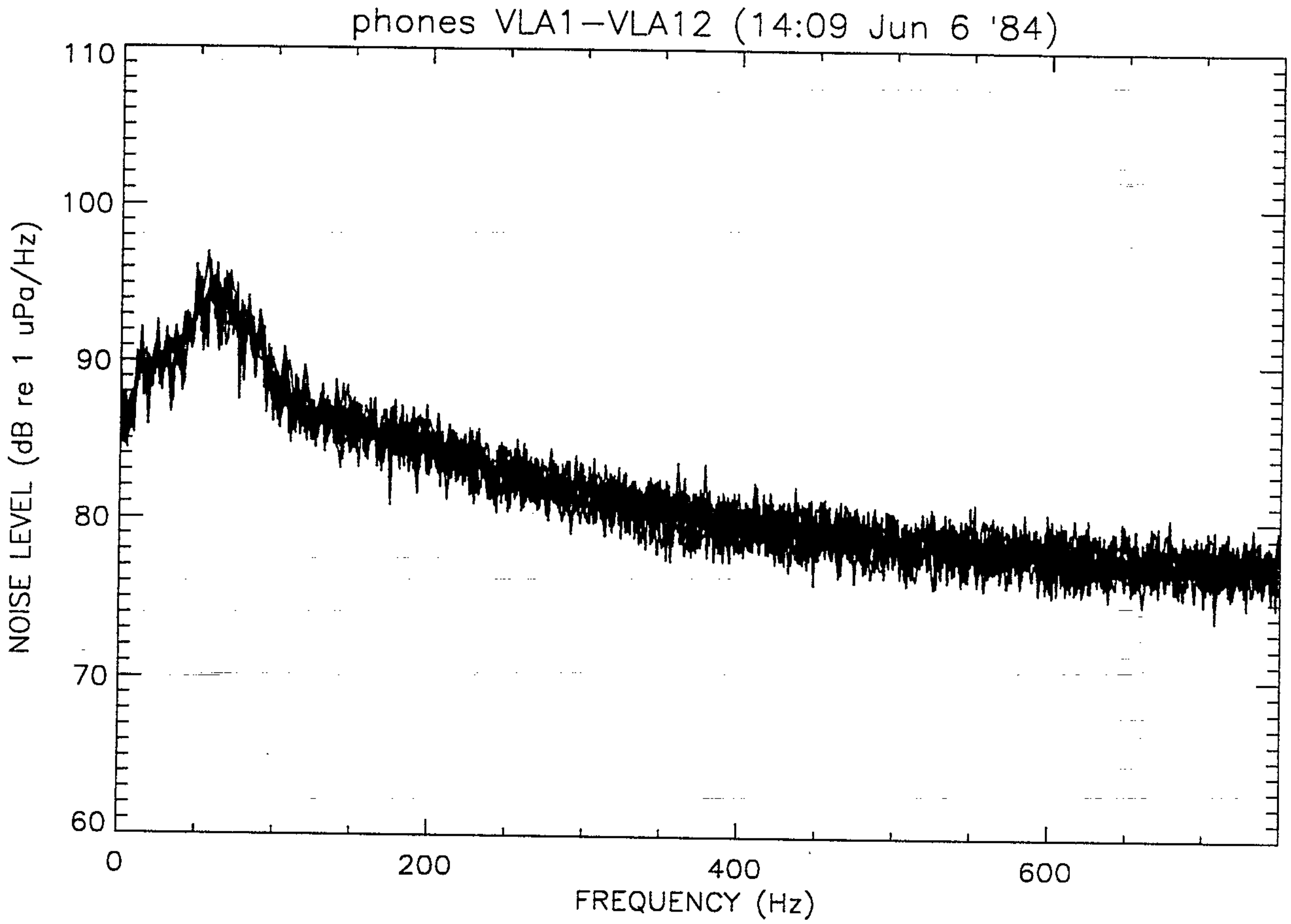

Figure A7. The omnidirectional noise level plot for Site 3. The data was recorded at 14:09 PST on June 6th, 1984. The estimated omnidirectional levels at 50, 100, 200, 400 and 600 Hz are 97, 88, 85, 80 and 78 dB respectively (See Table 2).

