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AFTAC Project No. VT/1705

PRELIMINARY EVALUATION OF SINGLE STATIONS OF THE LONG PERIOD EXPERIMENT NETWORK

SPECIAL REPORT NO. 7
EXTENDED ARRAY EVALUATION PROGRAM

Prepared by Stephen A. Benno

T. W. Harley, Program Manager
Area Code 703, 836-3882 Ext. 300

TEXAS INSTRUMENTS INCORPORATED
Services Group
P.O. Box 5621
Dallas, Texas 75222

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VERY LONG PERIOD EXPERIMENT NETWORK RMS NOISE LEVELS NOISE SPECTRAL CONTENT SURFACE WAVE DETECTION CAPABILITY $M_s - m_b$ DISCRIMINANT SIGNAL AND NOISE DATA DIGITALLY PROCESSED						

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INTRODUCTION

A. GENERAL

The Very Long Period Experiment represents an effort to install a small network of high-gain, high-quality seismometers and associated instrumentation at various locations throughout the world. The instrumentation has been described previously by Pomeroy et al (1969). To date instruments have been installed in Australia, Thailand, Alaska, Spain, Israel, Norway, and New Jersey. Detailed studies of the data from the station at Ogdensburg, New Jersey, were presented by Savino et al (1971). Also Savino presented preliminary results from all seven of the network stations at the MIT Seismic Discrimination meeting in January 1972, at Cambridge, Massachusetts. His results were obtained primarily from analysis of the photographic records at each station, while results of this study were obtained from the digital recordings.

In this report the seven individual stations are evaluated separately; the stations are evaluated as a network in Special Report No. 8 (Alsup, 1972) of this contract. The geographical location and code number of each station is shown in Table I-1.

Because the amount of digital data processed thus far has been relatively small and somewhat scattered in time, results presented represent only a preliminary evaluation of the seven stations. The evaluation includes analysis of the individual station RMS noise levels, noise spectral content, station surface wave detection capability, and behavior of the M_s-m_b discriminant. Also, calibration analysis is presented for the Thailand station. One important aspect of the Long Period Experiment has been a comparison of the station detection and classification capability at 20 and 40 seconds. Therefore, we have undertaken a

TABLE I-1

STATIONS OF THE LONG PERIOD NETWORK

Station	Code	Coordinates	
		Latitude (deg:min:sec)	Longitude (deg:min:sec)
Australia	1	20:05:18 S	146:15:16 E
Thailand	2	18:47:24 N	98:57:37 E
Alaska	3	64:53:58 N	148:00:20 W
Spain	4	39:51:36 N	04:01:12 W
Israel	5	29:19:48 N	34:32:12 E
Norway	6	59:39:00 N	09:37:48 E
Ogdensburg	7	41:04:00 N	74:37:00 W

detailed study of the surface wave magnitude, M_s, computed at 20 and 40 seconds and preliminary results of this study also are presented.

B. DATA BASE

Table I-2 shows the digital data processed for each of the seven stations. Attempts were made to analyze essentially all of the available data through November, 1971 at all stations except Ogdensburg. However, a substantial amount of the data at each station had to be eliminated due to the following problems:

- On a large number of occasions (nearly all of the Australian data) tape formatting problems in the digital systems prevented reading of the field tapes. Formatting problems included illegal sample rate, illegal number of channels present, and bad timing words in the header records. Also another type of error is the absence of the channel one sync flag in the first channel one sample point in each record.
- Several field tapes had short inter-record gaps which caused the tape drives to mis-position between records and hence caused problems in reading the header records (especially the Spain tapes).
- Some tapes had spurious end-of-file marks in the middle of the tapes, while other tapes were not terminated with an end-of-file mark.
- On several occasions, the field tapes had bad data due to various hardware problems (PTA's at Israel and the digital system at Thailand).

Table I-3 lists the number of events processed at each station. This table does not include a large number of Thailand and Israel events which were edited and not processed due to the afore-mentioned PTA and digital system

TABLE I-2

LPE DATA PROCESSED

AUSTRALIA January 24 - February 6, 1971	THAILAND January 24 - February 6, 1971 February 9 - February 14, 1971 March 22 - March 24, 1971 April 4 - April 30, 1971 May 3, 1971 May 16 - May 31, 1971 June 4, 1971 October 20 - October 26, 1971
ALASKA October 11 - October 18, 1970 January 24 - February 6, 1971 February 9 - February 15, 1971 March 3 - March 19, 1971 March 22 - March 24, 1971 August 8 - August 24, 1971 October 30 - November 9, 1971	SPAIN August 17 - September 1, 1971 September 10 - September 17, 1971
ISRAEL January 24 - February 6, 1971 February 9 - February 14, 1971 March 29 - April 30, 1971 May 16 - May 28, 1971 June 2 - June 13, 1971	NORWAY September 19 - September 24, 1971 October 3 - October 26, 1971 November 6 - November 9, 1971
OGDENSBURG December 17 - December 23, 1970 January 24 - February 6, 1971 March 22 - March 24, 1971 June 4, 1971 August 9 - August 24, 1971 September 10 - September 17, 1971 October 3 - October 26, 1971	

TABLE I-3

LPE EVENTS PROCESSED

Station	Events Edited	Bad Data	Interferring Event	Event Processed
Australia	7	1	2	4
Thailand	45	3	2	40
Alaska	84	11	8	65
Spain	30	2	2	26
Israel	34	1	4	29
Norway	32	0	1	31
Ogdensburg	64	2	5	57
TOTALS	296	20	24	252

problems. A total of 252 events were processed; however, multiple-station data were available for only a very limited number of these. Essentially all of these events were either in or on the edges of the Sino-Soviet bloc, and most of the events were either shallow (less than 60 km) or had unreported depth. A complete list of all the events edited for each station is given in Section IV.

The events analyzed came from a reference list which was a combination of PDE and LASA bulletin data. The LASA bulletin data was included because PDE coverage below $m_b = 4.5$ in the Sino-Soviet bloc is sparse. The LASA bulletin, while not offering complete coverage, does provide event data to $m_b = 4.0$ and below for some regions (e.g. the Kurile Islands). However, use of the LASA bulletin does provide some problems in that occasional deep events may be included in the event ensemble.

From Table I-3 it is evident that eight percent of the 276 good events could not be analyzed due to the presence of large interferring events. (It should be noted that numerous other events were not edited when PDE or LASA bulletin data showed that large interferring events would coincide with the event arrival at the station or stations of interest.) However, it is possible that most of the 20 interferred events would not have been masked at all seven of the stations. It is hoped that the interferring event problem can be analyzed further in the future when the entire network becomes operational.

SECTION II

STATION CALIBRATIONS

Of primary concern to the LPE analysis has been the unavailability of full frequency calibrations for all of the stations. Although full frequency calibrations were generated and recorded for all seven of the stations, we have been able to successfully read and analyze only one of the tapes(Alaska). Therefore, the calibration and instrument response data furnished to us by Lamont Doherty Geological Observatory has been used. The 40 second gain factors supplied by Lamont are shown in Table II-1. One factor about the various responses which should be noted is that they are all different in both shape and absolute levels (i.e., they are different between stations and between components at each of the stations).

As stated above, we were able to read the full frequency calibration data for the Alaska station. From these data we computed instrument responses and gain correction factors, which agreed with those supplied by Lamont. We also checked the gain factors for Alaska by computing spectra from a large signal recorded at the Alaska station and at the ALPA array. Both spectra were computed using the same technique and data, then the instrument responses were removed, and the resulting spectra agreed very well in both shape and absolute level.

However, during analysis of the Thailand data, it appeared that the calibration data for the station might be incorrect. The relationship between the 40 second gain factors for the station did not agree with those for the magnification curves supplied by Lamont, (Figure II-1(C)). Therefore we Fourier analyzed a daily calibration pulse for the station to check the supplied responses and gain factors. The pulses, shown in Figure II-1(A), were edited, Fourier transformed,

TABLE II-1

LAMONT 40 SECOND GAIN CORRECTION FACTORS

Station	Vertical (mμ/counts)	North-South (mμ/counts)	East-West (mμ/counts)
Australia*	.721	1.48	1.28
Thailand	.806	1.14	.806
Alaska**	1.33	1.64	1.26
Spain	.708	.625	.584
Israel	.794	1.34	1.75
Norway	.656	.530	.470
Ogdensburg	.927	.355	.397

* Computed at 30 seconds

** Effective May 1, 1971

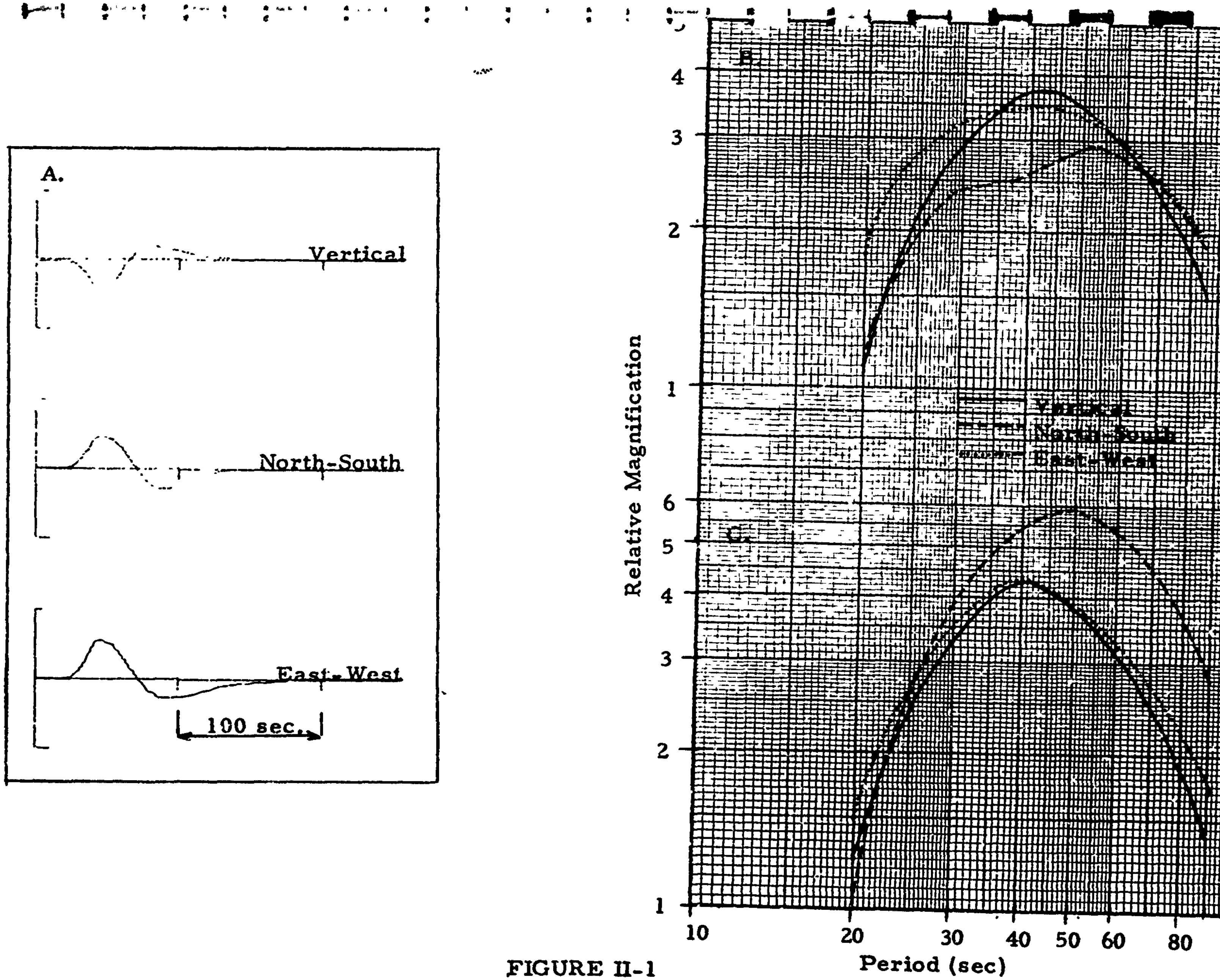


FIGURE II-1

THAILAND CALIBRATION ANALYSIS

A. Calibration Pulse from Thailand Digital Data, 05/30/71, 00:12:50
B. Calibration Frequency Response Curves
C. Lamont Frequency Response Curves (Murphy, 1971)

and then the amplitude at each frequency was computed by:

$$A(f) = \sqrt{\text{Real }(f)^2 + \text{Imaginary }(f)^2} \qquad (1)$$

where Real (f) and Imaginary (f) are the real and imaginary terms of the Fourier transform at frequency f. Next the system magnification at each frequency was computed as

$$y(f) = A * \omega^3 \qquad (2)$$

where $\omega = 2\pi f$.

The y(f) were then plotted versus period in Figure II-1(B); note the close agreement between the two vertical and East-West components (II-1(B) and II-1(C)); however, the North-South components are very different.

To check the instrument gain correction factors, the y(f) at 40 seconds in Figure II-1(B) were measured as

Vertical = .369

North-South = .282

East-West = .351

Since all three responses were computed from pulses generated using the same input current, we assumed that the output number y(f) times the instrument gain correction factor (Table II-1) should be the same for all three components. Therefore

$$.369*ZCF = .282*NCF = .351*ECF \qquad (3)$$

where ZCF, NCF, ECF are the gain correction factors at 40 seconds for the vertical, North-South, and East-West components, respectively. If we now assume that one of the Lamont supplied conversion factors is correct, we can solve for and check the other two. Therefore, let ZCF = .806, and

NCF = 1.05

ECF = 0.846

These numbers agree very well with those supplied by Lamont (Table II-1)

N-S = 1.14

E-W = 0.806

These results show the relationship between the gain correction factors is correct;

however, it does not show that the absolute calibration levels are correct. It is hoped that additional full frequency calibrations will be performed during the coming year so that the gain correction factors from computer counts to millimicrons of ground motion at each station can be verified.

SECTION III

NOISE ANALYSIS

To study the noise field at each of the stations, one hour noise samples were edited and analyzed for various time periods for the available data bases. The edited samples were Fourier transformed and then noise power spectral density plots were computed. Also, RMS noise levels in the 20-40 second band for the data were computed. In both the power spectral density and the RMS computations, the data were normalized using the 40 second calibration information, but the system responses were not removed.

A. SPECTRAL CONTENT

Figure III-1 shows a noise spectrum for Australia. The vertical component is relatively flat in the 20 to 50 second band and fairly well behaved at longer periods. Both horizontal components are about flat to 50 seconds, but both have higher levels at longer periods.

Figure III-2 shows a noise spectrum for Thailand. All three components increase rapidly at periods larger than 25 seconds, however the vertical component still is relatively low level at 50 seconds. Both horizontals are extremely noisy in this sample at longer periods. As will be shown later in this section, the horizontals for this site are generally two to three times as noisy as the vertical for RMS measurements between 20 and 40 seconds.

Figures III-3 and III-4 show spectra for two noise samples at the Alaska station. In Figure III-3, the spectra have a fairly strong peak at 16 to 18 seconds, but are relatively low level (below 40 dB) out to nearly 50 seconds. In the second case, Figure III-4, the spectra are low at the microseismic peak, but increase monotonically at periods longer than 20 seconds and reach levels of up to 50 dB at 50 seconds. It should be noted that these noise samples are only

