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EXTENDED ARRAY EVALUATION PROGRAM.  
SPECIAL REPORT NO. 11. EVALUATION OF THE  
NORWEGIAN SHORT-PERIOD ARRAY

Frode Ringdal, et al

Texas Instruments, Incorporated

Prepared for:

Advanced Research Projects Agency  
Air Force Technical Applications Center

2 November 1973

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20. continued

- Array processing performance
- Partial array performance
- Maximum likelihood estimation of the NORSAR event detection capability
- Evaluation of short-period discriminants.

The accumulated data base for this study has been 547 events, including 39 presumed explosions; 33 of which are from the Eurasian continent.

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**EVALUATION OF THE NORWEGIAN SHORT-PERIOD ARRAY - FINAL REPORT**

**SPECIAL REPORT NO. 11**

**EXTENDED ARRAY EVALUATION PROGRAM**

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## ABSTRACT

This report describes the final phase of the evaluation of the Norwegian short-period Seismic Array (NORSAR) which has been conducted by Texas Instruments, Incorporated at the Seismic Data Analysis Center. The report also summarizes results achieved during the complete evaluation study over the period 1 April 1971 to 30 September 1973.

The major areas of study covered by this report are:

- Array processing performance
- Partial array performance
- Maximum likelihood estimation of the NORSAR event detection capability
- Evaluation of short-period discriminants.

The accumulated data base for this study has been 567 events, including 39 presumed explosions; 33 of which are from the Eurasian continent.

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## SECTION I INTRODUCTION

This report presents the results of the final phase of the evaluation of the short period Norwegian Seismic Array (NORSAR). It extends the analysis reported in Special Report No. 6, (Barnard and Whitelaw, 1972) and Special Report No. 9, (Ringdal and Whitelaw, 1973) under the Extended Array Evaluation Program. The overall objectives of the NORSAR SP evaluation have been:

- Determine the best processing methods for enhancing the signal-to-noise ratio of Eurasian events
- Determine the array detection capability for Eurasian events
- Evaluate the performance of short period discriminants at NORSAR
- In conjunction with long period NORSAR data, determine the detection and discrimination capability of NORSAR for Eurasian events.

The fourth objective stated above will be the topic of a forthcoming report (Special Report No. 13, 1973), and will not be discussed here. Five analysis tasks were undertaken in order to meet the first three objectives:

- Noise analysis
- Signal analysis
- Evaluation of array processing effectiveness
- Detection threshold estimation

### Analysis of the behavior of SP discriminants.

Final results from noise and signal analysis were presented in Special Reports No. 6 (1972) and No. 9 (1973). No additional work on these subjects has been undertaken since then. Our efforts during the final phase have been focused on increasing the data base for detection and discrimination analysis and develop methods for reliable estimation of the array capabilities.

Section II of this report describes the results from the array processing evaluation, including a study of the performance of a potentially reduced NORSAR array. Section III presents regional estimates of the NORSAR detection thresholds, while SP discrimination capabilities are discussed in Section IV. An extensive summary of all major results achieved during the SP evaluation program is presented in Section V.

The NORSAR SP array is centered about 100 km due north of Oslo, Norway, at a latitude of  $60.8^{\circ}\text{N}$  and a longitude of  $10.8^{\circ}\text{E}$ . The array consists of 132 short period seismometers and has an aperture of about 100 km. The sensors are grouped in 22 six-element subarrays; each subarray has a center sensor and a five sensor ring and is 7-10 km in diameter (Figure 1-1).

The results presented in this report are based on seismic events and presumed explosions from 1971 and 1972. A total of 567 events have been processed; all but 15 of these were from Eurasia. The number of presumed explosions totals 33 from Eurasia and 6 from the Western Hemisphere. The complete data base for the NORSAR SP evaluation is listed in Appendix A; it includes the 344 events analyzed in Special Reports No. 6 (1972) and No. 9 (1973) as well as an additional 223 events, mostly from June and July of 1972, which have been processed since then.

Figure 1-2 presents a breakdown of the processed events by information source. Our events have been selected from seismic bulletins provided by four different organizations:

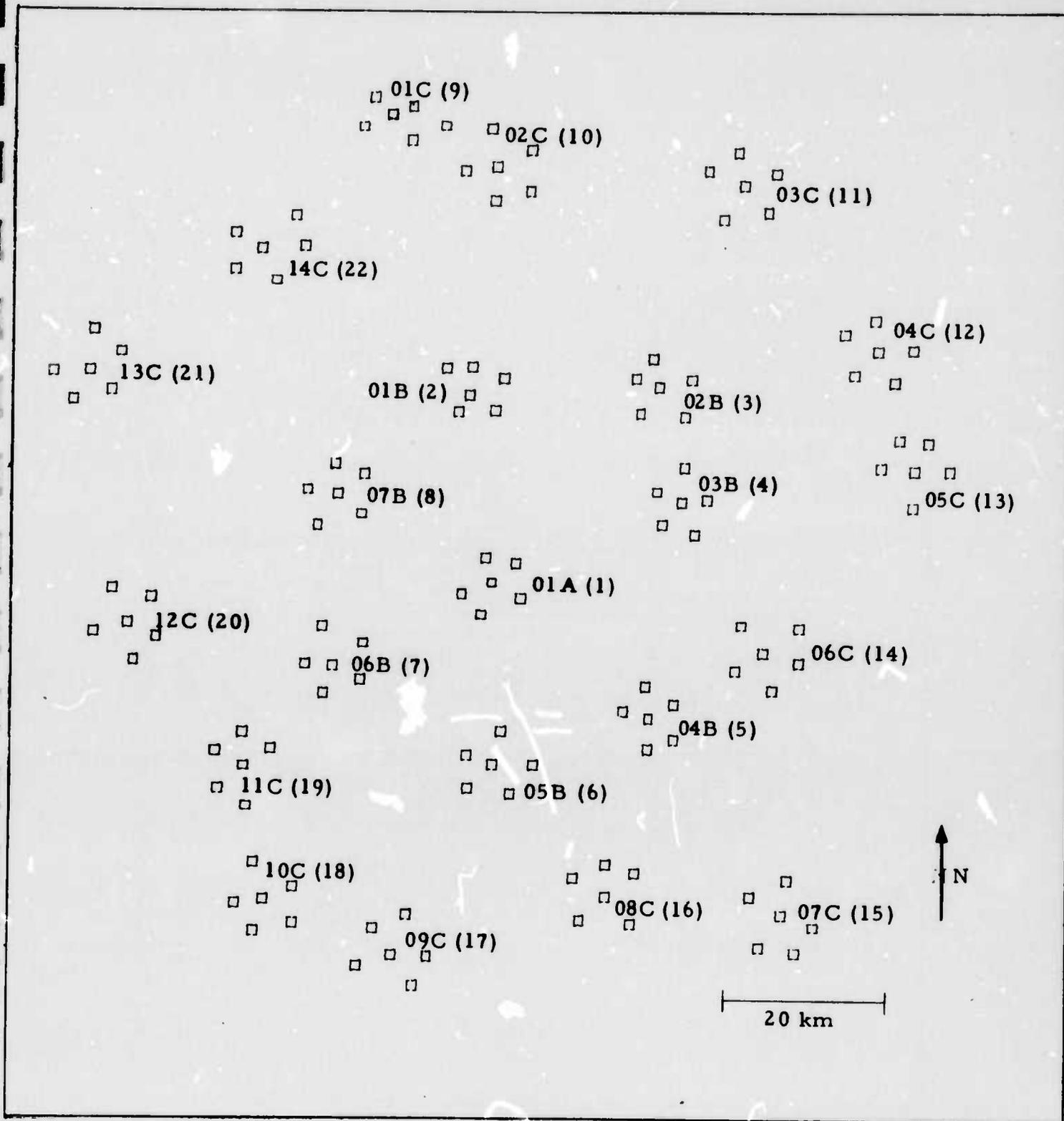


FIGURE I-1

NORSAR SHORT PERIOD ARRAY

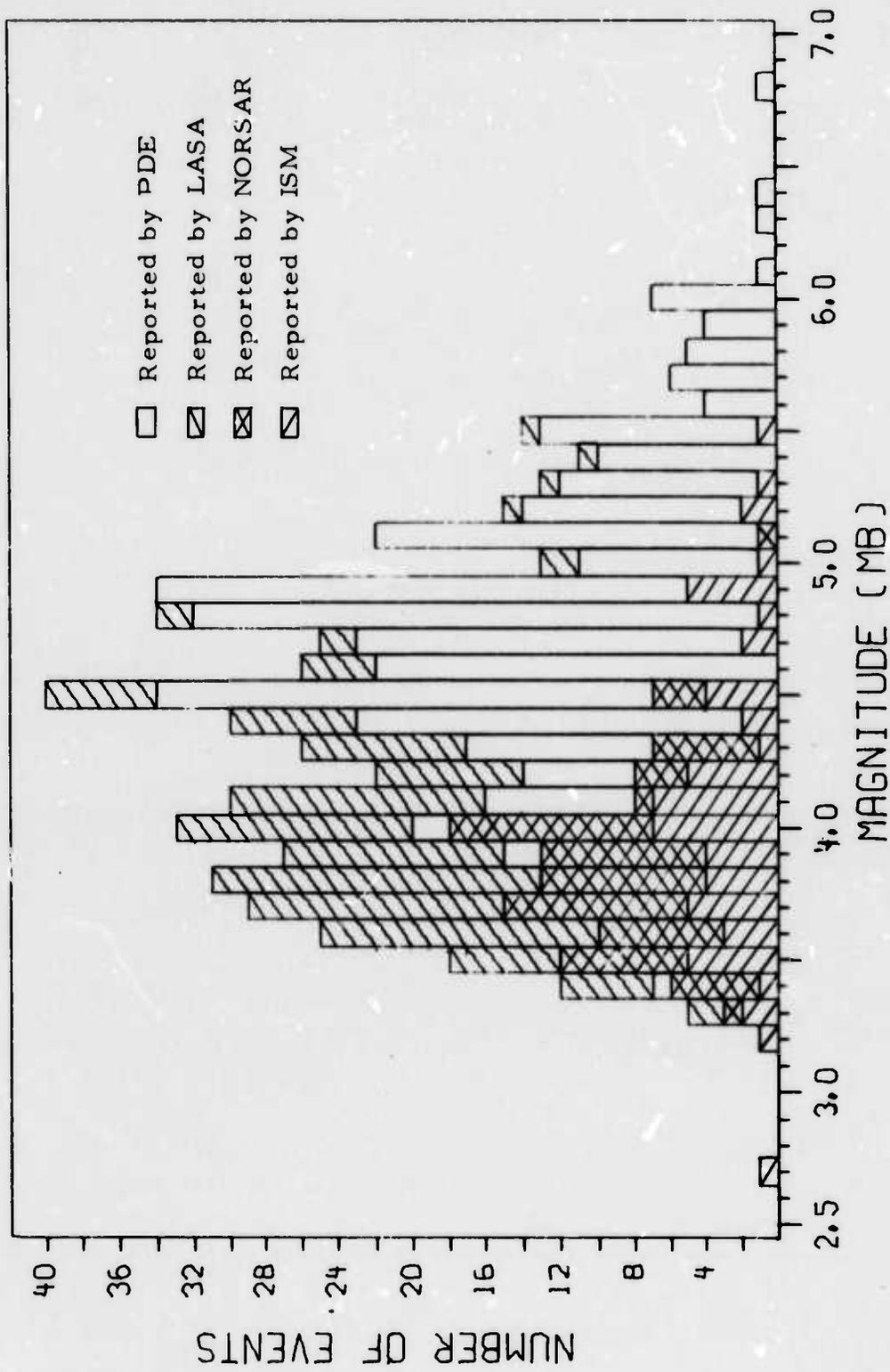


FIGURE I-2  
DISTRIBUTION BY DATA SOURCE OF PROCESSED EVENTS

- The PDE listings (Preliminary Determination of Epicenters) issued by the National Oceanic and Atmospheric Administration (NOAA).
- The LASA seismic bulletin issued by the Seismic Data Analysis Center (SDAC).
- The NORSAR seismic bulletin compiled at Kjeller, Norway.
- The bulletin from the International Seismic Month (ISM), which covers February 20 to March 19, 1972, and has been compiled at Lincoln Laboratories.

In all cases where an event was reported by more than one organization, we selected our source information according to the priority list: ISM, PDE, LASA, NORSAR. As can be seen from Figure I-2, most events of  $m_b$  above 4.5 have been reported by PDE, while LASA and NORSAR supply the detection information for most low magnitude events.

Our procedure in analyzing these events was first to estimate the P-wave signal arrival time at NORSAR for each event, and then to request SP data tapes from the NORSAR Data Center covering intervals of approximately 10 minutes around each expected arrival. These tapes were then processed using our NORSAR Short Period Array Evaluation Software Package (Texas Instruments Incorporated, 1971) to determine signal parameters and to produce plots of waveform traces. Finally, for each event, the TI analyst made a decision as to whether or not the event could be detected on NORSAR data, based upon visual inspection of the signal traces and personal judgement.

Figure I-3 is a histogram showing the distribution of processed events as a function of epicentral distance from NORSAR. The data base

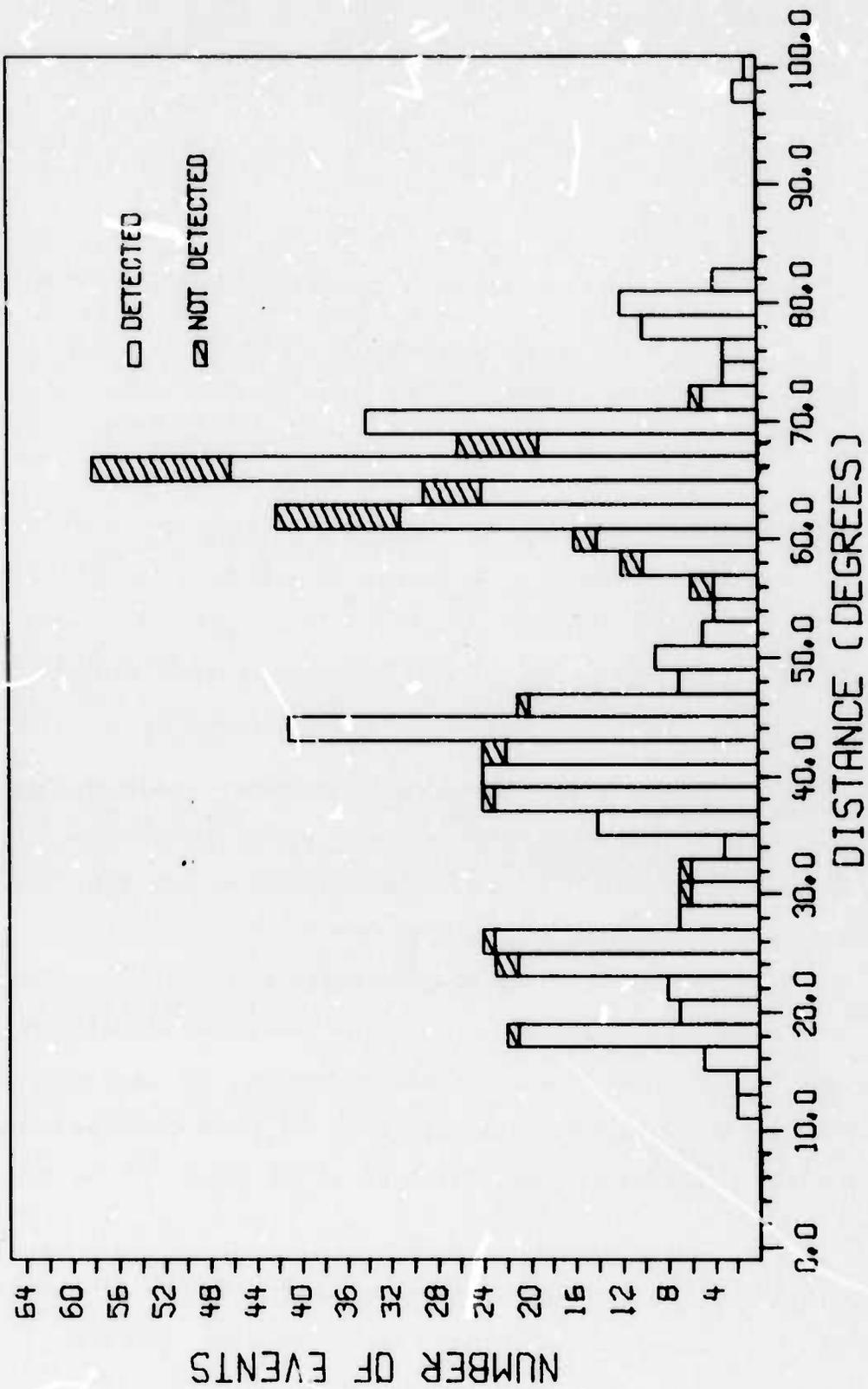


FIGURE I-3  
 NUMBER OF PROCESSED AND DETECTED EVENTS AS A FUNCTION  
 OF EPICENTRAL DISTANCE FROM NOR SAR

may conveniently be split into three regions, where the majority of events are located:

- The Mediterranean area (distance 15-30 degrees). Approximately 100 events from this region have been processed.
- Iran and Central Asia (distance 35-50 degrees). The number of events is approximately 150.
- Kamchatka and the Kurile Islands (distance 60-70 degrees). Approximately 200 events from this region are included in our data base.

As can also be seen from Figure I-3, very few of the processed events were not detected on NORSAR SP data, with the exception of the Kuriles-Kamchatka area events.

Throughout 1971 and 1972, the quality of the NORSAR SP data was excellent. For a total of 25 of the events selected by TI, no data was available from NORSAR. This corresponds to less than five percent of our data requests, and thus indicates that the array was operational for an average of more than 95 percent of the time. For about one-third of the processed events all 132 sensors were operational. In most other cases one or two subarrays were dead or contained calibration signals; the worst data loss was 33 sensors. Data spikes were observed for ten events, but in each case only one or very few sensors were affected; consequently these events could still be satisfactorily processed.

The phase reversals observed in 1971 data (Special Report No. 9, 1973) appeared to have been permanently corrected from about January 1972.

## SECTION II

### ARRAY PROCESSING PERFORMANCE

#### A. INTRODUCTION

In the course of the NORSAR SP evaluation study, several array processing techniques were examined for possible application to NORSAR short period data. It was decided at an early stage that adaptive multichannel methods would not be very effective, since the seismic noise is essentially incoherent in the frequency band on interest. Although signal frequency characteristics show large variations, we found that a "standard" filter (Special Report No. 6, 1972) would in most cases give close to optimum signal-to-noise ratio (SNR) improvements. Also, significant time delay anomalies (deviation from plane wave propagation along the great circle azimuth) were observed for all regions, thus causing considerable beamforming loss when plane wave delays were applied between subarrays. Finally, we observed large signal amplitude variations from subarray to subarray; this suggested that some form of weighted beamforming might be beneficial.

We thus concluded that the following array processing techniques should be evaluated in detail on NORSAR data:

- Bandpass filtering, using the standard filter
- Plane wave subarray beamforming
- Adjusted-delay array beamforming
- Diversity-stack array beamforming (i. e., applying weights proportional to subarray signal amplitudes prior to beamforming).

This section presents the results from these analyses. The data base contains statistics from 412 Eurasian events, of which 172 occurred in 1971 and the remainder in the first six months of 1972.

Also included in this section is a brief discussion of the performance of a potentially reduced NORSAR array. The most natural way to reduce the size of the array is to eliminate the outer ring of subarrays; thus leaving 8 subarrays as shown in Figure II-1. However, the Northeastern part of the array has consistently shown the best signal-to-noise ratios for Eurasian events; therefore, we decided also to evaluate the performance of a partial array consisting of 8 subarrays in the Northeast corner as shown in Figure II-2. A total of 60 Eurasian events from 1971 were selected as data base for the comparison of these two partial arrays to the full array.

In the subsequent discussions, beamforming and filtering gains have been obtained by computing the signal-to-noise ratio (SNR) for each event at each processing stage, and then defining gain as SNR improvement from one stage to another. The following formula has been applied:

$$\text{SNR} = 10 \cdot \log_{10} \left( \frac{S - N}{N} \right)$$

where  $S$  is the signal plus noise power over a 6.4 seconds window; (this window length is comparable to signal duration for medium size events and is also convenient for computational purposes; representing a power of two relative to our sampling rate of 0.1 seconds). Similarly,  $N$  represents the noise power averaged over a window of approximately one minute preceding the onset of the signal.

## B. ARRAY BEAMFORMING AND FILTERING PERFORMANCE

NORSAR short period beamforming is implemented as a two step process. The first step is subarray beamforming, which is performed separately for each of 22 subarrays. The second step, which we will refer to as array beamforming, consists of adding together 22 subarray beams with the proper time delays.

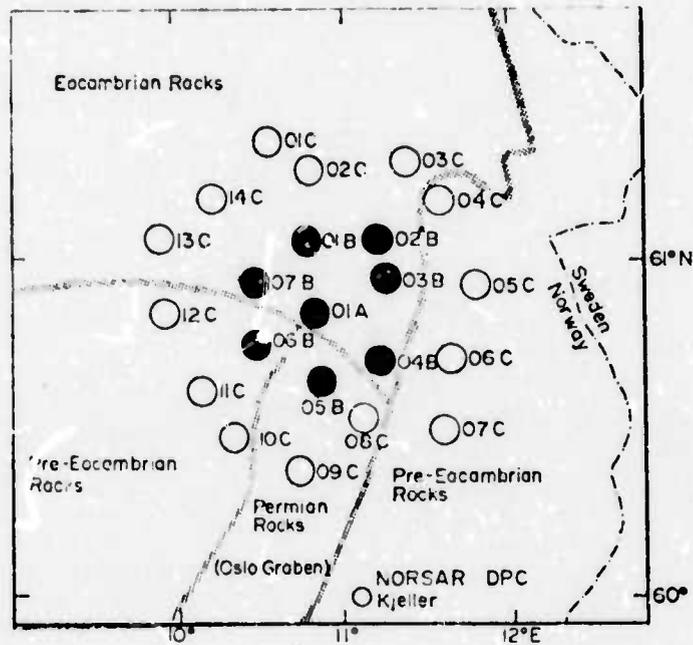


FIGURE II-1  
 GEOGRAPHICAL LAYOUT OF A PARTIAL NORSAR ARRAY  
 (FILLED CIRCLES) CONSISTING OF THE A AND B RINGS

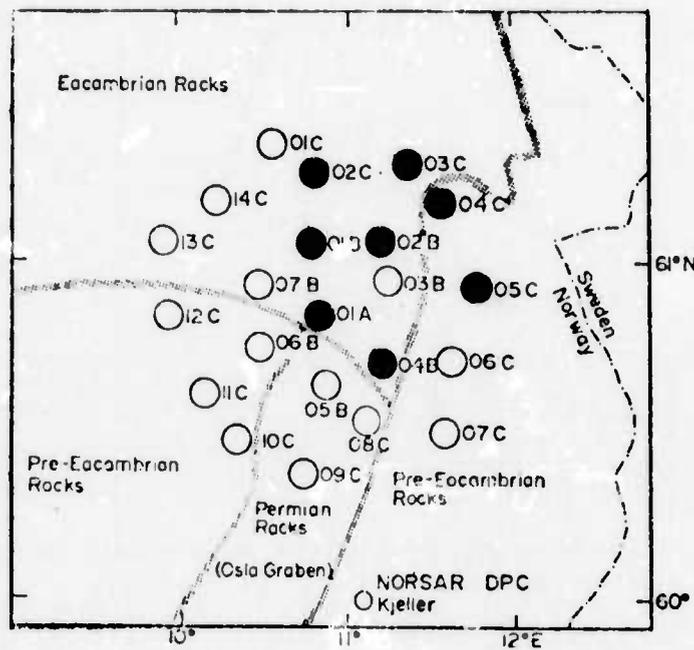


FIGURE II-2  
 GEOGRAPHICAL LAYOUT OF A PARTIAL NORSAR ARRAY  
 (FILLED CIRCLES) SITUATED IN THE NORTHEAST  
 CORNER OF THE FULL ARRAY

The performance of NORSAR subarray beamforming was evaluated in Special Report No. 9, (1973) and it has been verified that plane wave delays in general are appropriate for this purpose. SNR gains for subarray beamforming averages approximately 7 dB.

Table II-1 shows means and standard deviations of array beamforming and standard filter SNR gains for those events of 1971 whose average subarray SNR is at least 5 dB. The statistics from this set of events are considered representative of ideal array performance, since the beams, in this case, were generated using adjusted delays determined by examination of the subarray beam-to-reference subarray beam cross-correlation functions. In contrast, the array beam of each 1972 event was generated using delays determined from the previously processed master event with the nearest epicenter. Statistics from these events can be regarded to determine a conservative estimate of operational array performance.