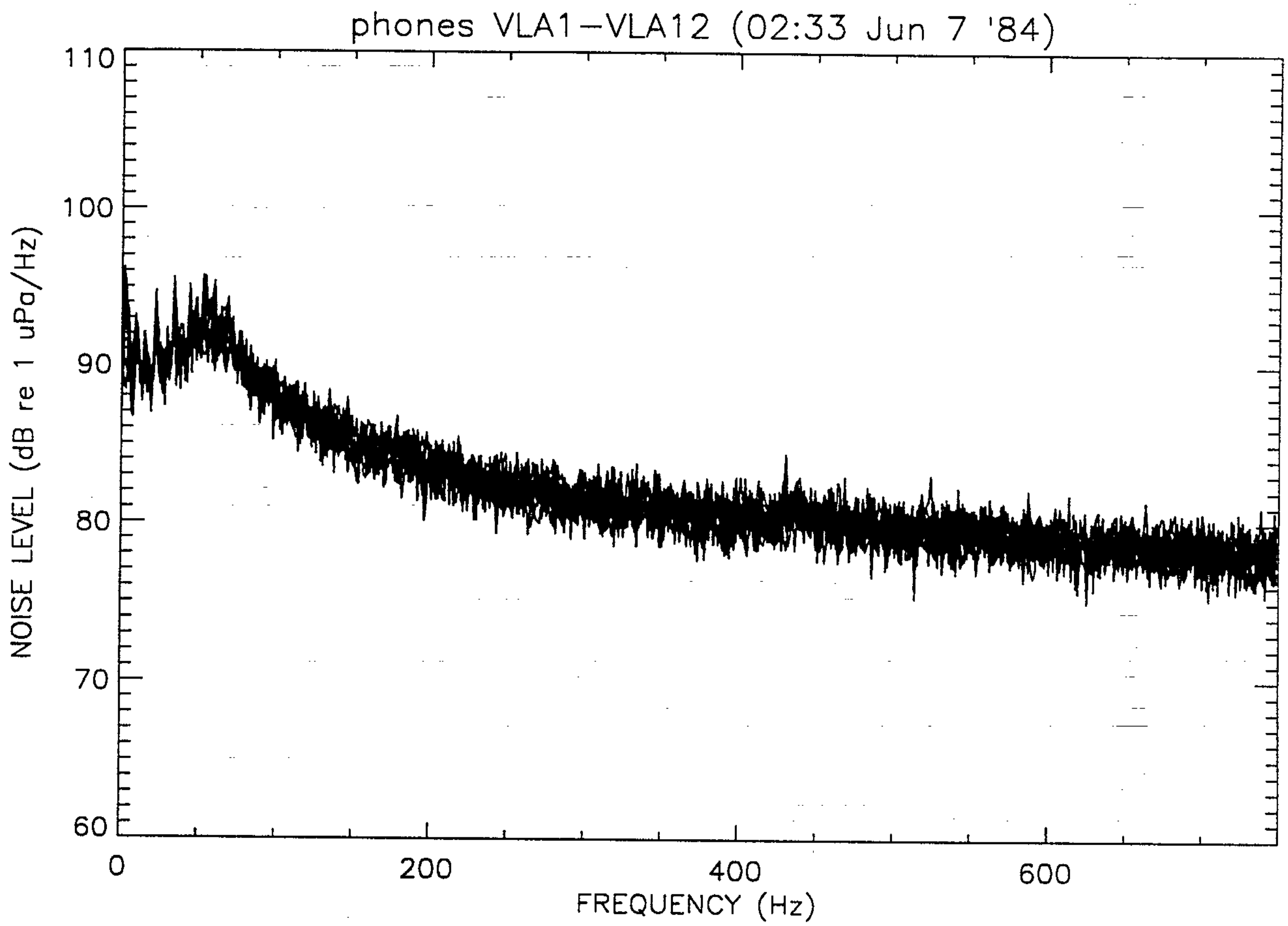

Figure A8. The omnidirectional noise level plot for Site 3. The data was recorded at 02:33 PST on June 7th, 1984. The estimated omnidirectional levels at 50, 100, 200, 400 and 600 Hz are 92, 88, 83, 80 and 79 dB respectively (See Table 2).