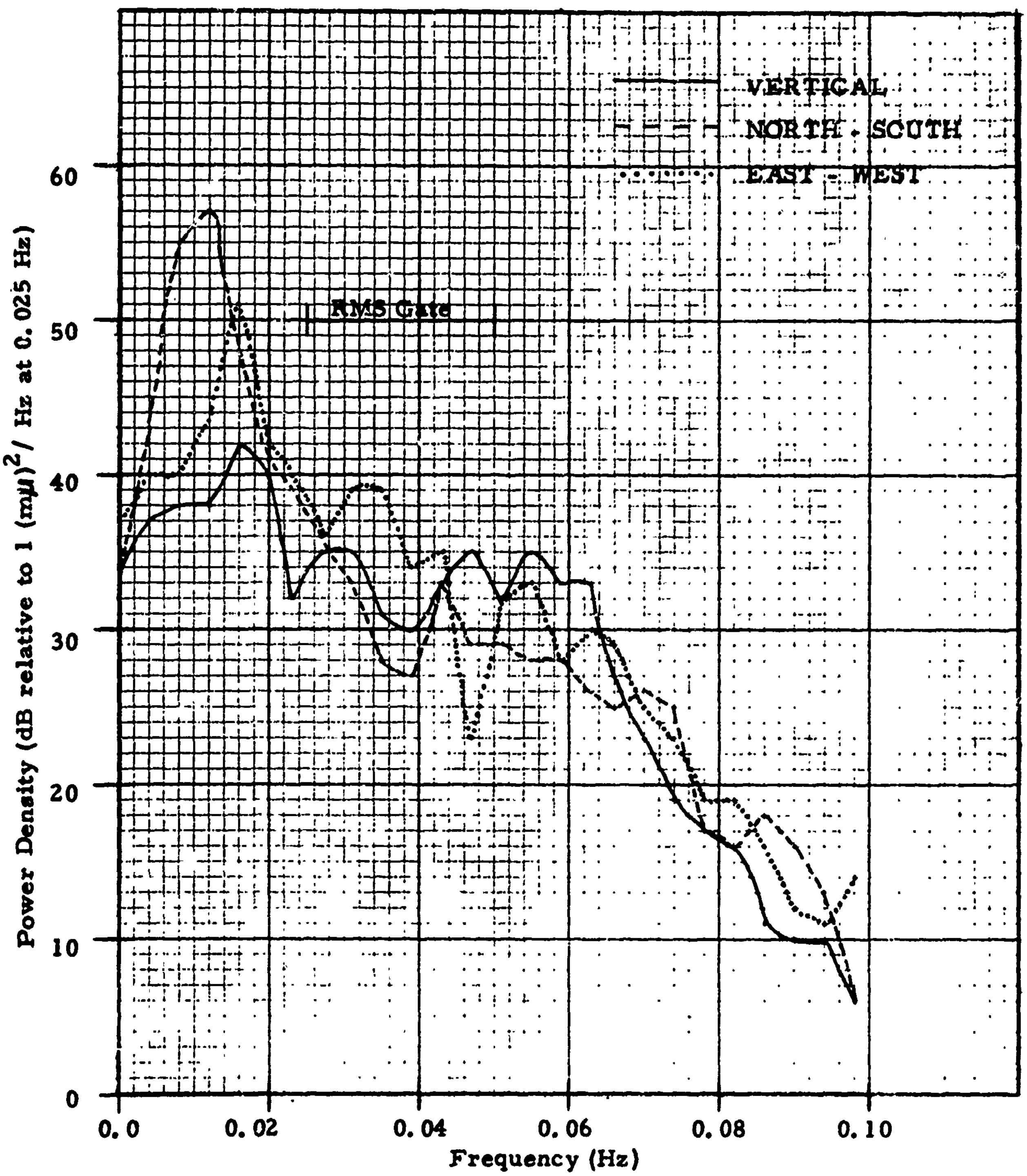


FIGURE III-1
AUSTRALIA NOISE POWER DENSITY SPECTRA
01/26/71 04:00:00

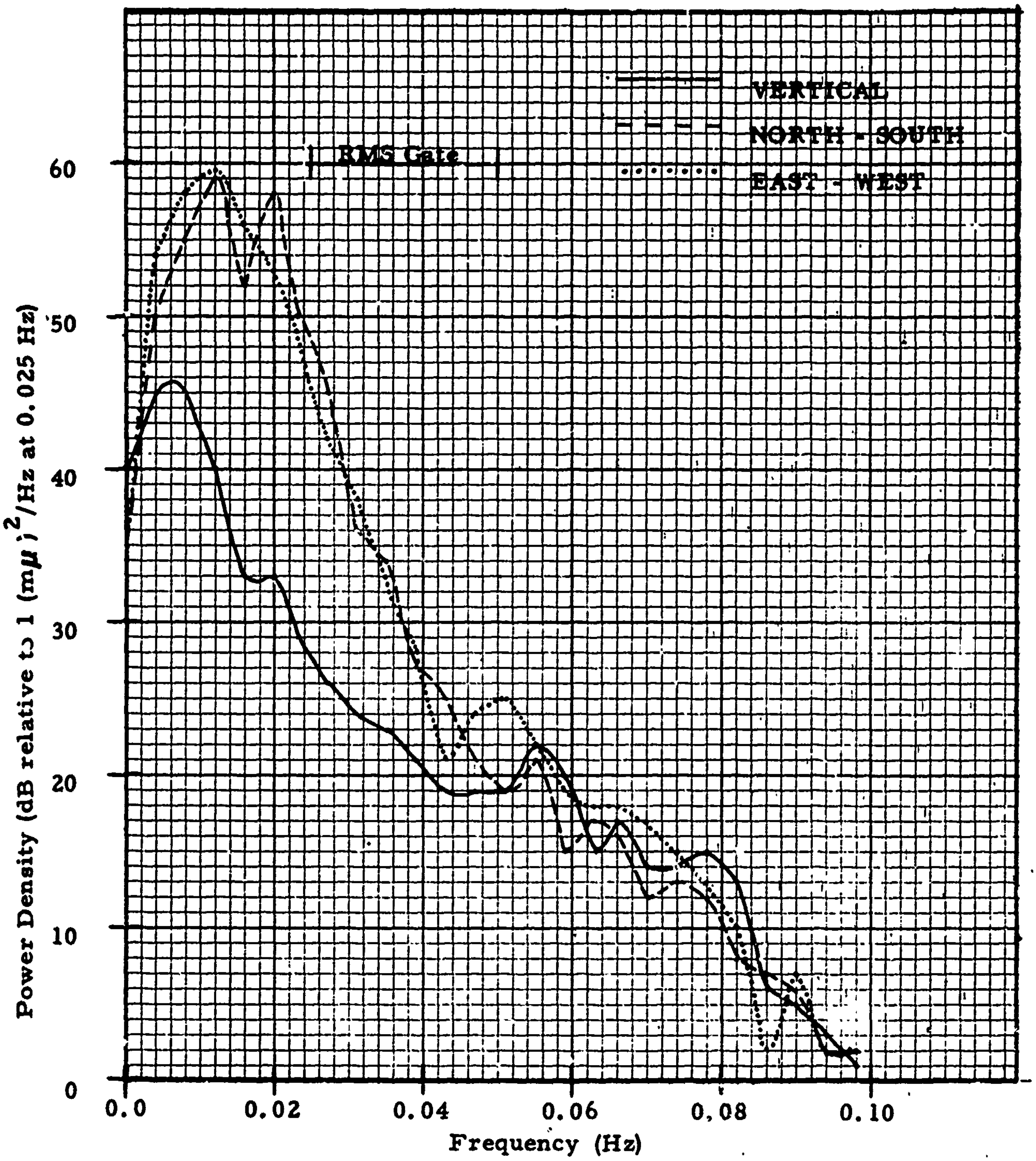


FIGURE III-2
THAILAND NOISE POWER DENSITY SPECTRA
2/2/71 6:56:00

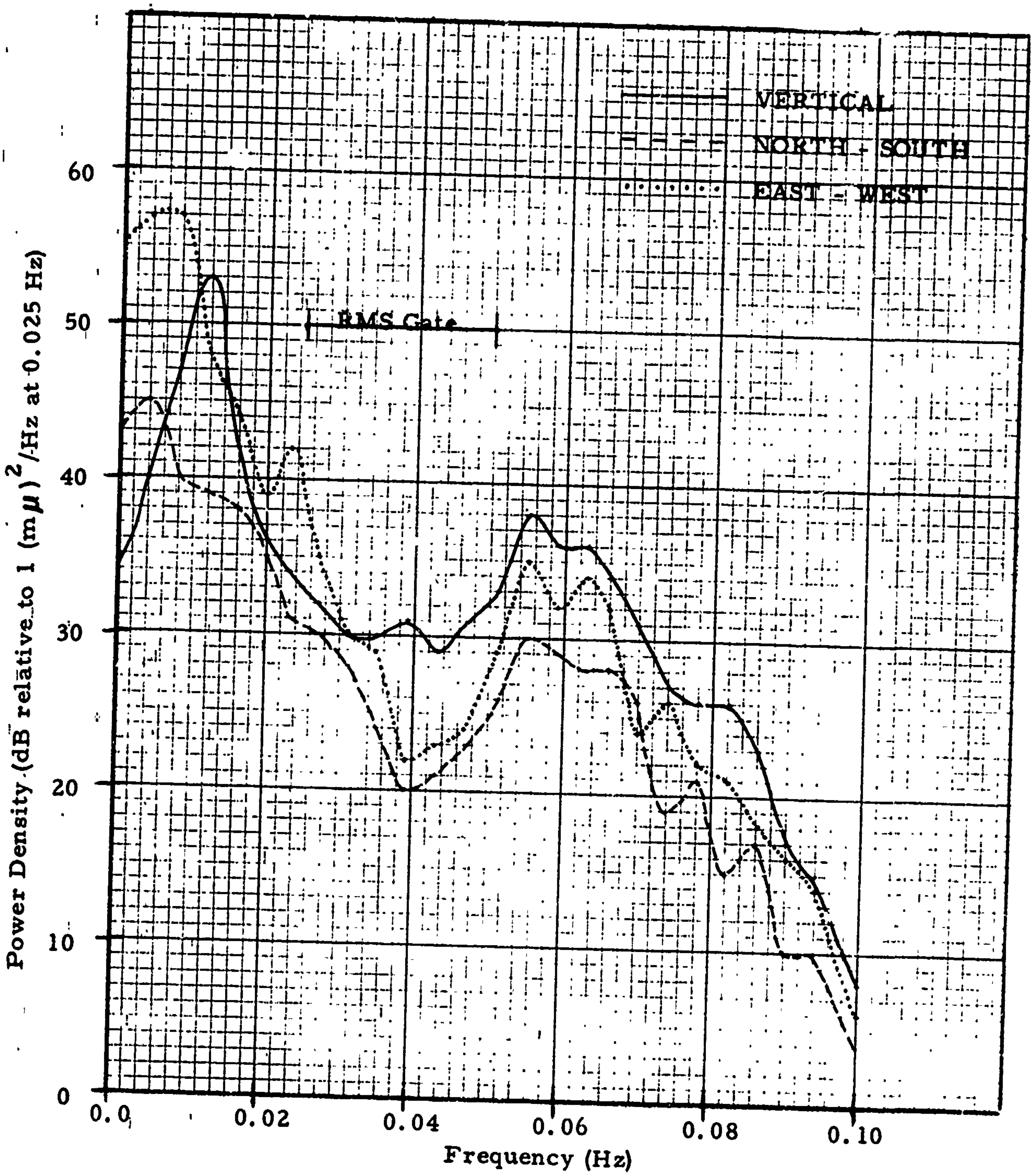


FIGURE III-3
ALASKA (AVERAGE 20-40 sec RMS LEVEL) NOISE POWER DENSITY SPECTRA 11/07/71 (DAY 311) 19:00:00

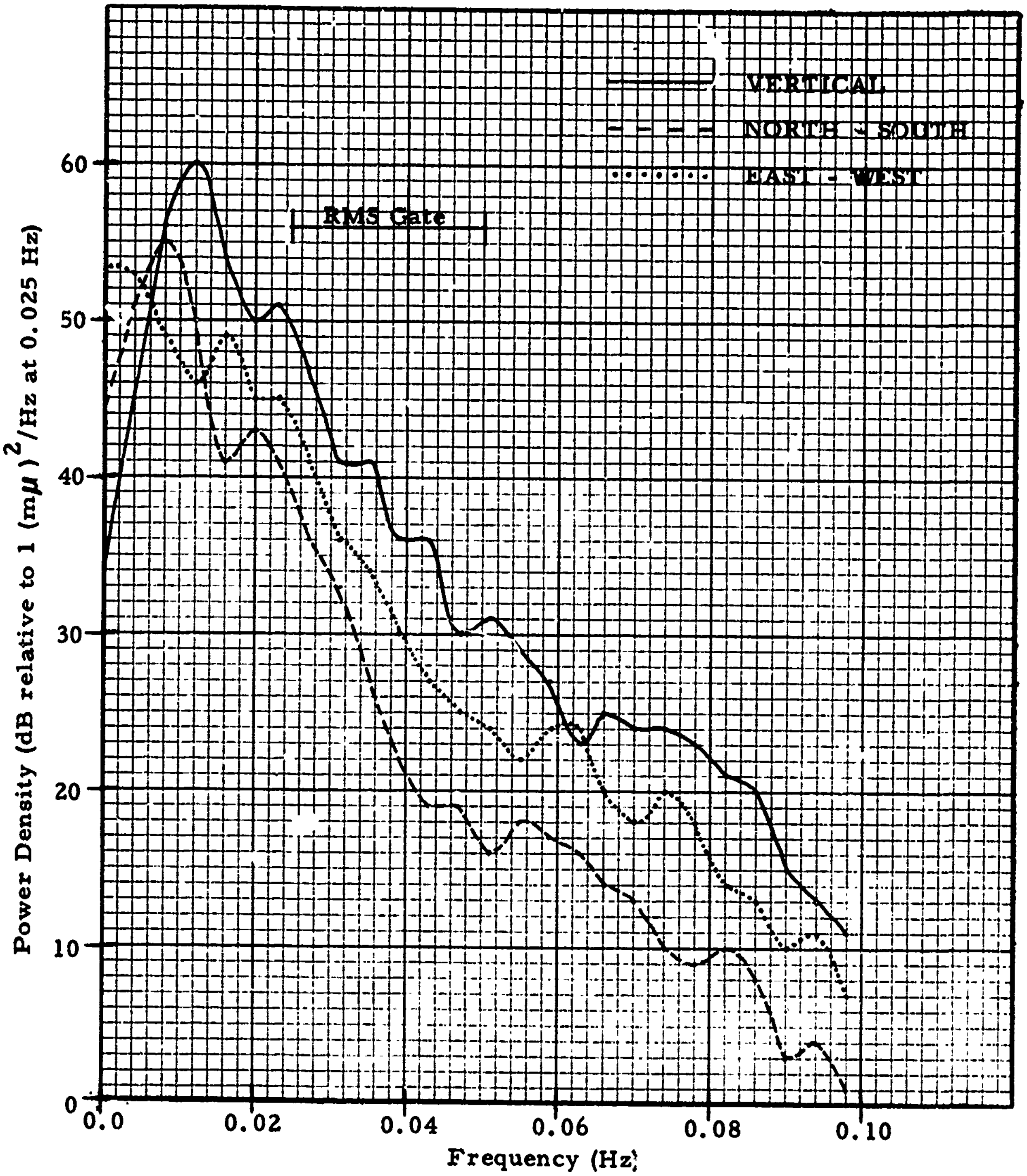


FIGURE III-4
ALASKA (HIGH 20-40 sec RMS LEVEL) NOISE POWER DENSITY SPECTRA
10/31/71 (DAY 304) 12:00:00

seven days apart in late 1971, suggesting that the Alaska noise characteristics are highly variable. One possible explanation for the high long-period noise level in Figure III-4 is that the system had not stabilized following maintenance performed on October 26 to 29, during which time the instrument vault was opened. If this were the sole cause of the high noise level, it could be expected that the noise level on October 30, 1971 (the day preceding the Figure III-4 noise sample) also would be high. However, vertical RMS noise level data (shown later) are low on day 303 and then jump on day 304, which indicates that the high level on day 304 probably is not due to an unstabilized system. Also, analysis of the Alaska Long Period Array (ALPA) data during the time period days 304-310 has shown relatively high noise levels for that station. Therefore, it appears that the relatively higher long period noise level shown in Figure III-4 is real. While no direct evidence to explain the cause of these high levels is available, it seems most reasonable to attribute them to atmospheric effects (e.g., condensation within the pressure tank or an imperfect pressure tank seal which may have made the instruments susceptible to pressure variations). The fact that the pressure tanks had been opened for maintenance prior to the time period these data were recorded tends to support this suggestion.

Figure III-5 shows a typical Spain noise spectrum. The vertical is relatively flat and quite low between 20 and 50 seconds, the East-West is acceptable to about 35 seconds after which it increases rapidly. However, the North-South component is very noisy.

Figure III-6 shows a typical Israel noise spectrum. The vertical component is relatively flat and very low level between 20 and 50 seconds, while the East-West component is fair in both respects. The North-South component appears to be the lowest of the three; however, there is some question as to the actual gain of the component. It appears that the Israel station should be one of the more sensitive stations in the network.

Figure III-7 shows a typical Norway noise spectrum. The vertical component is relatively flat between 20 and 50 seconds. Both horizontals are also

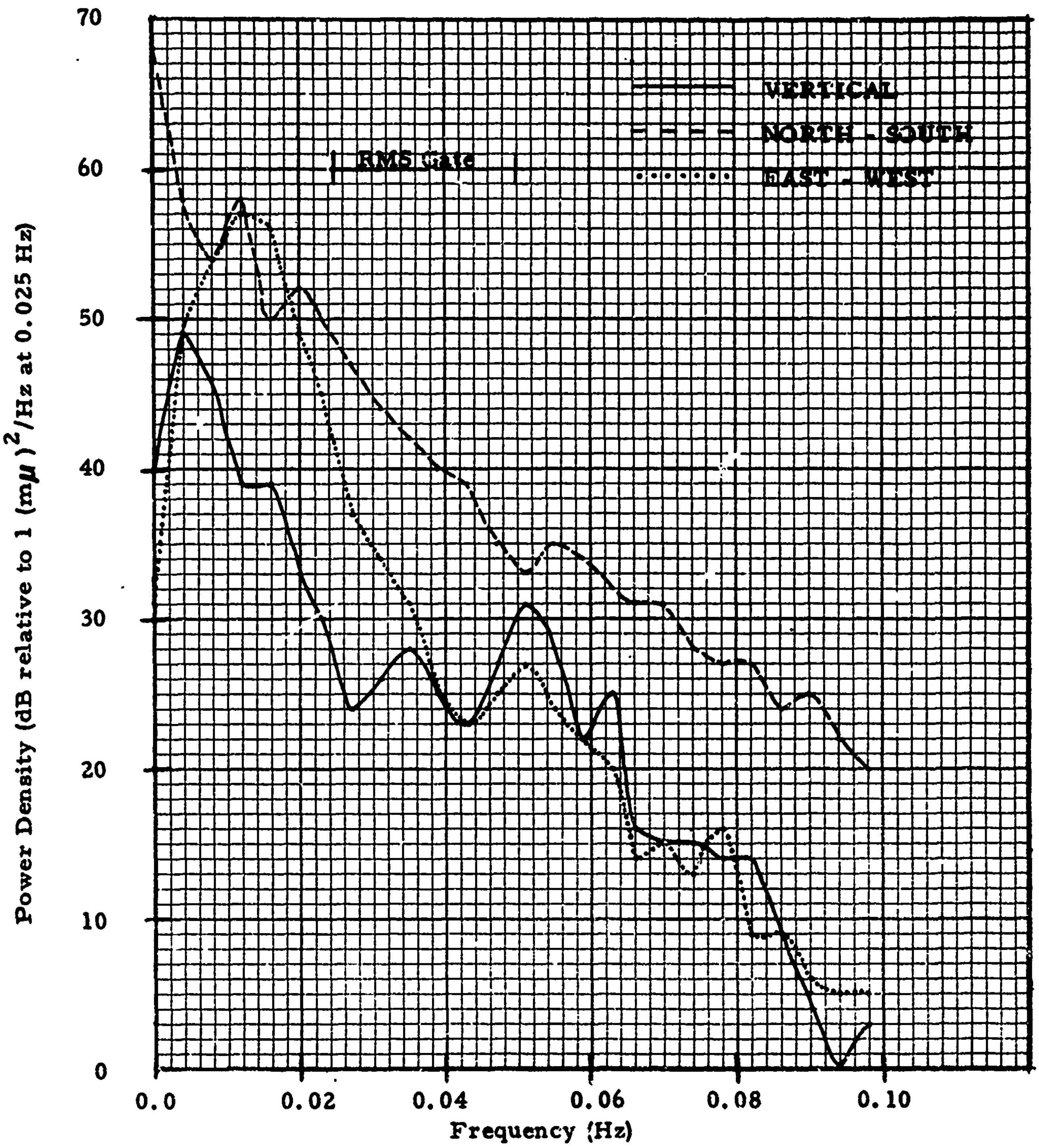


FIGURE III-5
SPAIN NOISE POWER DENSITY SPECTRA
8/19/71 6:00:00

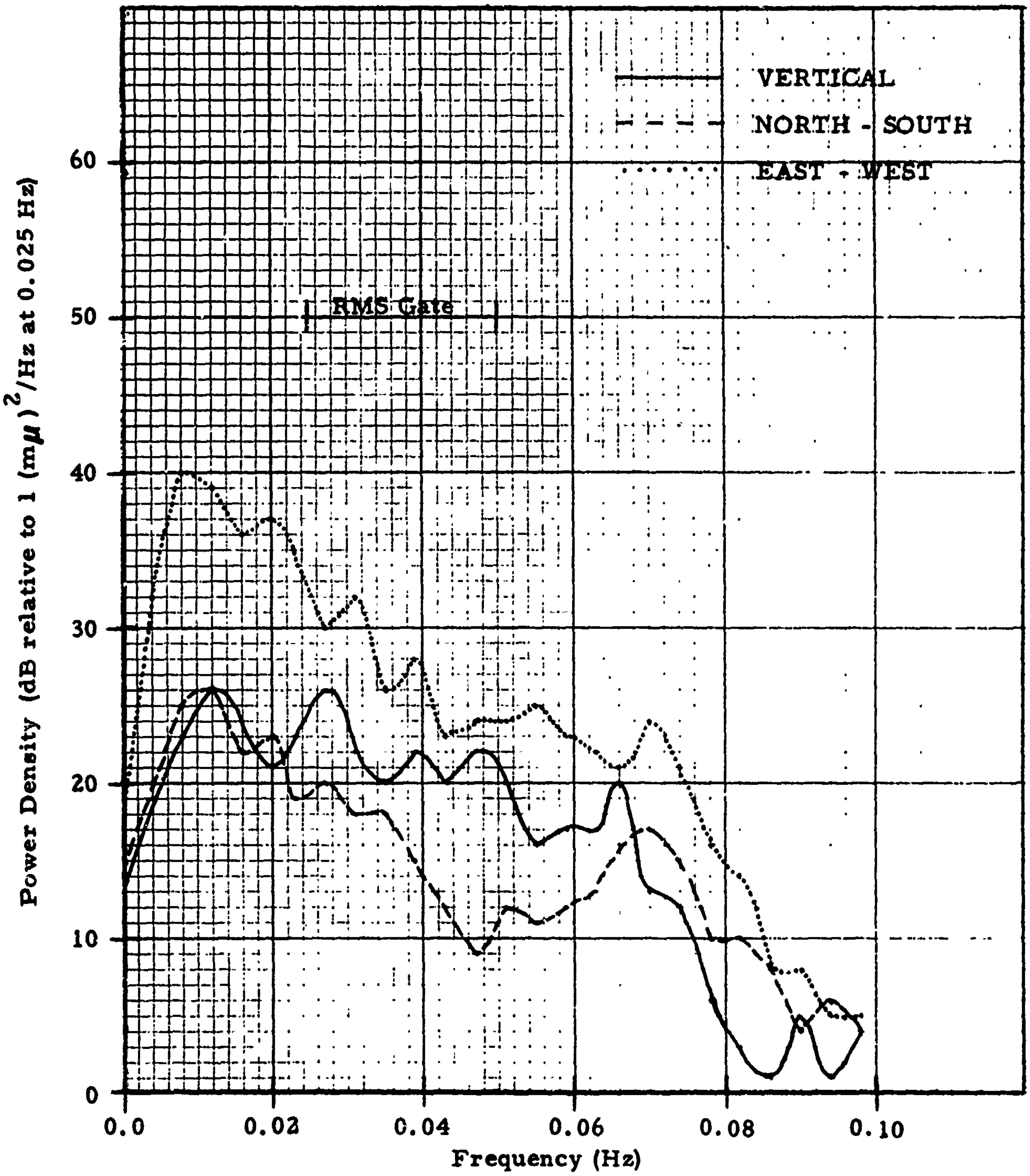


FIGURE III-6
ISRAEL NOISE POWER DENSITY SPECTRA
5/23/71 23:30:00

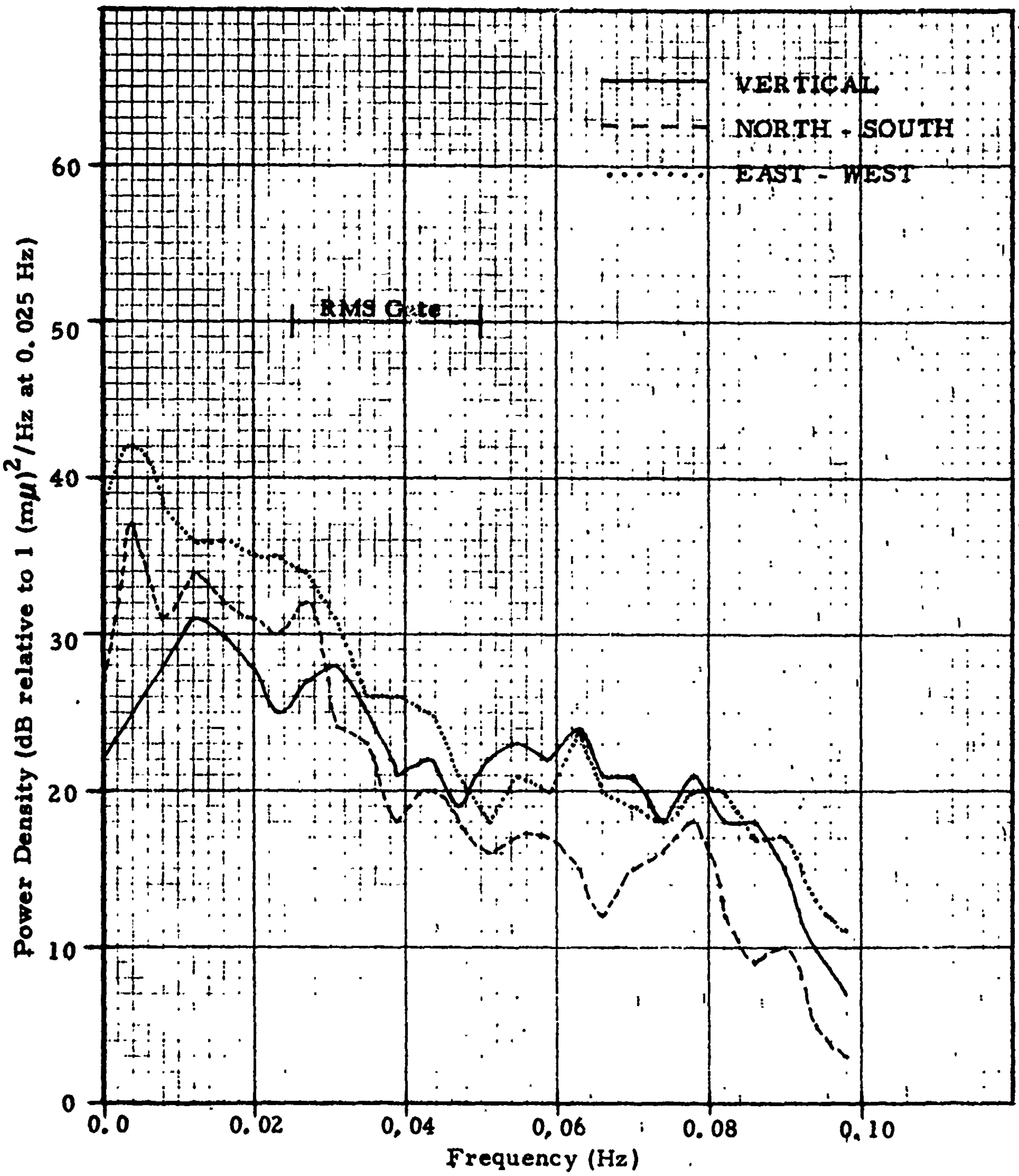


FIGURE III-7
NORWAY NOISE POWER DENSITY SPECTRA
09/20/71 01:00:00

relatively flat to about 30 seconds. However, all three components and especially the vertical, are relatively low level. It appears that Norway, also should be a sensitive station.

Figure III-8 shows a noise spectrum for the Ogdensburg station. All three components are relatively flat between 25 and 50 seconds. However, in addition to a large increase at periods greater than 50 seconds, all three components show a very large microseismic noise peak at about 18 seconds.

B. RMS LEVELS IN THE 20 TO 40 SECOND BAND

Figures III-9 to III-15 show RMS noise levels in the 20 to 40 second band for all three components at each station as a function of time. (The RMS frequency band is shown in the power spectra of Figures III-1 to III-8.) All data presented were recorded during 1971. The RMS levels are expressed in mμ of ground motion and were obtained by normalizing using the 40 second calibration information.

Figure III-9 shows the Australia RMS data. Only two noise samples were edited for this station and represent too small a sample from which to draw any definite conclusions. However, it does appear that the noise levels for this station should not differ greatly from that for the other six stations.

Figure III-10 shows the RMS levels for the Thailand station. The vertical component is fairly low and averages about 4 mμ. Both horizontals appear to be more variable and average about 9 to 10 mμ.

Figure III-11 shows the Alaska RMS data. Early in 1971 (left of the figure) all three components were similar and low level (2 to 6 mμ). Later data, however (right of the figure) are much noisier; a result of the higher spectral levels at long periods. The RMS noise levels for days 300 to 315 does tend to cluster into two groups, around 7 mμ and 15 mμ, respectively. As indicated earlier, it appears that the increase in RMS values from the first of the year to the higher levels around day 305 may be due, at least in part, to installation difficulties resulting from the removal of the pressure tanks during station maintenance.