The following principal points are noted in regard to Table II-1 and the additional statistics discussed above:

- Array beamforming gain from average subarray beam to adjusted-delay beam is  $10 \text{ dB} \pm 2 \text{ dB}$  for both wide-band and filtered data (Figure II-3). This compares with a theoretical ( $\sqrt{N}$ ) value of 13 dB. Outliers on the low end of the distribution shown in Figure II-3 represent events from epicentral regions such as Turkey, Greece, and Western Russia, which typically suffer high beamforming losses as a result of poor signal similarity across the array.
- Reference subarray to adjusted-delay beam SNR gain is not very large. Events from 1971 averaged  $4.5 \pm 3 \text{ dB}$  for wide-band data and slightly less for filtered data. The distribution of these gains is shown in Figure II-4. Outliers on the low

TABLE II-1  
 NORSAR SHORT PERIOD ARRAY PERFORMANCE STATISTICS  
 FOR 172 EVENTS FROM 1971

Beamforming Gains		
	Wide-Band	Standard Filter
Average Subarray to Adjusted-Delay Beam	$10.2 \pm 2.1$ dB	$9.8 \pm 2.1$ dB
Reference Subarray to Adjusted-Delay Beam	$4.6 \pm 3.1$ dB	$3.6 \pm 2.8$ dB
Adjusted-Delay Beam to Diversity-Stack Beam	$1.0 \pm 0.9$ dB	$1.6 \pm 1.0$ dB
Standard Filter Gains		
Reference Subarray Beam	$8.6 \pm 4.3$ dB	
Average Subarray Beam	$8.1 \pm 3.7$ dB	
Adjusted-Delay Beam	$7.8 \pm 4.2$ dB	
Diversity-Stack Beam	$8.3 \pm 4.1$ dB	
Combined Gain		
(Wide-Band Average Subarray Beam to Filtered Adjusted-Delay Beam)		
$17.9 \pm 4.5$ dB		

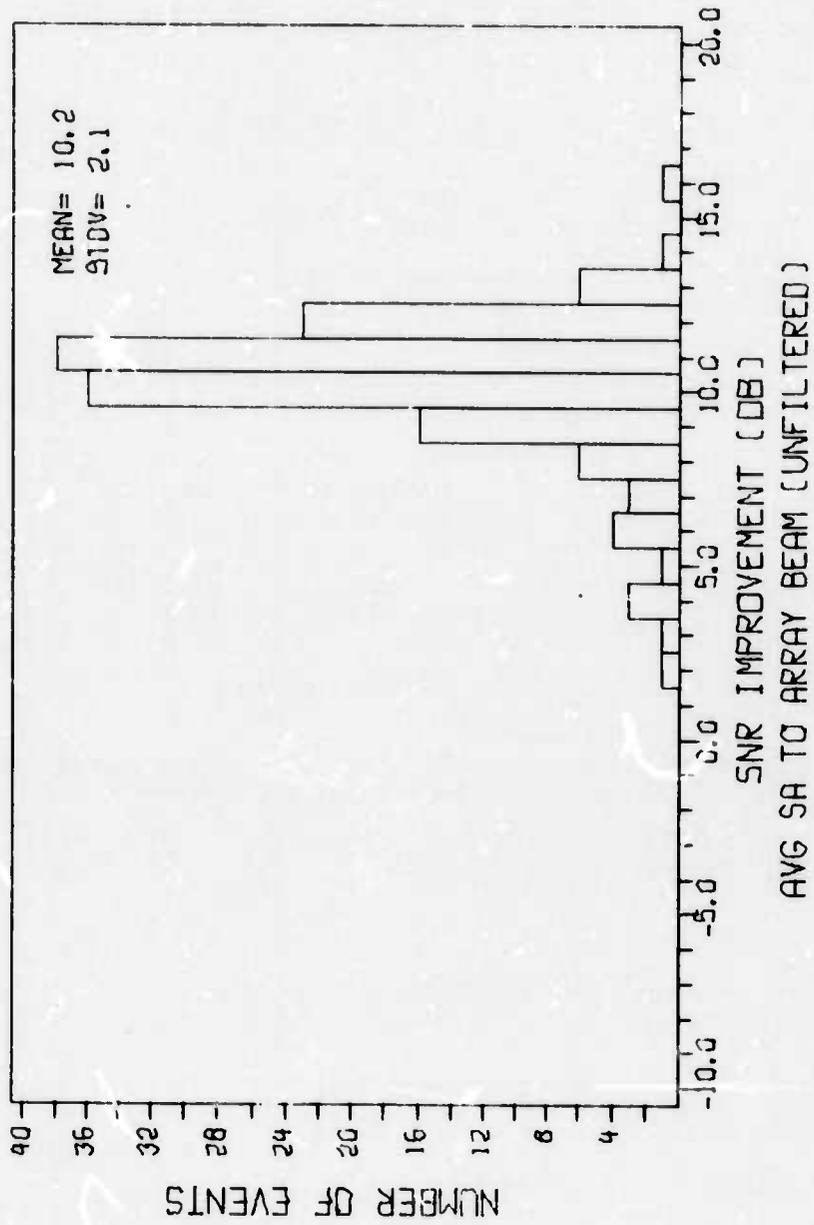


FIGURE II-3

DISTRIBUTION OF SNR GAINS FROM AVERAGE SUBARRAY TO ADJUSTED-  
DELAY ARRAY BEAM (1971 EVENTS; WIDE-BAND DATA)

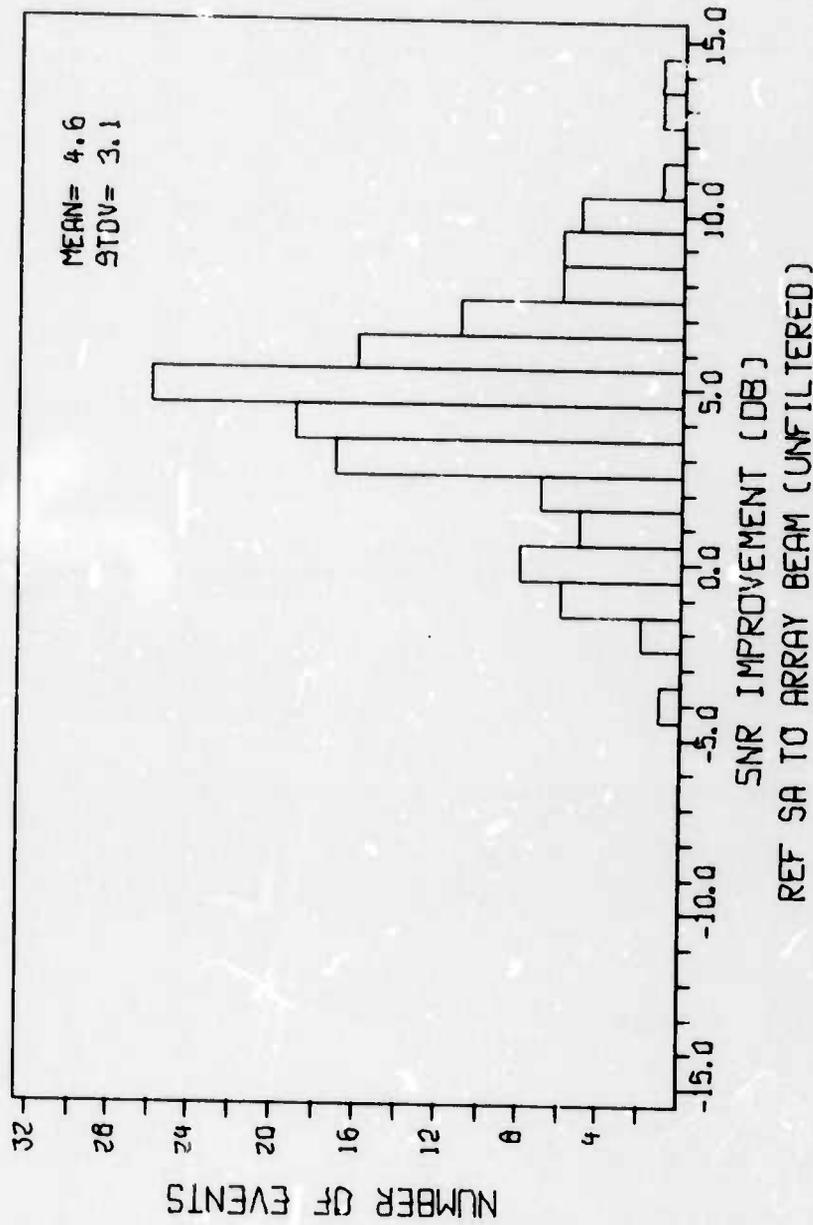


FIGURE II-4

DISTRIBUTION OF SNR GAINS FROM REFERENCE SUBARRAY TO ADJUSTED-  
DELAY ARRAY BEAM (1971 EVENTS; WIDE-BAND DATA)

side are contributed chiefly by events whose reference subarray is much better than the average subarray. Parenthetically, it was demonstrated in Special Report No. 9 that the degree of spread in subarray beam SNR's for a given event varies systematically from one epicentral region to another. Some of them, however, represent events with relatively poor signal similarity between subarrays.

- Diversity-stack beam performance relative to the adjusted-delay beam is  $1.0 \pm 0.1$  dB for wide-band data and slightly higher for filtered data, essentially the same as that noted in previous reports. Figure II-5 shows that values for all events are distributed closely about the mean. Negative values can be explained as the result of poor coherence among the stronger subarrays.
- Filter improvement is consistently more variable than beamforming improvement as a direct result of the wide variation in frequency content from event to event (Figures II-6, II-7). It was shown in Special Report No. 9 (1973), that this spectral variation is highly dependent on source region. Standard deviations are on the order of 4 dB for average and reference subarray beam and both array beams. Mean gains are about 8 dB for both average subarray and adjusted-delay beams. Slightly higher gains for reference subarray and diversity-stack beams are due to decreased attenuation of high frequencies in the signal.
- Mean total array processing gain, (Figure II-8) is  $18 \pm 4.5$  dB; including the 7 dB subarray beamforming gain mentioned before overall SNR gain (from unfiltered single sensor to filtered array beam) is about  $25 \pm 5$  dB.

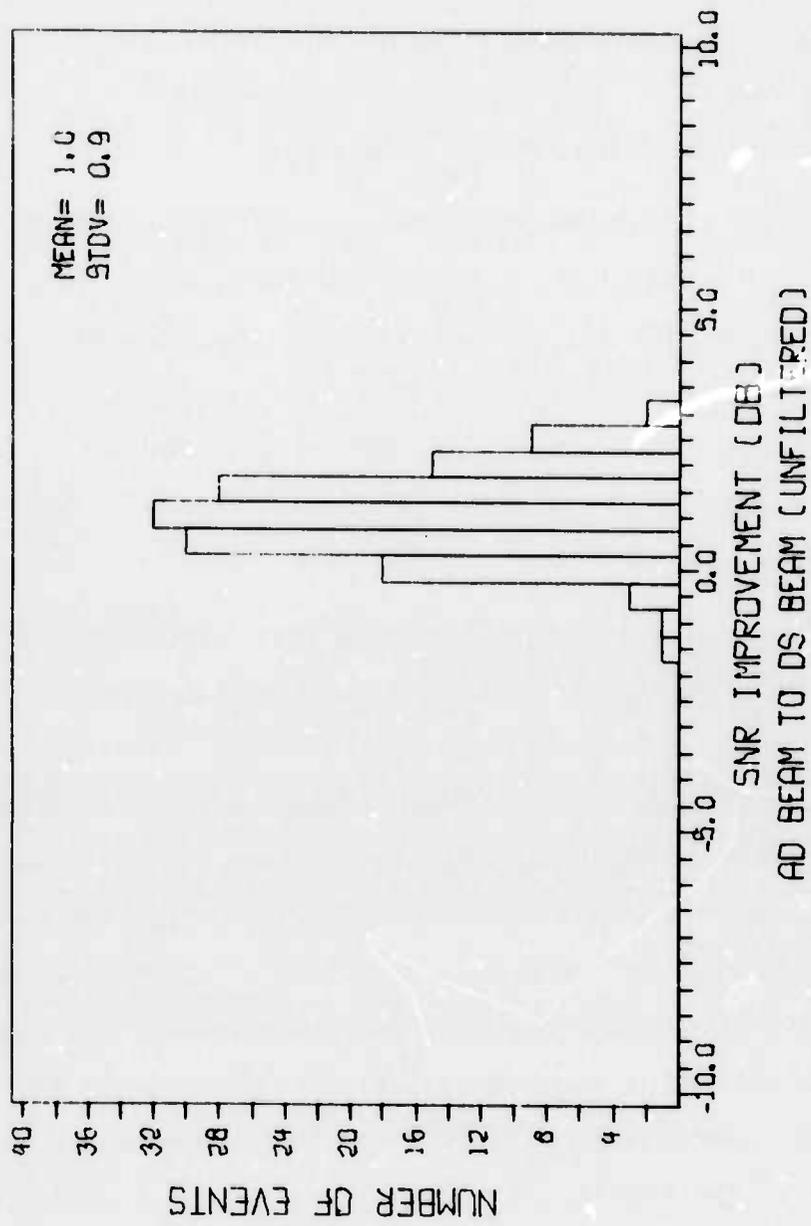


FIGURE II-5

DISTRIBUTION OF SNR GAINS FROM ADJUSTED-DELAY ARRAY BEAM TO DIVERSITY-STACK BEAM (1971 EVENTS; WIDE-BAND DATA)

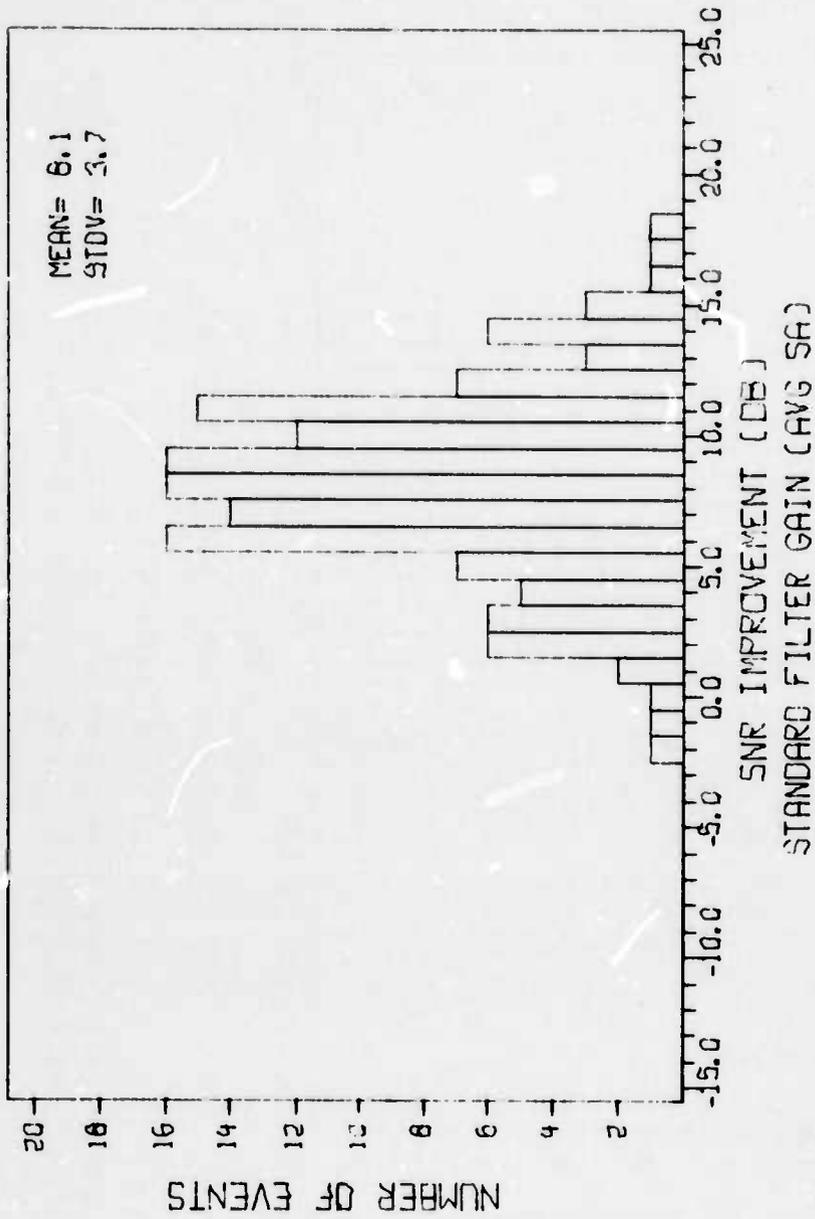


FIGURE II-6

DISTRIBUTION OF SNR GAINS ACHIEVED BY APPLICATION OF THE  
STANDARD FILTER AVERAGED OVER ALL SUBARRAY BEAMS  
(1971 EVENTS)

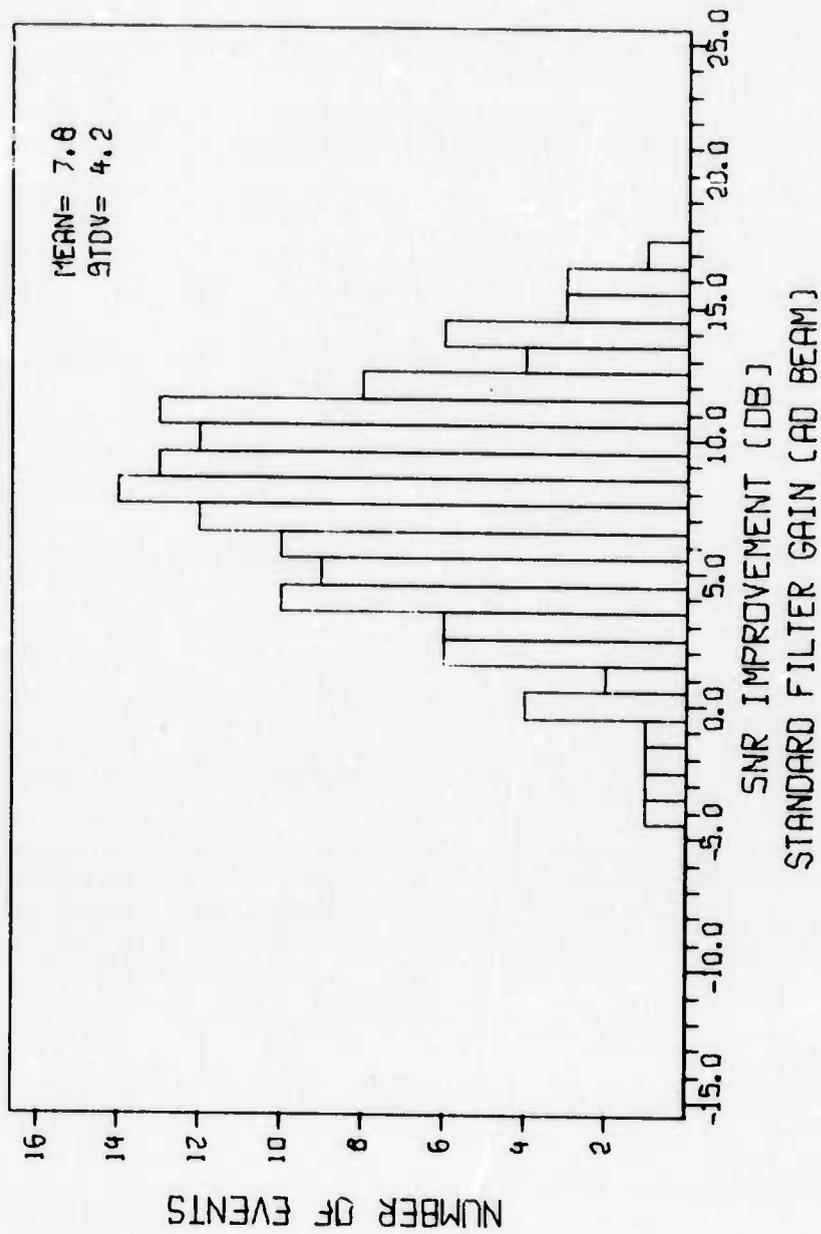


FIGURE II-7

DISTRIBUTION OF SNR GAINS ACHIEVED BY APPLICATION OF THE  
STANDARD FILTER TO THE ADJUSTED-DELAY ARRAY BEAM  
(1971 EVENTS)

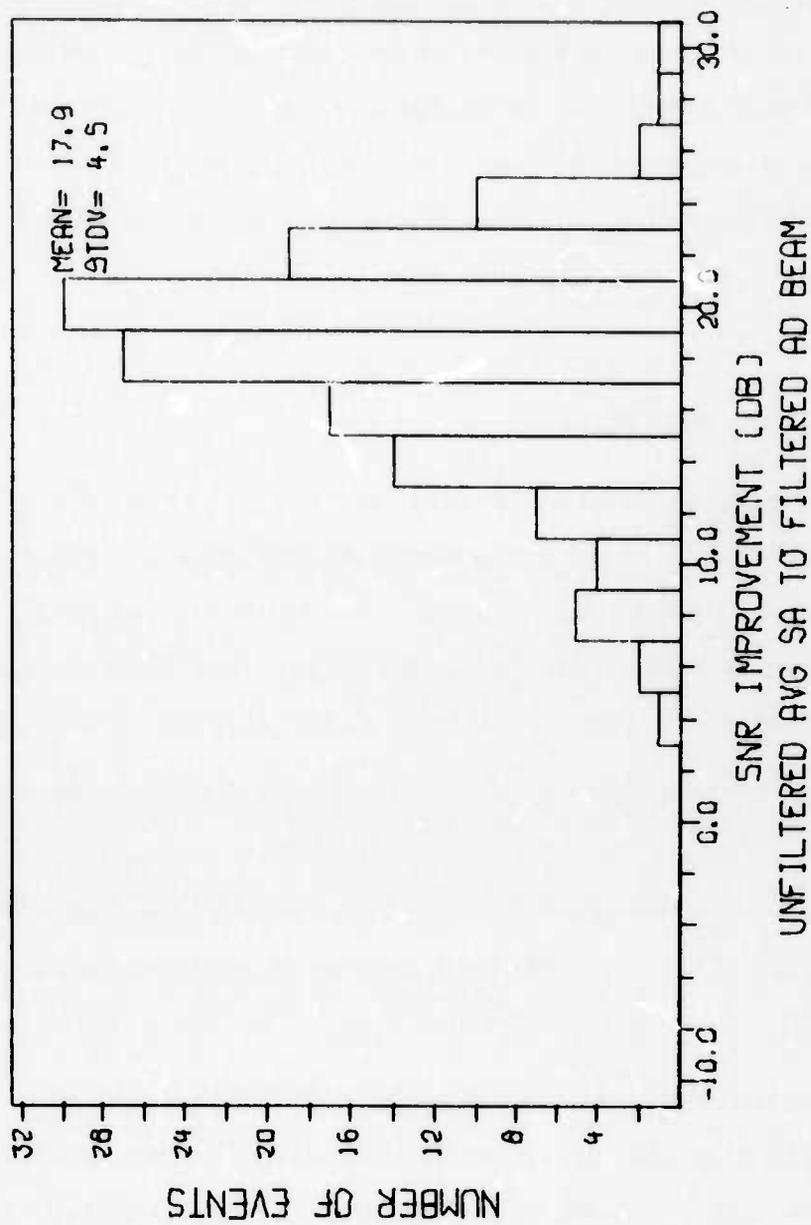


FIGURE II-8

DISTRIBUTION OF TOTAL SNR GAINS FROM THE WIDE-BAND  
AVERAGE SUBARRAY BEAM TO THE FILTERED  
ADJUSTED-DELAY ARRAY BEAM  
(STANDARD FILTER; 1971 EVENTS)

As mentioned previously, all the above numbers refer to 1971 events, for which "optimum" processing was performed. For our events from 1972, we obtained an adjusted-delay array beamforming gain of  $7 \pm 4$  dB relative to the average subarray beam for filtered signals. Thus we estimate that our use of delays from nearby master events results in a decline of about 3 dB in array performance, relative to the ideal case. Obviously, this loss may be reduced by applying interpolation techniques and also by enlarging the set of master events. Therefore, our statistics from 1971 and 1972 may conveniently be viewed as upper and lower bounds, respectively, of operational array performance.

### C. PARTIAL ARRAY PERFORMANCE

Performance of two eight-subarray partial arrays relative to that of the full array was evaluated on the basis of data from 60 events. Means and standard deviations of indicators of partial array performance are shown in Table II-2. Figures II-9 and II-10 show histograms of SNR loss from full array beam to partial array beam for the two partial arrays. Theoretical beamforming improvement by a partial array of this size is 9.0 dB, a decrease of 4.4 dB from the 13.4 dB for the full array.

In the case of the partial array composed of the inside rings of the full array (Figure II-1), the observed decline in performance averaged slightly less than 5 dB.

The second partial array (Figure II-2) was composed of subarrays in the northeast quadrant of the array which have shown consistently higher SNR's than the rest of the array for epicentral regions of interest (Special Report No. 9, 1973). The average performance of this partial array was only 2 dB worse than that of the full array.

Mean filter gain did not show any significant differences between the two partial arrays and the full array.