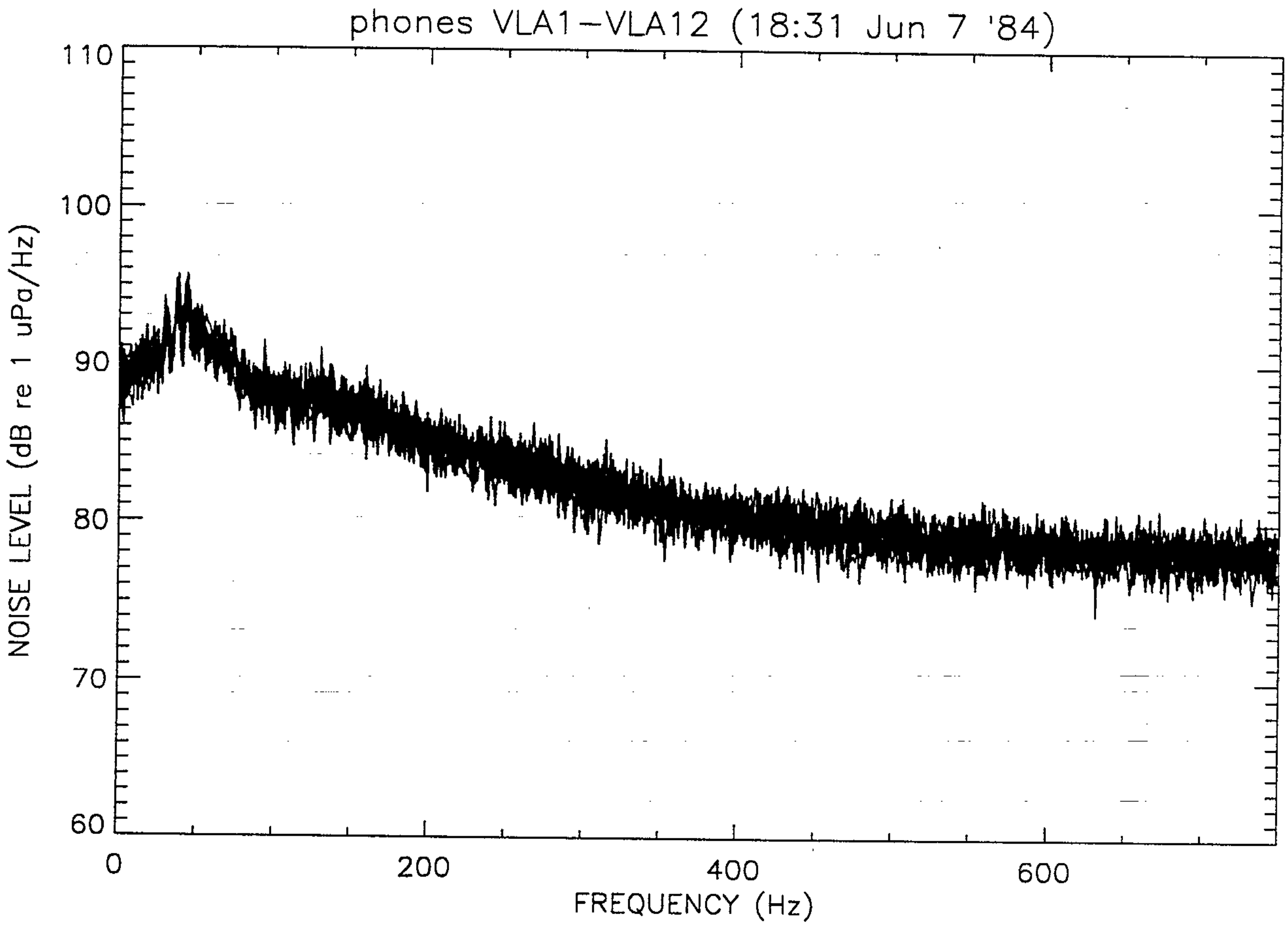

Figure A9. The omnidirectional noise level plot for Site 3. The data was recorded at 18:31 PST on June 7th, 1984. The estimated omnidirectional levels at 50, 100, 200, 400 and 600 Hz are 92, 88, 83, 80 and 79 dB respectively (See Table 2).