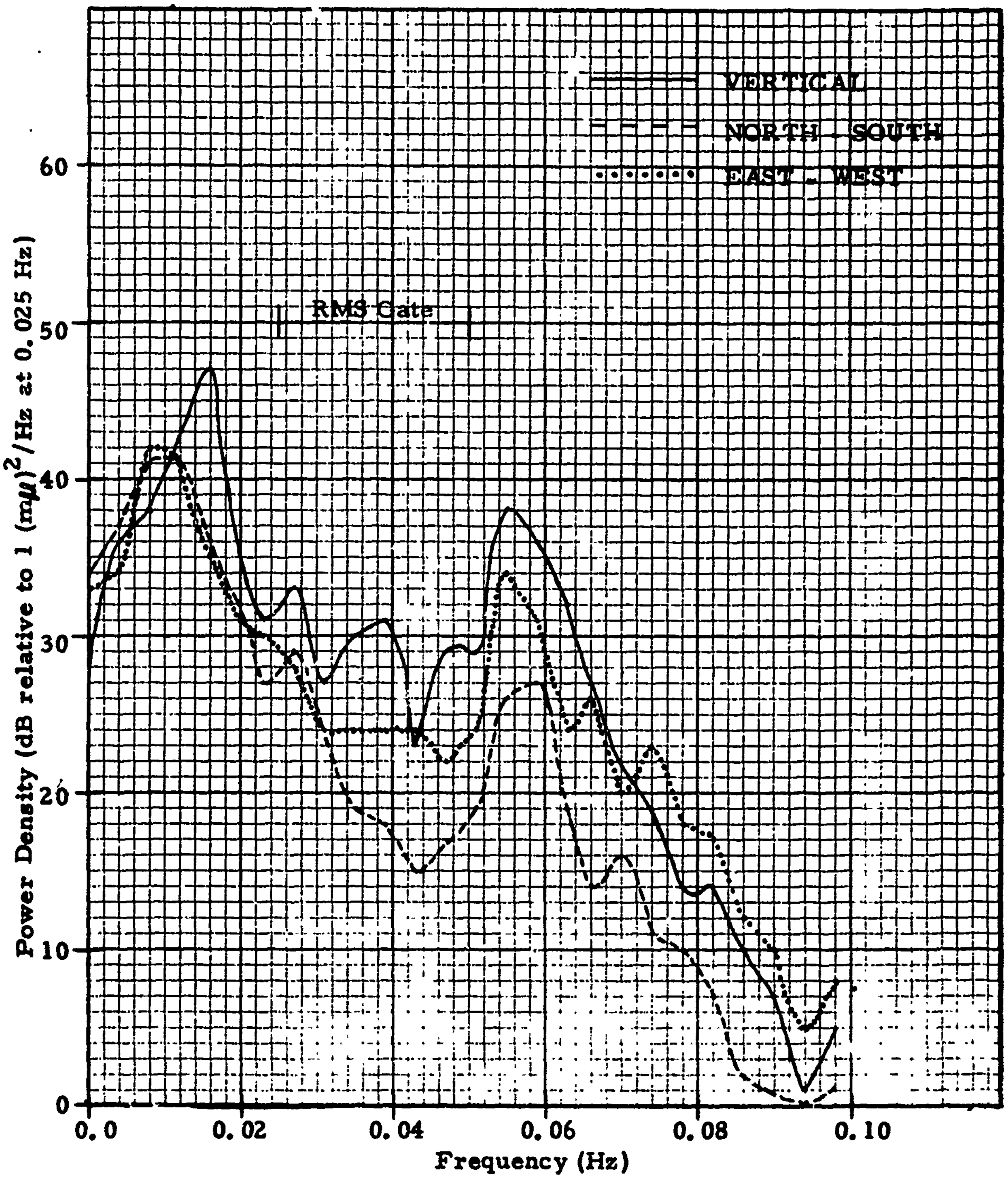
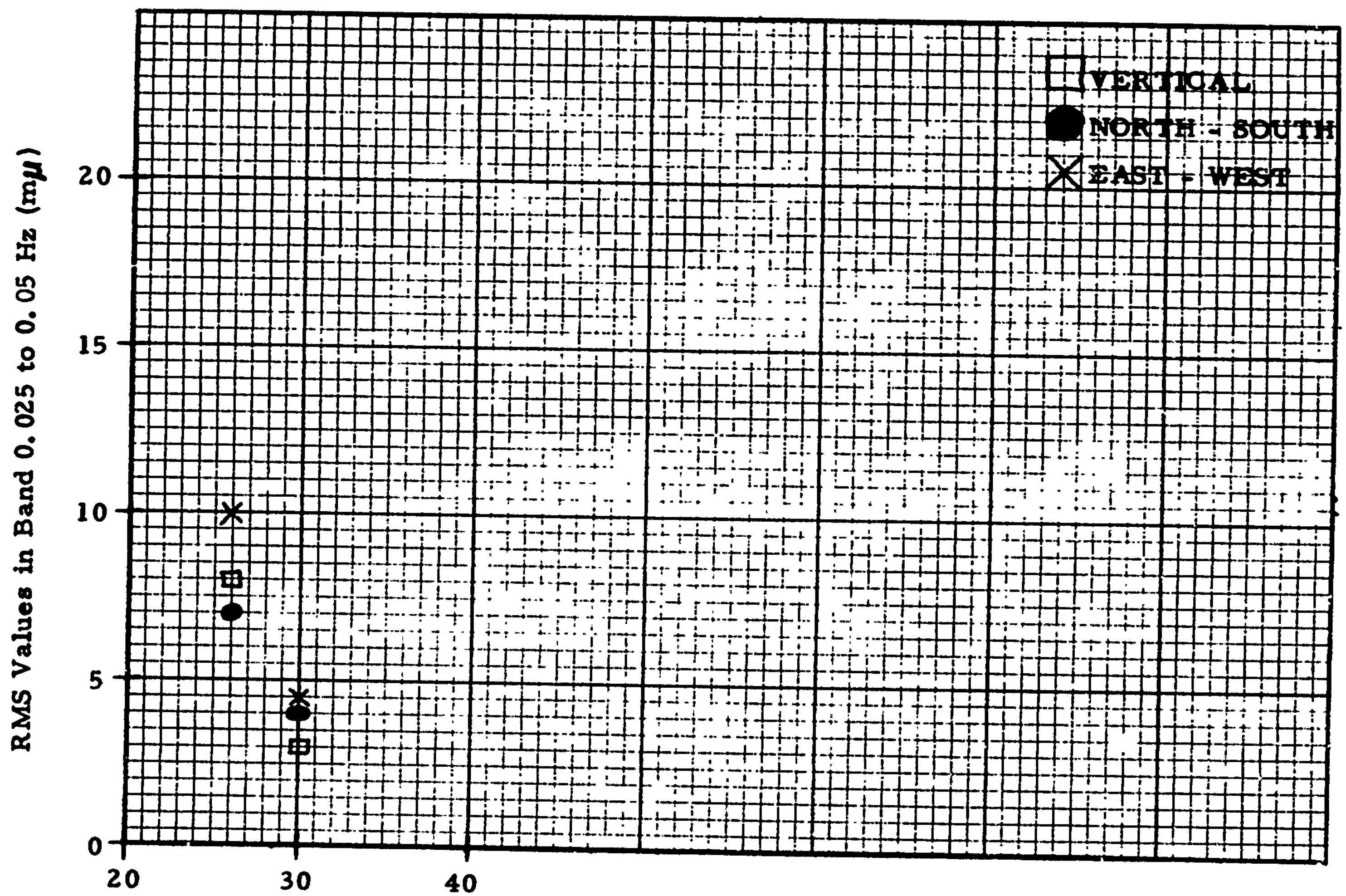


FIGURE III-8
OGDENSBURG NOISE POWER DENSITY SPECTRA
08/10/71 03:30:00



Day 1971

FIGURE III-9
AUSTRALIA NOISE RMS LEVELS

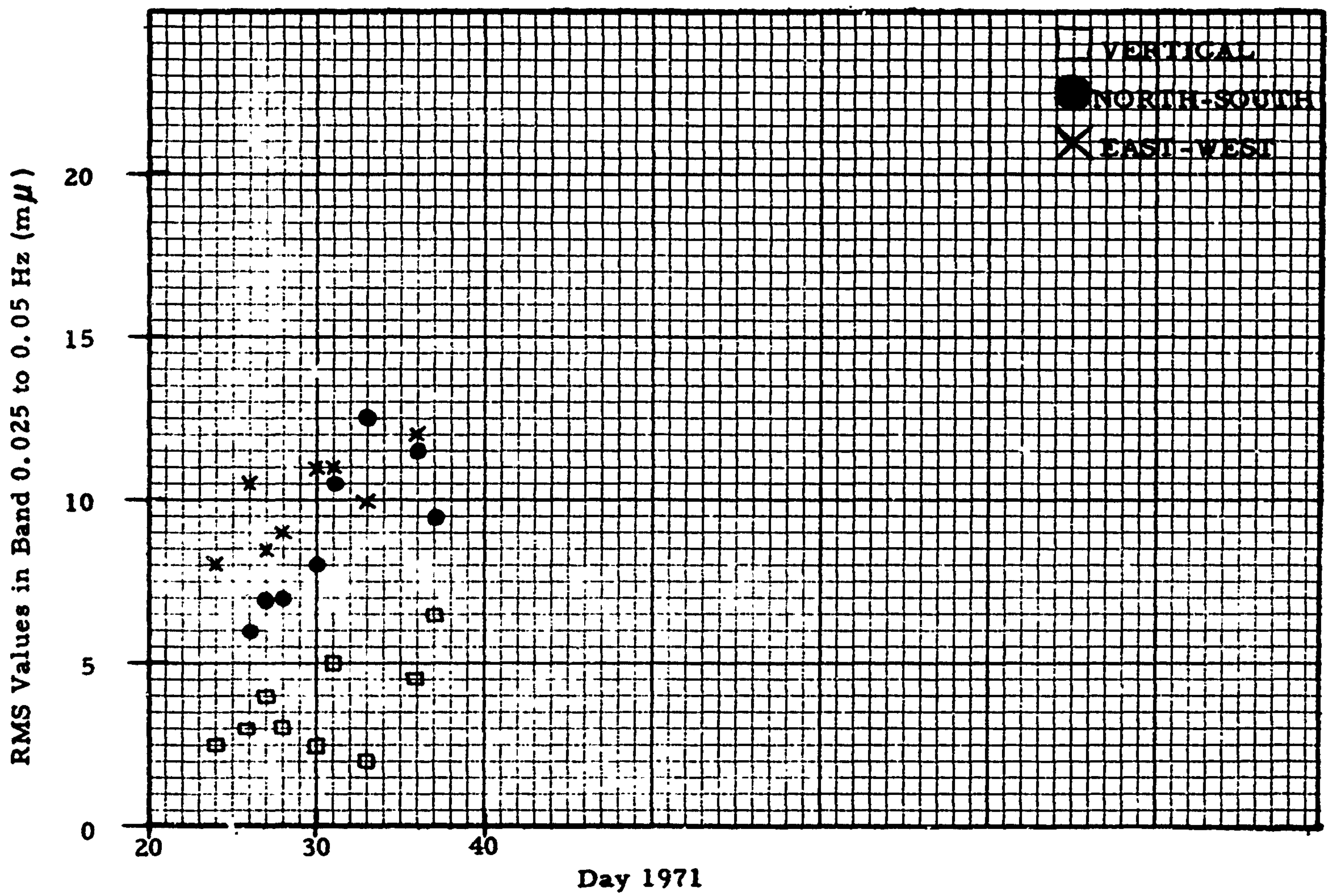


FIGURE III-10
THAILAND NOISE RMS LEVELS

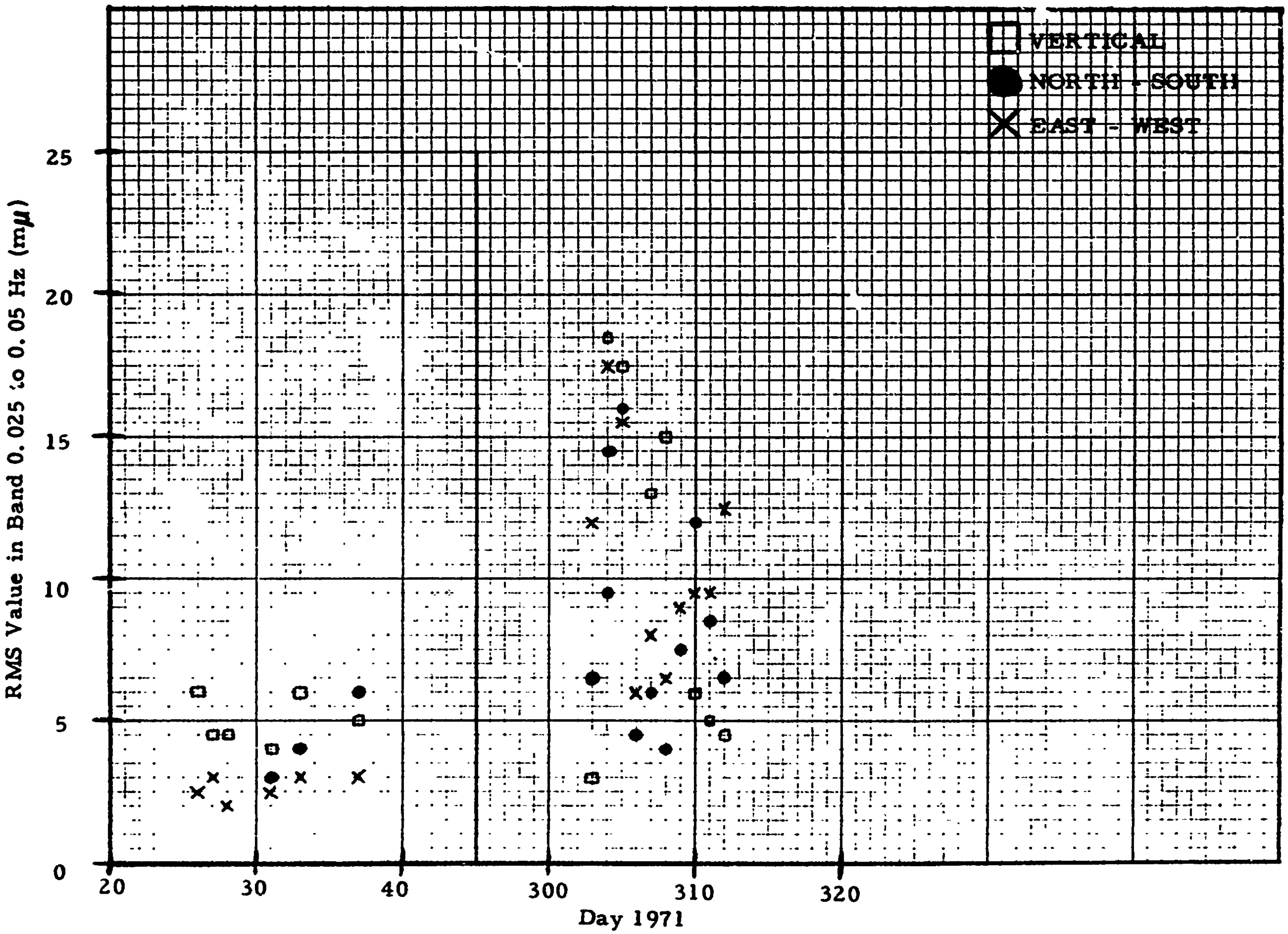


FIGURE III-11
ALASKA NOISE RMS LEVELS

Figure III-12 shows the Spain RMS noise levels. The vertical generally is below 6 mμ, although it does range up to 11 on a few occasions. The East-West is quite stable, about 5-7 mμ for days 230 to 240 and about 8-10 mμ for days 253 to 259. The North-South component is quite noisy at about 15 mμ for days 230 to 240 and 20 to 25 mμ for days 253 to 259. (The values on days 253, 255, and 256 are greater than 25 mμ.)

From Figure III-12, it appears that the noise level at the Spain station may increase during the fall and winter months. Thus, several noise samples recorded on January 9, 1972 were edited and analyzed. The average RMS noise levels for these samples are vertical —10 mμ, North-South —10 mμ, and East-West —7 mμ. The vertical level is slightly higher than observed for the earlier data, the East-West level is about the same, but, surprisingly, the North-South level is much lower. This suggests that the North-South component stabilized and its current performance may be comparable to the East-West component.

Figure III-13 shows the Israel RMS noise levels. The vertical and apparent North-South noise levels are below 5 mμ for all samples, and the East-West levels range from 4 to 10 mμ. As stated earlier, the low North-South levels may not be real because the North-South component was affected by a bad PTA during the first half of 1971.

Figure III-14 shows the noise RMS levels for the Norway station. For all three components, the levels generally range from about 3 to 8 mμ. Also, for the samples shown, the East-West component is usually the noisiest, and the North-South is a little quieter than the vertical.

Figure III-15 shows the noise RMS levels for the Ogdensburg station. The vertical RMS levels appear to be quite variable ranging from 3 to 20 mμ. Also, both horizontals are quieter than the vertical component.

Average RMS values were computed for each station and component and are tabulated in Table III-1. With the exception of the Ogdensburg and later