TABLE II-2  
 NORSAR SHORT PERIOD PARTIAL ARRAY  
 PERFORMANCE STATISTICS

Ratio of Partial Array Beam SNR to Full Array Beam SNR		
	Rings A and B	Northeast Quadrant
Wide-Band	- 4.8 ± 3.2 dB	- 2.1 ± 2.0 dB
Standard Filter	- 4.7 ± 2.4 dB	- 2.0 ± 1.9 dB
Adjusted-Delay Beam Filter Gains		
Full Array	Rings A and B	Northeast Quadrant
8.9 ± 4.3 dB	9.1 ± 5.4 dB	9.1 ± 3.6 dB

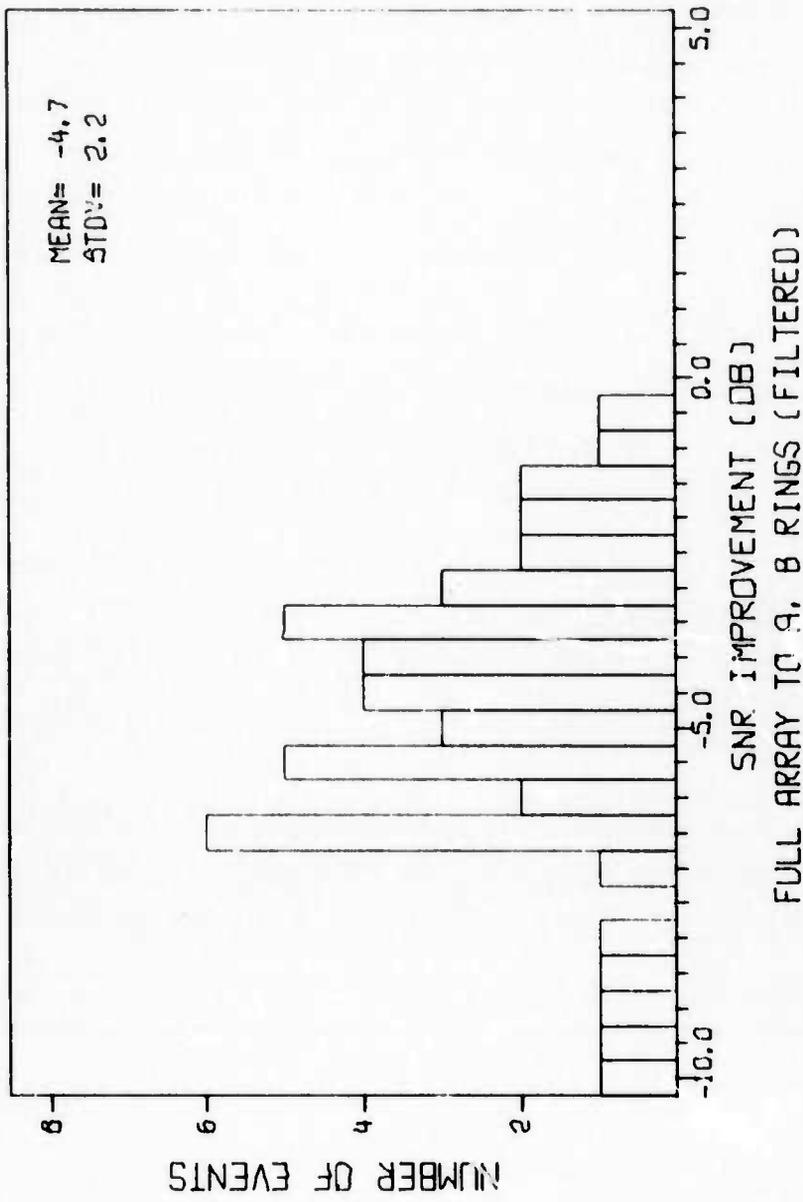


FIGURE II-9  
DISTRIBUTION OF BEAMFORMING GAINS FOR PARTIAL ARRAY I  
(A AND B RINGS) RELATIVE TO FULL ARRAY GAINS  
(DATA FILTERED BY STANDARD FILTER)

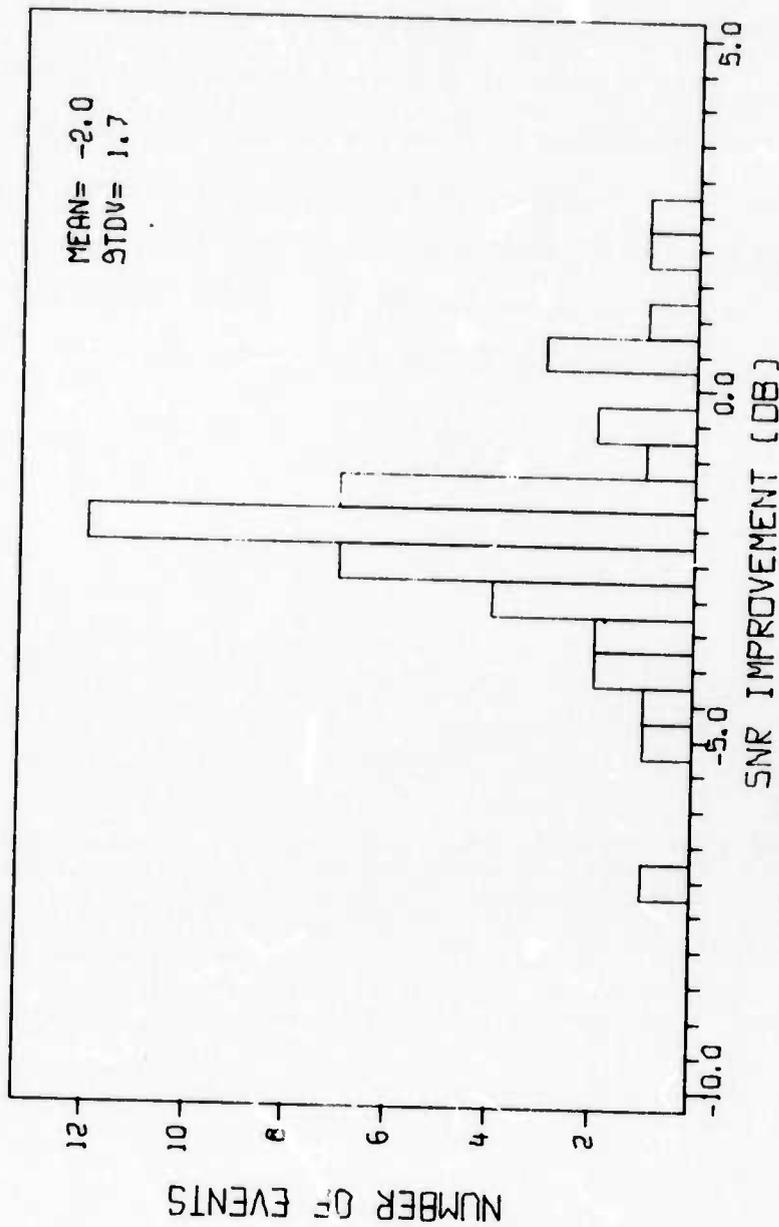


FIGURE II-10  
DISTRIBUTION OF BEAMFORMING GAINS FOR PARTIAL ARRAY II  
(NORTHEAST QUADRANT) RELATIVE TO FULL ARRAY GAINS  
(DATA FILTERED BY STANDARD FILTER)

It may thus be concluded that a partial array (of 8 subarrays) in the northeast corner of the NORSAR array will have a detection capability that is only slightly inferior to that of the full array for Eurasian events. Since the aperture of the partial array is only about one-half of that of the full array, a decline in the event location accuracy must also be expected. Finally, it should be stressed that our analysis is valid for Eurasian events only. In fact, for events from the Western Hemisphere, the northeast quadrant of the array no longer gives the highest signal amplitudes, and a different partial array configuration would probably be optimum for that case.

### SECTION III

## NORSAR TELESEISMIC DETECTION CAPABILITY

### A. INTRODUCTION

One of the main objectives of this study was to determine the detectability of P-waves using the short-period NORSAR array. For this purpose an adjusted delay array beam was formed for each event, and the decision detection/no detection was made by the TI analyst after visual inspection of the signal traces. For most events having bodywave magnitude lower than 4.5 prefiltering of the signal was performed using our standard filter, which is similar to the bandpass filter used in the NORSAR on-line Detection Processor. The procedure leading to the selection of this filter was outlined in Special Report No. 6, (1972). The NORSAR SP incremental detection thresholds were then estimated by observing the detection percentages as a function of event magnitude.

The method of estimation utilized in this report is a maximum likelihood procedure described by Ringdal (1974). Briefly, this method assumes that the probability  $P(m)$  of a seismic station detecting an event of bodywave magnitude  $m$  in a given region may be described by an error function:

$$P(m) = (2\pi\sigma^2)^{-1/2} \int_{-\infty}^m e^{-\frac{(t-\mu)^2}{2\sigma^2}} dt \quad (1)$$

In this model, then, the station detection potential for events from a specific region is characterized by the corresponding values of  $\mu$  and  $\sigma$ . The problem is therefore to estimate these two parameters.

The general procedure in estimating  $\mu$  and  $\sigma$  is as follows:

- Obtain a reference set of randomly selected events of various magnitudes.
- For each event in the reference set, make a decision as to whether or not the station has detected this event.
- Establish the likelihood function for the observed pattern of decisions: detection versus no detection, using the probability model (1). (This is easy since all decisions can be assumed independent.)
- Find the values of the parameters ( $\mu, \sigma$ ) that maximize the above likelihood function.

When applying this method to the NORSAR array, some consideration must first be given to the reference event set. It is essential that the events in the reference set, for any given magnitude, represent a randomly chosen subset of the total number of events occurring. In this way, the percent detected will be an unbiased estimate of the percentage that NORSAR would detect of the whole event population for each magnitude.

The randomness criterion above means that no event must be chosen with any a priori knowledge as to whether or not NORSAR can be expected to detect this event. (Apart, of course, from magnitude and location information.) Thus we require statistical independence between NORSAR and the reporting source with respect to event detection probability.

In order to achieve this independence, we deleted all events in our data base that had originally been selected using the NORSAR seismic bulletin as a source. We also excluded events reported by ISM where NORSAR had been listed as the primary source, (i. e., events that would probably not have been reported if NORSAR had not detected them). The slight bias introduced by the fact that NORSAR contributes to the compilation of the PDE

bulletins was considered insignificant for our purposes; we therefore included events reported by PDE in our reference set.

The data base for our detection threshold estimation was in this way reduced to 452 Eurasian events. 173 events were located on the Kamchatka-Kuriles arc; 38 of these were not detected on NORSAR data. Of the remaining 279 events, all but 12 were detected. This high detection rate is due partly to the good capability of the NORSAR array for Europe and Central Asia, partly to the lack of low magnitude events from this region in our data base; this, again, reflects a relatively poor coverage provided by LASA. As a consequence, it has not been feasible to perform a detection threshold estimation on a regional basis for the Eurasian continent.

For large events, the time delay adjustments for the array beamforming were computed by cross-correlating the subarray waveforms. For all low magnitude events, time delays were estimated on the basis of nearby large events. Thus it may be assumed that it would have been possible to obtain more precise regional corrections if a larger data base and more elaborate processing methods had been used. As a consequence, the estimates of the NORSAR short period detection capabilities presented here should be regarded as conservative.

Finally, it should be observed that all our estimates are in terms of LASA, PDE, or ISM magnitudes (which are considered to be mutually unbiased). It is important to quote the source stations when referring to our detection threshold estimates.

#### B. ESTIMATE OF THE NORSAR $m_b$ DETECTION THRESHOLD

Figure III-1 presents a histogram showing the NORSAR detection performance for the Kuriles-Kamchatka arc (Region 1) together with the associated maximum likelihood detection curve. The 90 percent incremental threshold estimate is around  $m_b = 4.3$ . The epicentral distances from NORSAR are between 60 and 75 degrees for events from this region.

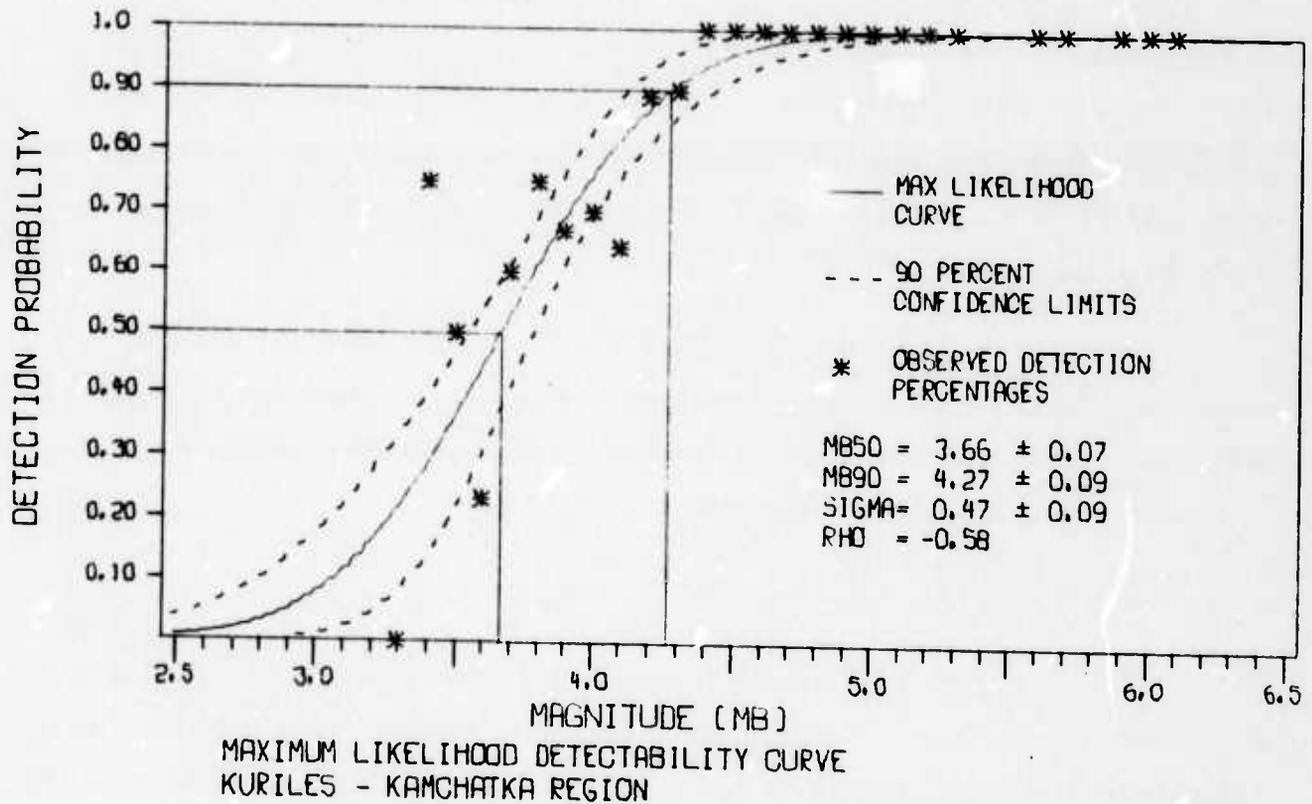
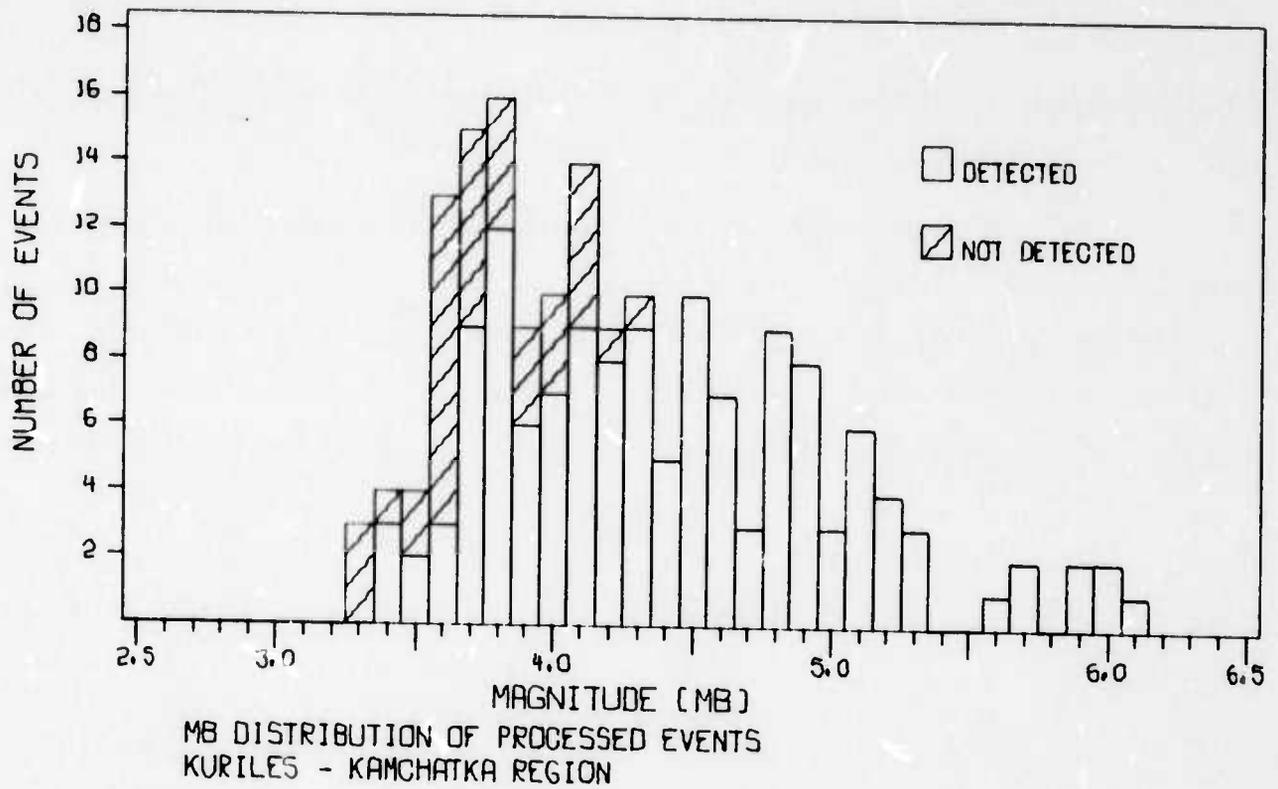


FIGURE III-1

NORSAR SP DETECTION STATISTICS FOR THE  
KURILES-KAMCHATKA REGION

A similar picture for Eurasia apart from Kuriles-Kamchatka (Region 2) is given in Figure III-2. Because of the relatively few low magnitude events in this data base, the detection curve cannot be estimated with any great degree of confidence for low  $m_b$  values. However, a reasonably accurate estimate of the 90 percent incremental detection threshold may still be obtained; it appears to lie around  $m_b = 4.0$ . Most of our events from Region 2 are from Europe and Central Asia, with epicentral distances to NORSAR ranging from 20 to 50 degrees.

It should be pointed out that several of our events for Region 2 have relatively unreliable  $m_b$  estimates. This is due to the fact that PDE includes near regional stations in their  $m_b$  computation, and therefore will often report too high a magnitude. In particular this applies to events for which only a few stations report an amplitude, since those stations are then likely to have a favorable radiation pattern for the event in question. As a partial solution to this problem, we decided to delete events with  $m_b$  values based on just one PDE station from our maximum likelihood estimation. Thus one event of  $m_b = 4.5$  and one of  $m_b = 4.8$  (ITA/035/04N) that were not detected were eliminated from consideration.

The detection statistics for all our events from Eurasia are presented in Figure III-3. The 90 percent incremental detection threshold is close to  $m_b = 4.2$ , and can be given with good confidence.

In order to examine a possible seasonal influence on the NORSAR detection capability, the data base was split into a summer event suite (origin date April through September) and a winter event suite (origin date October through March). The corresponding detection curves are presented in Figures III-4 and III-5. The incremental 90 percent threshold estimates are between 4.1 and 4.2 for the summer event suite and between 4.2 and 4.3 for the winter events. This difference of about 0.1  $m_b$  units may be attributed to the generally lower seismic noise level during the summer months.

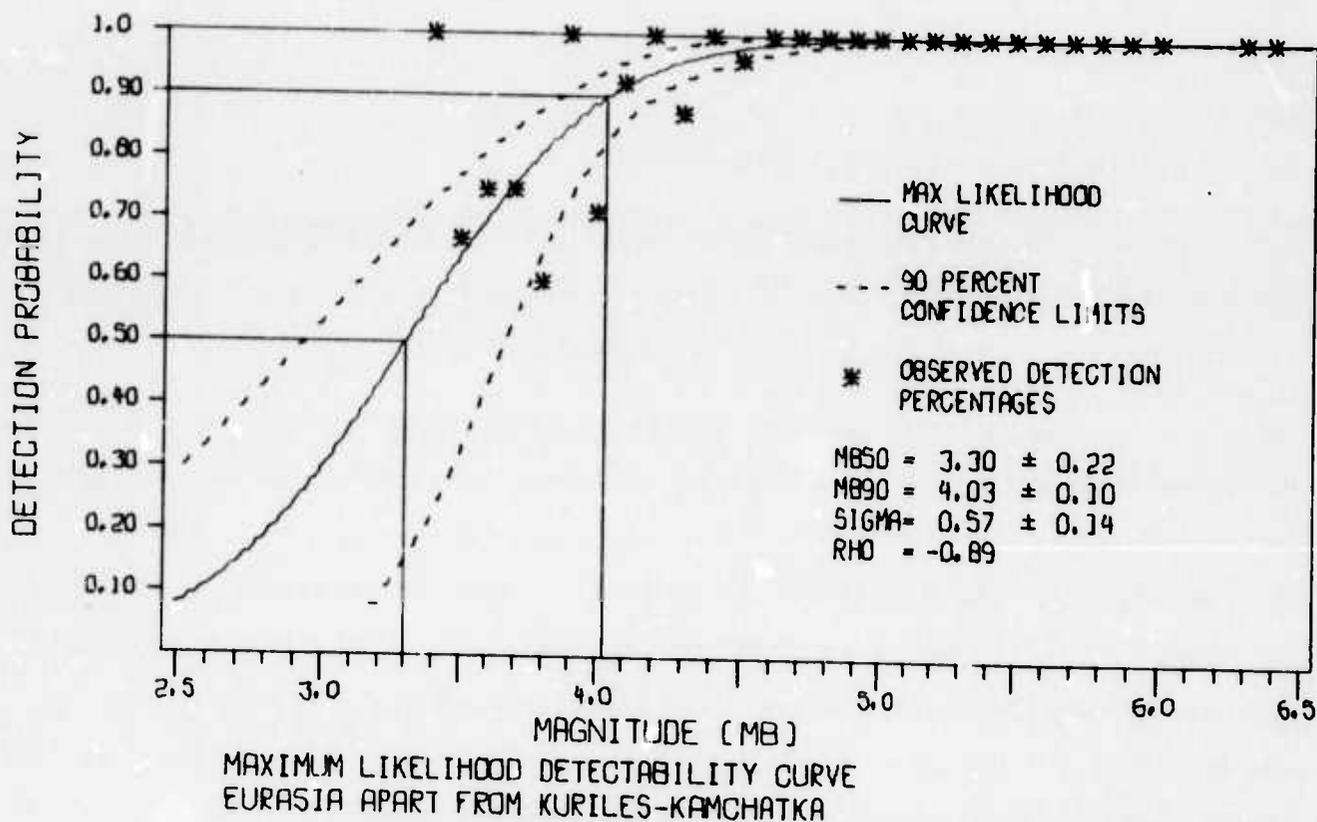
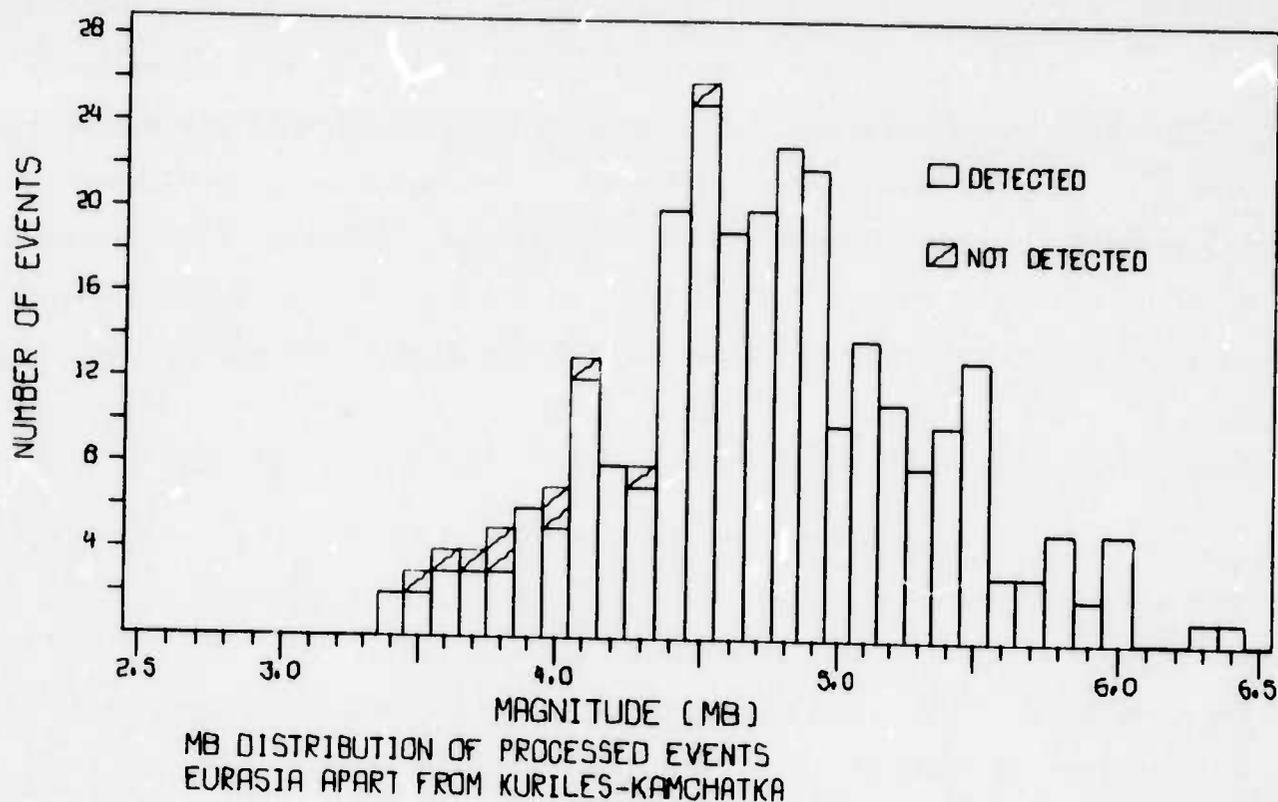
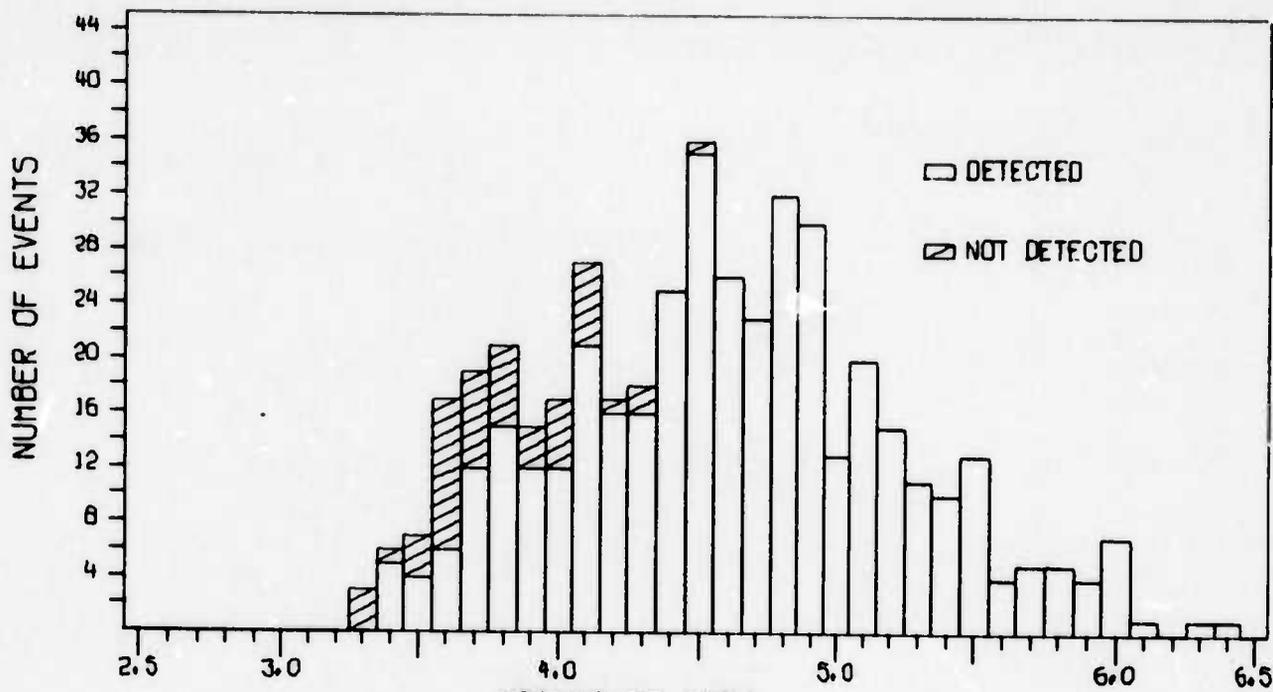