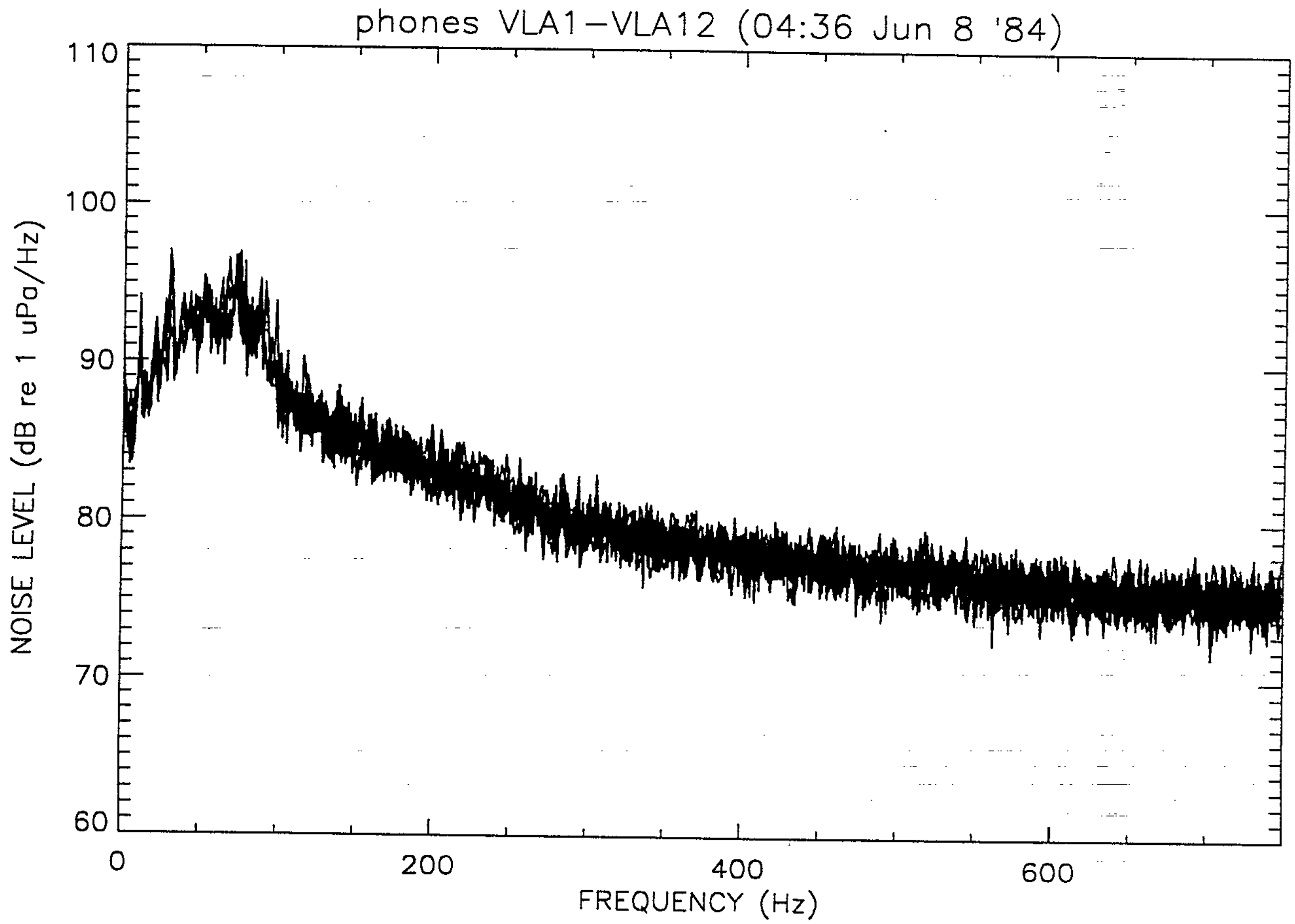

Figure A10. The omnidirectional noise level plot for Site 3. The data was recorded at 04:36 PST on June 8th, 1984. The estimated omnidirectional levels at 50, 100, 200, 400 and 600 Hz are 95, 88, 83, 78 and 76 dB respectively (See Table 2).