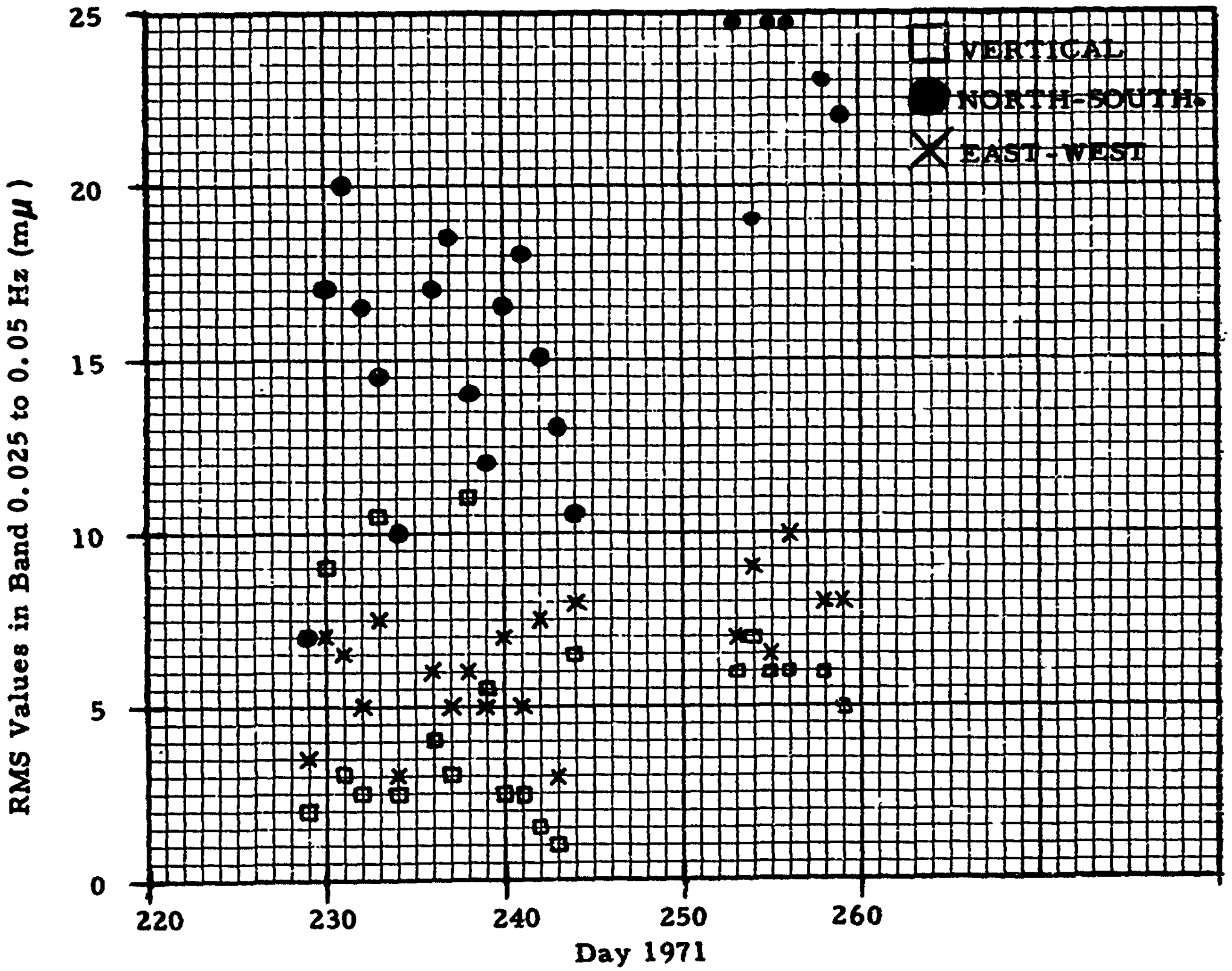


FIGURE III-12
SPAIN RMS NOISE LEVELS

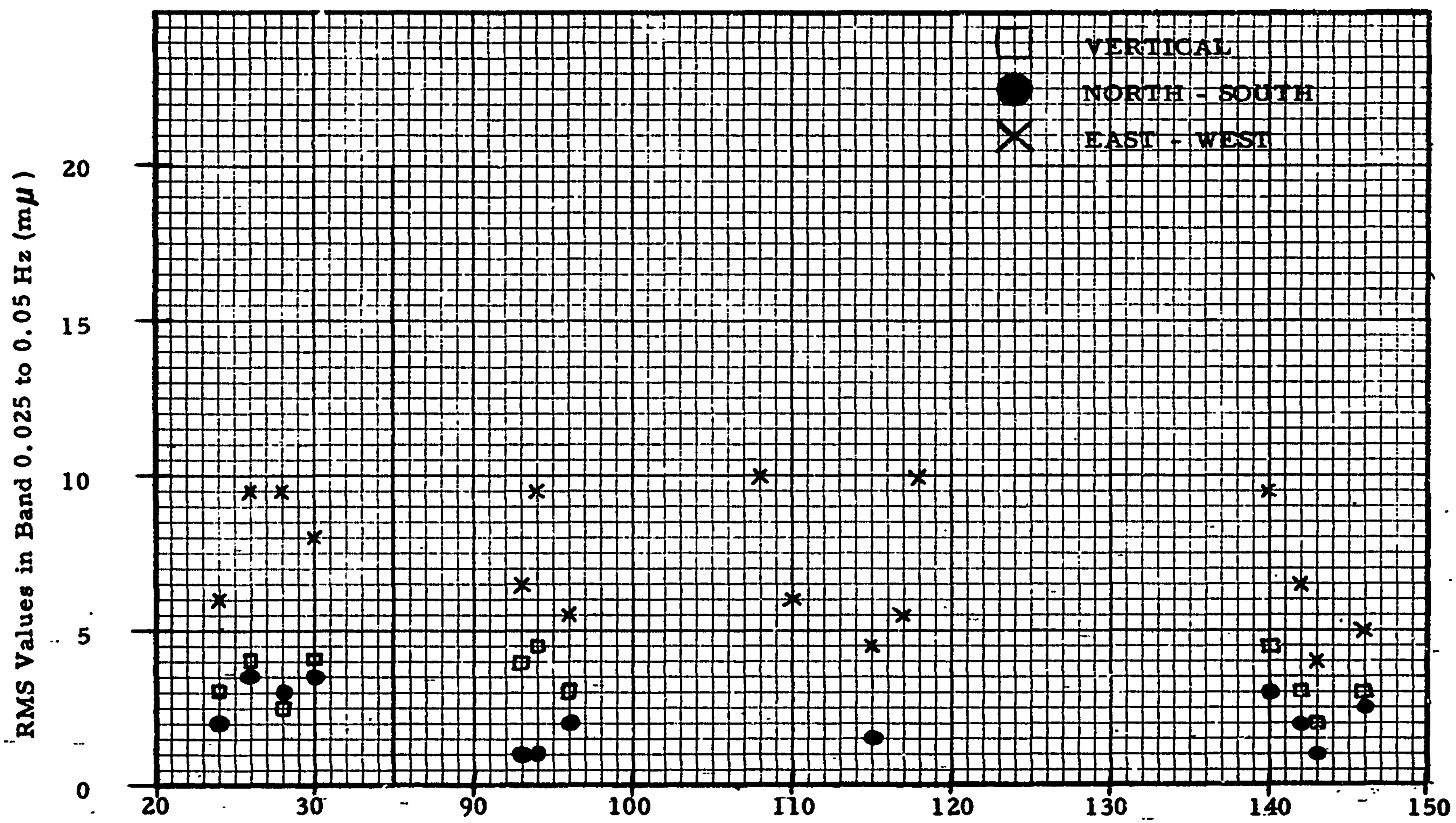


FIGURE III-13
ISRAEL NOISE RMS LEVELS

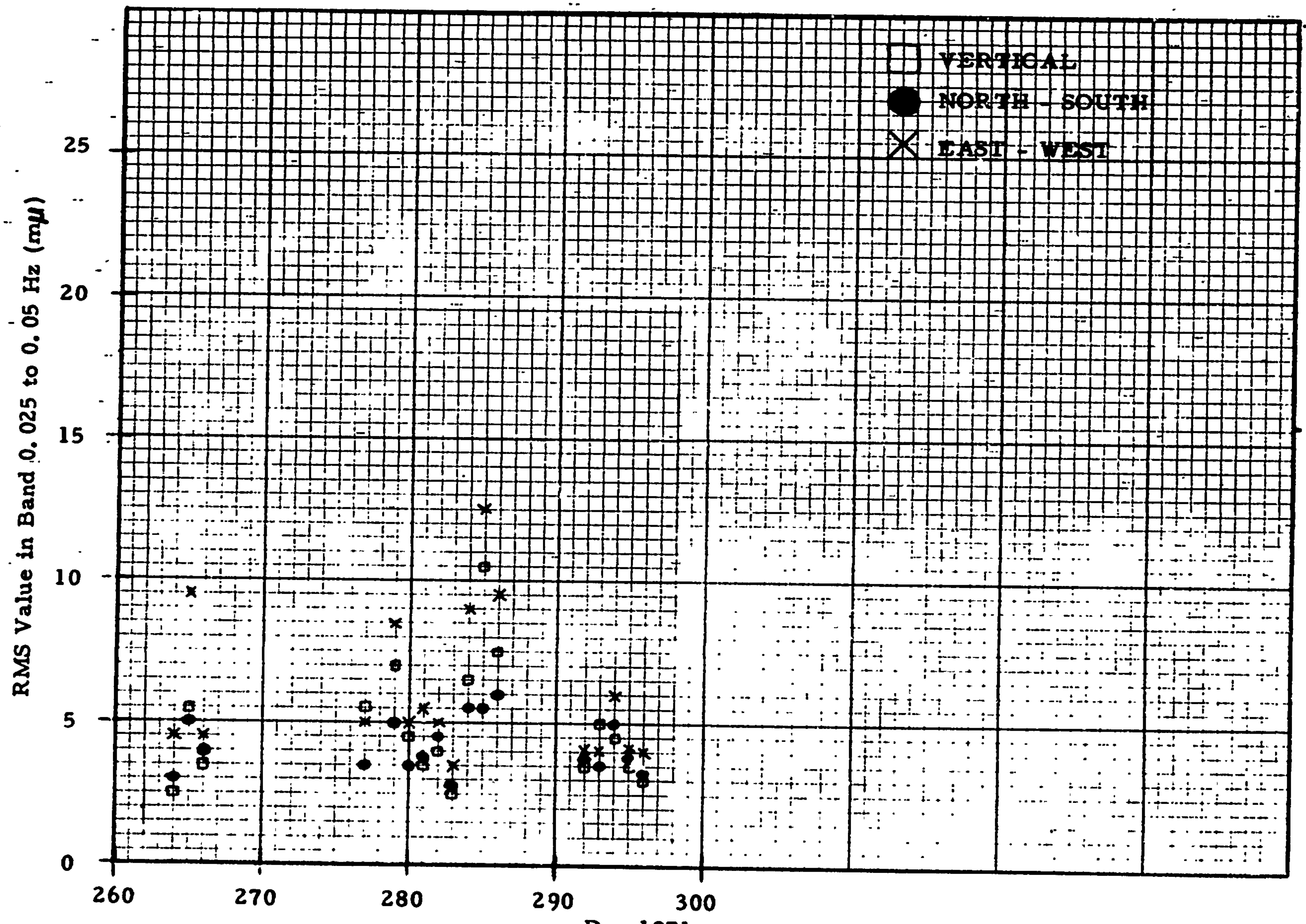


FIGURE III-14
NORWAY NOISE RMS LEVELS

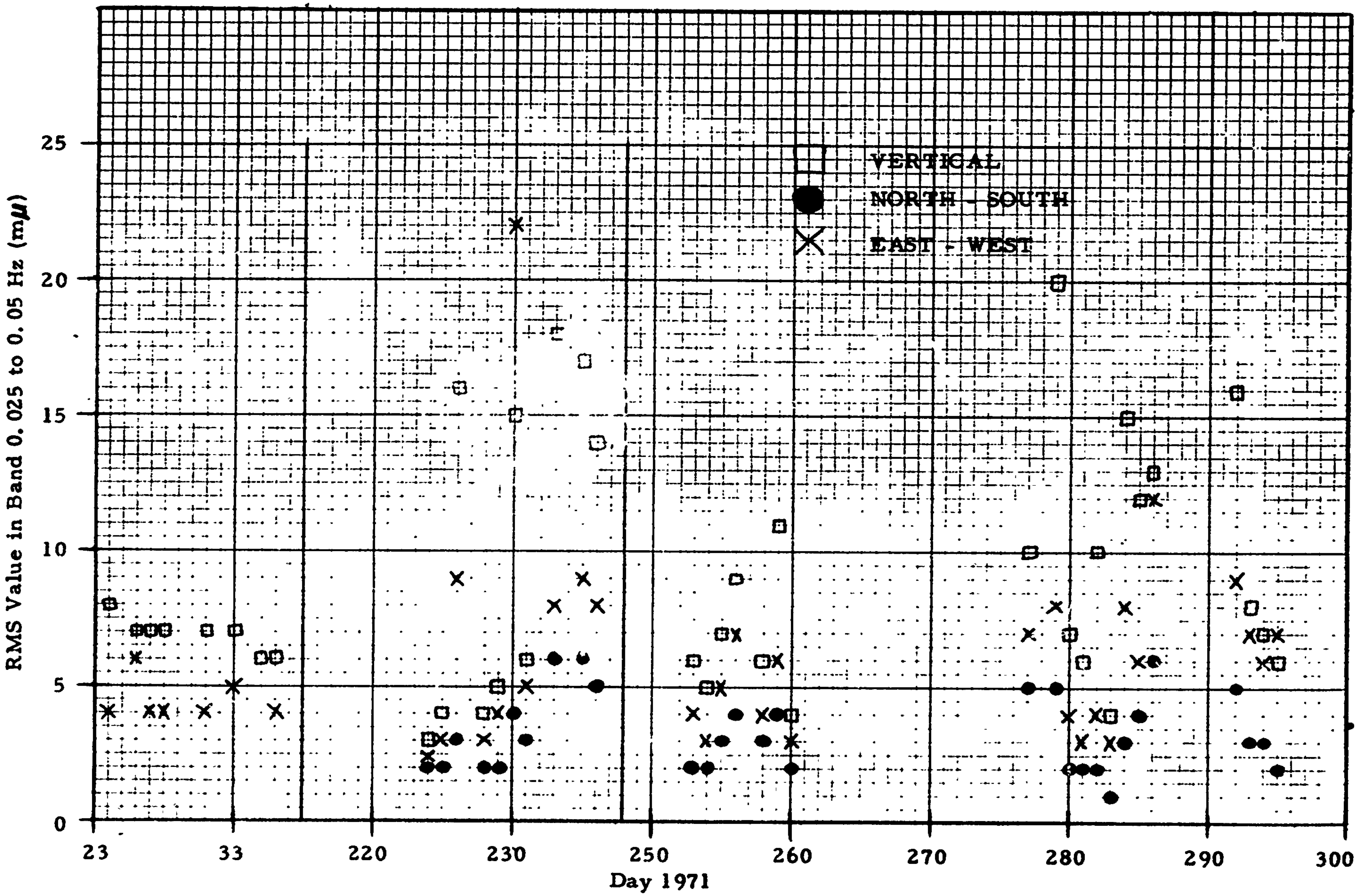


FIGURE III-15
OGDENSBURG NOISE RMS LEVELS

TABLE III-1

AVERAGE RMS VALUES IN BAND 0.025 TO 0.05 Hz IN MILLIMICRONS OF GROUND MOTION

Station	No. of Samples	Vertical	North-South	East-West
Australia	2	5.5	5.5	7.3
Thailand	9	3.7	9.0	9.9
Alaska	16	8.0	7.8	7.7
Spain	21	4.9	17.5	6.3
Israel	16	3.5	—	7.3
Norway	17	4.8	4.0	6.1
Ogdensburg	38	8.9	3.3	6.0

Alaskan data, the vertical RMS noise levels observed in the 20 to 40 second band are generally around 5 mμ, and the horizontal levels are more variable but generally higher than the vertical levels. Note that 20 to 40 second RMS noise levels (computed in the same way) for ALPA and NORSAR are usually about 7 or 8 mμ. There are two possible explanations for the lower RMS noise levels as compared to ALPA and NORSAR. First, since the system response was not removed in the RMS calculations, then the RMS noise level for the Long Period Experiment instruments, which are peaked near the earth noise minimum (40 seconds), should be somewhat lower than the level for the ALPA and NORSAR instruments which are peaked at 25 seconds (closer to the long period microseismic energy peak at 16 to 18 seconds). The second possible explanation for the lower RMS noise level is that the Long Period Experiment instruments are better shielded from atmospheric effects at longer periods, and so are "quieter" at longer periods. The latter possibility is supported by the previously discussed results on the increase in the Alaska RMS noise level after the instrument pressure tanks were opened.

SECTION IV
SIGNAL ANALYSIS

A. SURFACE WAVE DETECTION DATA

To study the earthquake surface wave detection capability for each station, the usable signals from each station (shown in Tables IV-1 to IV-7) were rotated to a vertical, transverse, and radial coordinate system, bandpass filtered using both 20 to 40 and 30 to 50 second passbands, and then graphs of detection for bodywave magnitude versus delta were plotted. The events analyzed were not matched filtered, since we do not yet have good matched filters for the various areas of interest; also, no multi-component processing was performed due to the large differences in the component instrument responses at each station. Thus some events which were not detected by the simple processing employed here may have been detected with the application of more sophisticated techniques. Also, the data ensembles are not large enough to define precisely the stations' detection thresholds; therefore, these results are presented only to provide a preliminary indication of the station performances in detecting a small suite of events.

Figure IV-1 shows the Australia detection data. Very little can be concluded from this figure due to the lack of available data for the Australian station. The one event not detected, $m_b = 4.8$, was from the Kurile Islands.

Figure IV-2 shows the Thailand event detection data. Essentially all of the events analyzed at Thailand were taken from the PDE data and are limited to $m_b \geq 4.3$. Three events ($m_b = 4.5$ from E. Caucasus, $m_b = 4.6$ from Kamchatka, and $m_b = 4.8$ from Kurile Islands) were not detected, although a possible Love wave detection was obtained for the E. Caucasus event. As mentioned earlier, the Thailand calibration data are uncertain, however it does appear that the Thailand surface wave amplitudes are generally lower than those for the other stations.

TABLE IV-1

AUSTRALIA EVENTS

Number	Date	Origin Time	Lat.	Long.	Depth	m_b	Δ^o	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
43	01/24/71	13:21:16	49.2N	156.3E	N	4.9	70	3.8	3.95	
44	01/24/71	13:28:44	49.2N	156.1E	36	5.2	70	4.1	4.4	
45	01/24/71	13:47:36	49.1N	156.3E	34	4.6	70	-	-	I
48	01/25/71	18:42:25	49.2N	156.4E	61	4.7	70	-	-	I
61	01/27/71	19:57:55	47.9N	154.0E	40	4.8	68	Not Detected		
70	02/01/71	14:21:43	42.3N	85.3E	N	4.8	84	-	-	B
76	02/05/71	09:09:58	25.2N	99.4E	N	5.3	64	4.65	5.15	

TABLE IV-2

THAILAND EVENTS
(PAGE 1 OF 3)

Number	Date	Origin Time	Lat.	Long.	Depth	mb	Δ°	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
43	01/24/71	13:21:16	49.2N	156.3E	N	4.9	55	T2.8	3.4	
44	01/24/71	13:28:44	49.2N	156.1E	36	5.2	55	3.9	5.25	
45	01/24/71	13:47:36	49.1N	156.3E	34	4.6	55	-	-	I
48	01/25/71	18:42:25	49.2N	156.4E	61	4.7	55	-	-	I
60	01/26/71	22:48:31	43.8N	39.2E	28	4.8	56	-	-	B
61	01/27/71	19:57:55	47.9N	154.0E	40	4.8	53	Not Detected		
62	01/28/71	15:51:07	35.0N	47.0E	43	4.6	49	T2.65	3.75	
67	01/30/71	20:15:41	30.5N	79.1E	56	4.6	22	T1.95	2.6	
69	02/01/71	01:12:27	37.2N	30.2E	35	4.5	62	3.0	4.3	
70	02/01/71	14:21:43	42.3N	85.3E	N	4.8	26	2.0	2.75	
71	02/02/71	07:59:57	23.8N	91.8E	48	5.4	8	3.0	3.9	
73	02/04/71	02:54:05	53.0N	162.8E	N	4.6	75	Not Detected		
74	02/04/71	05:27:46	44.0N	45.9E	N	4.5	51	Not Detected		L
76	02/05/71	09:09:58	25.2N	99.4E	N	5.3	6	3.85	3.95	
77	02/06/71	00:58:42	44.9N	148.0E	N	4.3	48	2.35	3.1	L
78	02/06/71	16:34:11	38.1N	73.3E	171	4.5	30	-	-	B
79	02/06/71	22:12:45	36.0N	69.9E	109	5.0	31	3.7	3.7	
82	01/27/71	20:45:43	76.7N	7.0E	N	4.9	72	T3.65	4.15	

TABLE IV-2

THAILAND EVENTS
(PAGE 2 OF 3)

Number	Date	Origin Time	Lat.	Long.	Depth	m_b	Δ^o	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
83	01/28/71	11:03:50	76.5N	8.1E	N	4.5	72	T3.1	4.3	
84	01/29/71	08:33:50	78.8N	8.0E	N	4.8	72	T3.5	4.4	
151	03/22/71	04:32:58	49.7N	78.2E	0	5.8	35	2.5	3.1	
152	03/23/71	06:59:56	61.3N	56.5E	0	5.6	52	-	-	B
153	03/23/71	09:26:29	71.0N	7.0W	N	6.0	77	5.5	6.15	
154	03/23/71	09:55:12	41.5N	79.3E	N	5.7	28	4.8	4.9	
155	03/23/71	20:51:03	41.5N	79.3E	N	6.0	28	4.7	4.95	
156	03/24/71	13:54:18	35.5N	98.2E	13	5.8	17	4.25	5.5	
158	03/24/71	20:54:29	41.5N	79.5E	18	5.3	28	3.3	3.6	
159	03/24/71	21:05:40	41.4N	79.4E	25	5.3	28	3.3	3.05	
160	06/04/71	07:56:55	84.5N	107.5E	N	5.0	66	2.9	3.7	
161	06/04/71	09:10:03	84.6N	108.0E	N	5.1	66	3.6	4.35	
162	06/04/71	14:10:46	32.2N	95.2E	N	5.0	14	2.7	2.7	
168	04/04/71	01:35:23	38.4N	73.3E	N	4.8	30	2.6	3.2	
169	04/06/71	03:02:57	39.6N	77.8E	N	4.5	28	2.25	2.6	
170	04/08/71	18:33:38	38.4N	73.3E	129	5.0	30	2.45	2.55	
171	04/18/71	07:24:14	39.1N	71.7E	N	4.5	31	2.4	3.0	
178	05/03/71	00:33:23	30.8N	84.5E	16	5.4	18	3.9	4.8	

TABLE IV-2

THAILAND EVENTS
(PAGE 3 OF 3)

Number	Date	Origin Time	Lat.	Long.	Depth	m_b	Δ^o	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
180	05/16/71	17:20:57	36.1N	77.9E	84	4.6	25	2.5	2.35	
181	05/17/71	08:43:22	24.3N	94.7E	167	4.7	7	2.2	1.95	
182	05/21/71	02:58:37	26.7N	101.8E	45	4.9	8	T1.65	3.15	
183	05/22/71	20:03:32	32.4N	92.1E	N	5.6	15	4.85	4.95	
185	05/25/71	04:02:58	49.8N	78.2E	0	5.2	35	T1.85	T2.45	
186	05/27/71	00:30:28	38.3N	69.0E	36	4.8	33	2.7	3.3	
187	05/30/71	11:56:00	25.3N	96.4E	N	4.9	7	T3.7	4.25	
189	05/30/71	21:39:01	25.3N	96.4E	N	4.9	7	3.45	4.1	
190	05/31/71	05:14:00	25.2N	96.5E	N	5.3	7	4.5	4.85	

TABLE IV-3

ALASKA EVENTS
(PAGE 1 OF 5)

Number	Date	Origin Time	Lat.	Long.	Depth	m_b	Δ^o	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
60	01/26/71	22:48:31	43.8N	39.2E	28	4.8	71	-	-	I
61	01/27/71	19:57:55	47.9N	154.0E	40	4.8	35	T2.9	3.15	
62	01/28/71	15:51:07	35.0N	47.0E	43	4.6	79	Not Detected		
63	01/29/71	21:23:43	55.7N	163.5E	N	4.6	25	T2.55	3.75	
67	01/30/71	20:15:41	30.5N	79.1E	56	4.6	78	2.85	3.7	
69	02/01/71	01:12:27	37.2N	30.2E	35	4.5	78	3.2	3.65	
70	02/01/71	14:21:43	42.3N	85.3E	N	4.8	65	-	-	I
71	02/02/71	07:59:57	23.8N	91.8E	48	5.4	80	3.6	4.3	
73	02/04/71	02:54:05	53.0N	162.8E	N	4.6	27	-	-	I
74	02/04/71	05:27:46	44.0N	45.9E	N	4.5	71	-	-	L, B
76	02/05/71	09:09:58	25.2N	99.4E	N	5.3	76	4.15	5.1	
77	02/06/71	00:58:42	44.9N	148.0E	N	4.3	40	2.65	3.5	L
78	02/06/71	16:34:11	38.1N	73.3E	171	4.5	72	3.25	4.05	
79	02/06/71	22:12:45	36.0N	69.9E	109	5.0	75	4.3	4.3	
81	01/26/71	08:08:44	77.1N	8.5E	N	4.6	37	T2.85	3.25	
82	01/27/71	20:45:43	76.7N	7.0E	N	4.9	38	3.7	4.1	
83	01/28/71	11:03:50	76.5N	8.1E	N	4.5	38	3.35	3.4	
84	01/29/71	08:33:50	78.8N	8.0E	N	4.8	36	3.1	3.75	

TABLE IV-3

ALASKA EVENTS
(PAGE 2 OF 5)

Number	Date	Origin Time	Lat.	Long.	Depth	m_b	Δ^o	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
85	01/31/71	04:33:27	76.6N	7.3E	N	4.7	38	T3.4	3.35	
86	10/11/70	05:29:17	43.5N	147.7E	50	5.2	41	-	-	I
87	10/11/70	08:46:21	51.5N	157.2E	N	4.8	31	-	-	I
88	10/11/70	10:26:34	53.8N	160.7E	N	5.0	27	-	-	B
89	10/13/70	20:10:41	52.3N	159.6E	N	4.6	29	T3.6	4.05	
90	10/14/70	05:59:57	73.3N	55.1E	0	6.7	41	4.6	5.3	
91	10/14/70	07:14:26	43.8N	146.9E	40	4.6	27	T2.85	4.05	
94	10/14/70	16:00:34	43.4N	148.0E	42	5.2	41	T3.8	5.2	
95	10/14/70	18:06:00	[illegible]	147.8E	N	5.1	41	T3.85	5.15	
96	10/14/70	18:15:37	43.5N	148.0E	30	5.5	41	5.1	6.15	
97	10/14/70	21:14:01	43.5N	147.0E	41	5.4	41	4.9	6.0	
98	10/15/70	00:26:28	43.9N	147.8E	N	4.7	40	3.6	4.3	
99	10/15/70	01:44:08	43.7N	147.8E	N	4.6	41	T3.4	4.2	
100	10/15/70	01:52:11	43.6N	147.8E	N	4.3	41	T3.55	4.15	
101	10/15/70	03:55:16	39.8N	77.2E	N	4.9	70	4.15	4.65	
102	10/15/70	04:42:19	39.8N	77.2E	N	4.6	70	3.45	4.2	
103	10/17/70	05:33:15	41.4N	79.2E	N	5.0	68	4.0	4.55	
104	10/17/70	13:39:50	43.7N	147.6E	N	4.7	41	T3.3	4.1	

TABLE IV-3

ALASKA EVENTS
(PAGE 3 OF 5)

Number	Date	Origin Time	Lat.	Long.	Depth	m_b	Δ^o	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
118	08/09/71	01:03:17	42.1N	83.4E	N	4.2	66	-	-	B
119	08/09/71	02:54:37	36.2N	52.7E	27	5.2	78	4.65	5.1	
121	08/12/71	08:14:18	46.0N	151.0E	N	4.2	37	3.05	3.25	L
123	08/12/71	20:57:58	49.7N	156.0E	45	4.5	32	2.5	3.7	
124	08/12/71	22:55:28	47.0N	150.0E	N	3.9	37	-	-	L, B
125	08/13/71	00:34:44	49.0N	156.0E	N	3.7	33	Not Detected		L
126	08/13/71	06:15:57	46.0N	151.0E	N	4.1	37	2.5	2.9	L
127	08/14/71	14:47:57	48.0N	153.0E	N	3.8	35	Not Detected		L
128	08/15/71	14:03:13	50.0N	160.0E	N	3.3	31	Not Detected		L
129	08/16/71	04:58:00	28.9N	103.7E	N	5.5	71	T4.15	4.7	
130	08/16/71	10:33:13	46.0N	149.0E	N	3.8	38	Not Detected		L
131	08/16/71	17:23:47	44.0N	148.0E	N	3.9	40	Not Detected		L
132	08/16/71	18:53:55	28.9N	103.7E	N	5.3	71	4.75	5.3	
133	08/16/71	22:37:33	28.9N	103.6E	N	5.4	71	T4.3	4.25	
134	08/17/71	09:36:15	28.9N	103.7E	N	4.9	71	3.4	4.1	
135	08/17/71	17:07:40	28.9N	103.7E	N	4.9	71	T3.2	4.25	
137	08/18/71	19:58:21	43.7N	147.5E	60	4.7	41	T2.15	3.5	
138	08/19/71	09:28:49	56.0N	162.0E	N	4.2	25	-	-	L, I

TABLE IV-3

ALASKA EVENTS
(PAGE 4 OF 5)

Number	Date	Origin Time	Lat.	Long.	Depth	m_b	Δ^o	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
139	08/19/71	14:56:58	46.0N	154.0E	55	3.9	36	-	-	L, B
141	08/19/71	22:15:38	49.3N	155.4E	N	6.0	33	5.4	6.1	
142	08/19/71	23:33:44	48.0N	158.0E	N	3.3	33	Not Detected		L
143	08/20/71	22:00:53	39.0N	104.0E	N	4.2	62	-	-	L, I
144	08/21/71	17:27:38	65.0N	160.0E	N	3.9	27	-	-	L, I
146	08/22/71	13:02:57	53.0N	156.0E	N	3.9	30	-	-	L, T
147	08/23/71	13:44:43	53.0N	164.0E	60	4.0	27	2.2	2.85	L
148	08/23/71	21:55:18	45.6N	151.0E	34	5.7	38	5.15	5.25	
149	08/24/71	09:52:54	46.0N	151.0E	N	4.3	37	T2.85	3.25	L
150	08/24/71	16:33:22	52.2N	91.4E	N	5.2	55	4.25	5.25	
151	03/22/71	04:32:58	49.7N	78.2E	0	5.8	60	3.35	3.55	
152	03/23/71	06:59:56	61.3N	56.5E	0	5.6	53	3.1	3.75	
153	03/23/71	09:26:29	71.0N	7.0W	N	6.0	42	5.35	5.7	
154	03/23/71	09:52:12	41.5N	79.3E	N	5.7	67	4.95	5.45	
155	03/23/71	20:51:03	41.5N	79.3E	N	6.0	67	4.95	5.5	
156	03/24/71	13:54:18	35.5N	98.2E	13	5.8	67	5.6	6.0	
158	03/24/71	20:54:29	41.5N	79.5E	18	5.3	67	-	-	B
159	03/24/71	21:01:55	41.4N	79.4E	25	5.3	67	-	-	B

TABLE IV-3

ALASKA EVENTS
(PAGE 5 OF 5)