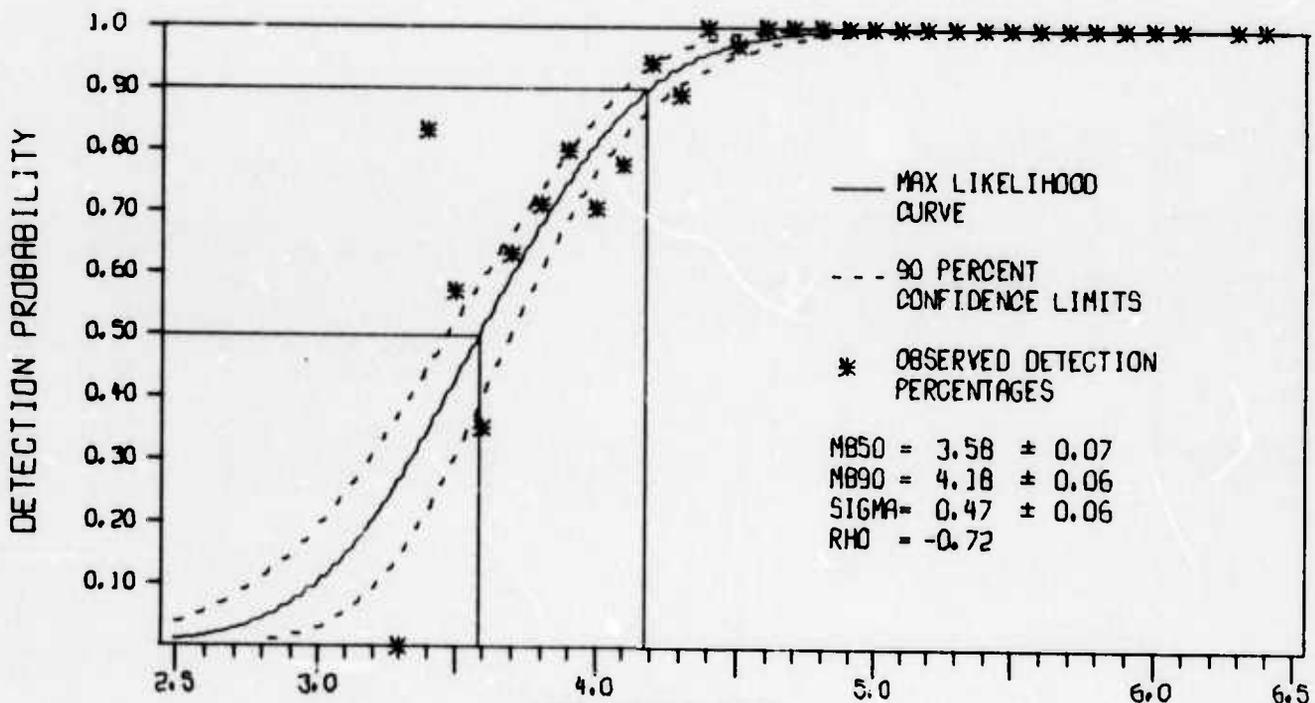
FIGURE III-2

NORSAR SP DETECTION STATISTICS FOR EURASIA  
APART FROM KURILES-KAMCHATKA



MAGNITUDE (MB)

MB DISTRIBUTION OF PROCESSED EVENTS  
ALL OF EURASIA



MAGNITUDE (MB)

MAXIMUM LIKELIHOOD DETECTABILITY CURVE  
ALL OF EURASIA

FIGURE III-3

NORSAR SP DETECTION STATISTICS FOR  
ALL EURASIAN EVENTS

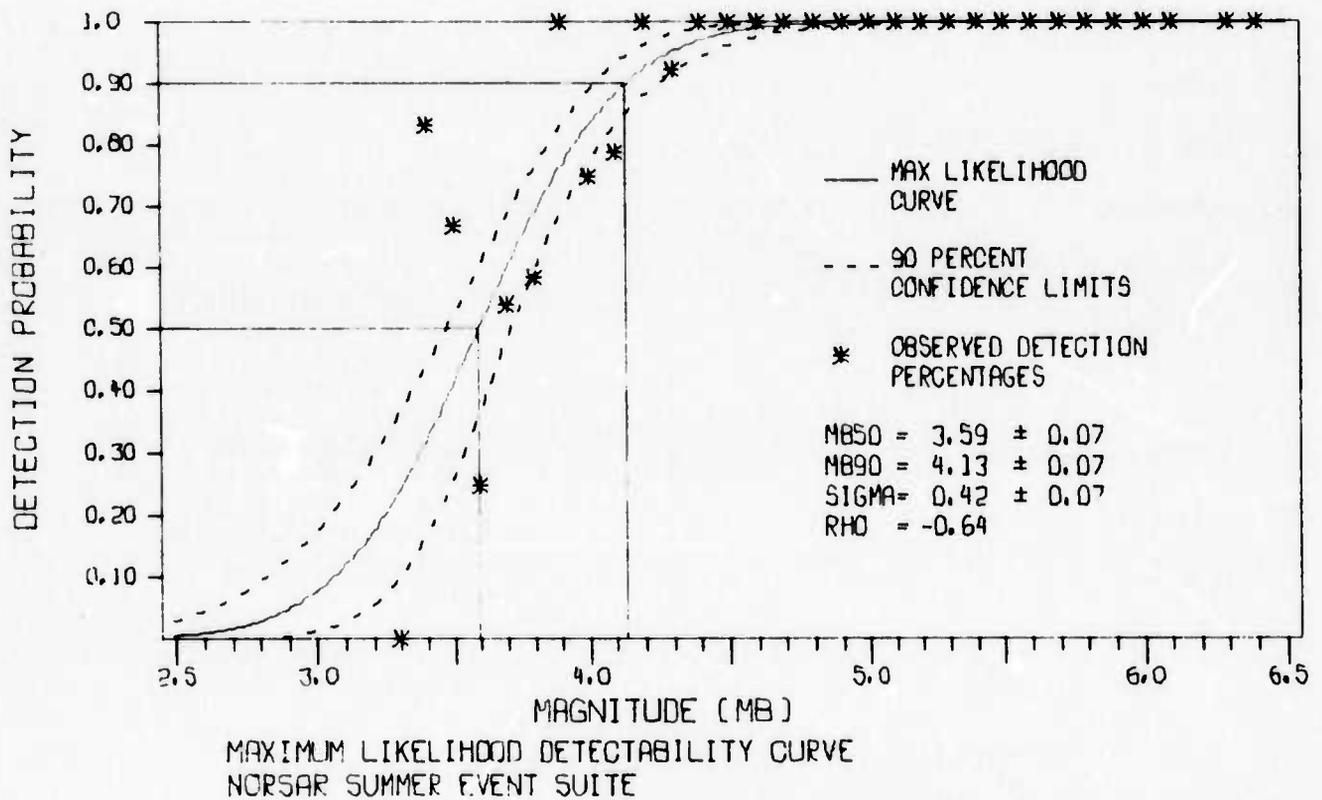
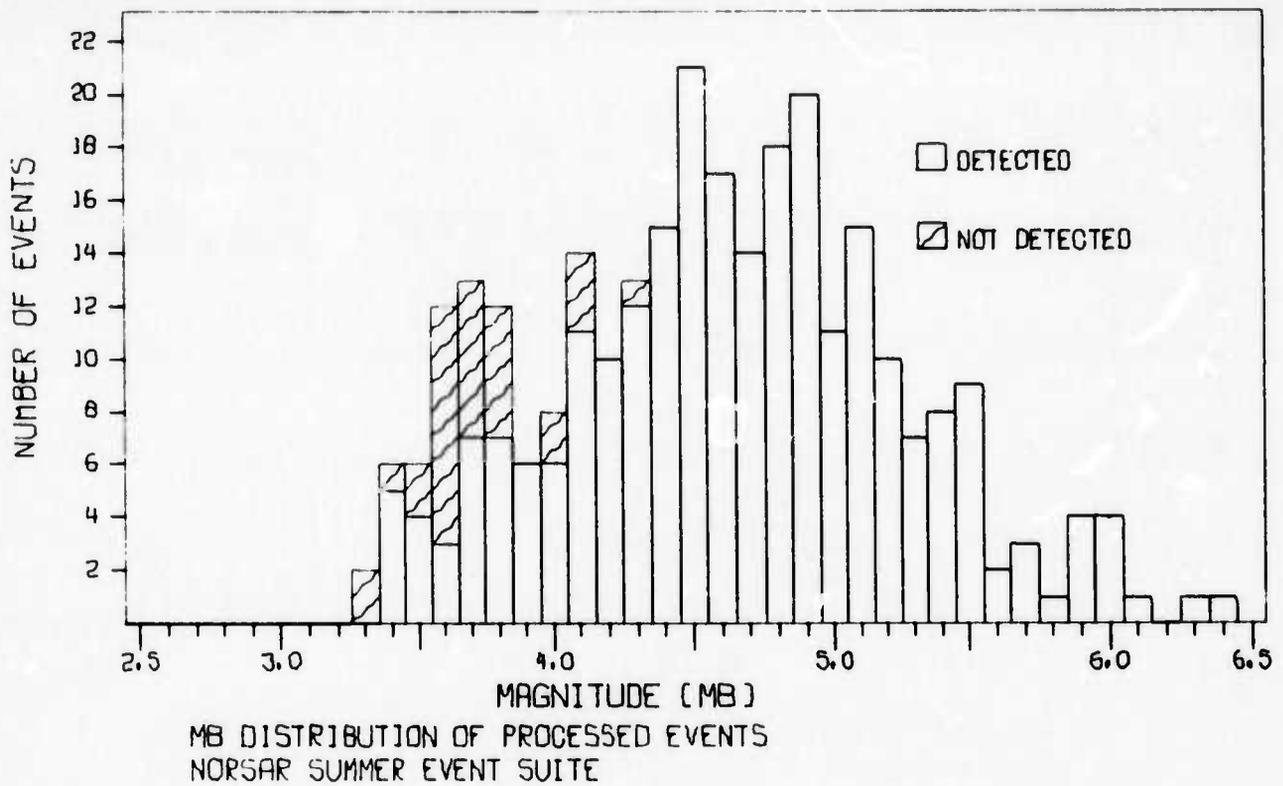


FIGURE III-4

NORSAR SP DETECTION STATISTICS FOR  
SUMMER EVENT SUITE

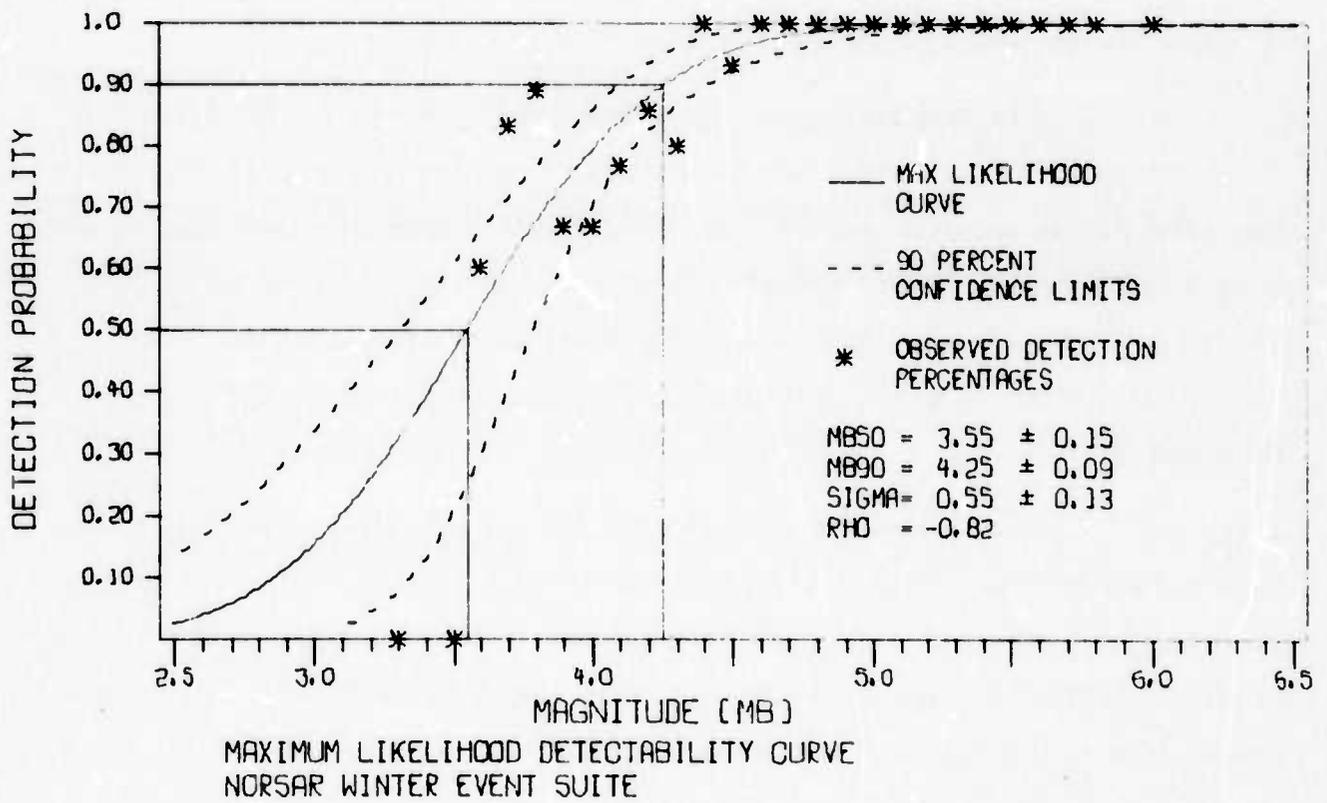
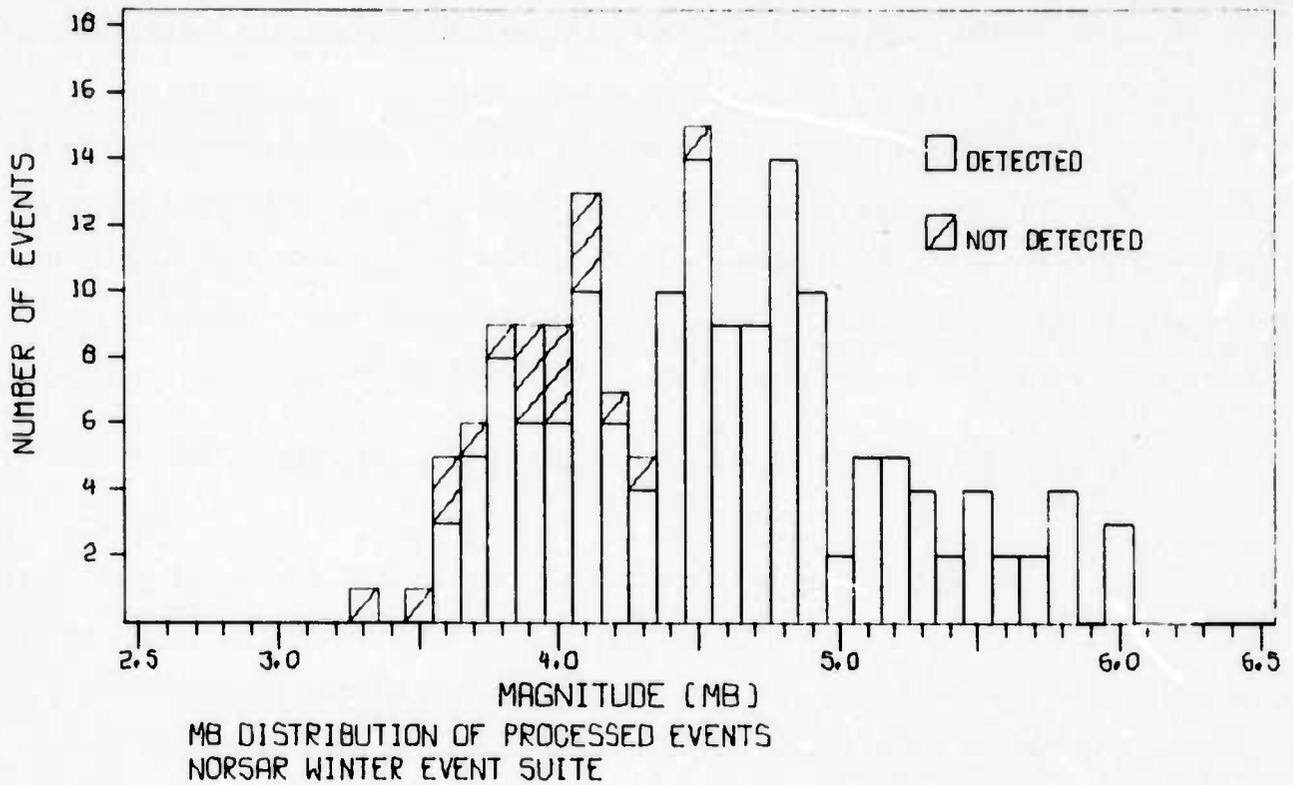


FIGURE III-5  
NORSAR SP DETECTION STATISTICS FOR  
WINTER EVENT SUITE

It is interesting to notice that the difference found here is less than the  $0.3 m_b$  units of seasonal difference observed for the NORSAR LP detection thresholds (Special Report No. 7, 1973). This confirms the observation from our SP noise analysis (Special Report No. 6, 1972) that the seismic noise filtered by the standard filter exhibits less seasonal variation than the wide-band noise level. This again is due to a shift in the microseismic peak towards lower frequencies as the noise level increases.

### C. ESTIMATE OF THE NORSAR OPERATIONAL DETECTION THRESHOLD

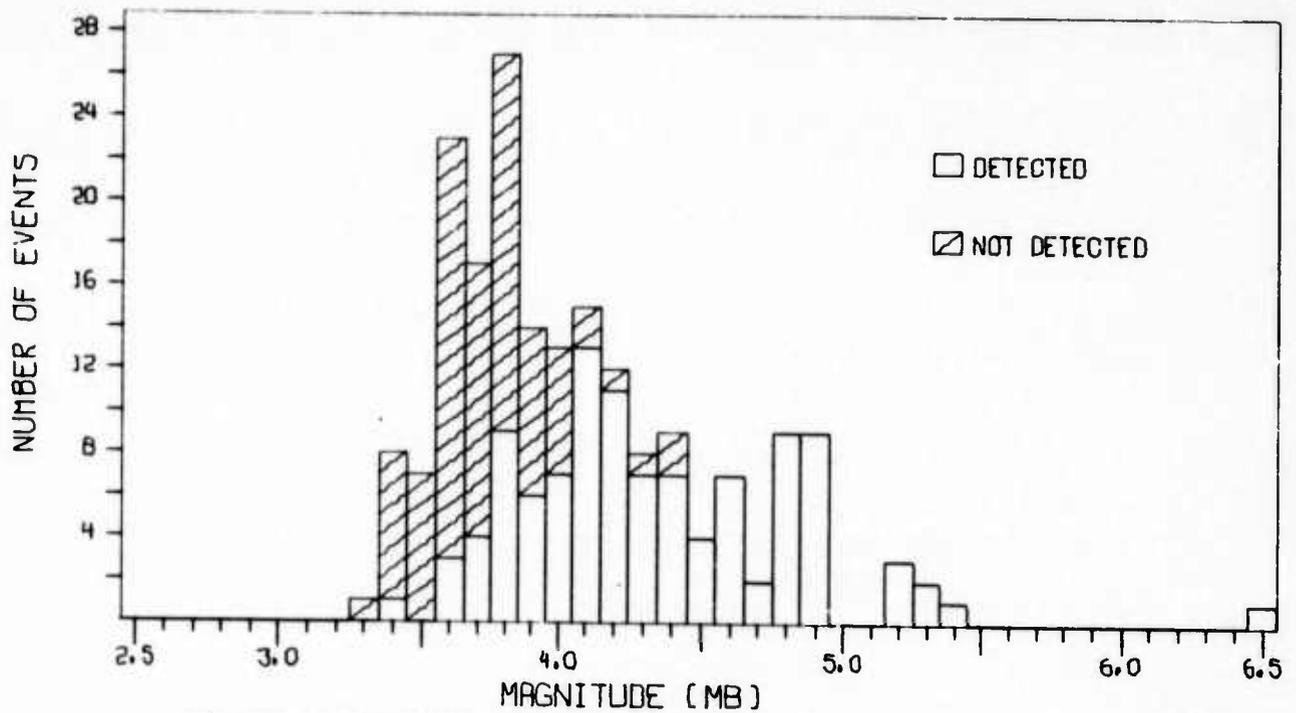
A comparison between the detection results from TI's analysis of NORSAR data and the NORSAR seismic bulletin was presented in Special Report No. 9, (1973). For the time period covered by that investigation (January to March 1972) it appeared that NORSAR was operating well below its potential. Considering that the weekly number of events reported by NORSAR has increased significantly since then, it would be of interest to determine the present operational detection level for the array.

For this purpose, we analyzed the NORSAR performance for two event swarms, one from South Honshu, December 3-20, 1972; the other from the Kurile Islands, June 17-30, 1973. LASA detections and  $m_b$  values were used as a reference, and detections occurring when NORSAR was out of operation were deleted. In this way statistics were compiled concerning detection/no detection information as presented in Table III-1 and Figures III-6 and III-7.

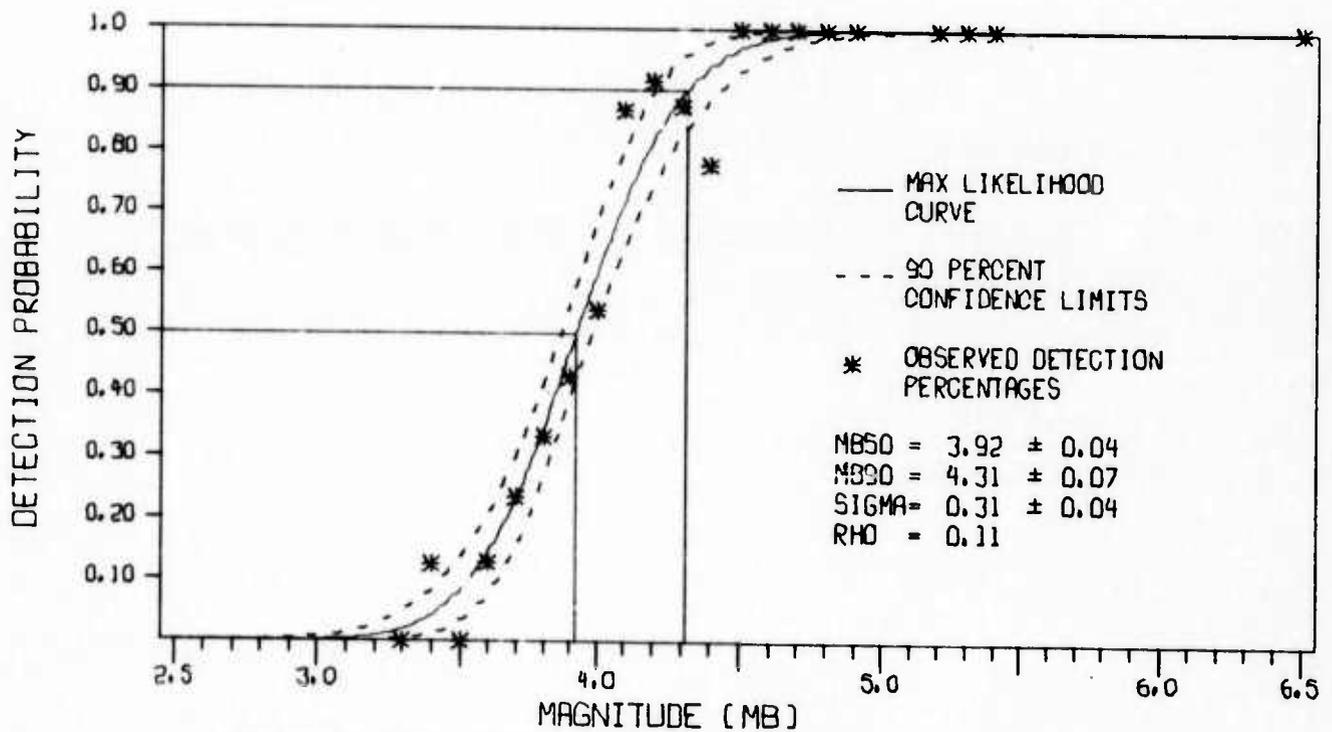
One interesting observation from Table III-1 is that NORSAR detected more events than LASA from the Kuriles swarm, while this picture was reversed for the South Honshu aftershocks. Both of these swarms were at almost identical epicentral distance from LASA and NORSAR. The main explanation is the NORSAR noise level, which was slightly less than  $0.2 m\mu$

TABLE III-1  
 NORSAR AND LASA EVENT DETECTION PERFORMANCE  
 FOR EARTHQUAKE SWARMS FROM SOUTH HONSHU  
 (DECEMBER 3-20, 1972) AND THE KURILE  
 ISLANDS (JUNE 17-30, 1973)

	Honshu Swarm	Kuriles Swarm
Distance from NORSAR (deg)	78	70
Distance from LASA (deg)	80	69
LASA Total Detected Events	192	364
NORSAR Total Detected Events	133	452
Common Events	106	284