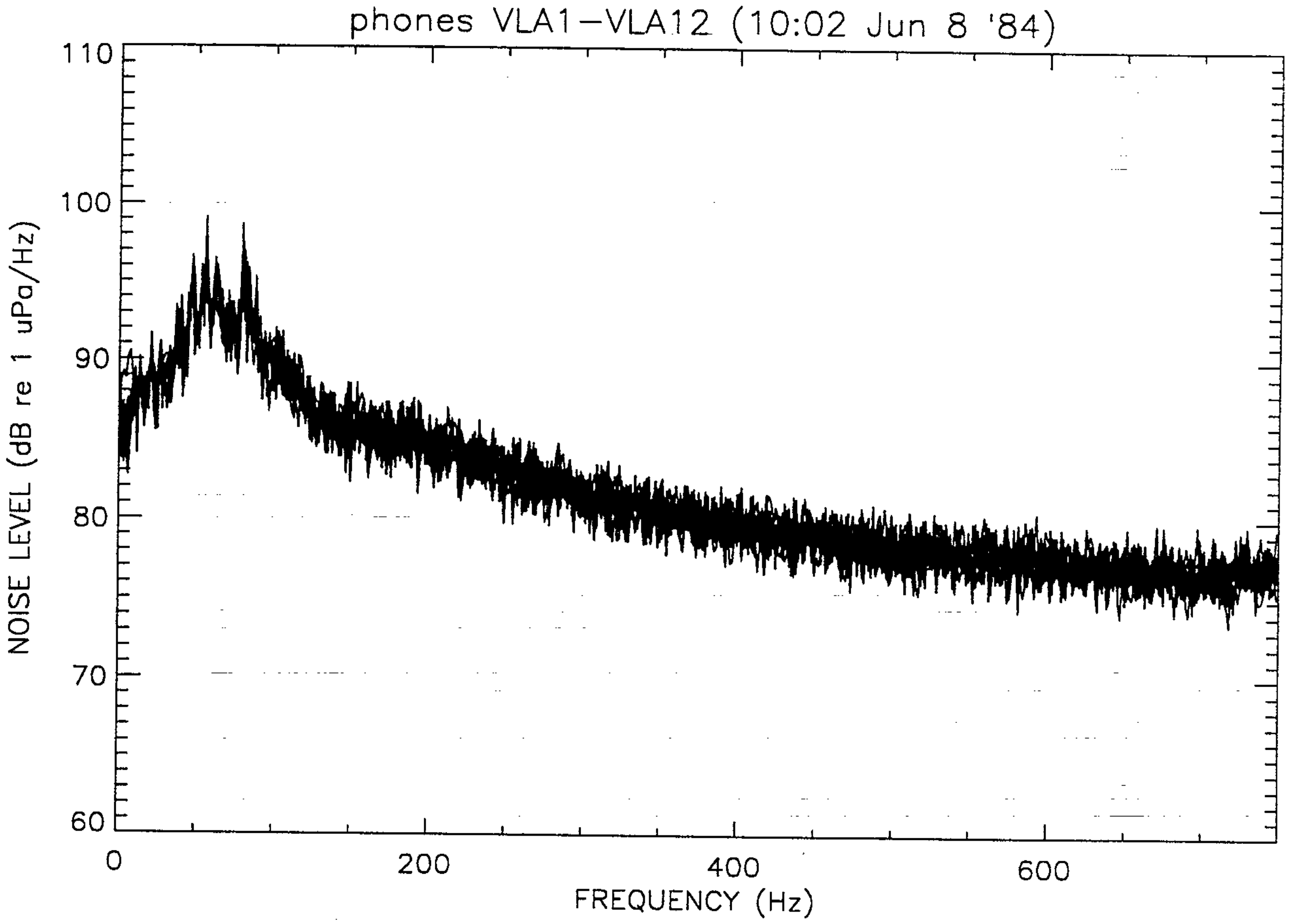

Figure A11. The omnidirectional noise level plot for Site 3. The data was recorded at 10:02 PST on June 8th, 1984. The estimated omnidirectional levels at 50, 100, 200, 400 and 600 Hz are 94, 89, 85, 79 and 77 dB respectively (See Table 2).