Number	Date	Origin Time	Lat.	Long.	Depth	m_b	Δ^o	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
376	10/30/71	09:27:49	50.0N	154.4E	N	4.3	33	-	-	B
378	10/30/71	20:56:46	56.0N	156.0E	N	4.2	28	-	-	B
382	11/01/71	05:30:09	46.0N	88.0E	30	4.8	61	3.95	4.3	L
385	11/02/71	06:11:49	47.0N	153.0E	N	4.1	36	-	-	B
388	11/03/71	08:41:48	49.0N	149.0E	25	3.9	36	Not Detected		L
390	11/03/71	10:32:08	44.0N	147.0E	40	4.8	41	LQ Only		L
391	11/03/71	14:44:33	53.0N	161.0E	60	4.7	28	2.5	3.05	L
399	11/06/71	01:22:33	55.0N	161.0E	80	4.1	27	LQ Only		L
402	11/06/71	19:43:53	39.0N	29.0E	N	5.8	76	-	-	B
407	11/08/71	01:24:15	50.0N	155.0E	N	3.9	33	Not Detected		L
410	11/08/71	22:45:56	45.0N	153.0E	[illegible]	3.8	38	3.3	3.9	L
412	11/09/71	02:34:50	44.0N	148.[illegible]	4[illegible]	3.8	40	Not Detected		L

TABLE IV-4

SPAIN EVENTS
(PAGE 1 OF 2)

Number	Date	Origin Time	Lat.	Long.	Depth	m_b	Δ^o	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
263	08/18/71	19:58:21	43.7N	147.5E	60	4.7	93	3.05	4.05	
266	08/19/71	09:28:49	56.0N	162.0E	N	4.2	83	Not Detected		L
267	08/19/71	15:07:57	46.0N	154.0E	55	3.9	92	Not Detected		L
270	08/19/71	22:26:23	49.3N	155.4E	N	6.0	89	5.6	6.1	
277	08/21/71	17:27:38	55.0N	160.0E	N	3.9	84	Not Detected		L
278	08/21/71	19:34:23	81.9N	119.0E	N	4.6	55	3.2	3.55	
280	08/22/71	11:07:22	83.0N	6.5W	N	4.6	43	LQ Only		
281	08/22/71	13:02:57	53.0N	156.0E	N	3.9	86	Not Detected		L
283	08/22/71	17:54:17	30.1N	50.7E	N	5.1	45	LQ Only		B
285	08/23/71	05:46:31	28.8N	103.7E		5.2	84	-	-	I
287	08/23/71	13:44:43	53.0N	164.0I		4.0	87	Not Detected		L
289	08/23/71	21:55:18	45.6N	151.0E	34	5.7	92	4.9	5.45	
291	08/24/71	09:52:52	45.3N	151.3E	N	4.7	92	2.9	3.8	
292	08/24/71	16:33:23	52.2N	91.4E	N	5.2	63	4.3	5.05	
294	08/25/71	00:30:45	28.2N	52.3E	N	4.1	47	-	-	T
296	08/25/71	06:15:23	41.0N	77.0E	90	4.4	59	Not Detected		L
297	08/25/71	07:17:59	39.0N	31.0E	N	4.0	27	-	-	B
301	08/26/71	02:13:19	49.0N	148.0E	N	3.8	88	Not Detected		L

TABLE IV-4

SPAIN EVENTS
(PAGE 2 OF 2)

Number	Date	Origin Time	Lat.	Long.	Depth	m_b	Δ°	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
302	08/26/71	03:13:20	45.0N	153.0E	N	3.8	93	Not Detected		L
304	08/26/71	06:55:09	30.0N	50.7E	45	4.8	45	3.35	4.2	
305	08/26/71	07:17:18	52.0N	150.0E	N	4.7	85	-	-	B
306	08/26/71	11:35:54	42.0N	75.0E	N	4.2	58	T3.2	4.6	L
307	08/26/71	12:11:35	36.0N	44.0E	N	4.4	38	LQ Only		L
311	08/27/71	05:20:15	30.2N	50.7E	54	5.0	45	2.95	3.5	
312	08/27/71	07:59:11	30.1N	50.7E	63	4.4	45	2.6	2.8	
315	08/28/71	16:34:44	37.6N	55.8E	N	4.8	46	-	-	I
316	08/28/71	16:48:55	42.0N	133.0E	N	4.2	89	Not Detected		L
320	08/29/71	15:16:57	36.5N	78.5E	N	5.0	63	LQ Only		B
322	08/30/71	15:06:44	44.0N	148.0E	N	4.2	92	Not Detected		L
325	08/31/71	01:52:17	36.5N	70.8E	87	4.3	57	Not Detected		

TABLE IV-5

ISRAEL EVENTS
(PAGE 1 OF 2)

Number	Date	Origin Time	Lat.	Long.	Depth	m_b	Δ^o	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
43	01/24/71	13:21:16	49.2N	156.3E	N	4.9	86	3.85	4.7	
44	01/24/71	13:28:44	49.2N	156.1E	36	5.2	86	4.2	5.0	
45	01/24/71	13:47:36	49.1N	156.3E	34	4.6	86	3.8	4.7	
48	01/25/71	18:42:25	49.2N	156.4E	61	4.7	86	-	-	I
60	01/26/71	22:48:31	43.8N	39.2E	28	4.8	15	2.45	3.65	
61	01/27/71	19:57:55	47.9N	154.0E	40	4.8	86	Not Detected		
62	01/28/71	15:51:07	35.0N	47.0E	43	4.6	12	2.6	3.1	
63	01/29/71	21:23:43	55.7N	163.5E	N	4.6	85	LQ Only		
82	01/27/71	20:45:43	76.7N	7.0E	N	4.9	49	3.9	4.5	
83	01/28/71	11:03:50	76.5N	8.1E	N	4.5	49	T3.3	3.95	
195	03/31/71	20:00:31	39.6N	74.8E	38	4.8	34	2.75	3.3	
196	03/31/71	21:50:10	34.6N	50.3E	31	4.4	14	2.6	3.55	
197	04/03/71	04:49:03	32.3N	95.1E	N	5.7	51	5.65	5.85	
198	04/03/71	04:50:45	32.3N	95.4E	N	5.8	52	5.65	5.9	
199	04/03/71	0[illegible]:34:50	32.3N	95.1E	N	5.1	51	-	-	B
200	04/03/71	10:19:25	33.2N	46.5E	51	4.1	10	2.7	3.15	
201	04/04/71	01:35:23	38.4N	73.3E	N	4.8	33	3.3	3.65	
202	04/04/71	06:12:27	30.5N	67.8E	15	-	29	3.45	4.1	

TABLE IV-5

ISRAEL EVENTS
(PAGE 2 OF 2)

Number	Date	Origin Time	Lat.	Long.	Depth	m_b	Δ^o	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
203	04/06/71	03:02:57	39.6N	77.8E	N	4.5	37	2.6	3.05	
204	04/06/71	06:49:52	29.8N	51.9E	10	5.2	15	4.3	4.85	
206	04/13/71	20:43:00	28.2N	55.6E	44	4.8	19	-	-	R
208	04/17/71	16:37:38	41.0N	37.0E	N	4.8	12	LQ Only		B
219	05/17/71	14:16:18	37.7N	29.9E	N	4.8	9	3.35	3.5	
222	05/20/71	03:06:45	37.6N	30.0E	N	4.8	9	2.95	3.3	
224	05/22/71	14:02:07	35.6N	58.3E	36	4.8	21	2.25	3.3	
225	05/22/71	16:43:59	38.8N	40.5E	3	6.0	11	4.75	4.95	
226	05/22/71	17:32:29	38.9N	40.5E	N	4.5	11	-	-	I
227	05/22/71	17:34:15	38.8N	40.6E	13	4.8	11	-	-	I
232	05/23/71	02:36:35	37.6N	29.6E	N	4.3	9	-	-	I
234	05/23/71	05:19:08	37.6N	30.1E	11	4.5	9	LQ Only		B
235	05/23/71	20:11:22	37.6N	29.9E	N	4.7	9	LQ Only		B
237	05/24/71	02:20:14	38.8N	40.5E	N	4.7	11	2.9	3.2	
243	05/26/71	02:41:46	35.5N	58.2E	26	5.4	21	4.15	5.2	
244	05/27/71	00:30:28	38.3N	69.0E	36	4.8	30	3.3	3.85	

TABLE IV-6

NORWAY EVENTS
(PAGE 1 OF 2)

Number	Date	Origin Time	Lat.	Long.	Depth	m_b	Δ^o	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
329	09/19/71	19:56:10	45.0N	152.0E	50	3.9	71	Not Detected		L
331	09/19/71	22:47:11	45.0N	152.0E	N	4.0	71	3.1	3.6	L
333	09/20/71	06:16:59	44.0N	33.0E	N	4.0	21	2.85	3.4	L
334	09/20/71	08:02:50	43.0N	33.0E	N	4.2	22	2.0	3.5	L
335	09/20/71	10:57:49	43.0N	32.0E	N	4.2	22	2.45	2.95	L
338	09/21/71	01:04:11	36.0N	45.0E	N	4.4	33	3.1	3.65	L
339	09/21/71	09:13:52	32.4N	91.8E	N	5.0	59	3.6	4.7	
341	09/21/71	16:48:52	37.3N	30.2E	37	4.8	26	3.6	4.0	
343	09/22/71	14:20:10	46.4N	140.8E	14	4.8	67	5.2	5.6	
345	09/22/71	20:27:40	44.0N	148.0E	N	4.7	71	T2.7	3.5	L
346	09/23/71	00:51:09	47.0N	138.0E	N	5.1	65	2.95	3.6	L
349	09/23/71	21:08:03	53.0N	120.0E	15	4.2	54	T2.25	3.0	L
350	09/24/71	01:33:51	50.0N	152.0E	35	3.9	66	-	-	I
413	10/03/71	17:18:54	36.8N	29.9E	27	4.4	26	3.1	3.3	
414	10/04/71	10:00:02	61.6N	47.1E	13	5.1	18	T1.9	T2.35	
415	10/05/71	18:53:06	39.0N	29.8E	9	4.5	24	2.5	3.2	
416	10/05/71	22:45:04	31.6N	50.7E	66	4.1	39	2.55	3.15	
417	10/06/71	01:46:36	38.3N	30.2E	19	4.6	25	3.1	3.55	

TABLE IV-6

NORWAY EVENTS
(PAGE 2 OF 2)

Number	Date	Origin Time	Lat.	Long.	Depth	m_b	Δ^o	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
418	10/06/71	23:43:29	37.5N	72.1E	107	4.8	45	3.2	3.95	
419	10/09/71	06:02:57	50.0N	77.7E	0	5.4	39	2.55	3.05	
420	10/09/71	22:29:16	37.3N	30.2E	33	4.5	26	2.45	3.0	
421	10/04/71	16:43:32	42.9N	13.1E	33	5.0	17	2.7	3.7	
422	10/04/71	22:21:57	43.1N	12.9E	43	4.4	17	2.05	2.65	
423	10/05/71	18:31:18	27.2N	55.8E	39	5.1	45	3.7	3.85	
424	10/10/71	02:10:51	37.2N	30.1E	26	4.3	26	2.0	2.5	
425	10/12/71	11:44:42	44.5N	11.0E	25	4.6	15	2.35	2.85	
426	10/21/71	06:02:57	50.0N	77.6E	0	5.6	39	T2.8	T3.0	
427	10/22/71	05:00:00	51.6N	54.5E	6	5.3	26	T2.1	T2.5	
428	10/23/71	11:49:21	29.6N	51.3E	33	4.5	41	3.4	3.85	
429	11/06/71	19:43:47	39.0N	29.7E	14	5.0	24	3.7	3.95	
430	11/08/71	03:06:36	27.1N	54.5E	36	5.6	45	5.05	5.5	
431	11/09/71	00:16:59	27.0N	54.5E	33	4.8	45	3.5	4.05	

TABLE IV-7

OGDENSBURG EVENTS
(PAGE 1 OF 4)

Number	Date	Origin-Time	Lat.	Long.	Depth	m_b	Δ^o	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
43	01/24/71	13:21:16	49.2N	156.3E	N	4.9	79	-	4.55	
44	01/24/71	13:28:44	49.2N	156.1E	36	5.2	79	4.2	5.0	
45	01/24/71	13:47:36	49.1N	156.3E	34	4.6	79	-	4.7	
60	01/26/71	22:48:31	43.8N	39.2E	28	4.8	76	Not Detected		
61	01/27/71	19:57:55	47.9N	154.0E	40	4.8	81	Not Detected		
62	01/28/71	15:51:07	35.0N	47.0E	43	4.6	87	Not Detected		
63	01/29/71	21:23:43	55.7N	163.5E	N	4.6	71	LQ Only		
67	01/30/71	20:15:41	30.5N	79.1E	56	4.6	104	2.9	3.9	
69	02/01/71	01:12:27	37.2N	30.2E	35	4.5	76	T3.25	4.0	
70	02/01/71	14:21:43	42.3N	85.3E	N	4.8	95	Not Detected		
71	02/02/71	07:59:57	23.8N	91.8E	48	5.4	114	2.85	4.9	
73	02/04/71	02:54:05	53.0N	162.8E	N	4.6	86	-	-	I
76	02/05/71	09:09:58	25.2N	99.4E	N	5.3	114	4.75	5.35	
77	02/06/71	00:58:42	44.9N	148.0E	N	4.3	86	-	-	T, L
81	01/26/71	08:08:44	77.1N	8.5E	N	4.6	49	3.5	4.0	
82	01/27/71	20:45:43	76.7N	7.0E	N	4.9	48	4.2	4.75	
83	01/28/71	11:03:50	76.5N	8.1E	N	4.5	49	3.75	4.25	
84	01/29/71	08:33:50	78.8N	8.0E	N	4.8	49	3.85	4.65	

TABLE IV-7

OGDENSBURG EVENTS
(PAGE 2 OF 4)

Number	Date	Origin Time	Lat.	Long.	Depth	m_b	Δ^o	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
85	01/31/71	04:33:27	76.6N	7.3E	N	4.7	49	3.9	4.15	
109	12/17/70	07:00:57	49.7N	78.1E	0	5.5	86	T3.5	T4.1	
110	12/17/70	09:21:13	83.4N	115.4E	N	4.8	55	-	-	I
113	12/18/70	22:28:54	50.2N	156.7E	61	5.1	78	3.5	4.1	
114	12/20/70	11:01:48	39.4N	29.2E	38	5.0	74	4.5	5.15	
115	12/21/70	00:22:27	39.3N	29.4E	39	4.2	74	-	-	B
117	12/17/70	02:17:06	39.3N	29.3E	N	4.4	74	3.4	4.1	
118	08/09/71	01:03:17	42.1N	83.4E	N	4.2	95	Not Detected		
119	08/09/71	02:54:37	36.2N	52.7E	27	5.2	89	4.4	5.5	
121	08/12/71	08:14:18	46.0N	151.0E	N	4.2	84	Not Detected		
123	08/12/71	20:57:58	49.7N	156.0E	45	4.5	79	3.2	3.9	
124	08/12/71	22:55:28	47.0N	150.0E	N	3.9	83	-	-	B, L
125	08/13/71	00:34:44	49.0N	156.0E	N	3.7	80	Not Detected		L
126	08/13/71	06:15:57	46.0N	151.0E	N	4.1	84	Not Detected		L
128	08/15/71	14:03:13	50.0N	160.0E	N	3.3	77	Not Detected		L
129	08/16/71	04:58:00	28.9N	103.7E	N	5.5	110	4.45	4.85	
130	08/16/71	10:33:13	46.0N	149.0E	N	3.8	85	Not Detected		L
131	08/16/71	17:23:47	44.0N	148.0E	N	3.9	87	Not Detected		L

TABLE IV-7

OGDENSBURG EVENTS
(PAGE 3 OF 4)

Number	Date	Origin Time	Lat.	Long.	Depth	m_b	Δ^o	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
132	08/16/71	18:53:55	28.9N	103.7E	N	5.3	110	4.7	4.9	
133	08/16/71	22:37:33	28.9N	103.6E	N	5.4	110	3.6	4.8	
134	08/17/71	09:36:15	28.9N	103.7E	N	4.9	110	T3.7	4.5	
135	08/17/71	17:07:40	28.9N	103.7E	N	4.9	110	-	-	I
137	08/18/71	19:58:21	43.7N	147.5E	60	4.7	87	3.4	3.75	
138	08/19/71	09:28:49	56.0N	162.0E	N	4.2	72	-	-	I
139	08/19/71	14:56:58	46.0N	154.0E	55	3.9	83	Not Detected		L
141	08/19/71	22:15:38	49.3N	155.4E	N	6.0	80	5.35	5.95	
142	08/19/71	23:33:44	48.0N	158.0E	N	3.3	80	Not Detected		L
144	08/21/71	17:27:38	65.0N	160.0E	N	3.9	73	-	-	I, L
146	08/22/71	13:02:57	53.0N	156.0E	N	3.9	76	-	-	T, L
147	08/23/71	13:44:43	53.0N	164.0E	60	4.0	73	Not Detected		L
148	08/23/71	21:55:18	45.6N	151.0E	34	5.7	84	5.0	5.65	
149	08/24/71	09:52:54	46.0N	151.0E	N	4.3	84	T3.25	3.55	L
150	08/24/71	16:33:22	52.2N	91.4E	N	5.2	87	4.35	5.65	
151	03/22/71	04:32:58	49.7N	79.2E	0	5.8	86	T3.05	T3.7	
152	03/23/71	06:59:56	61.3N	56.5E	0	5.6	70	3.3	4.1	
153	03/23/71	09:26:29	71.0N	7.0W	N	6.0	44	5.6	5.95	

TABLE IV-7

OGDENSBURG EVENTS
(PAGE 4 OF 4)

Number	Date	Origin Time	Lat.	Long.	Depth	m_b	Δ^o	LR Vertical $M_s(40)$	LR Vertical $M_s(20)$	Comments
154	03/23/71	09:52:12	41.5N	79.3E	N	5.7	94	5.45	5.75	
155	03/23/71	20:51:03	41.5N	79.3E	N	6.0	94	5.6	5.75	
156	03/24/71	13:54:18	35.5N	98.2E	13	5.8	103	5.7	6.3	
158	03/24/71	20:54:29	41.5N	79.5E	18	5.3	94	4.1	4.3	
159	03/24/71	21:05:40	41.4N	79.4E	25	5.3	94	4.25	4.3	
160	06/04/71	07:56:55	84.5N	107.5E	N	5.0	54	3.1	3.8	
161	06/04/71	09:10:03	84.6N	108.0E	N	5.1	54	4.2	4.4	
162	06/04/71	14:10:46	32.2N	95.2E	N	5.0	106	3.25	3.4	
164	12/22/70	20:53:04	28.3N	43.9W	N	5.4	28	4.6	5.25	
165	12/23/70	07:00:57	43.8N	54.8E	0	6.1	84	3.95	4.35	

LEGEND FOR TABLES IV-1 TO IV-7

$M_s(20)$ - $M_s(40)$: T - The M_s value is from the maximum amplitude in the expected signal gate.

Comments : L - Epicenter information from LASA Bulletin.

T - Event not processed due to tape read errors.

B - Event not processed due to bad data on field tape.

I - Event not analyzed due to interferring event.

R - The Rayleigh wave for the event was recorded, but M_s was not calculated due to erratic data on the field tape.