MAGNITUDE (MB)  
 MB DISTRIBUTION OF PROCESSED EVENTS  
 NORSAR BLTN HONSHU SWARM DECEMBER 1972



MAXIMUM LIKELIHOOD DETECTABILITY CURVE  
 NORSAR BLTN HONSHU SWARM DECEMBER 1972

FIGURE III-6

NORSAR OPERATIONAL DETECTION STATISTICS  
 SOUTH HONSHU SWARM, DECEMBER 1972

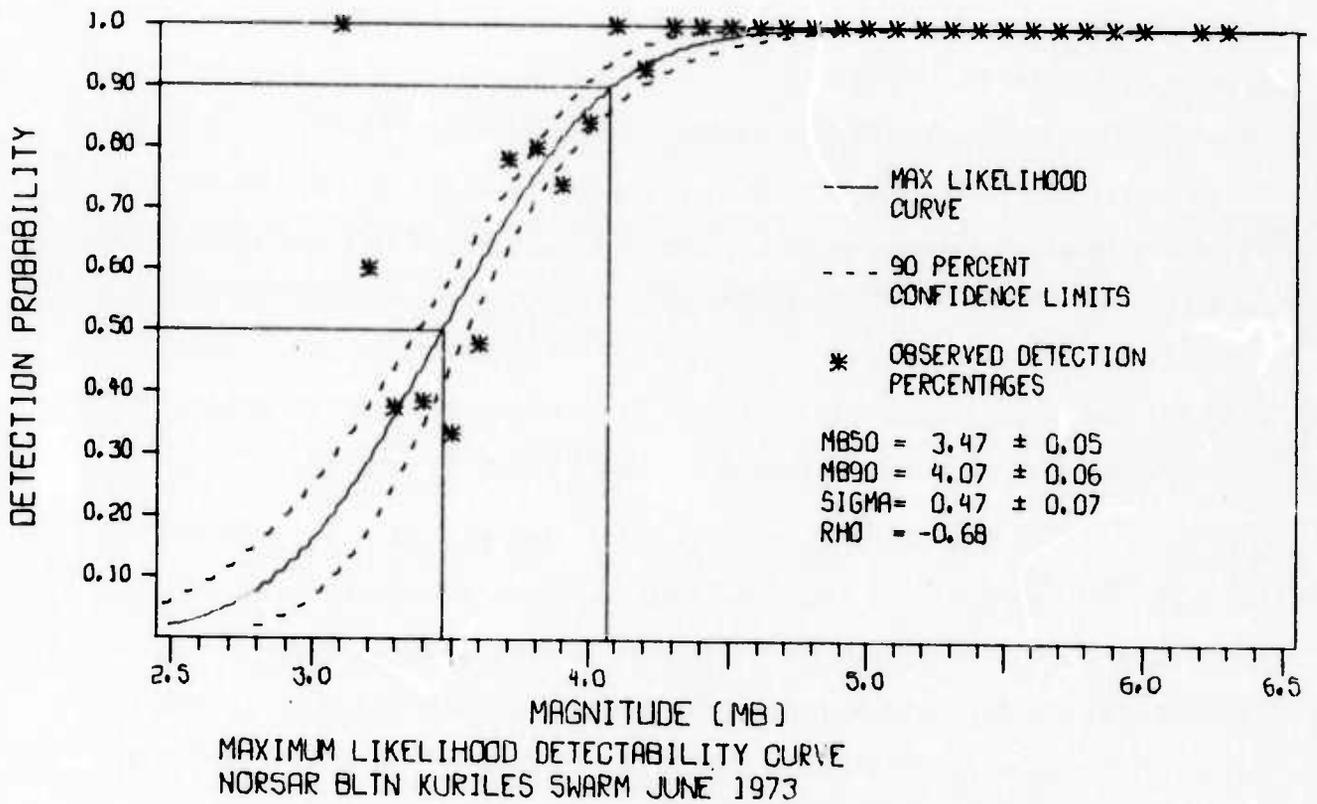
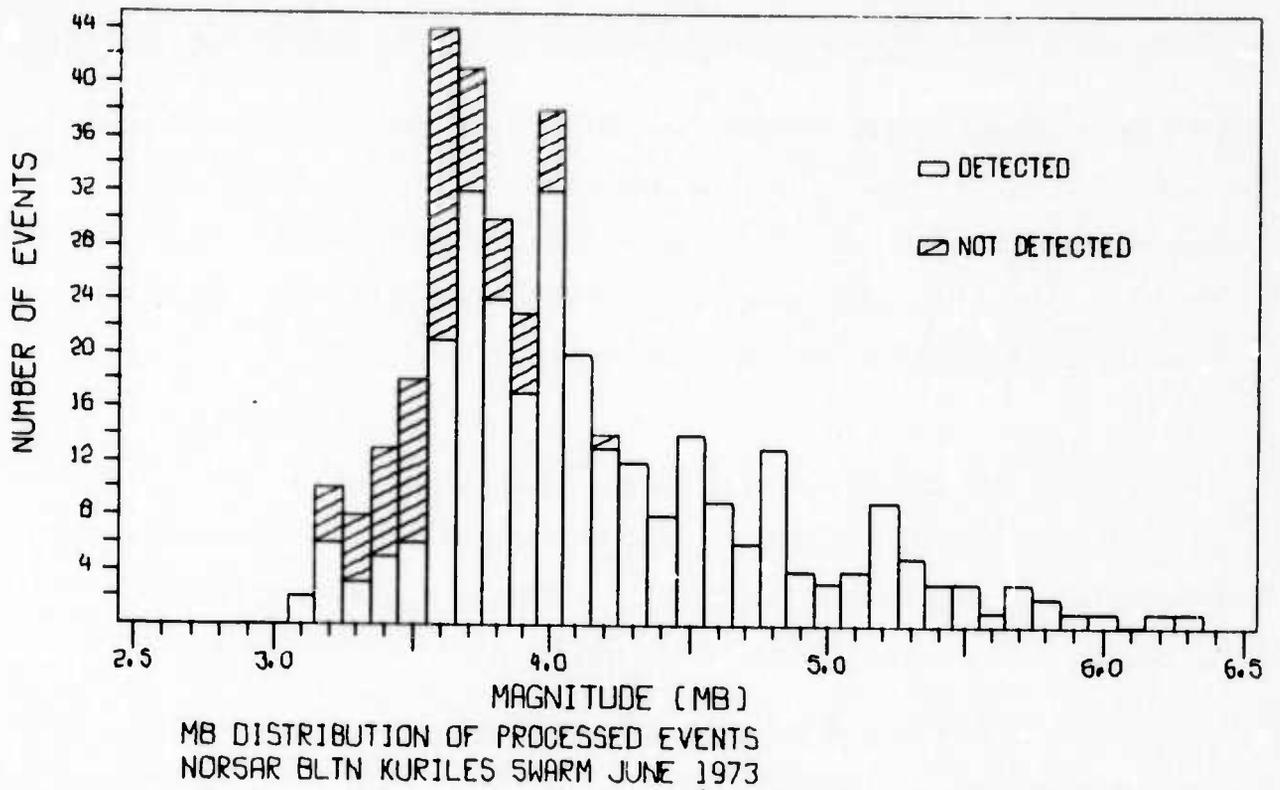


FIGURE III-7

NORSAR OPERATIONAL DETECTION STATISTICS  
KURILES ISLANDS SWARM, JUNE 1972

RMS on the bandpass filtered (1.2 - 3.2 Hz) array beam in December 1972, while less than 0.1 m $\mu$  in the last part of June 1973. This, of course, caused the 90 percent detection level for the Kuriles swarm to be significantly lower than that of the Honshu swarm, (4.1 compared to 4.3). The difference is even greater in the 50 percent thresholds (3.5 and 3.9).

It is interesting to notice the much larger spread in the detection curve for the Kuriles swarm compared to the Honshu curve, ( $\sigma = 0.47$  to  $\sigma = 0.31$ ). Part of this difference may be due to a greater variation in the seismic noise level during June 1973, but mostly it seems to reflect more variability in the source mechanisms for the Kuriles aftershocks.

In order to compare TI's detectability estimates to the observed array performance, it is most correct to compare the 50 percent detectability limits. This is because there is an inherently larger spread in the detectability curve when the events span a larger region and a longer period of time as opposed to an aftershock sequence. By compensating for the differences between the actual noise levels during the two event swarms and the annual average level of 0.16 m $\mu$  on the filtered array beam (Special Report No. 6, 1972) we obtained estimates of 3.7 and 3.85 for the 50 percent operational detection levels for Kuriles and Honshu, respectively, during normal noise conditions. These numbers are only slightly higher than the TI estimate of 3.65 for the Kuriles-Kamchatka arc. Thus it appears that NORSAR presently operates very close to its optimum capability for this region.

It has not been possible to determine the present NORSAR operational capability for near regional events in a way similar to the above procedure. Our investigations presented in Special Report No. 9 (1973) showed that the NORSAR performance was significantly below the array's potential for close-in regions at that time. However, it is believed that improved regional time delay corrections and the implementation of envelope beamforming in the NORSAR Detection Processor may have altered the picture since then.

One final remark seems highly relevant in view of the observed array detection capabilities for the two earthquake swarms examined in this section: The variability of the NORSAR seismic noise level is considerable, even within the short period detection filter band, and no general statement about the NORSAR detection capability should be made without taking due reservations for this factor.

## SECTION IV

### SHORT PERIOD DISCRIMINATION

#### A. INTRODUCTION

This section presents the results achieved by applying five standard short period discriminants to NORSAR data. The discriminants are briefly described as follows:

##### 1. P30 Mean Square

This discriminant, which is a measure of event complexity, is computed by crosscorrelating 4 seconds of the waveform (beginning a few points before P-wave onset) with the next 30 seconds of the waveform and with the noise preceding the signal. A mean square, weighted by the lag, is then computed from the correlations over both 30 seconds of the noise and 30 seconds of the signal. The noise mean square is subtracted from the signal mean square to obtain the discriminant used (Texas Instruments Incorporated, 1971).

##### 2. Autocorrelation Mean Square

This discriminant is also a measure of complexity. The autocorrelations of a 30-second noise gate and of a 30-second signal gate are computed and a weighted mean square then derived from these correlations for the noise and signal. The discriminant is derived from the signal mean square minus the noise mean.

##### 3. Envelope Difference

This discriminant is also derived from the P30 correlation by computing the mean-square difference between the envelope correlation and a fixed decaying exponential, the decay rate of which is the average rate for an

ensemble of 16 explosions recorded at LASA. As with the first two statistics, envelope difference is a measure of complexity.

#### 4. Dominant Period

This discriminant is computed by finding the cycle in the waveform with a maximum absolute amplitude; the dominant period is the duration of this cycle in seconds. This parameter can be estimated with some confidence, even for events with a relatively low signal-to-noise ratio. The dominant period discriminant is a rough measure of spectral energy distribution.

#### 5. Spectral Ratio

This discriminant is derived from the signal power spectrum over a gate beginning just before the signal arrival. The power spectrum is smoothed over three frequency points, and the power in three bands is computed; Band 1: 0. -0.55 Hz; Band 2: 0.55 - 1.5 Hz; Band 3: 1.5 - 5.0 Hz. These bands have been selected based on NORSAR data. Spectral ratios computed were Band 3 to Band 2 and Band 3 to Band 1, respectively.

In order to evaluate the performance of the individual discriminants as well as the possible combined criteria, a measure of the separation achieved between earthquakes and presumed explosions was computed for each discriminant. Since all our discriminants are two-dimensional, (discriminant value versus  $m_b$ ), the problem of obtaining such a measure reduces to measuring the separation of two point sets in a plane. The following method was adapted (see Figure IV-1).

1. For any given straight line, the distances from the line were computed for all points corresponding to events in the earthquake and presumed explosion populations.

2. The two sets of real numbers thus obtained were considered as sampled from two Gaussian populations; one  $N(\mu_1, \sigma_1)$  (earthquakes) and one  $N(\mu_2, \sigma_2)$  (presumed explosions).

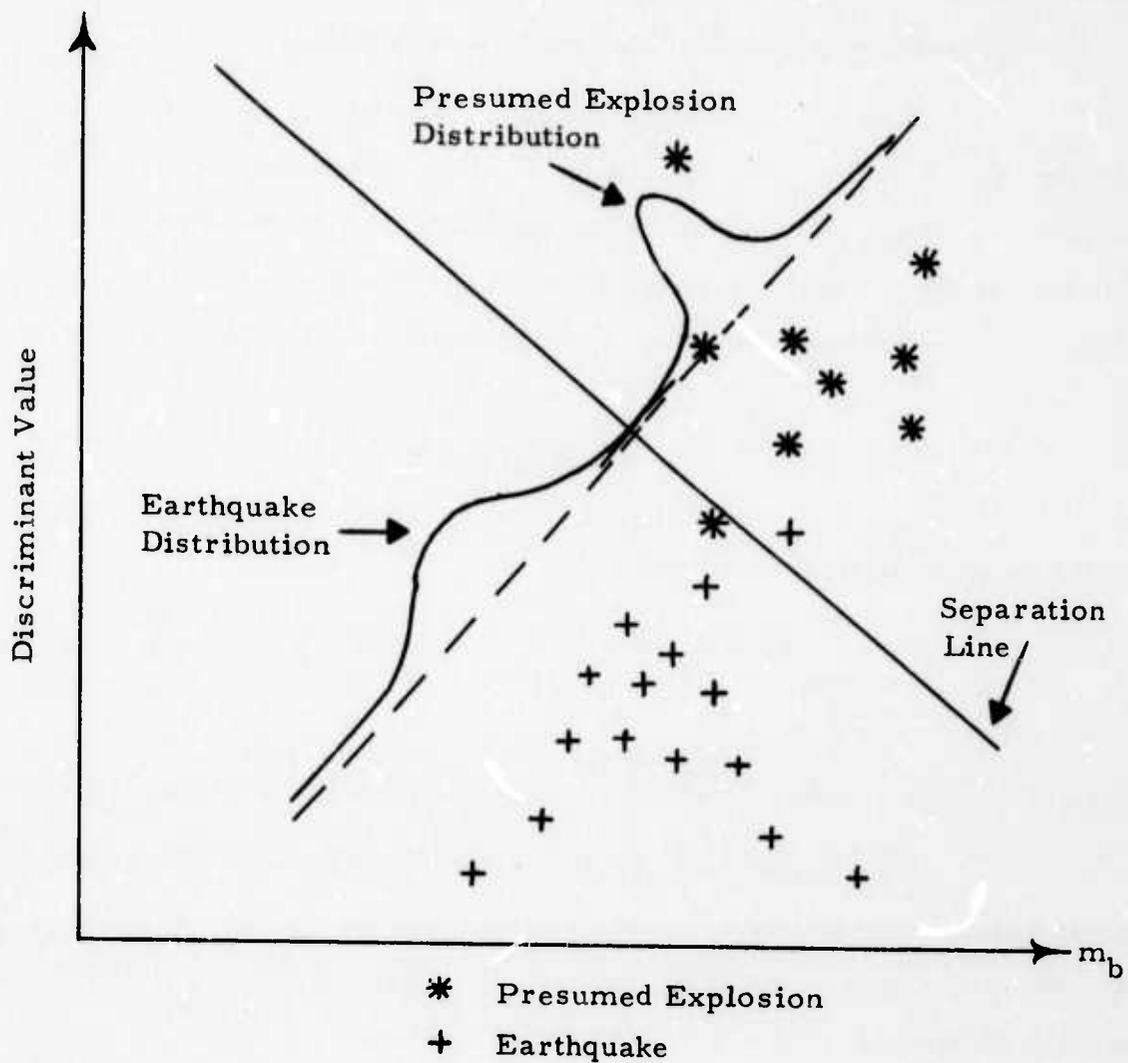


FIGURE IV-1

ILLUSTRATION OF A METHOD TO MEASURE THE SEPARATION  
BETWEEN TWO POINT SETS IN A PLANE

3. The straight line that gave two Gaussian populations with the best separation was chosen, and the measure of separation was defined as the corresponding probability of correct classification.

There is no unique method of computing the separation of two Gaussian distributions with unequal variances. We chose under 3 above to measure the separation by computing the worst case probability of misclassification, applying the well-known minimax principle (see e. g. van Trees (1968)). The minimax separation threshold between the two populations is given as

$$T = \frac{\mu_2 \sigma_1 + \mu_1 \sigma_2}{\sigma_1 + \sigma_2}$$

and the associated probability of error is

$$P(\text{miss}) = P(\text{false alarm}) = \Phi \left( - \frac{|\mu_1 - \mu_2|}{\sigma_1 + \sigma_2} \right)$$

where  $\Phi$  is the standard cumulative Gaussian distribution function.

Thus it is seen that for the above threshold  $T$ , the conditional probabilities of correctly identifying an earthquake and correctly identifying a presumed explosion are identical, and therefore provide a well-defined measure of the separation of the two populations.

Finally, it may be observed that the above method suggests an easy way to evaluate the separation properties of multivariate discriminants. In fact, since the method reduces a two-dimensional discriminant to two sets of real numbers, it can be applied successively to reduce any given array of discriminant values to the one-dimensional case.

#### B. NORSAR SHORT PERIOD DISCRIMINATION RESULTS

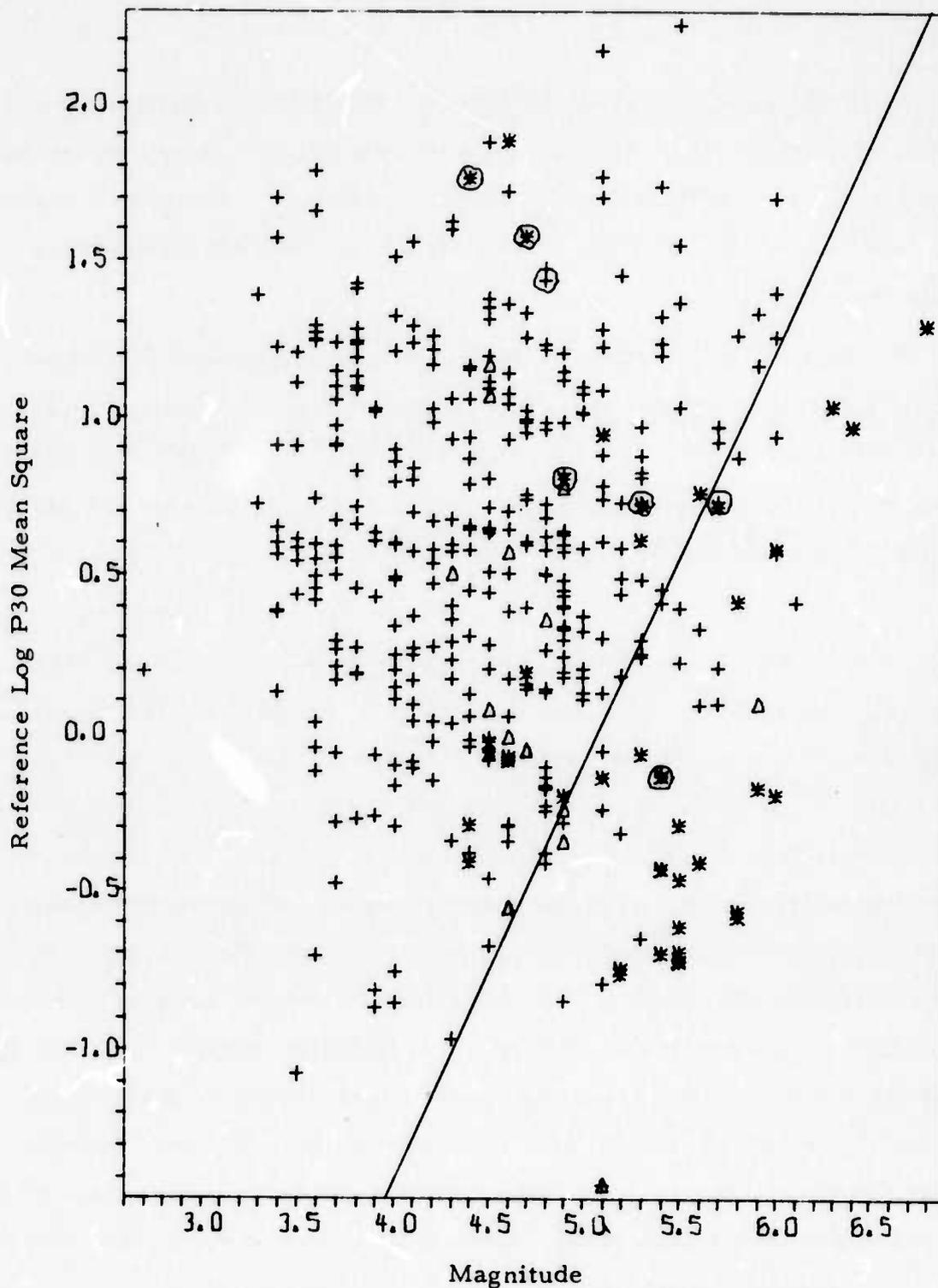
Short period discriminant values for the discriminants defined in Subsection IV-A are plotted as a function of body-wave magnitude for a

total of 414 events in Figures IV-2 through IV-13. Shallow earthquakes and earthquakes of unknown depth are represented by a cross. Deep earthquakes (of depths greater than 100 km) are denoted by a triangle. Presumed explosions are indicated by an asterisk. Events from the Western Hemisphere are surrounded by a circle.

The "best separation line" as defined in Subsection IV-A between shallow Eurasian earthquakes and Eurasian presumed explosions is drawn for each of the Figures IV-2 through IV-13. Note that this line has been found on the basis of all events with  $m_b \geq 4.4$ ; this is because all our presumed explosions are of at least this magnitude.

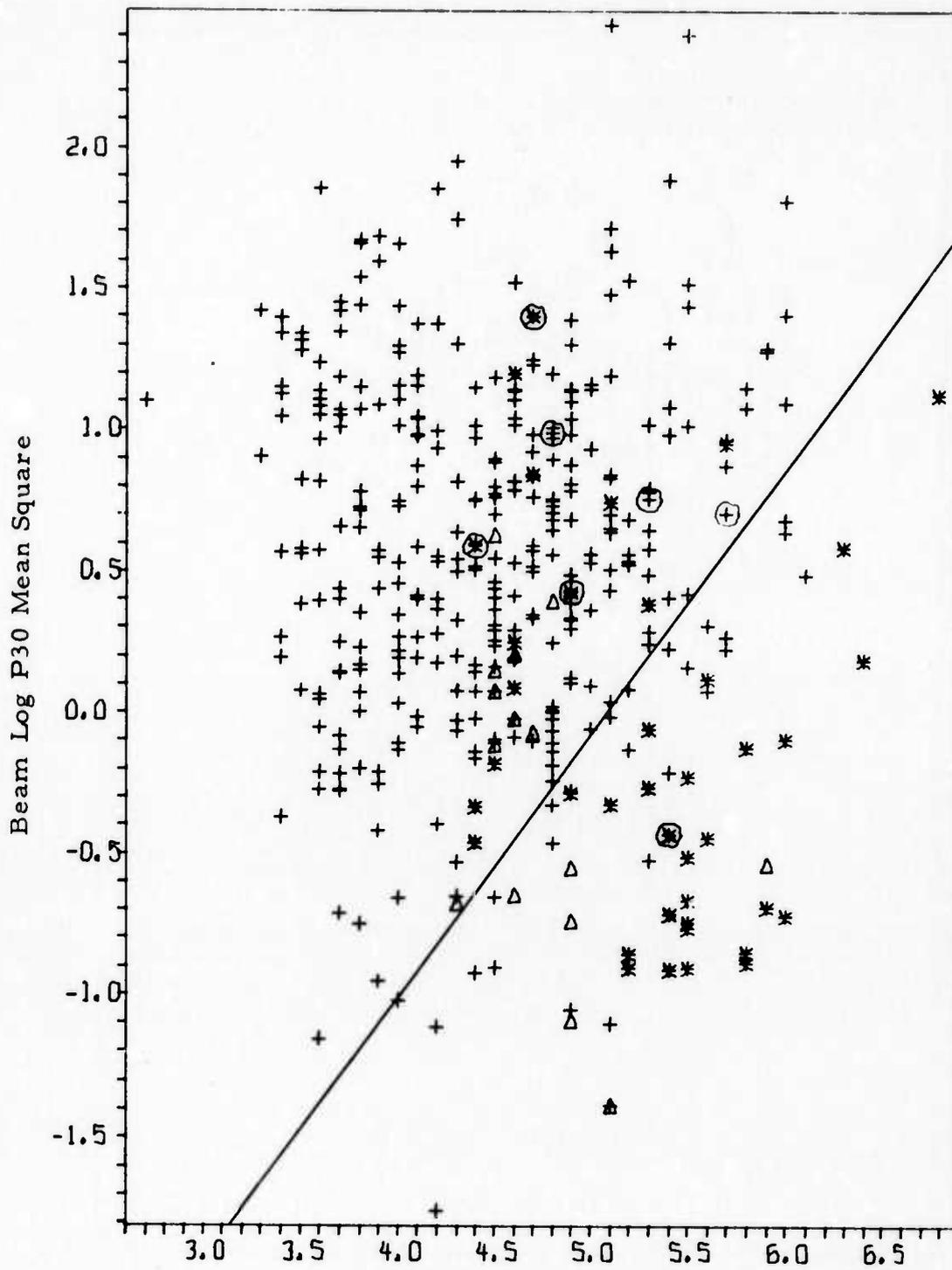
Table IV-1 lists the results obtained when evaluating the various criteria according to the method introduced in Subsection IV-A. The probabilities of correct identification are generally between 80 and 90 percent. For all discriminants except the envelope difference, better separation is achieved on the array beam than when using the reference subarray, although the differences are not large. As can be expected, the values of the discriminants at the subarray and array level are highly correlated with correlation coefficients up to 0.90. The spectral ratio criteria show the best performance both on the subarray and array level, with Band 3/Band 1 appearing to give the best separation. This particular criterion was found to identify correctly 92 percent of the events. However, some reservations should be made on the grounds that this spectral ratio to a large degree measures signal-to-noise ratio. The good performance may thus in part be due to the short epicentral distance to our presumed explosions, which again causes a high SNR relative to  $m_b$  for these events (Figure IV-14).