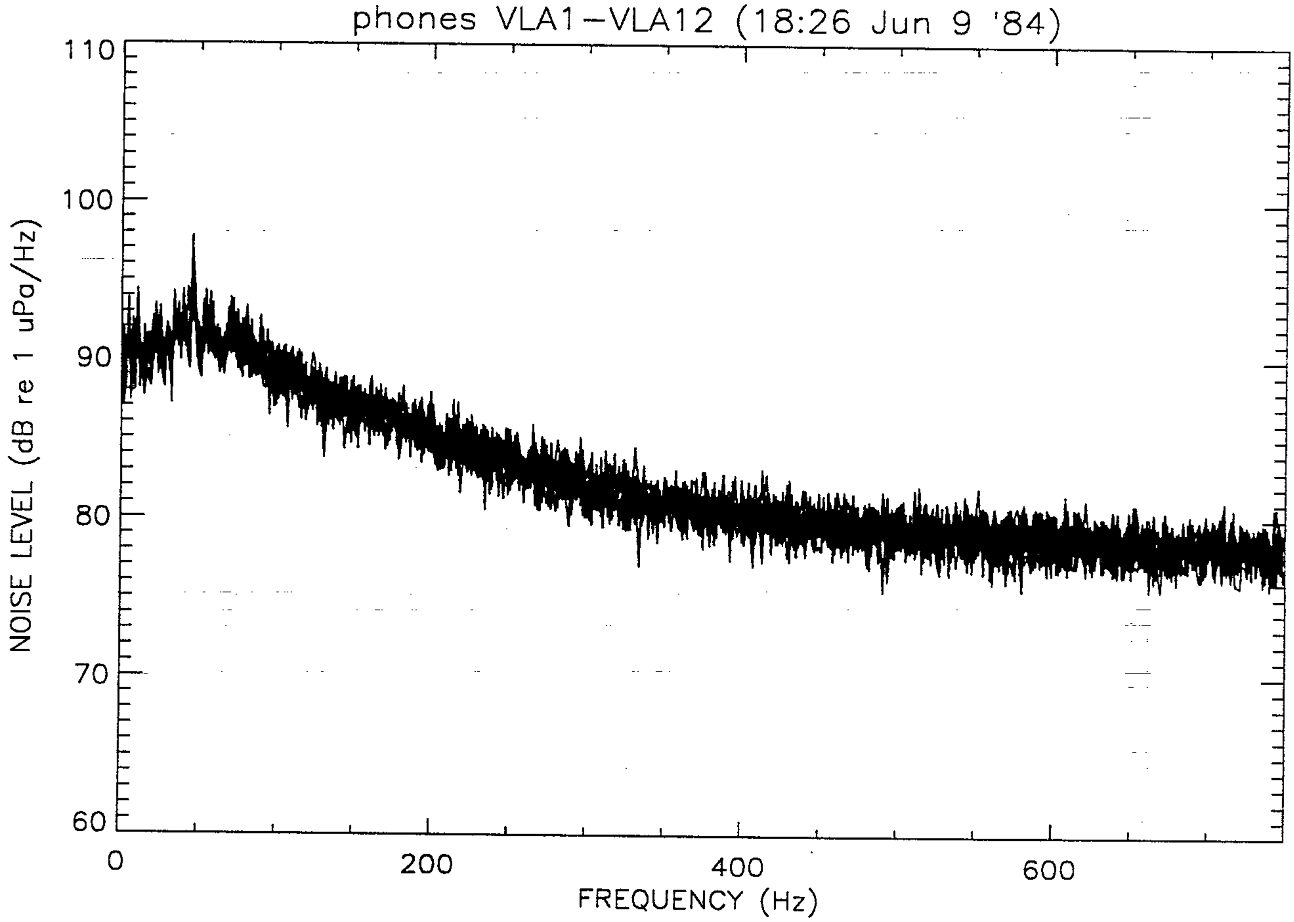

Figure A12. The omnidirectional noise level plot for Site 2. The data was recorded at 18:26 PST on June 9th, 1984. The estimated omnidirectional levels at 50, 100, 200, 400 and 600 Hz are 93, 89, 85, 80 and 78 dB respectively (See Table 2).

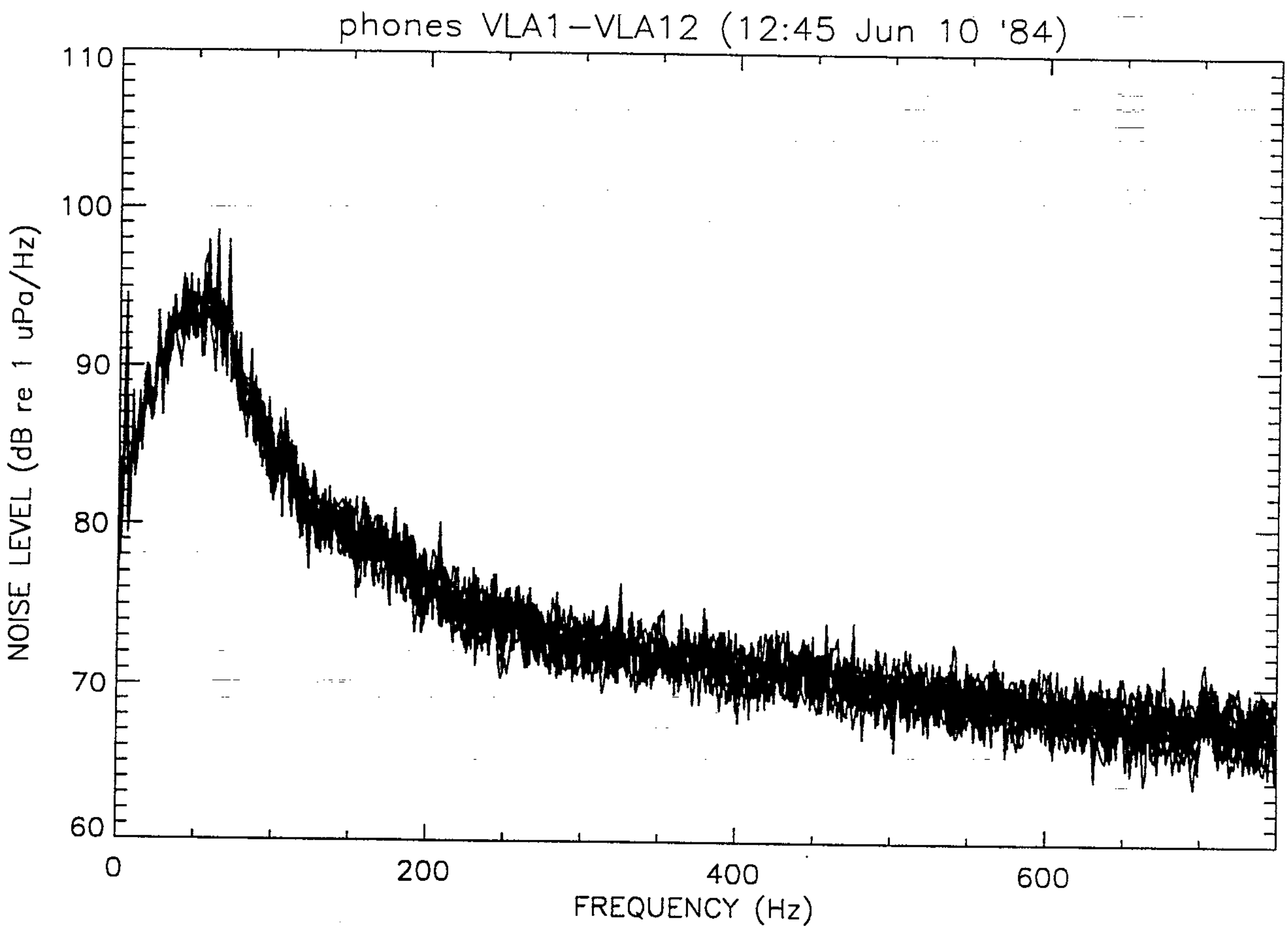

Figure A13. The omnidirectional noise level plot for Site 2. The data was recorded at 12:45 PST on June 10th, 1984. The estimated omnidirectional levels at 50, 100, 200, 400 and 600 Hz are 94, 84, 76, 71 and 68 dB respectively (See Table 2).