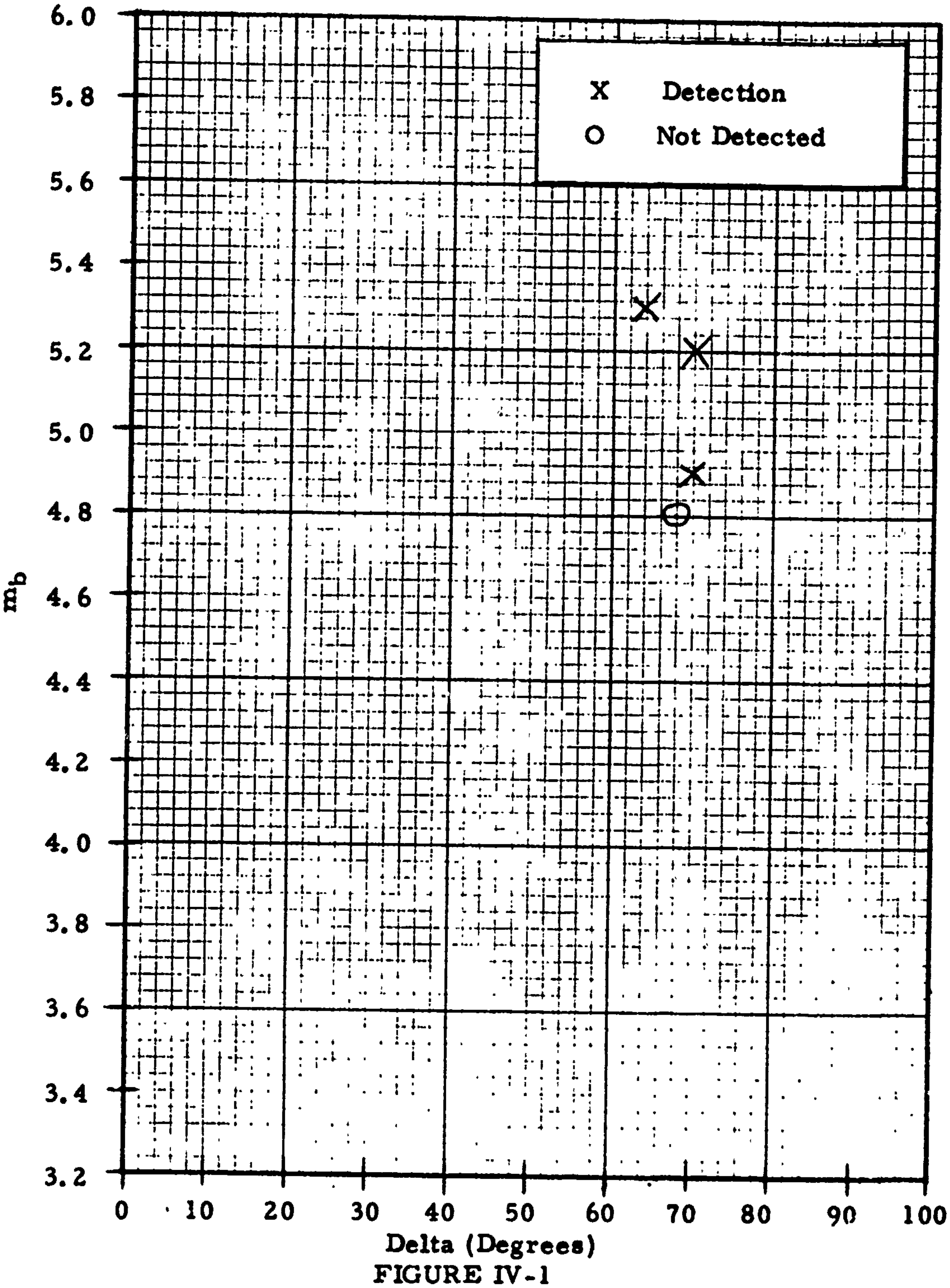


FIGURE IV-1
AUSTRALIA EVENT DETECTION vs. DELTA

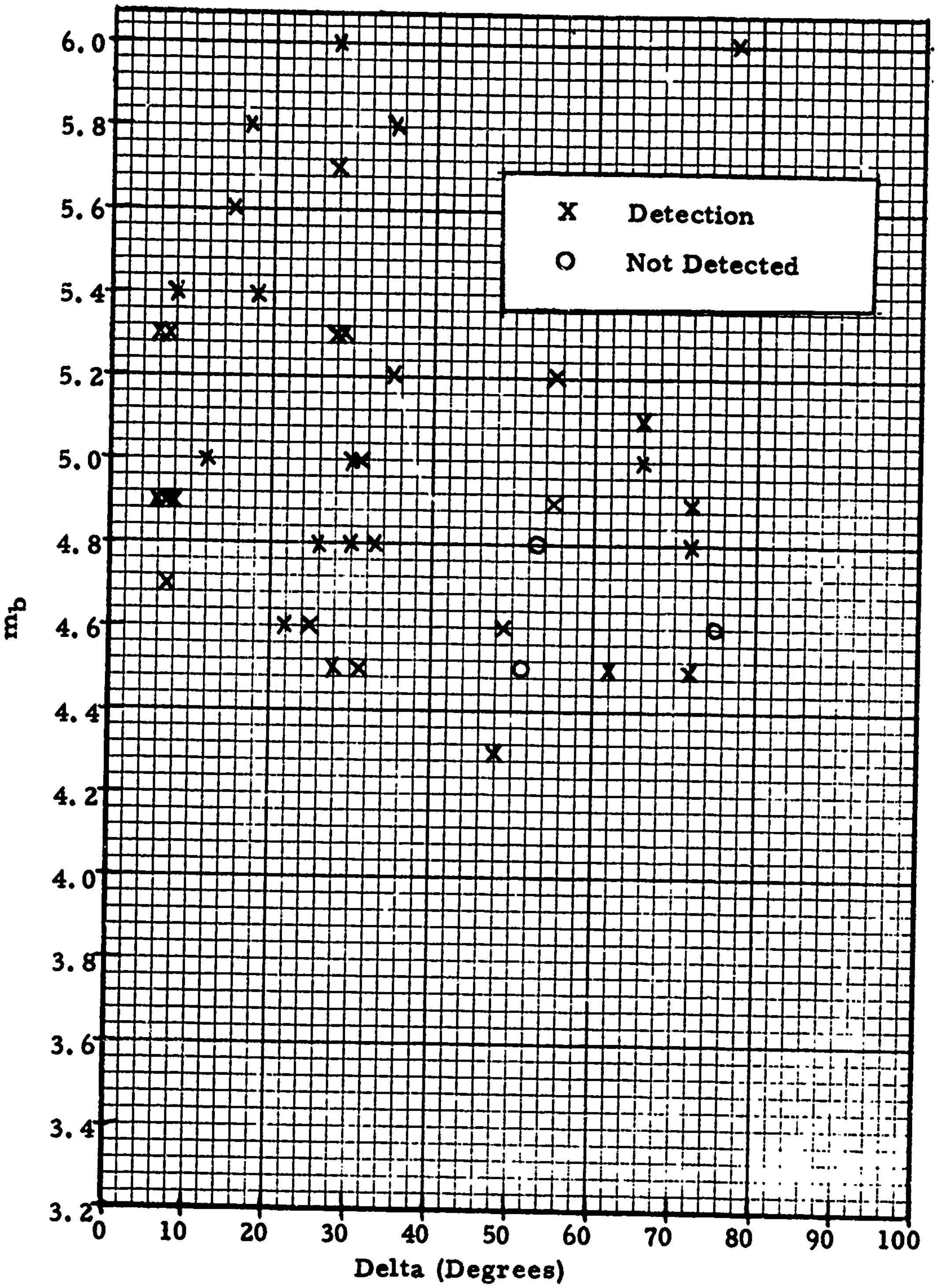


FIGURE IV-2
THAILAND EVENT DETECTION vs. DELTA

Figure IV-3 shows the Alaska detection data. The large cluster of events between 27 and 41 degrees are Kuriles-Kamchatka earthquakes; the events below $m_b = 4.4$ were reported primarily by LASA. From the Kuriles-Kamchatka region all events with $m_b \geq 4.0$ were detected, while no events below m · ‘ 0 were detected. The events in the 60 to 80 degree range were primaril · m Nothern China and the surrounding areas. In this range, available events were limited to $m_b \geq 4.5$. Only one event, an $m_b = 4.6$ from Western Iran was not detected. It should be noted that about one-half of the events analyzed were from the low noise level period at the beginning of 1971, and the other half from the higher noise period near the end of 1971.

Figure IV-4 shows the Spain detection data. The cluster of events between 83 and 95 degrees are from the Kuriles-Kamchatka area. The remainder of the Spain events are scattered throughout seismic areas in the Sino-Soviet bloc. Five events with $m_b \geq 4.0$ were not detected, including an $m_b = 4.4$ from Kirgiz-Sinkiang ($\Delta = 59^\circ$).

Figure IV-5 shows the Israel detection data. Most of the events were less than 30 degrees epicentral distance, although a few Kuriles-Kamchatka events (at 85°) are included. All of the events analyzed at the Israel station, except one $m_b = 4.8$ from the Kurile Islands, were detected. The Israel detection threshold appears to be below the m_b level of the events processed to date; recall that Israel has one of the lowest RMS noise levels and a relatively flat noise spectrum in the 20 to 40 second range.

Figure IV-6 shows the Norway detection data. All of the events analyzed were detected except for an $m_b = 3.9$ from the Kurile Islands. The cluster of events near twenty degrees were from Iran, Turkey, Italy, and the Black Sea area. The other events were from the Kurile Islands, Tibet, the East Coast of Russia, and Tadzhik.

Figure IV-7 shows the Ogdensburg detection data. For Ogdensburg all events with $m_b > 4.8$ and all events with delta less than 70 degrees were

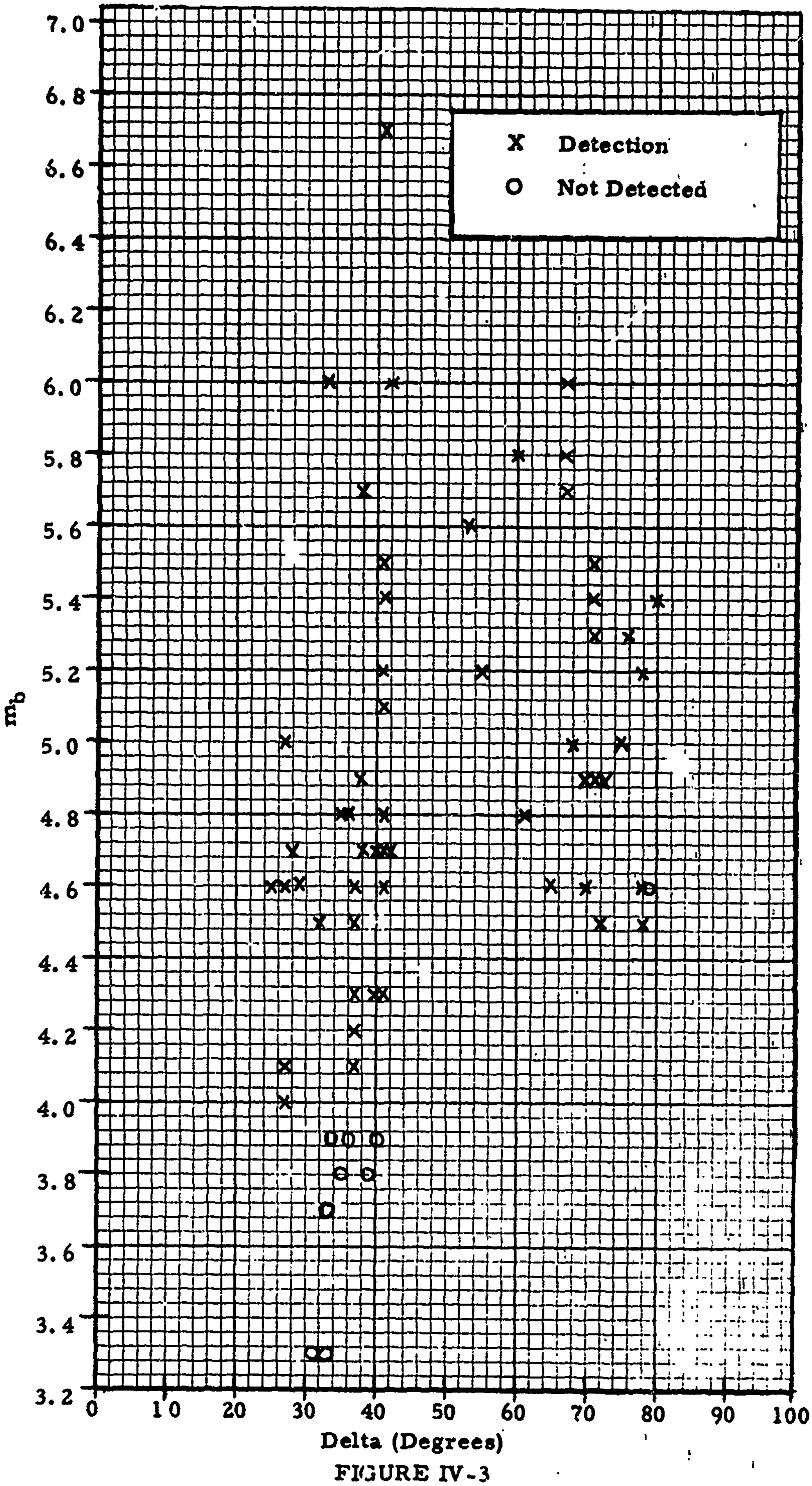


FIGURE IV-3
ALASKA EVENT DETECTION vs. DELTA

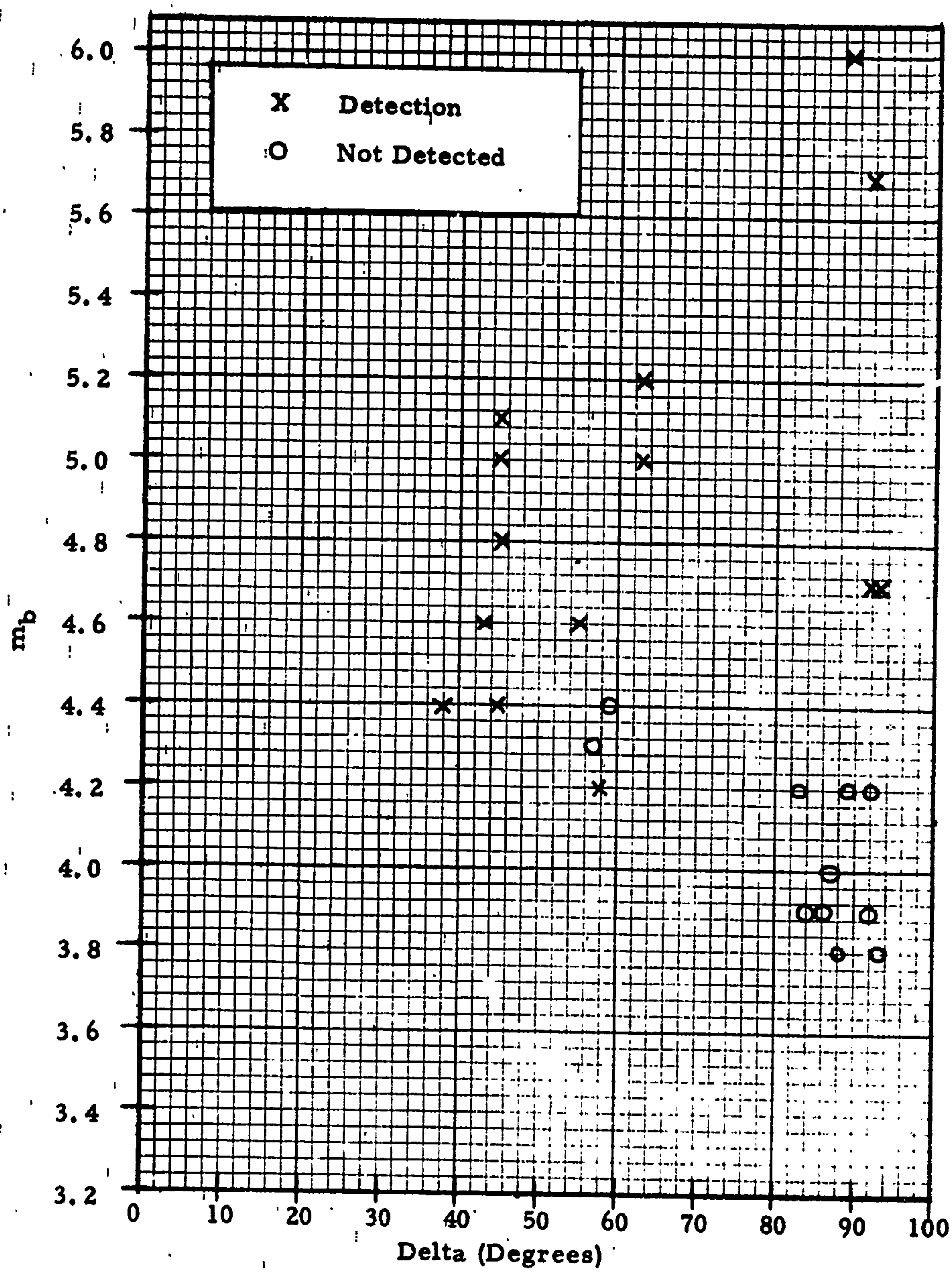


FIGURE IV-4
SPAIN EVENT DETECTION
vs. DELTA

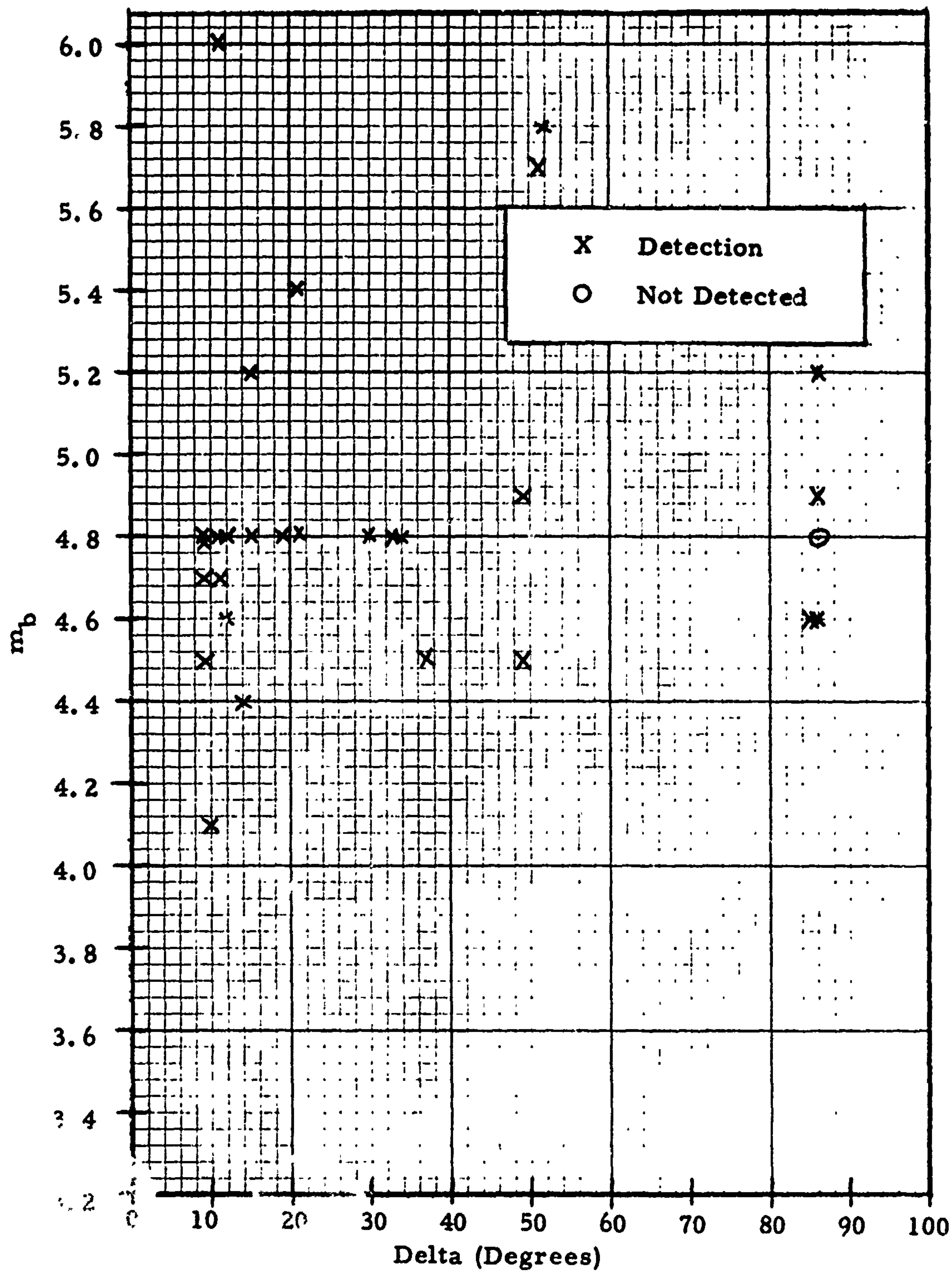


FIGURE IV-5
ISRAEL EVENT DETECTION
vs. DELTA

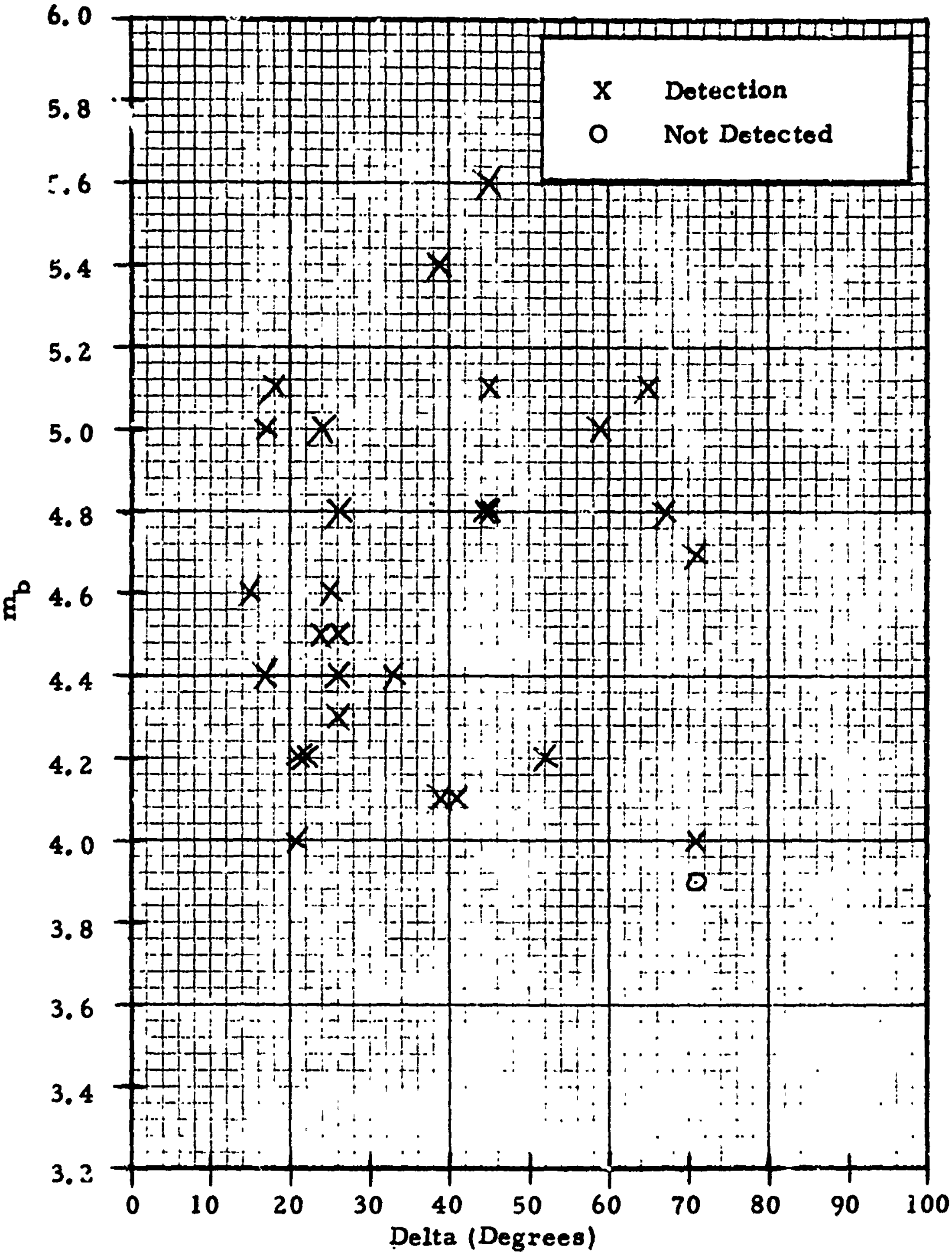


FIGURE IV-6
NORWAY EVENT DETECTION vs. DELTA

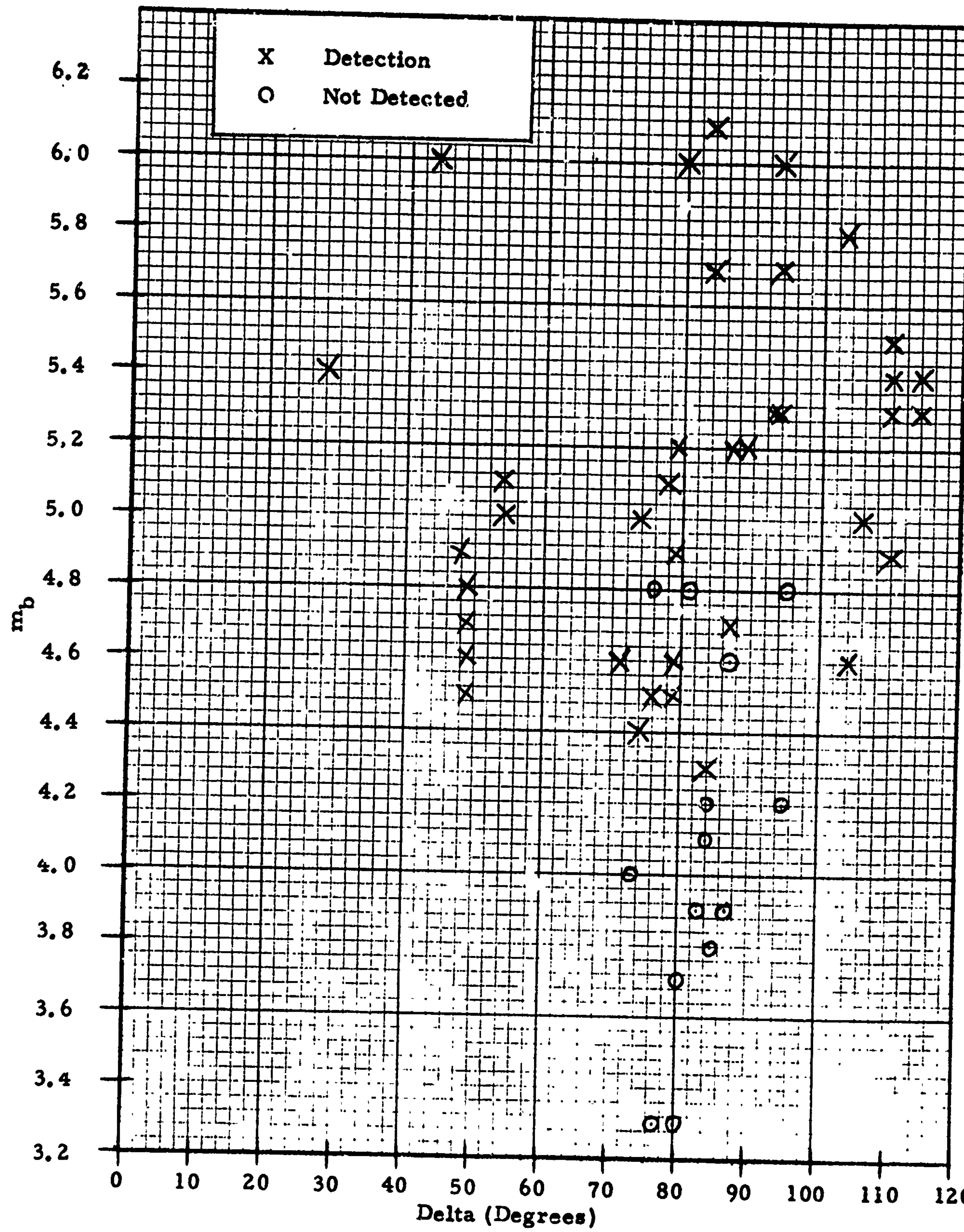


FIGURE IV-7
OGDENSBURG EVENT DETECTION vs. DELTA

recorded. The large cluster of small events, $m_b \leq 4.2$, which were not detected were from the Kurile Islands region and the $m_b = 4.2$ at 95 degrees was from Northern Sinkiang Province. The four large events not recorded were from Northern Sinkiang Province ($m_b = 4.8$, Delta = 95), Western Iran ($m_b = 4.6$, Delta = 87), Kurile Islands ($m_b = 4.8$, Delta = 81), and Caucasus ($m_b = 4.8$, Delta = 76).