Table IV-2 presents the separation properties achieved by combining any two of our criteria at the array beam level. The improvements are not large; the best performance (93 percent correct identification) is obtained by combining Log P30 with Spectral Ratio 3/1. Incidentally, the separation



- + Eurasian Earthquake (shallow or unknown depth)
- Δ Deep Eurasian Earthquake (100 km or greater)
- \* Presumed Explosion from Eurasia
- ⊕ North American Earthquake
- ⊗ Presumed Explosion from North America

FIGURE IV-2  
 REFERENCE SUBARRAY P30 MEAN SQUARE DISCRIMINANT



- + Eurasian Earthquake (shallow or unknown depth)
- Δ Deep Eurasian Earthquake (100 km or greater)
- \* Presumed Explosion from Eurasia
- ⊕ North American Earthquake
- ⊗ Presumed Explosion from North America

FIGURE IV-3

ADJUSTED-DELAY BEAM P30 MEAN SQUARE DISCRIMINANT

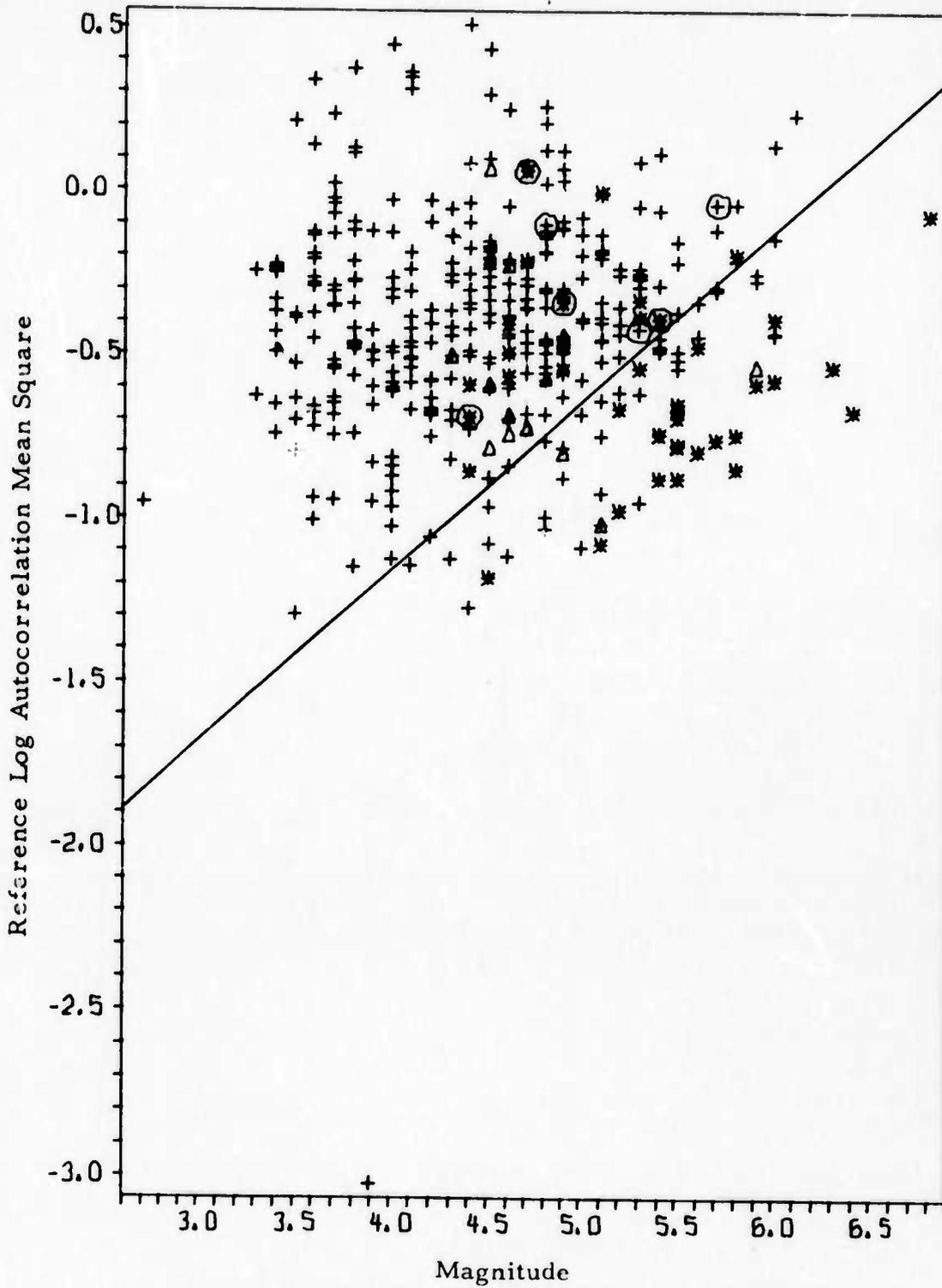
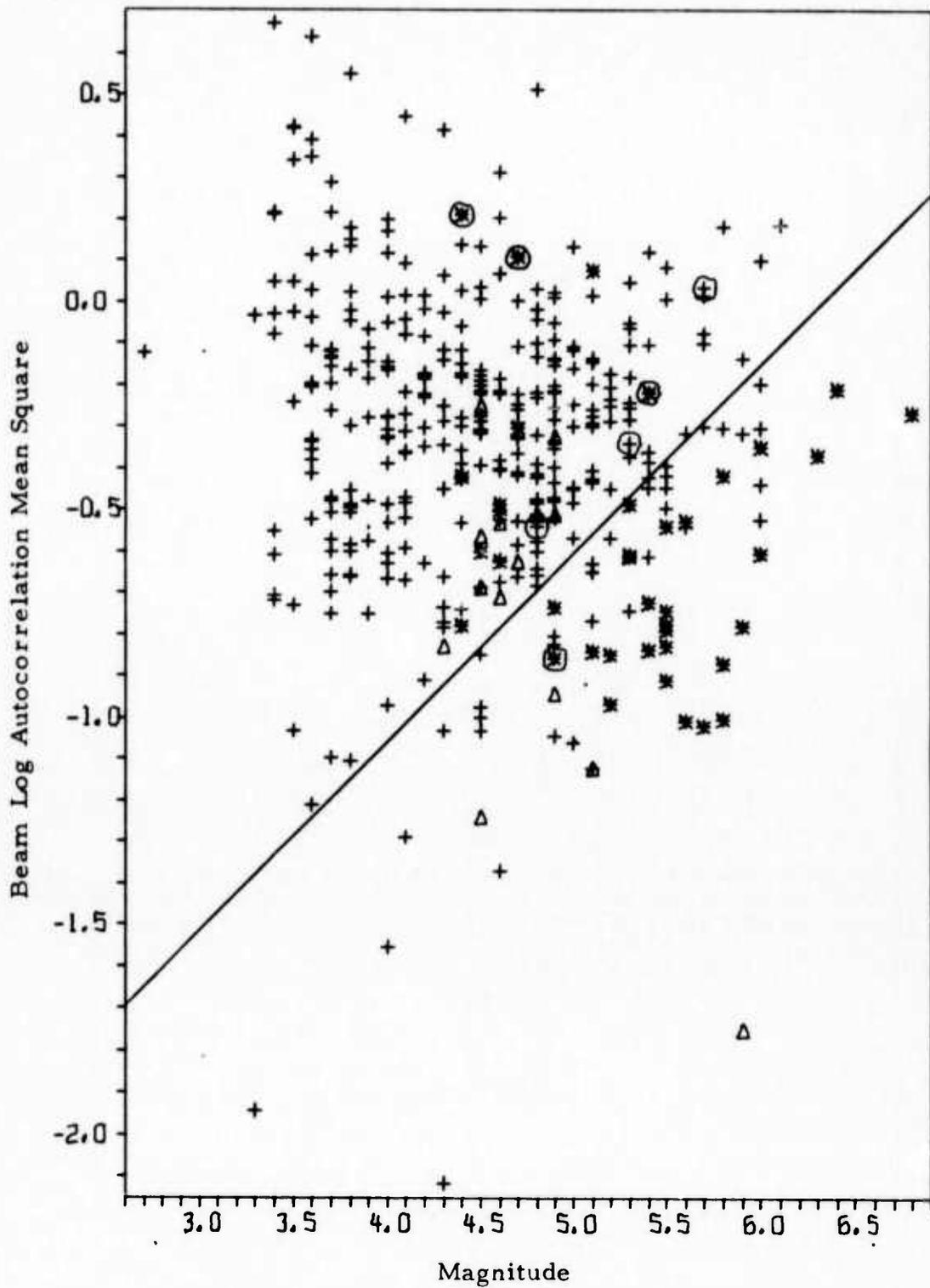


FIGURE IV-4  
 REFERENCE AUTOCORRELATION MEAN SQUARE



- + Eurasian Earthquake (shallow or unknown depth)
- Δ Deep Eurasian Earthquake (100 km or greater)
- \* Presumed Explosion from Eurasia
- ⊕ North American Earthquake
- ⊗ Presumed Explosion from North America

FIGURE IV-5

ADJUSTED-DELAY BEAM AUTOCORRELATION MEAN SQUARE

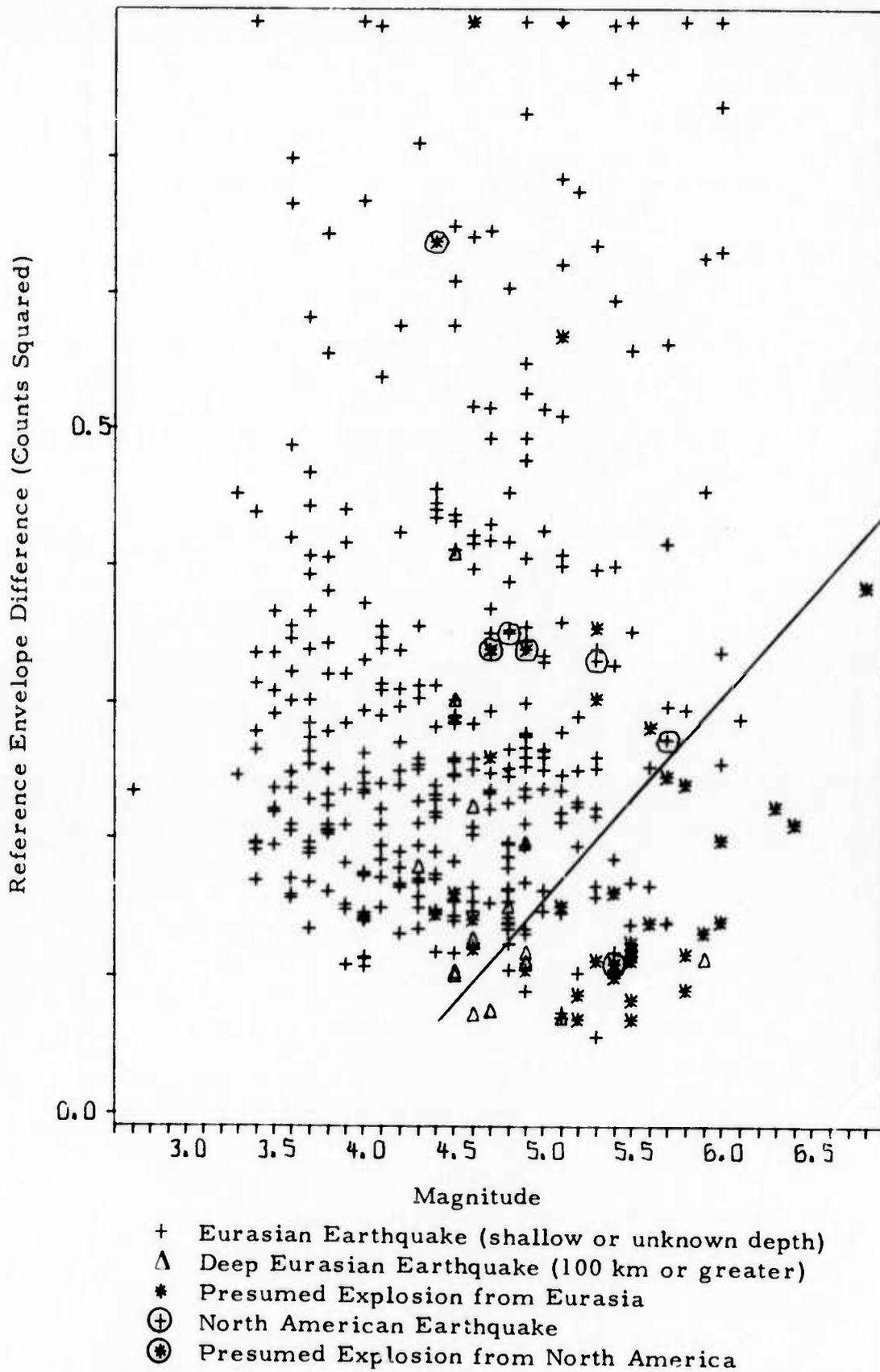
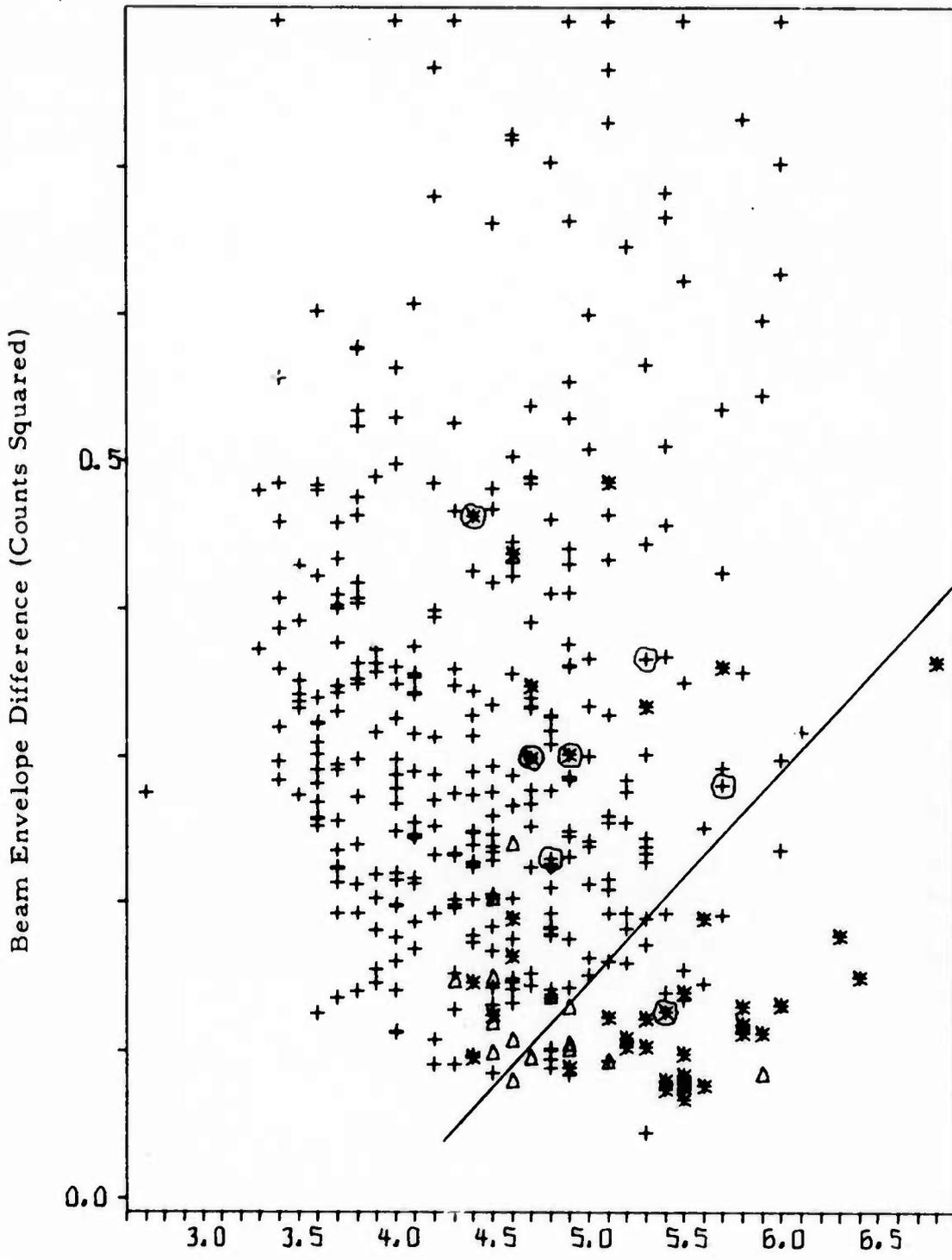


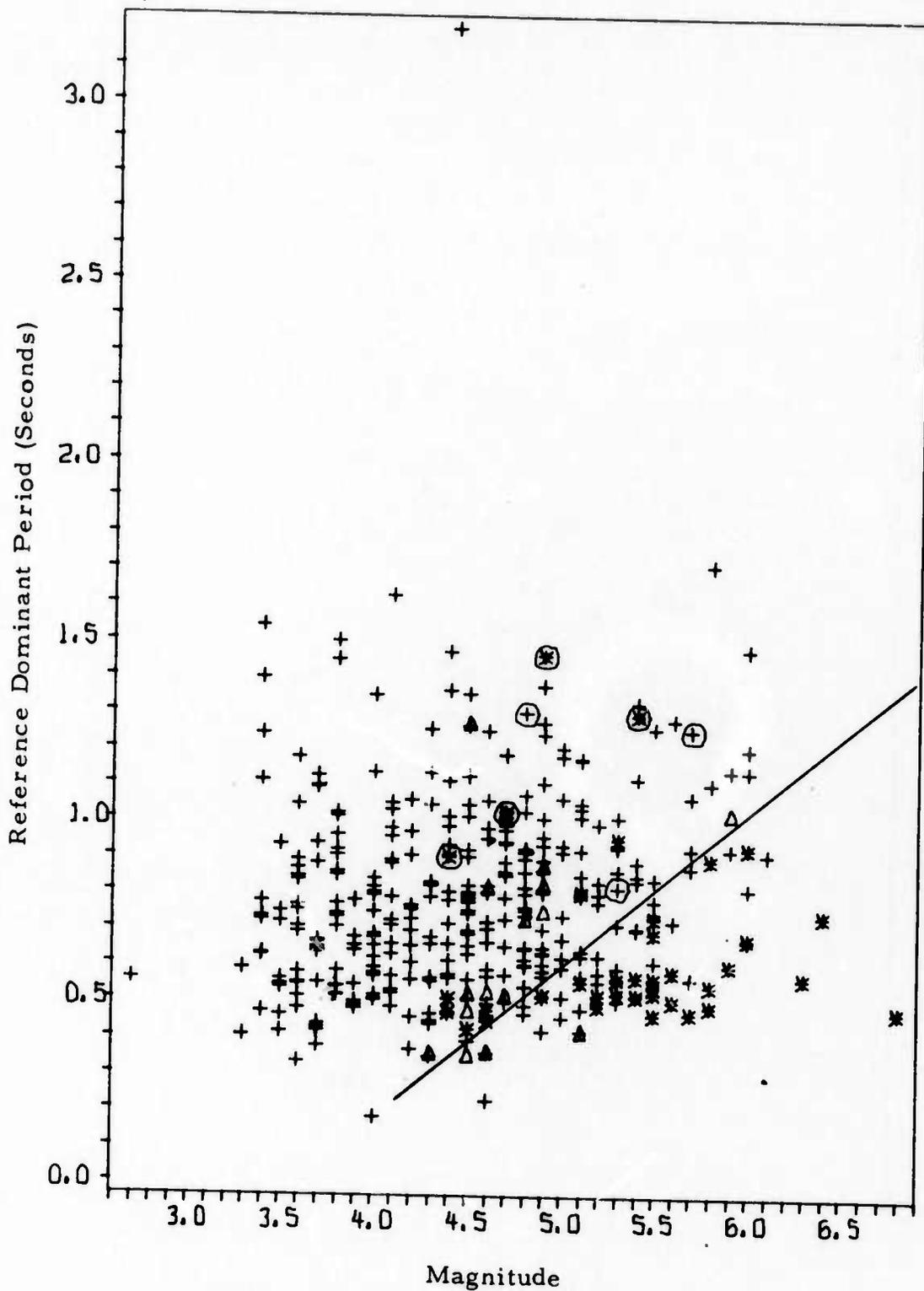
FIGURE IV-6  
 REFERENCE ENVELOPE DIFFERENCE (COUNTS SQUARED)



- + Eurasian Earthquake (shallow or unknown depth)
- Δ Deep Eurasian Earthquake (100 km or greater)
- \* Presumed Explosion from Eurasia
- ⊕ North American Earthquake
- ⊗ Presumed Explosion from North America

FIGURE IV-7

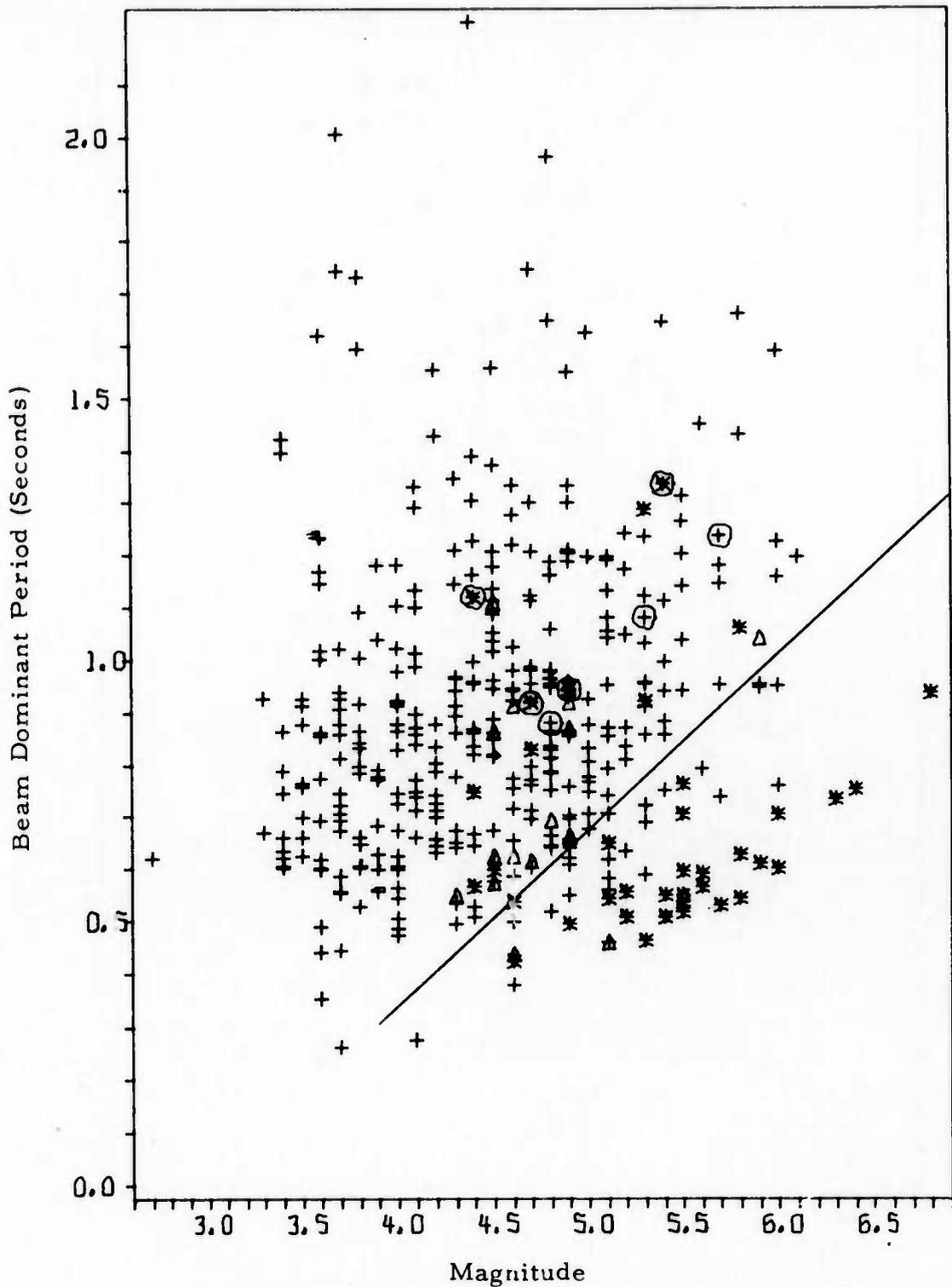
ADJUSTED-DELAY BEAM ENVELOPE DIFFERENCE (COUNTS SQUARED)



- + Eurasian Earthquake (shallow or unknown depth)
- Δ Deep Eurasian Earthquake (100 km or greater)
- \* Presumed Explosion from Eurasia
- ⊕ North American Earthquake
- ⊗ Presumed Explosion from North America

FIGURE IV-8

REFERENCE DOMINANT PERIOD (SECONDS)



- + Eurasian Earthquake (shallow or unknown depth)
- Δ Deep Eurasian Earthquake (100 km or greater)
- \* Presumed Explosion from Eurasia
- ⊕ North American Earthquake
- ⊗ Presumed Explosion from North America

FIGURE IV-9

ADJUSTED-DELAY BEAM DOMINANT PERIOD (SECONDS)