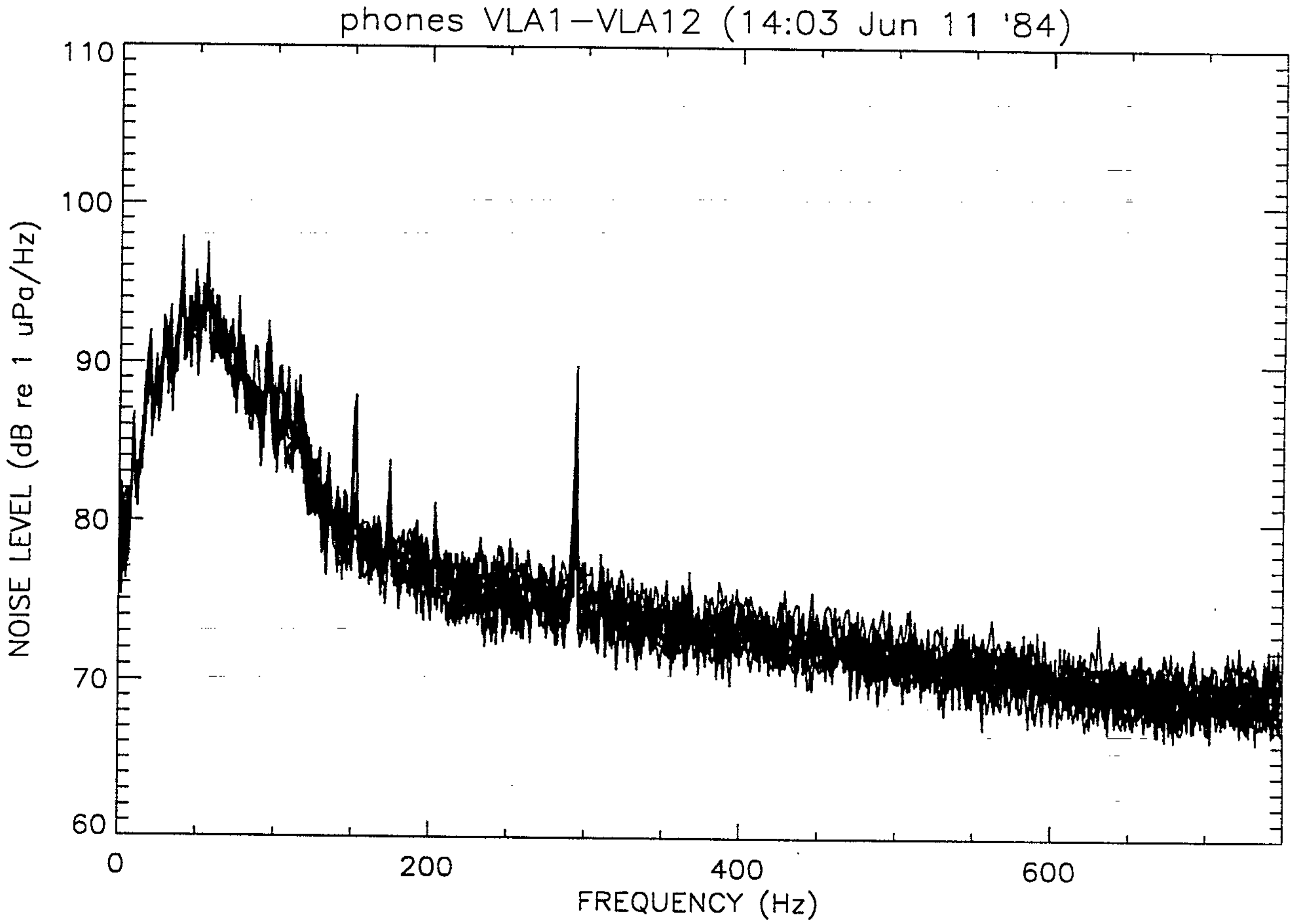

Figure A14. The omnidirectional noise level plot for Site 2. The data was recorded at 14:03 PST on June 11th, 1984. The estimated omnidirectional levels at 50, 100, 200, 400 and 600 Hz are 93, 86, 76, 73 and 70 dB respectively (See Table 2).