B. BEHAVIOR OF M_s-m_b

Figures IV-8 to IV-15 show M_s-m_b plots for the seven stations. In these figures, only events with either normal or shallow depths are shown.

The m_b values were taken from either PDE or LASA bulletins, and the M_s values were calculated using:

$$M_s = \log \frac{A}{T} + 0.92 + \log \Delta, \quad \Delta < 25^\circ$$

$$M_s = \log \frac{A}{T} + 1.66 \cdot \log \Delta, \quad \Delta \geq 25^\circ \text{ (Evernden, 1971)}$$

Where: A is the peak-to-peak amplitude in $m\mu$

T is the period

Δ is the distance in degrees

For this study all amplitude measurements, except those in Figure IV-10, were made using the largest peak-to-peak excursion for the vertical Rayleigh waves in the period range between 17 and 25 seconds. (Figure IV-10 was made from Love wave measurements at Thailand). Due to the limited number of events from known test areas analyzed, data for presumed explosions of Savino et al (1971) from the Ogdensburg station and our presumed explosion data from the Alaskan station (hereafter called the presumed explosion data set) have been included on some of the M_s-m_b plots. Also for reference, Richter's M_s-m_b curve for earthquakes is shown.

Figure IV-8 shows the M_s-m_b plot for the Australian data. As in the Australia detection plot, the number of events analyzed is too small to reach any definite conclusions. The three events shown are separated from the presumed explosion data set.

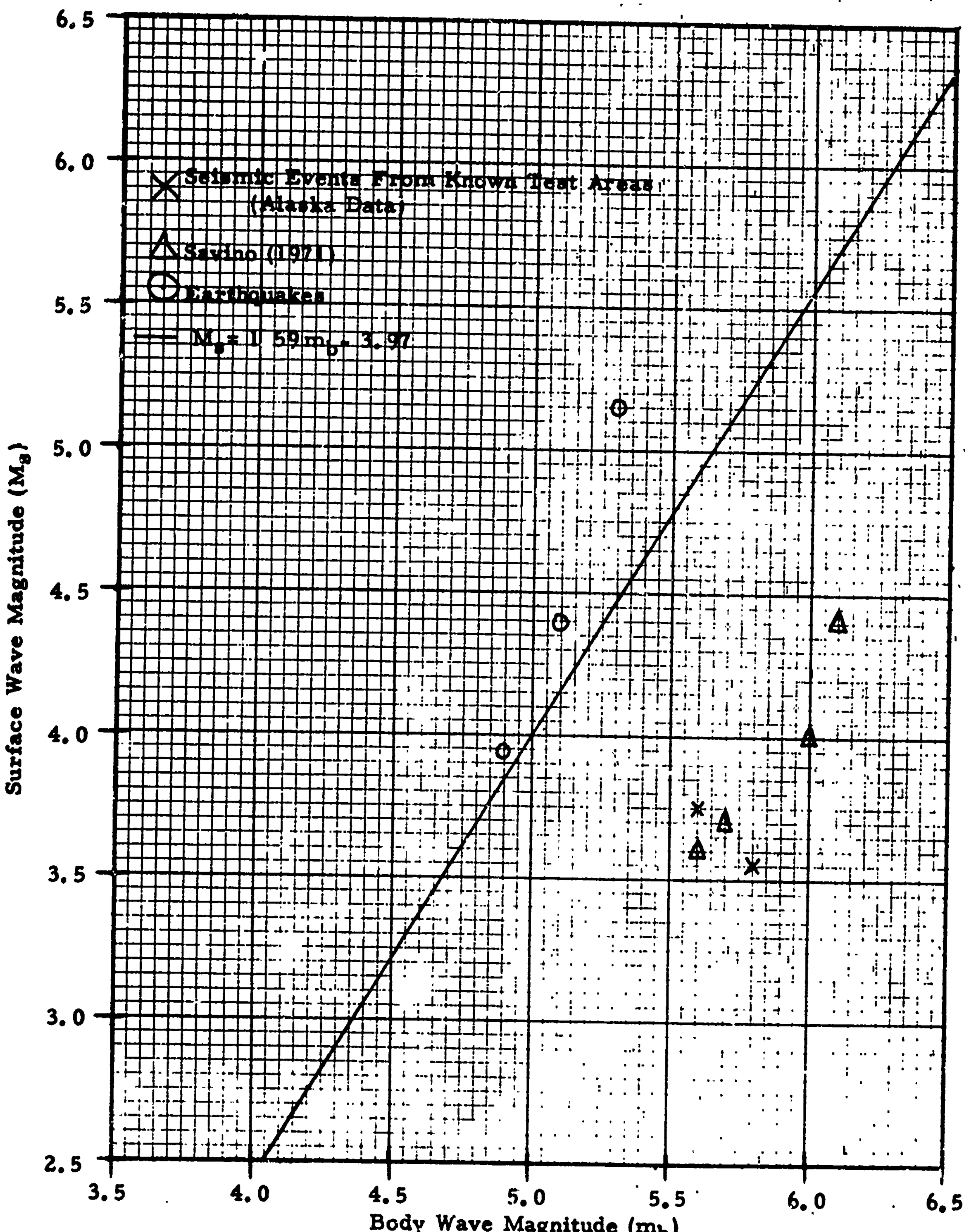


FIGURE IV-8
AUSTRALIA M_s-m_b

Figure IV-9 shows the M_s-m_b plot from Thailand. Although the earthquakes show some separation from the two events from known test areas (recorded at Thailand), the separation is not as clear as that shown for other stations. It appears that the Rayleigh waves for events from north of the Thailand station are being severely attenuated as they propagate to the station, or the Thailand station is situated in a nodal direction to the fault planes of events from North of the station. To study this the two Thailand horizontal components were equalized, using an amplitude scale factor, and rotated to a transverse-radial coordinate system. Then M_s values were recalculated from the Love waves. The Love wave and vertical Rayleigh wave M_s values are shown in Table IV-8 and are plotted versus m_b in Figure IV-10. (As seen in Table IV-8, there will not be an LQ data point for each LR point in Figure IV-10.) The earthquake Love wave M_s values average about 0.6 magnitude units more than the Rayleigh wave M_s values. Love waves were not detected from either presumed explosion; however the threshold values increased by about 0.6 units because of the higher noise level on the Thailand horizontal components. Therefore it is not possible to determine from the available data sample the behavior of M_s-m_b at this station except to say that is appears that the use of Love wave data for events north of the station may be necessary for discrimination.

Figure IV-11 shows the M_s-m_b data for the Alaskan data. This figure shows generally good separation between the earthquake population and the presumed explosion data set. Two earthquakes at "A" (m_b= 4.7, M_s= 3.1) and "B" (m_b= 4.8, M_s= 3.2) have somewhat low values; both events were relatively deep (60 and 40 km respectively), according to PDE. Note that Savino's data points for presumed explosions (Ogdensburg data) tend to agree with those obtained from the Alaska station.

Figure IV-12 shows the M_s-m_b data for Spain. The data are very limited, but separation between the earthquake and presumed explosion data set values is typical. Two of the ten earthquakes at points "A" (m_b= 4.4, M_s= 2.8)

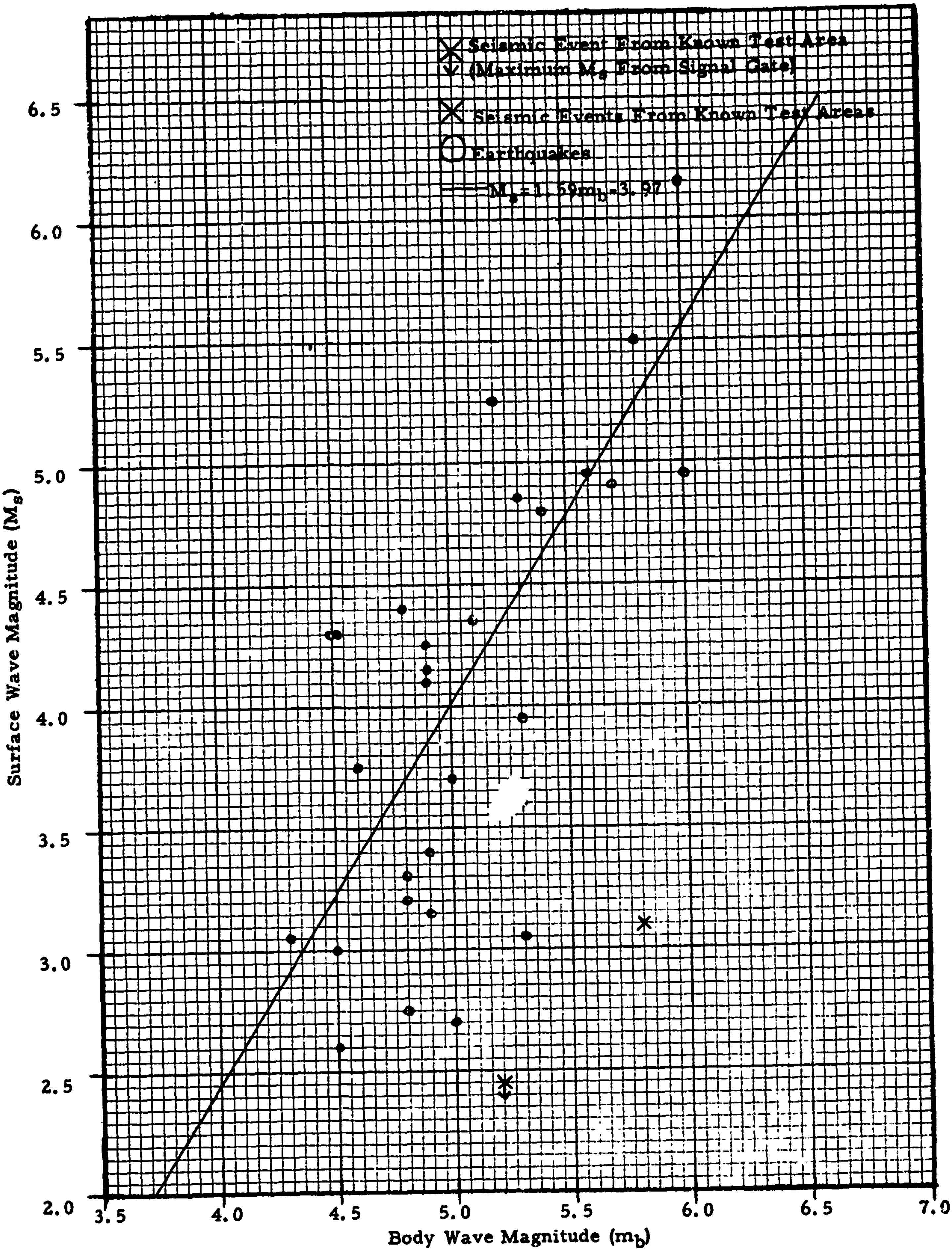


FIGURE IV-9

THAILAND M_s-m_b

TABLE IV -8

TH \ILAND M_s COMPARISON OF LQ AND LR WAVES
(PAGE 1 OF 2)

Number	m_b	M_s(LQ-20 sec)	M_s(LR-20 sec)
43	4.9	I	3.4
44	5.2	5.5	5.25
62	4.6	Not Detected	3.75
69	4.5	4.1	4.3
70	4.8	3.95	2.75
76	5.3	5.3	3.95
77	4.3	B	3.1
82	4.9	4.85	4.15
83	4.5	4.55	4.3
84	4.8	5.0	4.4
151	5.8	T3.5	3.1
153	6.0	6.2	6.15
154	5.7	5.5	4.9
155	6.0	6.25	4.95
156	5.8	5.9	5.5
158	5.3	4.8	3.6
159	5.3	4.9	3.05
160	5.0	4.25	3.7
161	5.1	5.0	4.35
162	5.0	4.45	2.7
168	4.8	4.2	3.2
169	4.5	3.4	2.6

TABLE IV-8

THAILAND M_s COMPARISON OF LQ AND LR WAVES
(PAGE 2 OF 2)

Number	m_b	M_s(LQ-20 sec)	M_s(LR-20 sec)
171	4.5	4.0	3.0
178	5.4	5.7	4.8
182	4.9	3.4	3.15
183	5.6	6.0	4.95
185	5.2	T3.5	T2.45
186	4.8	3.55	3.3
187	4.9	4.9	4.25
189	4.9	5.05	4.1
190	5.3	5.35	4.85

LEGEND

T - The M_s value is from the maximum amplitude in the expected signal gate.

B - Event not detected due to bad data on field tape.

I - Event not detected due to interferring event.

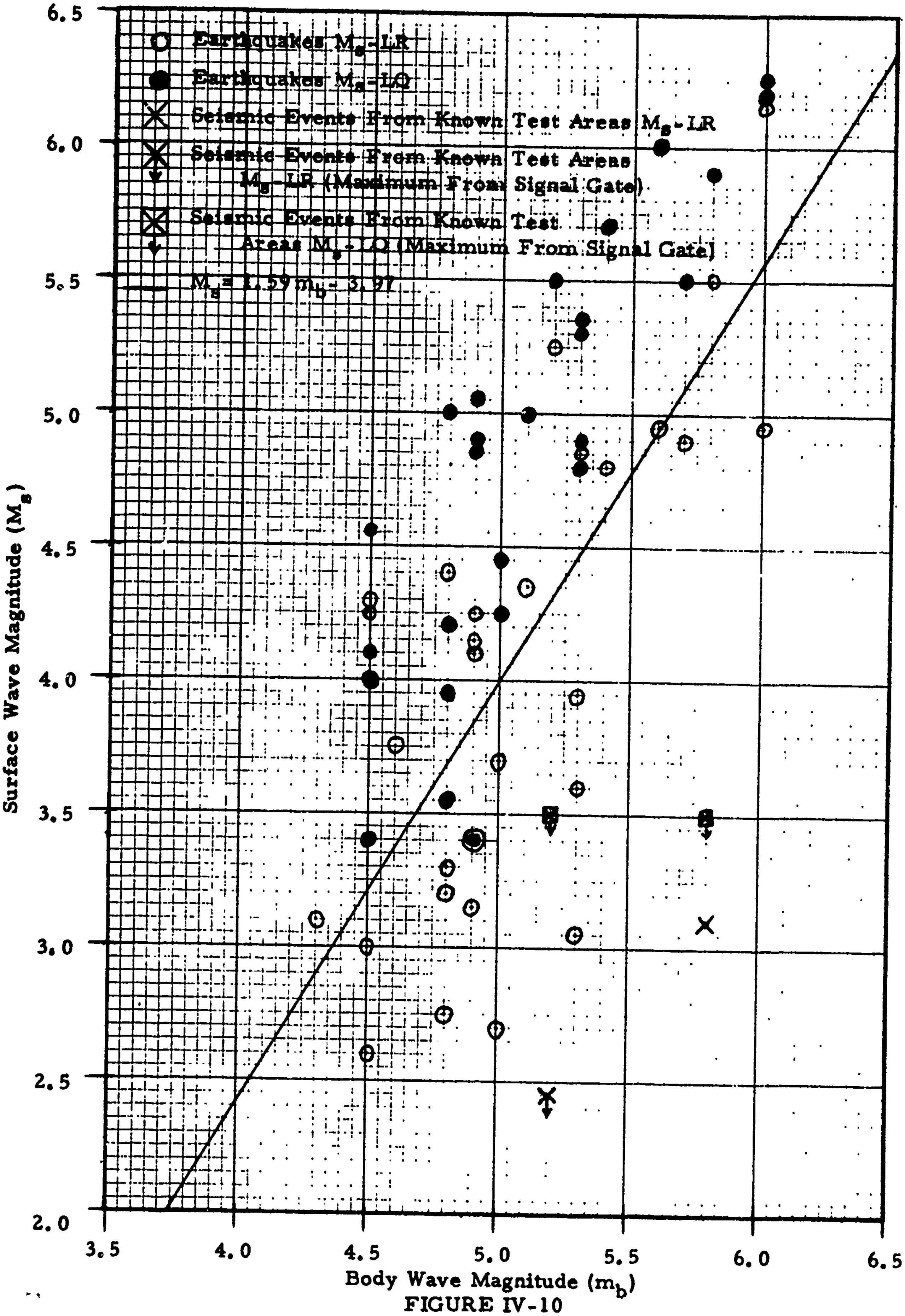


FIGURE IV-10

COMPARISON OF THAILAND M_s-m_b FOR LOVE AND RAYLEIGH WAVES

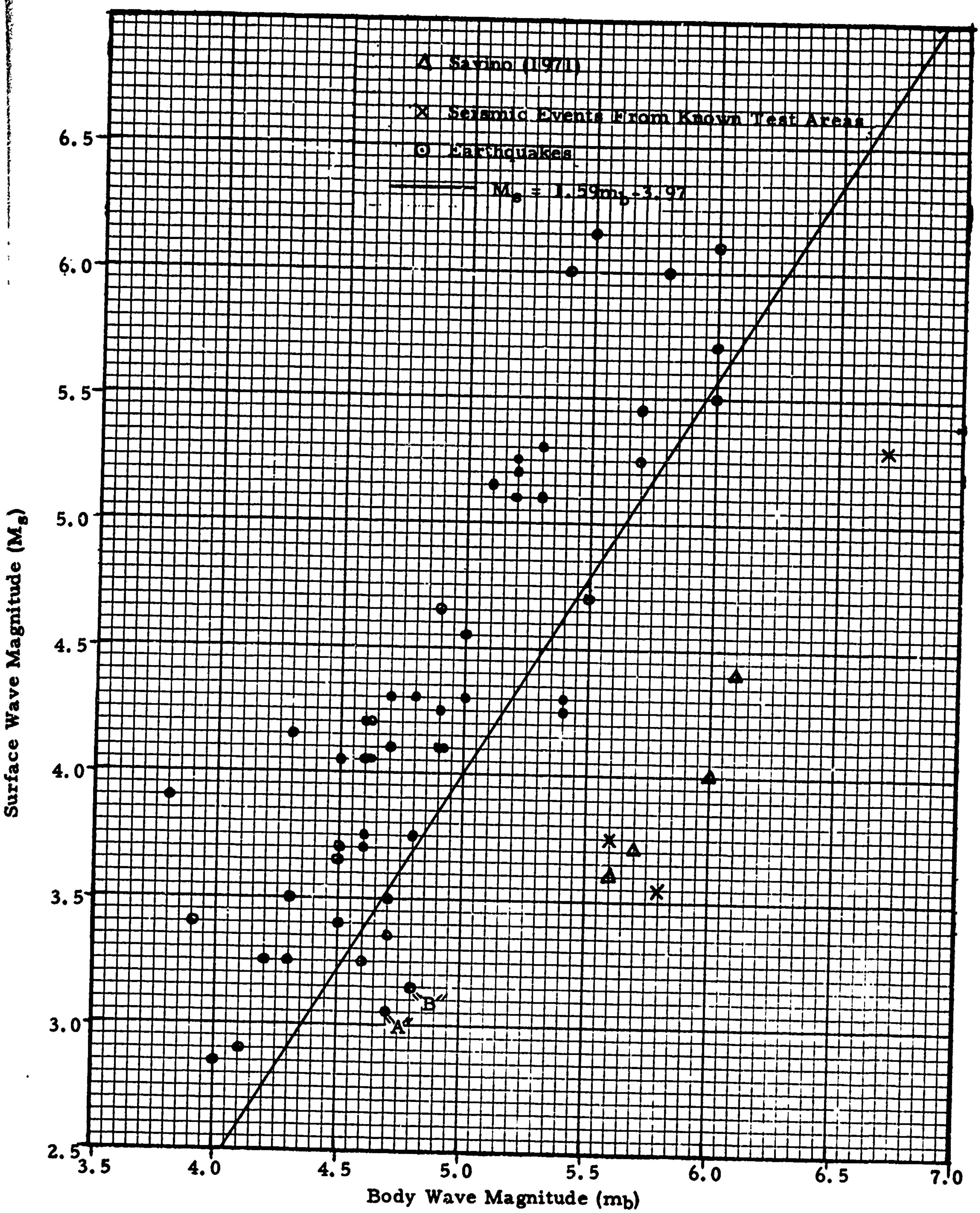


FIGURE IV-11

ALASKA M_s-m_b

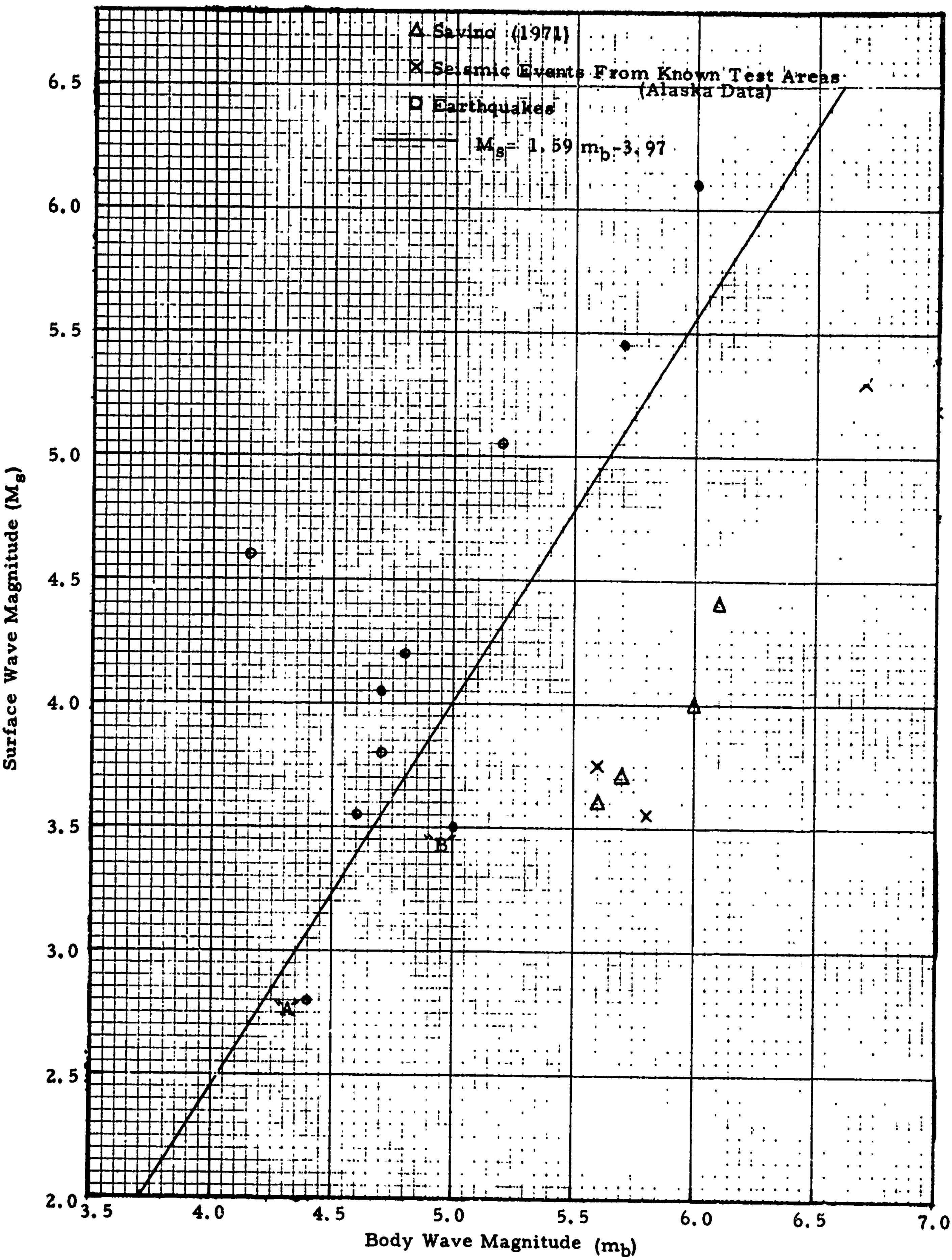


FIGURE IV-12
SPAIN M_s-m_b

and "B" (m_b= 5.0, M_s= 3.5) appear to be somewhat low. Both of these events are relatively deep (A= 63 km and B= 54 km) which may account for their low values.