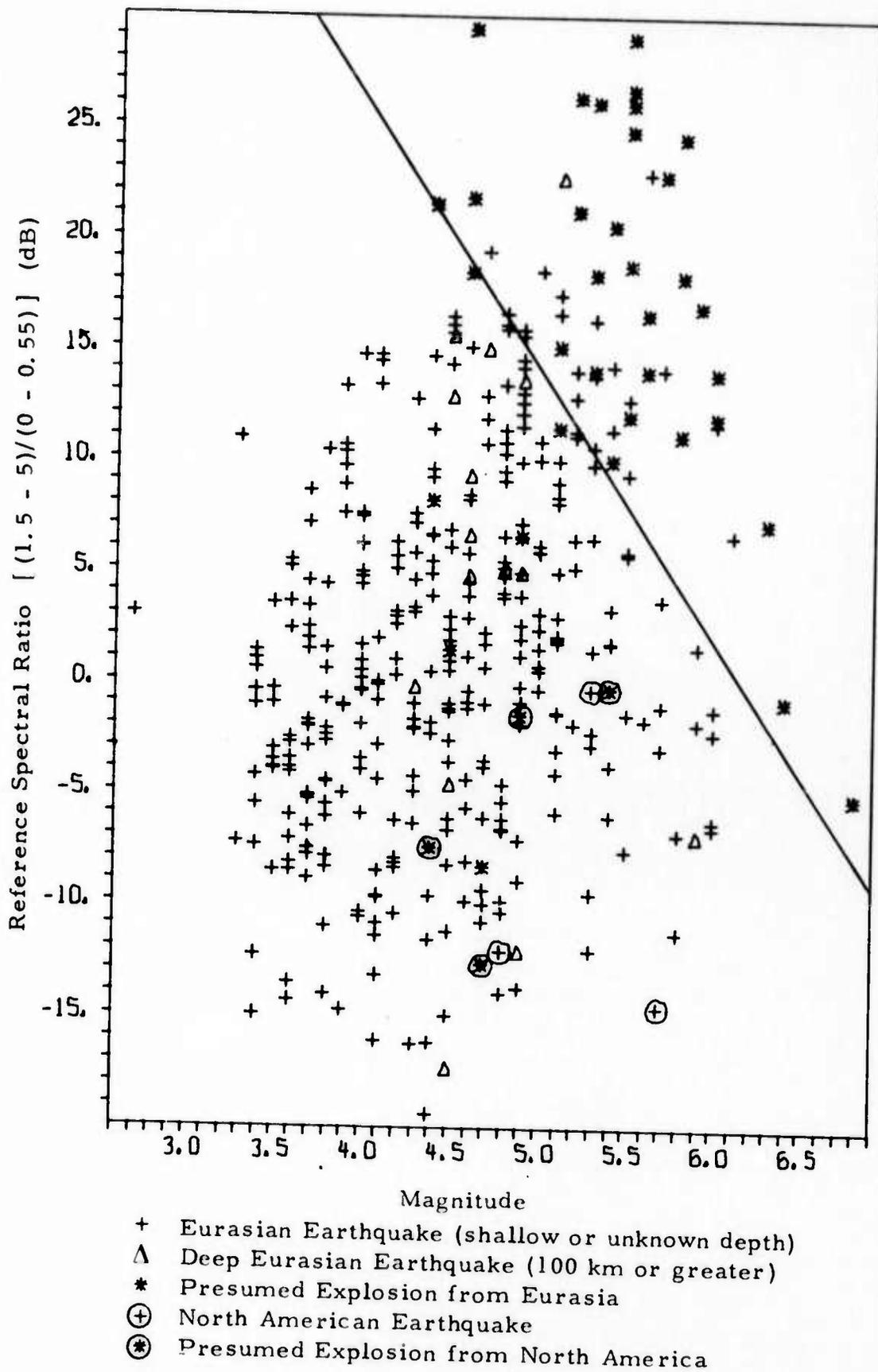
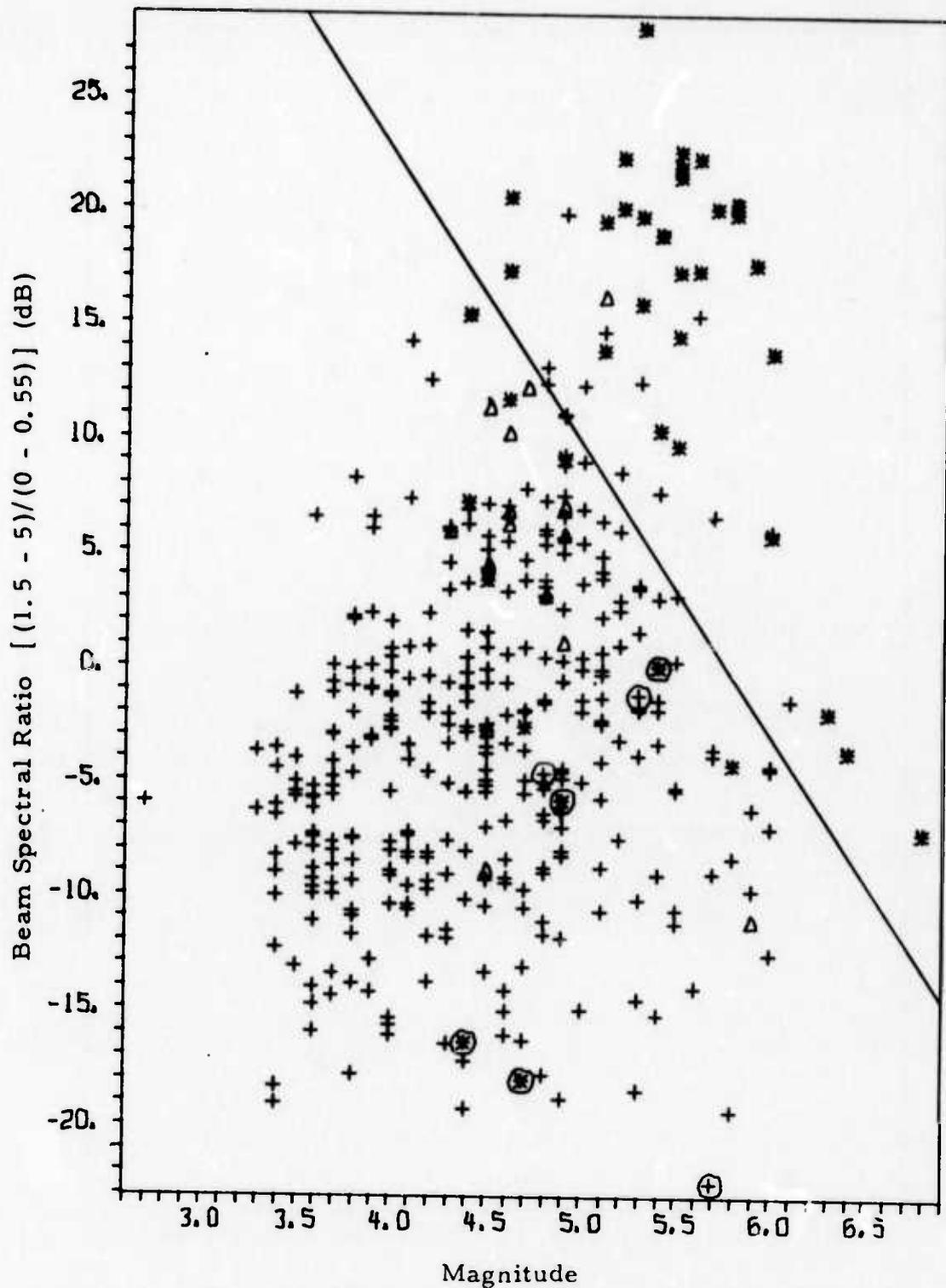


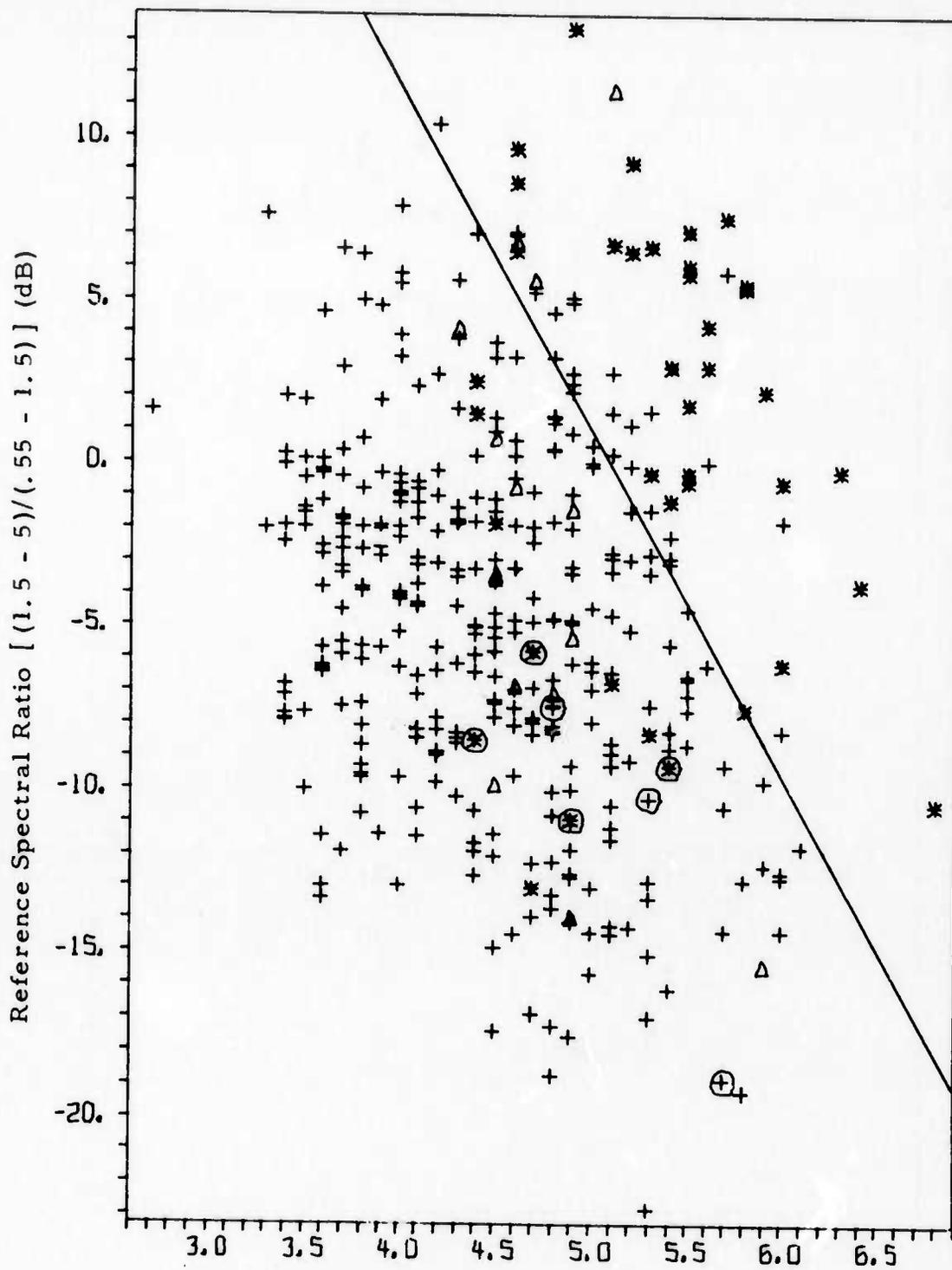
FIGURE IV-10  
 REFERENCE SPECTRAL RATIO  $[(1.5 - 5)/(0 - 0.55)]$  (dB)



- + Eurasian Earthquake (shallow or unknown depth)
- $\Delta$  Deep Eurasian Earthquake (100 km or greater)
- \* Presumed Explosion from Eurasia
- $\oplus$  North American Earthquake
- $\otimes$  Presumed Explosion from North America

FIGURE IV-11

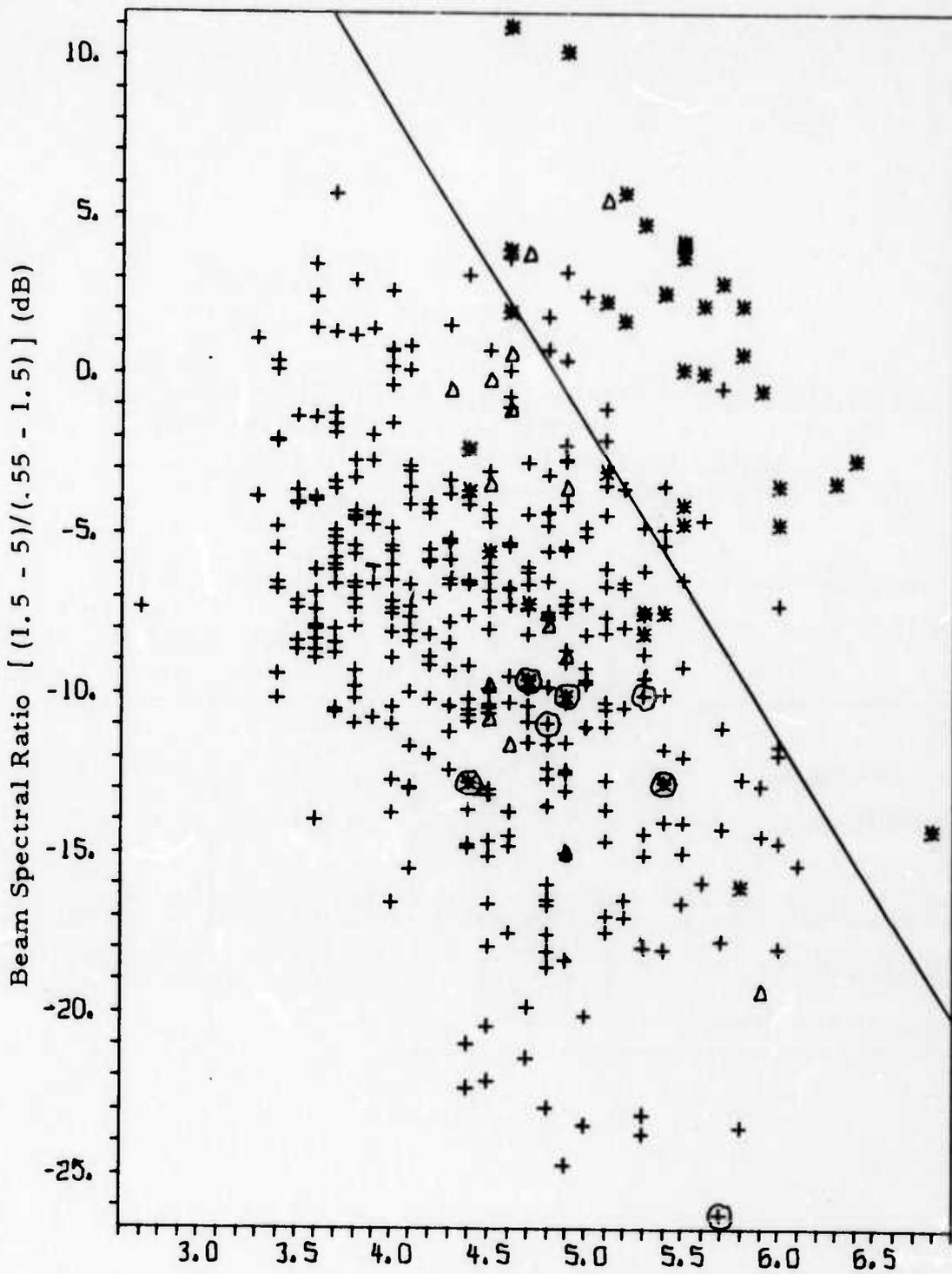
ADJUSTED-DELAY BEAM SPECTRAL RATIO  
 $[(1.5 - 5)/(0 - 0.55)]$  (dB)  
 IV-15



- + Eurasian Earthquake (shallow or unknown depth)
- Δ Deep Eurasian Earthquake (100 km or greater)
- \* Presumed Explosion from Eurasia
- ⊕ North American Earthquake
- ⊗ Presumed Explosion from North America

FIGURE IV-12

REFERENCE SPECTRAL RATIO  $[(1.5 - 5)/(0.55 - 1.5)]$  (dB)



- + Eurasian Earthquake (shallow or unknown depth)
- Δ Deep Eurasian Earthquake (100 km or greater)
- \* Presumed Explosion from Eurasia
- ⊕ North American Earthquake
- ⊗ Presumed Explosion from North America

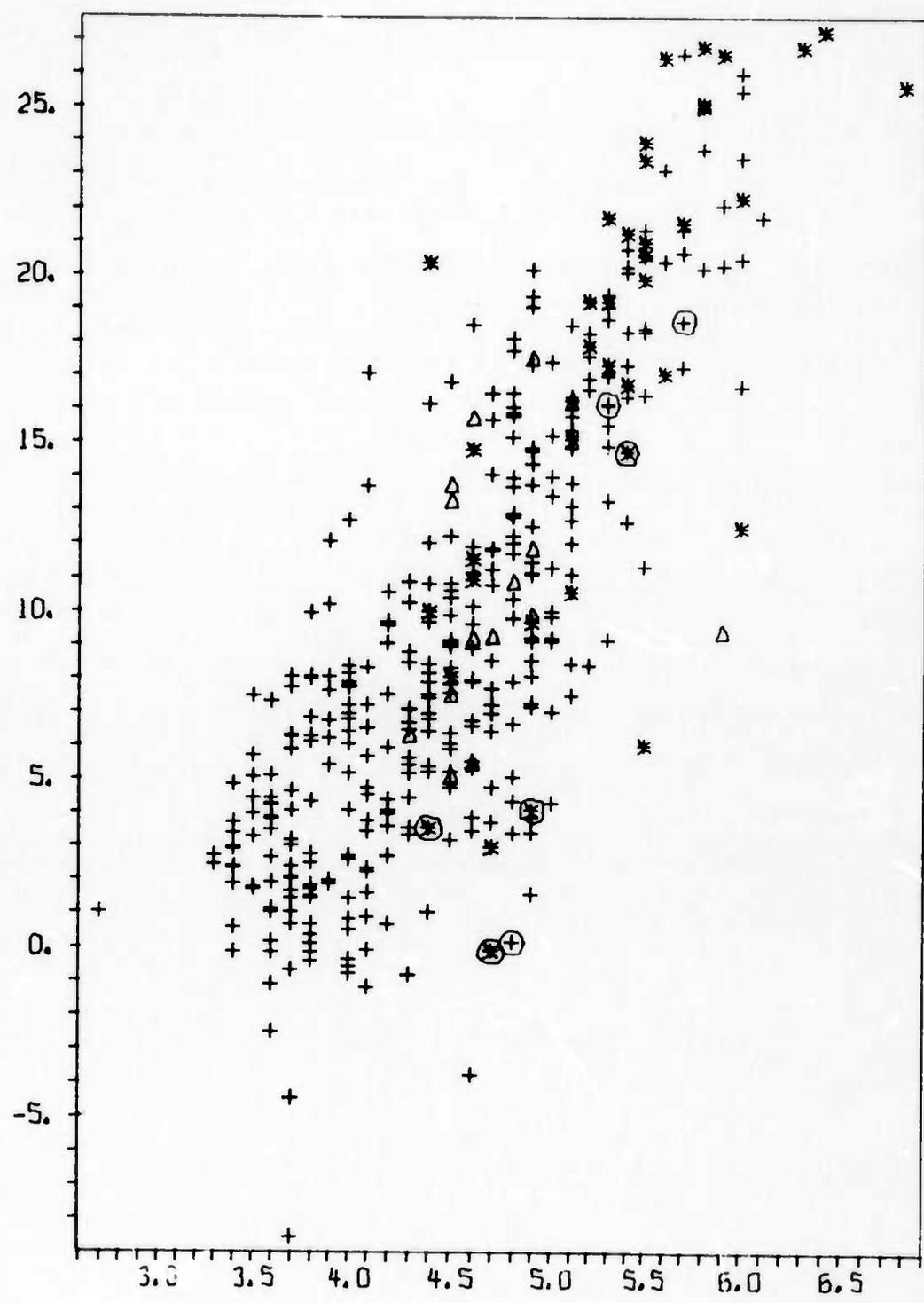
FIGURE IV-13

ADJUSTED-DELAY BEAM SPECTRAL RATIO  
 [ (1.5 - 5)/(0.55 - 1.5) ] (dB)

TABLE IV-1  
 PROBABILITIES OF CORRECT IDENTIFICATION (SHALLOW  
 EARTHQUAKE vs. PRESUMED EXPLOSION USING  
 SHORT PERIOD DISCRIMINANTS FOR  
 EURASIAN EVENTS OF  $m_b \geq 4.4$

	Reference Subarray	Adj. Delay Array Beam	Correlation Between Ref. SA And AB Criteria
Log P30	0.831	0.861	0.86
Log Autocorrelation	0.816	0.847	0.66
Envelope Difference	0.796	0.784	0.90
Dominant Period	0.816	0.878	0.66
Spectral Ratio 3/1	0.874	0.917	0.84
Spectral Ratio 3/2	0.875	0.898	0.89
All Discriminants Combined	0.897	0.934	

BEAM  
SIGNAL TO NOISE RATIO (DB)



MAGNITUDE

FIGURE IV-14

SIGNAL-TO-NOISE RATIO VERSUS MAGNITUDE ( $m_b$ ) FOR  
WIDE-BAND ARRAY BEAMS AT NORSAR

TABLE IV-2  
 PROBABILITIES OF CORRECT IDENTIFICATION (SHALLOW EARTHQUAKE  
 vs. PRESUMED EXPLOSION) USING COMBINATIONS OF TWO  
 SHORT PERIOD DISCRIMINANTS APPLIED  
 AT THE ARRAY BEAM LEVEL  
 (EURASIAN EVENTS OF  $m_b \geq 4.4$ )

		Combined With:					
		1	2	3	4	5	6
1.	Log P30	0.861	0.882	0.862	0.910	0.932	0.929
2.	Log Autocorrelation	0.882	0.847	0.857	0.892	0.922	0.908
3.	Envelope Difference	0.862	0.857	0.784	0.885	0.923	0.906
4.	Dominant Period	0.910	0.892	0.885	0.878	0.922	0.906
5.	Spectral Ratio 3/1	0.932	0.922	0.923	0.922	0.917	0.927
6.	Spectral Ratio 3/2	0.929	0.908	0.906	0.906	0.927	0.898

provided by this combination is essentially equal to that obtained by combining all the criteria (Table IV-1); this shows that there is not much more to be gained by any multivariate discriminant with our definition of separation.

In order to measure the interdependence of our SP discriminants, we computed the correlation coefficients between each pair of discriminants at the array beam level as shown in Table IV-3. Presumed explosions and earthquakes were treated separately. Not unexpectedly these computations show that the three discriminants based on spectral characteristics are strongly interrelated (correlation coefficients 0.6 to 0.8), as is also the case, to a somewhat lesser extent, with the complexity criteria. However, correlations across these two classes are generally low, although in most cases positive. This confirms the observation from Table IV-2 that the highest improvements in separations are generally obtained by combining one spectral and one complexity type discriminant.

As an alternative way of combining complexity with spectral information, it was attempted to apply the standard filter prior to computation of the complexity discriminants. This resulted in some improvement in separation, but the performances were still not comparable to those of the spectral criteria.

Finally, several frequency bands were examined to see if alternative choices could improve appreciably the spectral ratio discriminants. It was found, however, that it was not possible to obtain any significant improvement this way, and we therefore may consider the measured performance of our spectral ratios as typical for this kind of discriminant.

As was stated in Section I, the combined performance of short and long period discriminants at NORSAR will be evaluated in a forthcoming report. That report will also provide detailed case studies of events that fail to be classified properly by the combined criteria.

TABLE IV-3

CORRELATION COEFFICIENTS BETWEEN SP ARRAY BEAM DISCRIMINANT VALUES FOR EURASIAN EVENTS OF  $m_b \geq 4.4$ . NUMBERS BELOW THE DIAGONAL REPRESENT THE SHALLOW EARTHQUAKE POPULATION, WHILE NUMBERS ABOVE THE DIAGONAL CORRESPOND TO PRESUMED EXPLOSIONS.

		Correlated With					
		1	2	3	4	5	6
1.	Log P30	1.00	0.59	0.80	0.26	0.31	0.15
2.	Log Autocorrelation	0.27	1.00	0.49	0.43	0.49	0.37
3.	Envelope Difference	0.71	0.14	1.00	0.23	-0.03	0.18
4.	Dominant Period	0.20	0.47	0.17	1.00	0.63	0.85
5.	Spectral Ratio 3/1	0.25	0.40	0.15	0.68	1.00	0.56
6.	Spectral Ratio 3/2	0.04	0.45	0.08	0.61	0.74	1.00

SECTION V  
SUMMARY AND CONCLUSIONS

This section summarizes the results achieved during the two and one-half year NORSAR short period evaluation program.

1. Data Quality

The SP data recorded at NORSAR has been of consistently high quality throughout the evaluation period, which spanned the time interval from March 1971 through December 1972. On the basis of more than 500 events and 70 noise samples processed by TI for this period, the following observations were made:

- Data was available from NORSAR for more than 95 percent of the time intervals requested by TI.
- In most cases at least 20 subarrays were operational. The worst data loss for a single event was 33 out of 132 sensors.
- Data spikes were observed for 10 events, but these events could still be processed.
- Phase reversals affected 8 sensors during parts of 1971, but was not observed on 1972 data.
- The SP seismometers appeared to be well equalized across the NORSAR array.

2. Noise Analysis

The following conclusions concerning noise analysis are based on 72 sample intervals:

- The noise spectral shape is very simple, with a peak at about 3 to 6 seconds and a rapid fall-off toward shorter periods. The spectral shape does not change significantly across the array.
- Noise levels are very similar across the array. Maximum single sensor variations typically are  $\pm 6$  dB, and most sensors are within  $\pm 3$  dB of the average single sensor level. Variation among subarray beam noise levels is  $\pm 2$  dB.
- Wideband RMS noise level shows a significant variation with time, and correlates strongly with storm activity in the North Atlantic Ocean. The spectral peak generally shifts towards lower frequencies as the noise level increases. Wintertime wideband noise levels are on the average 6 dB higher than summertime levels; this difference is less evident when the "standard" bandpass filter is applied.
- Typical RMS noise levels are:  $0.5 \text{ m}\mu \pm 6$  dB for the wide band array beam.  $0.12 \text{ m}\mu \pm 3$  dB for the array beam through the standard filter. This last number is about a factor of 2 higher than the detection band noise level for LASA.
- Multiple coherence levels within a subarray are low except at the 3 to 6 seconds microseismic peak. Inter-subarray multiple coherencies are low over the entire 0 to 5.0 Hz band.

### 3. Signal Analysis

Our conclusions from the signal analysis are based upon the processing of 567 events; and can be summarized as follows:

- Except for a few close-in, high frequency events signal similarity is good within a subarray. Among subarrays, however, similarity is quite variable.

- Amplitude variations across the array are large, typically 4:1, while variations as high as 10:1 have been observed for Kazakh events. The amplitude patterns are strongly dependent upon source location, but consistent behavior is generally seen within narrow regions. It appears that most of the amplitude variations may be explained by scattering effects due to the irregular structure of the Mohorovicic discontinuity underneath the NORSAR array.
- Time delay anomalies (deviation from plane wave propagation along the great circle path) are not significant for subarray beamforming. Anomalies are significant, however, between subarrays and are occasionally as large as 1 second. Consistent sets of anomalies can in general be obtained for all regions except those within  $30^{\circ}$  epicentral distance of NORSAR.
- Time-domain signal traces from various regions show as expected, a general tendency towards lower complexity as the epicentral distance ( $\Delta$ ) increases. Exceptions to this rule were some high complexity signals observed for Kamchatka events ( $\Delta = 65^{\circ}$ ) and Taiwan events ( $\Delta = 80^{\circ}$ ).
- Signal spectral characteristics show strong regional variations, even between regions very close together, and do not always follow the expected tendency towards lower frequencies as the epicentral distance increases. Significant high frequency energy (2 Hz or more) was observed for events from Greece ( $\Delta = 25^{\circ}$ ), Tadzhik ( $\Delta = 40^{\circ}$ ) and the Kurile Islands ( $\Delta = 70^{\circ}$ ). Signals of dominant low frequency (lower than 1 Hz) were seen mainly from Italy ( $\Delta = 20^{\circ}$ ), Turkey ( $\Delta = 25^{\circ}$ ), Kirgiz ( $\Delta = 45^{\circ}$ ) and Taiwan ( $\Delta = 80^{\circ}$ ).