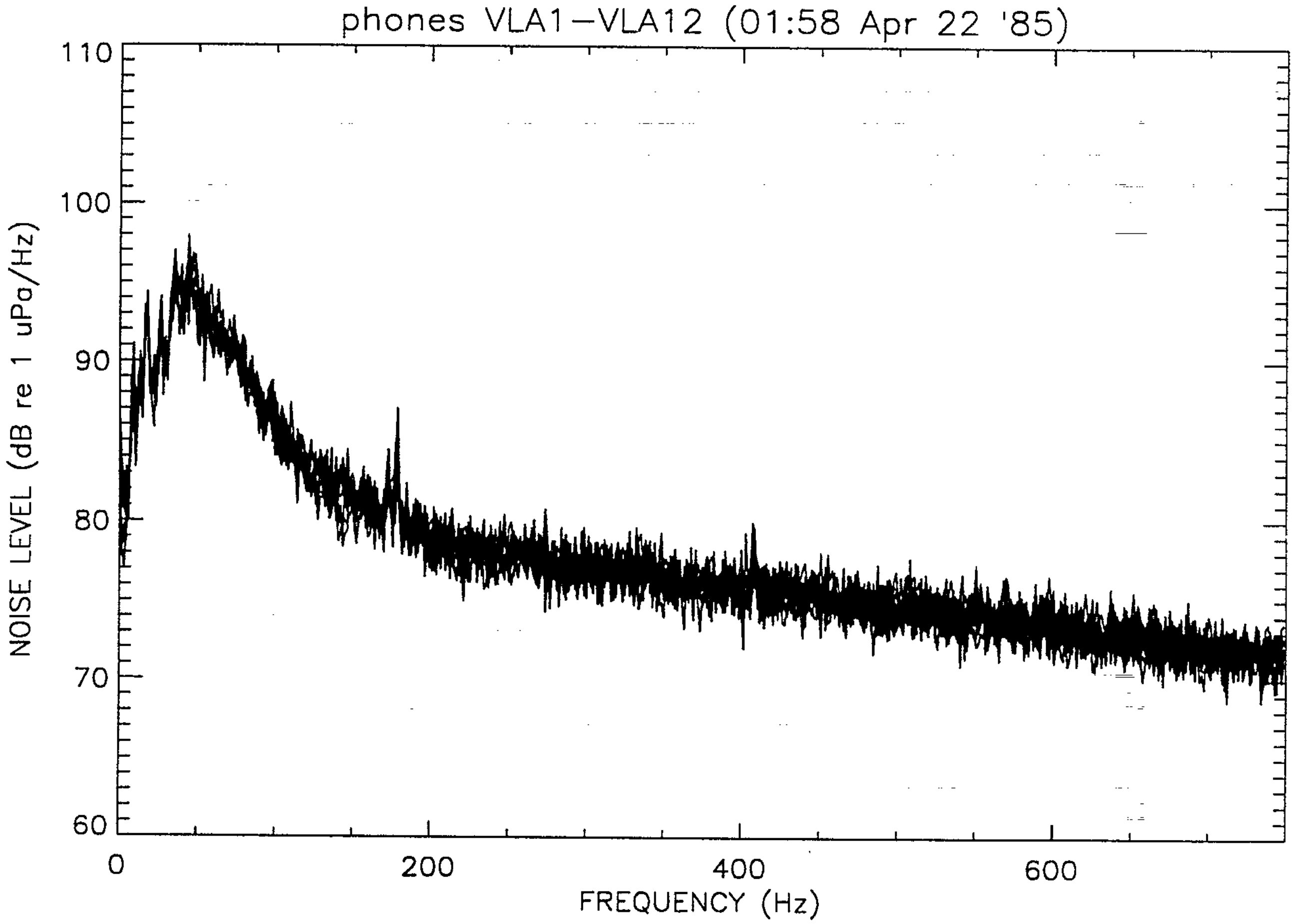

Figure A15. The omnidirectional noise level plot for Site 4. The data was recorded at 01:58 PST on April 22nd, 1985. The estimated omnidirectional levels at 50, 100, 200, 400 and 600 Hz are 94, 85, 78, 76 and 73 dB respectively (See Table 2).

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Abstract:

This paper describes ambient noise data recorded at several locations on and near the continental shelf off the west coast of Vancouver Island. The data were obtained in both shallow and deep-water with the Multi Element Vertical Array (MEVA) at various locations during a three year period. These data had not been examined to date; however, given the increased interest in shallow-water acoustic environments, it was considered timely to perform a detailed analysis of the available data. Four sites are examined, two located in deep water (2500-2600 m) just off the continental shelf, and two located in shallow water (400-500 m) on the continental shelf. One deep water site was monitored more or less continually over a four day period, and the data provide a good measure of the temporal variation present in the ambient noise. The analysis includes estimates of the omnidirectional noise level at the four sites as a function of both frequency and water depth (the depth dependency is obtained by examining a time series of the acoustic data recorded for selected individual hydrophones in the MEVA array). Directional estimates of the ambient noise field are also presented. The directional estimates are obtained by beamforming the recorded data over a selected time period and displaying the results in the form of coloured frequency-vs.-elevation angle surfaces.

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Vertical Array

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