Figure IV-13 shows the M_s-m_b data for the Israel data. Again typical separation between the earthquake and presumed explosion data set values is observed. One point, "A" (m_b= 6.0, M_s= 4.9) is somewhat low. We have no explanation as to cause for the low M_s value for point "A", as it is a shallow event (depth = 3 km); however the event is fairly close to the station (delta = 11 degrees) which possibly could affect the M_s value.

Figure IV-14 shows the M_s-m_b data for the Norway data. The figure shows very good separation between the earthquake population and the presumed explosion data set. (Note that the four events from known test areas in this figure were from Norway data.) It appears that classification using the M_s-m_b discriminant for the Norway station should be very good.

Figure IV-15 shows the M_s-m_b data for the Ogdensburg data. This figure shows fair separation between the earthquake and seismic events from known test area populations. However, four points—"A," "B," "C," and "D"—might be questionable. Point "A" from Tibet (m_b = 5.0, M_s = 3.4) is very low, and point "B" from Severnaya Zemlya (m_b = 5.0, M_s = 3.8) is somewhat low. We have no explanation for the low M_s values for these two events; however, the M_s value for the Tibet event was also very low for the Thailand LR waves (M_s = 2.7). Point "C" appears higher than the other seismic events from known test areas (Ural Mountains, m_b = 5.6, M_s = 4.1), and point "D" is a threshold value.

In summary, it appears that the M_s-m_b relationship for the LPE stations will be typical of that observed at other stations (i.e. LASA and ALPA). That is, separation between earthquakes and events from known test areas will be generally good, with the exception of occasional earthquakes which fall somewhat below the bulk of the earthquake population. Also, separation for the Norway station appears to be very good, and classification for the Thailand station appears to require the use of M_s measurements from Love as well as Rayleigh waves.

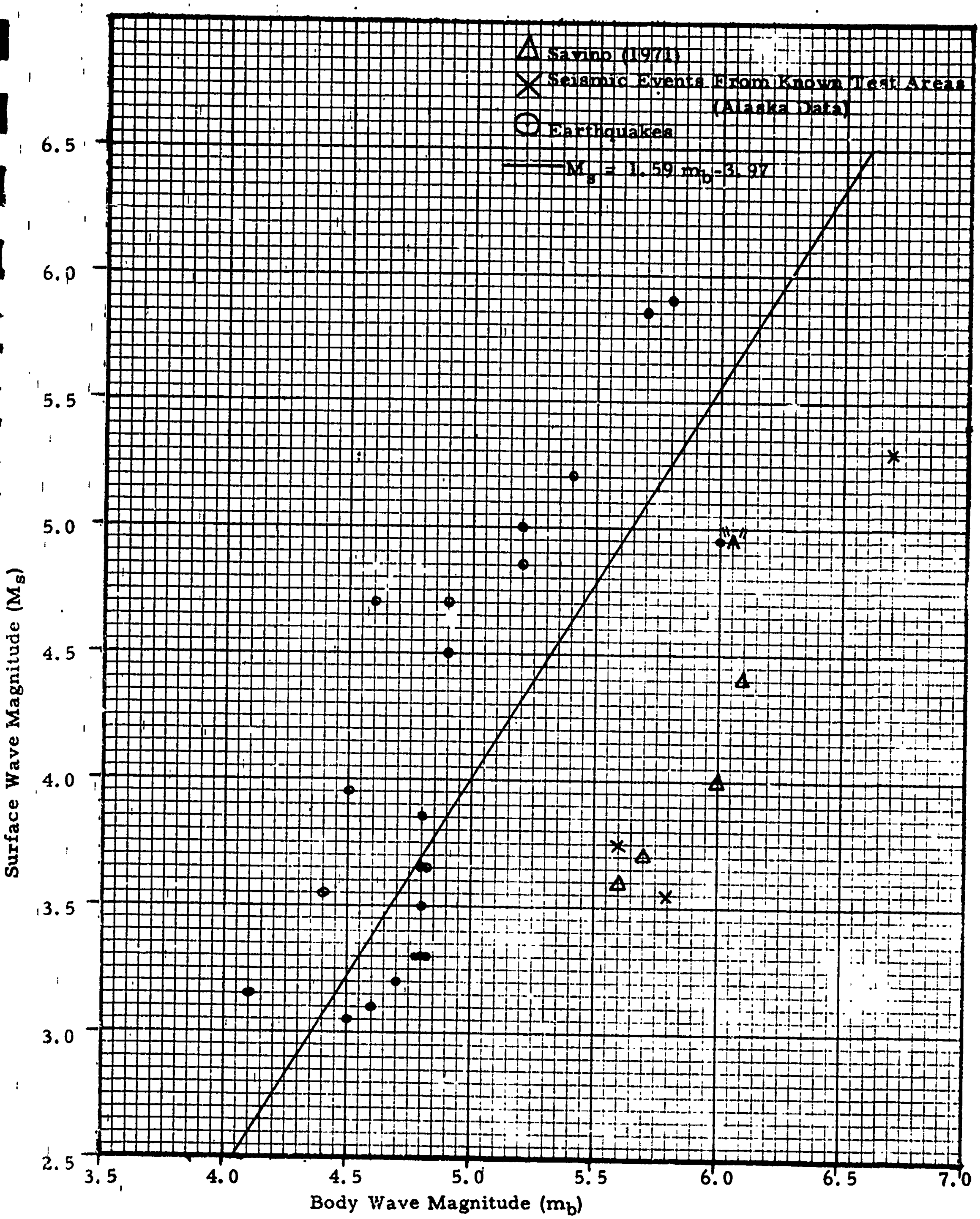


FIGURE IV-13

ISRAEL M_s-m_b

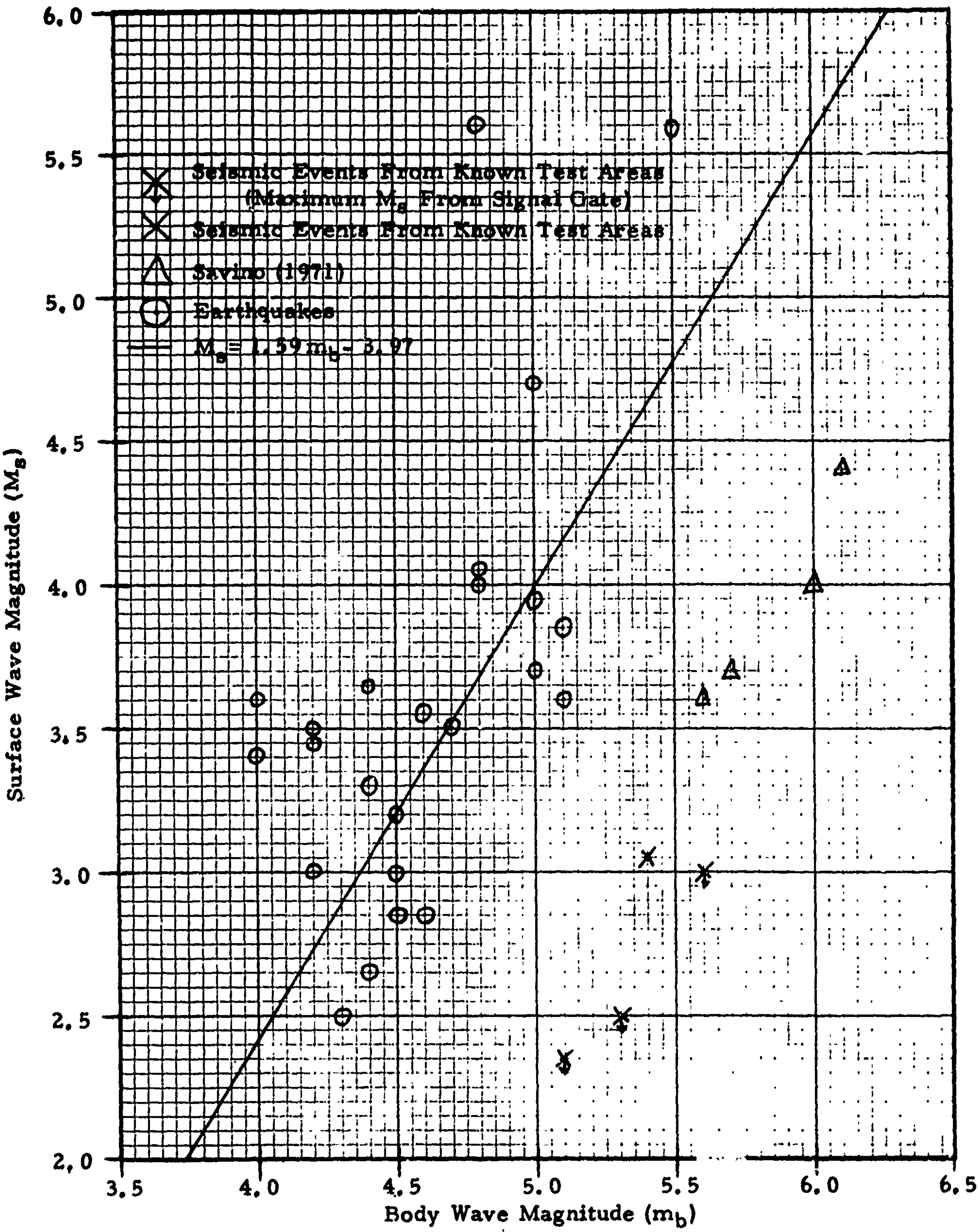


FIGURE IV-14
NORWAY M_s-m_b

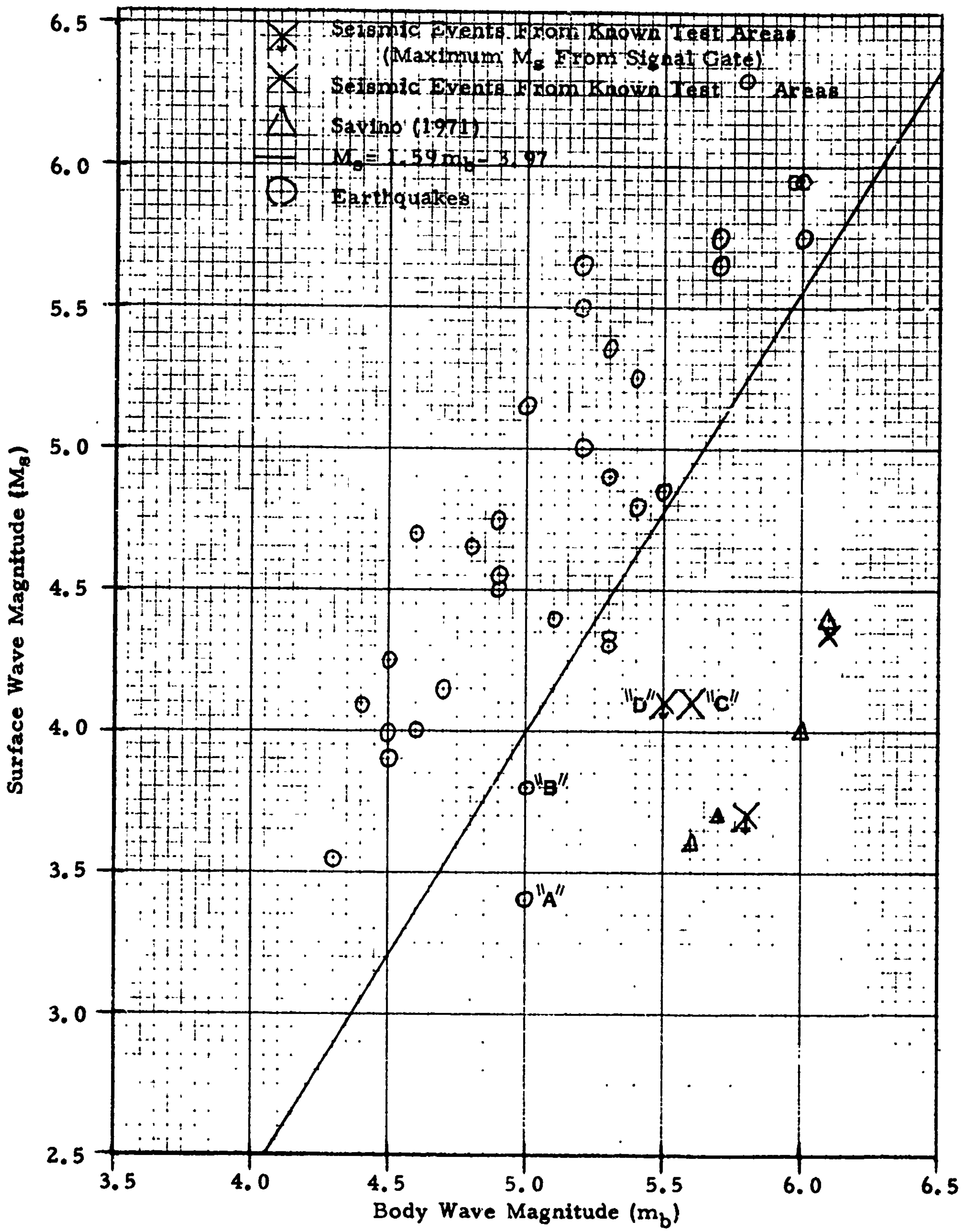


FIGURE IV-15
OGDENSBURG M_s-m_b

C. $M_s(40)$ - $M_s(20)$ RELATIONSHIP

One important aspect of the Very Long Period Experiment is a study of the relationship between surface wave magnitudes computed at 20 seconds, $M_s(20)$, and 40 seconds, $M_s(40)$. Savino et al (1971) suggested that for the Ogdensburg station, the M_s-m_b discriminant for $M_s(40)$ produced a larger separation between earthquakes and explosions than did the M_s-m_b discriminant for $M_s(20)$. $M_s(40)$ versus $M_s(20)$ was plotted for the shallow events shown in Tables IV-1 to IV-7. In this plot, Figure IV-16, only events which were clearly detected at both 20 and 40 seconds are included. Note that of the 171 shallow earthquakes analyzed there were 31 events for which 20-second but no 40-second energy was detected.

First, second and third order ploynomials were fitted to the data of Figure IV-16 using the least-mean-square error criterion with $M_s(20)$ as the independent variable. The straight line fit is shown by the dashed line in the figure and has the form

$$M_s(40) = .95\, M_s(20) - .39.$$

The second and third order polynomials showed no significant curvature and produced only minimal decreases in the mean-square-error when compared to the first order polynomial. These results show that the first order fit to the data is adequate. The approximate one-to-one slope obtained implies that the relative amount of 20 to 40 second energy remains constant (on the average) over the magnitude range $3 \leq M_s(20) \leq 6$. A one-to-one slope is consistent with that presented by Aki (1967), where he shows that the displacement spectral density should remain constant over the period range 20 to 500 seconds for earthquakes having M_s values between 3.5 and 5.5.

If the displacement spectral density is the same at 20 and 40 seconds, then neglecting effects such as frequency-dependent attenuation and source depth the $M_s(40)$ values should be 0.3 units below the $M_s(20)$ values. A magnitude difference of 0.39 was obtained for these data (if the slope was constrained to be

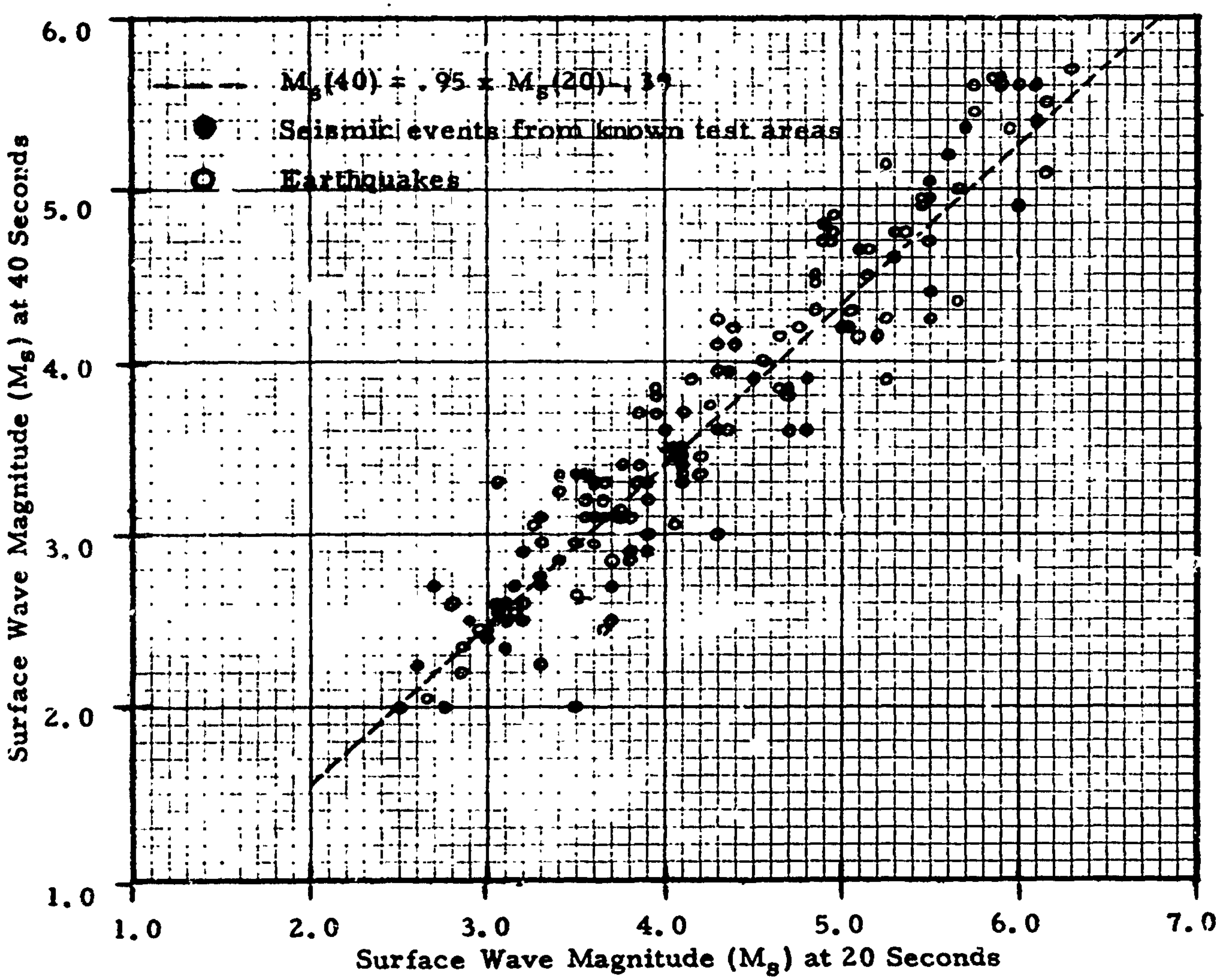


FIGURE IV-16

COMPARISON OF SURFACE WAVE MAGNITUDES FOR M_s=40 AND 20 SECONDS

1:1 the difference was 0.59); this implies that on the average 40-second amplitudes are a factor of 1.2 to 2 smaller than 20 second amplitudes. Factors of this size are consistent with data presented by Savino et al (1971).

As previously mentioned, 31 of the 171 earthquakes were detected at 20 and not at 40 seconds, indicating that the station's detection capabilities are somewhat better at 20 seconds. These 31 events were from various seismic regions, were well distributed over the 0 to 60 km depth range, and occured over a wide range of epicentral distances (from 7 to 110 degrees). Therefore, it is difficult to explain the apparently poorer detection capability at 40 seconds on the basis of either source or path effects.

As indicated previously the signal amplitudes at 40 seconds were about 1/2 those at 20 seconds; preliminary measurements of noise amplitudes give about the same relationship. This suggests that the signal-to-noise ratios (and hence detection thresholds) should be about the same, which appears to be contrary to observation.

One possible explanation for this discrepancy is as follows. Detection at 40 seconds was made from visual analysis of the vertical component after application of a 30 to 50 second bandpass filter. At some of the stations the noise levels increase rapidly at periods slightly larger than 40 seconds; this energy would not be attenuated by the bandpass filter and would tend to obscure the 40-second signal energy, if present. The percentage of misses at 40 seconds was highest for Alaska and Thailand, where the noise increases rapidly at periods beyond 40 seconds, and lowest at Israel, Ogdensburg, and Norway, where noise levels are relatively low to beyond 50 seconds. Thus it appears that the 40-second detection capability could be improved over that indicated here by selecting a more appropriate bandpass filter at stations where the long period noise levels increase ra[illegible]ly. However, there do appear to be some events where the 40 second energy [illegible]mply is absent.

Finally, a very important observation from Figure IV-16 is that the presumed explosion $M_s(40)$ - $M_s(20)$ values do not separate from the earthauake population. This implies that the average separation between earthquakes and presumed explosions is not greater for $M_s(40) : m_b$ than it is for $M_s(20) : m_b$. While it is clear that the observation is correct for this event ensemble, data from more presumed explosions are required before a definite conclusion can be reached. It should also be pointed out that the 40-second data may still be preferable for discrimination if the scatter in the $M_s - m_b$ plots is reduced.

SECTION V
CONCLUSIONS

Preliminary evaluation of the seven stations of the Very Long Period Experiment network has led to the following conclusions:

1. The vertical noise spectra generally are about flat and low level between 20 and 40 seconds, however they do increase rapidly at periods beyond 40 seconds at some stations. The horizontal noise spectra generally begin to increase at periods shorter than 40 seconds.

2. The vertical RMS noise levels in the 20 to 40 second band are generally around 5 $m\mu$, the horizontal levels are more variable but generally higher than the vertical levels.

3. Our data base is not yet large enough to make definitive estimates of the stations' detection thresholds. However, some preliminary statements can be made:

- Generally, the stations' detection thresholds for shallow focus earthquakes appear to be in the range 4.0 to 4.5 m_b for 30° epicentral distance and 4.5 to 5.0 for 60° to 80°.

- Israel and Norway appear to be somewhat more sensitive than the other stations. Thailand ·ot particularly noisy, but recorded surface waves seem to be lower amplitude than at other stations.

- The detection capabilities at 20 seconds appears to be somewhat better than that at 40 seconds; the difference may not be as large as indicated by our data if careful bandpass filtering is done at each station.

4. The $M_s:m_b$ plots for the seven stations analyzed are typical of those observed at other stations. Separation between earthquakes and events from known test areas is generally good, except for a few earthquakes at each station which have $M_s:m_b$ values somewhat below the bulk of the earthquake population. (It should be remembered that Love wave M_s values may be necessary to give good separation to the Thailand $M_s:m_b$ plot.)

5. The relative amount of 40 and 20 second energy does not appear to depend on event magnitude for events with $3 \leq M_s \leq 6$.

6. Based on results from a large number of earthquakes and a small number of explosions, it appears that no increase in average separation between earthquakes and presumed explosions will be obtained by using $M_s(40):m_b$ instead of $M_s(20):m_b$.

SECTION VI
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