- Our limited ensemble of Western Hemisphere events show substantially less high frequency energy than the Eurasian events.
- NORSAR body wave magnitudes average about 0.2  $m_b$  units lower than either PDE or LASA values, with a standard deviation of 0.3 around this bias. It appears that this negative bias may be explained as signal loss in array beamforming. The PDE-NORSAR  $m_b$  differences appear to be larger at low magnitudes; this is believed to be because PDE in those cases computes an  $m_b$  based upon only a few stations with favorable radiation patterns, thus resulting in too high  $m_b$  values.

#### 4. Array Processing Performance

- $\sqrt{N}$  noise rejection is achieved over the entire 0 to 5 Hz band both for subarray and array beamforming. The only exceptions to this rule are occasional strong Rayleigh wave noise fields (3-6 second periods) during storm activity in the North Atlantic Ocean that show coherency at the subarray level. Thus noise rejection totals about 21 dB (8 for subarray and 13 for array beamforming).
- Signal degradation for subarray beamforming is 1 dB  $\pm$  0.5 dB in the detection frequency band.
- Signal degradation for array beamforming is quite variable, but in the teleseismic zone the following values were found:  
3 dB  $\pm$  2 dB for wide band signals  
3.5 dB  $\pm$  2 dB in the detection frequency band.
- Diversity-stack beamforming gives the following SNR improvement over the adjusted-delay array beam:  
1.0 dB  $\pm$  0.9 dB for wide band signals  
1.6 dB  $\pm$  1.0 dB in the detection frequency band.

- For detection of Eurasian events, a filter with corner frequencies at about 1.2 and 2.8 Hz and a very sharp rolloff at low frequencies appears to be about optimum. This "standard" filter is similar to the 1.2-3.2 Hz bandpass filter used in the NORSAR on-line Detection Processor.
- Gain in SNR from applying the standard filter was highly variable and showed as expected a strong regional dependence. Average value was found to be  $8 \pm 4$  dB both at the subarray and array beam levels.
- The total net gain of the NORSAR array; i. e., the SNR improvement from the average wide-band single sensor to the adjusted-delay array beam filtered with the standard filter was found to be  $25 \text{ dB} \pm 5 \text{ dB}$ .
- The performance of two partial NORSAR arrays, each consisting of eight subarrays, were evaluated by examining SNR losses for 60 Eurasian events relative to the full array. A partial array consisting of the A and B rings gave an average loss of 4.7 dB SNR, while a partial array situated in the Northeast corner of NORSAR averaged a loss of only 2 dB.

#### 5. Event Detection Capabilities

Event detection thresholds were estimated on the basis of 452 processed events from 1971 and 1972 that had been reported by sources independent of NORSAR. A maximum-likelihood method was utilized in the estimation procedure. The following results were obtained: (Note that all the threshold estimates are relative to  $\rho_{DE}$ , LASA, or ISM magnitudes.)

- 90 percent incremental  $m_b$  detection threshold for all of Eurasia combined is approximately 4.2. This conforms well to the corresponding level of 3.9 for LASA reported by Dean et al., (1971), considering that the NORSAR noise level in the detection band is about a factor of 2 higher (0.3  $m_b$  units).
- For the Kuriles-Kamchatka arc (epicentral distance 60-70 degrees) the 90 percent threshold is slightly below 4.3. The average value for the remainder of Eurasia (distances generally 20-55 degrees) is around 4.0.
- The winter 90 percent threshold was found to be slightly higher (0.1  $m_b$  units) than the summer level. This difference is attributed to seasonal variations in the seismic noise level.
- A theoretical estimate of the NORSAR detection threshold based upon seismic noise levels and measured processing losses gave results consistent with the direct method.
- The operational event reporting performance of the NORSAR system was found to be well below array capability in early 1972, especially for near regional events. A significant improvement was observed one year later for the Japan-Kuriles region, where the array then appeared to be operating at close to optimum capacity.

#### 6. Short Period Discrimination

Five standard short period discriminants were applied to a total of 414 events, including 31 presumed explosions, 27 of which were from Eurasia. The main results are as follows:

- Our SP discriminants do not appear to work well for events from the Western Hemisphere.

- Discriminants based on spectral energy distribution seem to be superior to discriminants based upon the complexity of the signal waveform.
- No single discriminant was able to separate completely between presumed explosions and earthquakes. The best separation was obtained by considering the spectral ratio of energy in the bands 1.5 - 5.0 Hz and 0 - 0.55 Hz, although reservations must be taken due to a possible bias caused by the high SNR values for all events in the presumed explosion population.
- A combination of SP criteria yielded some improvement in separation, but no substantial change. The best improvement was obtained by combining one complexity discriminant with one spectral discriminant.
- A preliminary study of the performance of short period discriminants versus that of  $M_s - m_b$  and other SP-LP criteria gave the expected result that the latter ones in general produce a better separation between earthquakes and presumed explosions.

SECTION VI  
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APPENDICES

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APPENDIX A  
THE COMBINED 1971 - 1972 DATA BASE

All events processed during the NORSAR short-period evaluation are listed in Table A-1. The events are in chronological order starting on March 1, 1971 and ending on December 28, 1972. The parameters listed are: event designation, date, origin time (GMT), latitude and longitude, depth (km) and body-wave magnitude as reported by the source institution.

The following abbreviations are used for the original source of information:

- P : Parameters taken from Preliminary Determination of Epicenters Monthly Summary
- I : Parameters taken from the International Seismic Month event list
- S : Parameters taken from the SDAC/ LASA Weekly Summary
- N : Parameters taken from the NORSAR Seismic Event Summary

Note that in the cases where several sources were reporting the same event, our source was selected according to the following priority list: ISM, PDE, SDAC/ LASA, NORSAR.

The "comment" field provides information relative to our processing of each event, and the following codes have been used:

- ND : Not detected on NORSAR data by the TI analyst.
- MBN : Body-wave magnitude has been computed based on NORSAR data.
- E : The event is a presumed explosion.

TABLE A-1  
EVENT PARAMETERS  
(PAGE 1 OF 13)

EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LONG	DEPTH	MR	SOURCE QTY	COMMENT
KUR/060/07N	03/01/71	06.53.32	50.7N	154.5E	190	4.3	D	
TAI/062/04N	03/03/71	04.01.45	26.9N	125.0E	157	4.5	D	
JAP/063/07N	03/04/71	07.48.30	40.7N	143.5E	27	5.2	D	
MED/063/08N	03/04/71	08.58.29	23.5N	28.3E	NOP	4.0	C	NP
JAP/065/11N	03/06/71	11.45.40	23.1N	142.0E	50	4.1	C	
U7P/065/23N	03/06/71	23.02.02	40.8N	68.6E	185	4.6	C	
JAP/066/02N	03/07/71	02.50.02	43.0N	145.8E	50	3.8	C	
TAL/066/21N	03/07/71	21.55.17	4.3N	127.1E	09	4.9	D	
THR/067/23N	03/08/71	22.44.47	37.5N	29.7E	21	4.7	D	
GPE/069/04N	02/09/71	04.58.38	38.7N	20.3E	16	4.4	D	
CAL/068/15N	03/09/71	15.25.16	36.8N	122.2W	11	4.8	D	
JAP/068/21N	03/09/71	21.19.52	26.6N	142.1E	64	4.4	D	
KUR/069/05N	03/10/71	05.21.03	45.4N	151.2E	60	4.3	D	
SZE/070/04N	03/11/71	04.43.37	28.7N	103.7E	56	5.1	D	
KIR/070/24N	03/11/71	22.59.46	40.1N	77.1E	NOP	4.4	D	MPN
ALI/071/08N	03/12/71	08.24.47	51.5N	177.4E	NOR	4.0	C	NP
MGN/071/08N	03/12/71	08.56.04	47.7N	113.9W	32	4.3	D	NP
PYU/072/02N	03/13/71	02.37.40	26.8N	129.8E	25	4.4	F	
JAP/072/03N	03/13/71	02.59.38	40.1N	142.4E	57	5.1	P	
PYU/072/03N	03/13/71	03.32.20	26.8N	129.7E	NOP	4.3	D	MPN
VAN/072/23N	03/13/71	23.51.35	50.4N	129.9W	NOR	5.7	D	
S&K/073/07N	03/14/71	06.41.10	46.2N	142.2E	257	4.5	D	
KM1/073/12N	03/14/71	12.15.14	53.9N	160.5E	35	5.2	D	
KM2/073/12N	03/14/71	12.24.04	54.0N	160.6E	NOR	4.8	D	
JAP/074/14N	03/15/71	14.12.10	21.1N	141.8E	NOR	4.3	D	
GPE/074/15N	03/15/71	15.23.17	37.2N	24.0E	32	4.8	D	
SIN/075/22N	03/16/71	22.28.22	39.1N	75.7E	NOR	4.5	D	
TAI/075/22N	03/16/71	22.52.09	23.8N	121.5E	40	4.6	D	
SWP/076/02N	03/17/71	02.15.46	46.0N	45.4E	NOR	4.1	C	NP
KUR/077/03N	03/18/71	03.13.15	49.2N	156.3E	NOR	5.1	D	
KUR/077/08N	03/18/71	08.11.04	49.3N	155.2E	60	2.0	C	NP
KAZ/081/04N	03/22/71	04.22.57	49.7N	79.2E	0	5.8	D	
UPA/082/04N	03/23/71	06.59.56	61.2N	56.5E	0	5.6	D	
KIR/082/08N	03/23/71	09.52.12	41.5N	79.2E	NOR	5.7	D	
KIR/082/20N	03/23/71	20.47.17	41.5N	79.2E	NOR	4.0	D	
TSI/083/13N	03/24/71	13.54.17	25.5N	98.2E	12	5.8	D	
KIR/083/20N	03/24/71	20.54.28	41.5N	79.2E	18	5.3	D	
ANG/087/08N	03/28/71	08.23.19	11.9N	95.1E	NOR	5.5	D	
SIN/090/20N	03/31/71	20.00.21	39.6N	74.9E	33	4.9	D	
TIR/092/07N	04/02/71	07.24.50	32.2N	95.1E	NOR	5.1	D	
TAD/094/01N	04/04/71	01.35.22	39.4N	73.2E	NOR	4.3	D	
KUR/095/00N	04/05/71	00.00.04	44.1N	147.4E	NOR	4.2	C	
KUR/095/17N	04/05/71	16.49.08	45.5N	151.9E	NOR	5.1	P	
KUR/098/03N	04/08/71	03.23.50	46.2N	151.2E	NOR	3.2	C	
KUR/099/04N	04/09/71	03.56.07	43.4N	147.6E	50	4.8	D	

TABLE A-1  
EVENT PARAMETERS  
(PAGE 2 OF 13)

EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LON	DEPTH	MD	SOURCE		COMMENT
							PLTN		
KAM/099/08N	04/09/71	09.33.20	56.3N	162.7E	45	4.9	P		
KUR/099/15N	04/09/71	15.05.00	44.3N	147.0E	126	5.1	P		
YUG/100/02N	04/10/71	02.56.05	42.5N	10.1E	21	4.6	P		
GKH/101/02N	04/11/71	02.26.53	59.0N	157.3E	NOR	4.0	S		ND
KUR/101/08N	04/11/71	08.47.05	46.2N	153.0E	NOR	4.5	P		
KUR/102/18N	04/12/71	19.06.32	43.4N	147.3E	35	4.1	S		
IRA/102/19N	04/12/71	19.03.25	28.3N	55.6E	44	4.0	D		
SIP/105/18N	04/15/71	19.53.57	70.1N	155.0E	NOR	3.5	S		ND
KA7/108/23N	04/18/71	23.14.19	45.8N	76.1E	NOR	4.5	S		
GPF/109/02N	04/19/71	02.43.52	39.0N	20.5E	16	5.1	D		
TAC/110/03N	04/20/71	03.48.27	38.3N	73.5E	130	4.9	D		
KA7/115/03N	04/25/71	03.32.58	49.8N	78.1E	0	5.4	D		
HIN/123/19N	05/01/71	19.56.11	36.3N	70.3E	230	4.5	D		
TIP/123/00N	05/02/71	00.33.22	30.8N	84.5E	14	5.4	D		
TUR/126/04N	05/06/71	04.24.33	39.0N	29.7E	22	4.6	P		
CAS/135/04N	05/16/71	04.53.05	38.1N	49.1E	NOR	4.6	P		
URA/136/07N	05/16/71	06.55.32	52.0N	56.0E	NOR	3.2	S		ND
YUN/141/02N	05/21/71	02.59.37	26.7N	101.8E	45	4.9	D		
KUR/142/12N	05/22/71	12.59.53	49.0N	154.0E	NOR	3.2	S		ND
TUR/143/01N	05/23/71	01.02.54	37.6N	30.1E	NOR	4.4	D		
KAZ/145/04N	05/25/71	04.02.57	49.8N	78.2E	0	5.2	D		
TAC/147/00N	05/27/71	00.30.27	39.3N	69.0E	34	4.2	D		
S7M/155/03N	06/04/71	09.10.02	94.6N	109.0E	NOR	5.1	D		
TIB/155/14N	06/04/71	14.10.44	32.2N	95.2E	NOR	5.0	D		
NFC/156/10N	06/05/71	10.21.29	37.3N	113.7E	NOR	4.7	D		
KAZ/157/04N	06/06/71	04.02.57	50.0N	77.9E	0	5.5	D		
TUP/161/09N	06/10/71	09.31.54	39.1N	29.4E	NOR	4.9	D		
ERS/165/14N	06/14/71	14.25.56	56.2N	123.5E	NOR	4.6	D		
KAM/166/14N	06/15/71	14.04.02	52.8N	160.8E	55	5.1	D		
KIR/166/23N	06/15/71	23.17.32	41.6N	79.2E	NOR	4.9	D		
NEV/167/14N	06/16/71	14.50.00	37.0N	116.0W	0	4.9	D		
KUR/169/09N	06/17/71	09.32.05	44.4N	149.0E	NOR	4.9	D		
KAZ/170/04N	06/19/71	04.02.57	50.0N	77.7E	0	5.5	D		
KIR/170/17N	06/19/71	17.23.02	41.5N	79.3E	NOR	5.2	D		
KIR/170/21N	06/19/71	21.05.45	41.5N	79.4E	NOR	4.7	D		
KAZ/181/04N	06/30/71	03.56.57	50.0N	79.1E	0	5.4	D		
WRS/183/17N	07/02/71	17.00.01	67.0N	69.0E	NOR	4.4	S		
KIR/184/04N	07/02/71	04.26.22	41.3N	79.3E	17	4.9	D		
KUR/185/15N	07/04/71	15.25.21	42.7N	147.5E	NOR	4.7	D		
TAC/188/04N	07/07/71	03.52.53	39.6N	73.1E	62	4.5	D		
NEV/189/14N	07/08/71	14.00.00	37.1N	116.1W	0	5.5	D		
KUR/190/16N	07/09/71	16.44.15	42.5N	147.7E	46	4.9	D		
KUR/191/02N	07/10/71	02.04.22	51.0N	153.0E	NOR	3.6	S		
KUR/191/03N	07/10/71	03.05.00	43.6N	147.7E	34	4.9	D		
KUR/191/09N	07/10/71	09.01.34	45.0N	150.5E	NOR	4.6	D		

**TABLE A-1**  
**EVENT PARAMETERS**  
**(PAGE 3 OF 13)**

EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LCN	DEPTH	MP	SOURCE RITA	COMMENT
KUR/191/14N	07/10/71	14.28.56	42.5N	147.0E	55	4.9	P	
URA/191/16N	07/10/71	14.59.59	64.2N	55.2E	0	5.3	P	
KAM/193/02N	07/12/71	02.12.29	53.1N	160.0E	NOP	4.0	D	
KUR/193/06N	07/12/71	06.08.15	45.0N	149.0E	NOP	4.6	S	
KUP/199/12N	07/18/71	12.32.38	51.0N	157.0E	NOP	4.2	S	NO
KAM/201/05N	07/20/71	05.33.24	56.0N	161.0E	NOP	3.7	S	
WPS/202/15N	07/21/71	15.49.27	52.0N	54.0E	NOR	3.8	S	NO
KUR/202/23N	07/21/71	23.50.14	47.0N	147.0E	NOR	3.8	S	NO
HOK/203/16N	07/22/71	16.04.16	41.0N	147.0E	NOP	3.6	S	NO
KUR/204/12N	07/22/71	12.45.12	46.0N	150.0E	NOP	3.7	S	NO
KUR/205/04N	07/24/71	04.19.41	45.0N	147.0E	NOP	3.6	S	NO
SWR/205/11N	07/24/71	11.11.42	48.0N	28.0E	NOR	3.5	S	
KUP/206/00N	07/25/71	00.41.26	50.0N	154.0E	NOR	4.1	S	NO
KAM/206/01N	07/25/71	01.23.19	55.0N	163.0E	NOP	4.0	S	NO
KAM/206/09N	07/25/71	09.12.34	53.0N	160.0E	NOR	3.7	S	
KUR/206/08N	07/25/71	08.35.19	44.0N	147.0E	NOP	4.0	S	
SIN/207/01N	07/26/71	01.48.33	39.0N	77.2E	NOR	6.0	D	
PLS/210/19N	07/29/71	19.40.10	39.6N	20.4E	NOR	4.5	P	
KUR/213/02N	08/01/71	02.06.06	50.4N	156.8E	20	5.6	P	
KUR/214/02N	08/02/71	02.57.24	50.8N	158.1E	NOR	3.6	S	NO
KYU/214/13N	08/02/71	13.59.41	22.0N	120.9E	NOR	3.6	S	
KAM/217/01N	08/05/71	01.05.57	50.0N	156.8E	NOP	3.7	S	NO
SIN/221/01N	08/09/71	01.03.16	42.1N	03.4E	NOR	4.2	D	
IRA/221/02N	08/09/71	02.54.37	36.2N	52.7E	27	5.2	P	
SZE/228/04N	08/16/71	04.58.00	28.9N	103.7E	NOR	5.5	P	
SZE/228/18N	08/16/71	13.25.24	28.8N	103.7E	NOR	4.8	D	
NEV/230/14N	08/18/71	14.00.00	37.1N	116.0N	0	5.4	P	
TAI/231/08N	08/19/71	08.28.52	23.9N	121.0E	23	5.4	P	
KUR/231/22N	08/19/71	22.15.37	49.3N	155.4E	NOR	6.0	D	
IRA/234/17N	08/22/71	17.54.14	20.1N	50.7E	NOR	5.1	P	
SZE/235/05N	08/23/71	05.36.11	28.8N	102.7E	NOR	5.2	P	
KUR/235/21N	08/23/71	21.55.17	45.6N	151.0E	24	5.7	D	
CPS/236/16N	08/24/71	16.33.22	52.2N	91.4E	NOR	5.2	D	
IRA/237/00N	08/25/71	00.30.44	23.2N	52.3E	NOR	4.1	P	
HOK/237/10N	08/25/71	10.41.43	42.1N	142.3E	69	4.1	P	
IRA/238/06N	08/26/71	06.55.08	30.0N	50.7E	45	4.8	D	
IRA/239/05N	08/27/71	05.20.15	30.2N	50.7E	54	5.0	D	
IRA/239/07N	08/27/71	07.59.11	20.1N	50.7E	62	4.4	D	
HON/239/13N	08/27/71	13.49.59	40.9N	143.8E	NOP	4.9	D	
RYU/240/15N	08/29/71	15.57.47	23.3N	120.7E	35	5.7	D	
IRA/240/16N	08/28/71	16.24.44	37.6N	55.8E	NOP	4.8	P	
SIN/241/15N	08/29/71	15.16.56	26.5N	79.5E	NOR	5.0	D	
HIN/241/01N	08/31/71	01.52.14	26.5N	70.9E	27	4.2	P	
HON/245/09N	09/02/71	02.30.22	22.0N	127.7E	34E	4.7	P	
IRA/245/18N	09/02/71	18.24.47	20.1N	50.8E	45	5.1	D	

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EVENT PARAMETERS  
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EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LON	DEPTH	MR	SOURCE	
							PLTA	COMMENT
IRA/245/22N	09/02/71	22.21.30	30.1N	50.9E	39	5.0	P	
SZE/246/18N	09/03/71	18.42.15	29.9N	103.7E	NCR	4.8	P	
TUR/248/12N	09/05/71	12.19.56	27.2N	30.2E	20	4.5	P	
SAK/248/19N	09/05/71	18.55.57	43.0N	142.0E	NCR	4.3	S	
ERS/248/21N	09/05/71	21.12.57	46.6N	140.9E	NCR	4.6	P	
SAK/249/06N	09/06/71	06.45.59	46.4N	141.1E	16	5.7	P	
SAK/249/13N	09/06/71	12.27.10	46.7N	141.4E	29	6.1	P	
SAK/249/20N	09/06/71	20.10.47	46.6N	141.2E	NCR	5.0	P	
RUM/251/04N	09/08/71	04.10.18	45.2N	27.0E	140	3.4	P	
HON/251/07N	09/08/71	07.25.14	37.2N	141.2E	56	5.5	P	
SAK/251/11N	09/08/71	11.48.23	46.4N	141.4E	6	5.2	P	
IRA/251/12N	09/08/71	12.53.34	29.2N	60.0E	12	5.4	P	
ERS/251/16N	09/08/71	16.59.57	46.2N	140.9E	16	5.9	P	
TUR/251/17N	09/08/71	17.01.09	27.3N	30.3E	6	4.8	P	
ERS/251/19N	09/08/71	19.22.15	46.4N	140.9E	19	5.3	P	
TUR/251/22N	09/08/71	22.25.15	41.1N	42.9E	22	4.9	P	
TUR/252/15N	09/09/71	15.10.03	37.2N	20.2E	23	5.3	P	
ERS/252/21N	09/09/71	21.06.20	46.6N	140.9E	NCR	4.5	P	
KUR/252/23N	09/09/71	23.01.06	44.4N	150.9E	7	6.7	P	
AFG/255/05N	09/12/71	05.03.25	37.0N	71.3E	120	4.5	P	
HIN/256/01N	09/12/71	01.45.25	35.7N	69.9E	120	4.9	P	
KUR/256/13N	09/13/71	13.01.29	48.5N	148.9E	269	4.5	P	
HON/258/14N	09/15/71	14.55.05	29.1N	143.4E	17	5.9	P	
PAT/261/02N	09/18/71	02.12.39	51.9N	178.6E	112	4.6	P	
NEV/262/00N	09/19/71	00.58.35	39.4N	118.9E	10	4.5	P	
WES/262/11N	09/19/71	11.00.06	57.9N	41.1E	NCR	4.5	P	
TUR/264/01N	09/21/71	01.04.18	38.2N	43.9E	19	4.2	P	
TIP/264/09N	09/21/71	09.13.51	32.4N	91.8E	NCR	5.0	P	
TUR/264/16N	09/21/71	16.48.51	37.2N	20.2E	37	4.4	P	
ERS/265/14N	09/22/71	14.20.10	46.4N	140.9E	14	4.2	P	
AFG/268/08N	09/25/71	08.53.20	37.8N	69.7E	56	4.5	P	ND
GRE/269/05N	09/26/71	05.44.34	37.2N	22.2E	107	4.1	P	
TAL/269/15N	09/26/71	15.25.18	2.2N	125.8E	48	5.3	P	
HIN/269/23N	09/26/71	23.48.25	36.3N	70.2E	229	4.6	P	
NZM/270/06N	09/27/71	05.59.55	73.4N	55.1E	9	6.4	P	
TUR/271/05N	09/28/71	05.10.24	37.1N	30.1E	26	4.7	P	
TAL/271/14N	09/28/71	14.04.41	2.7N	126.0E	169	5.9	P	
HON/271/14N	09/28/71	14.13.09	40.2N	143.4E	45	4.2	P	
NEV/272/14N	09/29/71	14.00.00	37.0N	116.0W	9	4.4	P	ND
TUR/273/08N	09/30/71	08.45.58	27.7N	20.1E	NCR	4.5	P	
RAT/273/11N	09/30/71	11.52.26	51.3N	178.8E	41	5.0	P	
SIP/273/21N	09/30/71	21.31.25	61.6N	140.3E	NCR	5.4	P	
TUR/276/07N	10/03/71	07.44.26	38.9N	29.9E	23	4.7	P	
TUR/276/17N	10/03/71	17.18.52	36.9N	29.9E	27	4.4	P	
WRS/277/10N	10/04/71	10.00.02	61.6N	47.1E	33	5.1	P	

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EVENT PARAMETERS  
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EVENT DESIGNATION	DATE	ORIGI TIME	LAT	LOA	DEPTH	MA	SOURCE RITN	COMMENT
SIP/278/01N	10/05/71	01.40.41	67.5N	172.8W	NCP	5.3	P	
IRA/278/18N	10/05/71	18.21.17	27.2N	55.8E	20	5.1	P	
TUR/278/18N	10/05/71	18.53.06	29.0N	29.3E	0	4.5	P	
IRA/278/22N	10/05/71	22.45.04	31.6N	50.7E	66	4.1	P	
TUR/279/01N	10/06/71	01.46.39	38.3N	20.2E	10	4.6	P	
RAT/279/11N	10/06/71	11.27.54	52.1N	178.2E	120	4.0	P	
NEV/281/14N	10/08/71	14.20.00	27.1N	116.0W	0	4.7	P	
KAT/282/06N	10/09/71	06.02.57	50.0N	77.7E	0	5.4	P	F
IRA/288/14N	10/15/71	14.19.21	37.3N	54.6E	20	4.7	P	F
AFC/288/16N	10/15/71	16.22.12	37.0N	71.8E	167	4.0	P	
EKZ/294/06N	10/21/71	06.02.57	50.0N	77.6E	0	5.6	P	
WRS/295/05N	10/22/71	05.00.00	51.6N	54.5E	6	5.2	P	F
CAN/310/22N	11/06/71	22.00.00	51.5N	179.1E	2	6.9	P	F
EKZ/333/06N	11/29/71	06.02.57	49.8N	78.1E	0	5.5	P	F
EKZ/349/07N	12/15/71	07.52.59	50.0N	77.9E	0	4.0	P	F
KAT/356/06N	12/22/71	06.59.56	47.9N	48.2E	0	6.0	P	F
EKZ/364/06N	12/30/71	06.20.58	49.7N	78.1E	0	5.8	P	F
SIR/001/15N	01/01/72	15.04.19	59.7N	153.8E	NCP	4.1	S	ND
KUR/001/16N	01/01/72	16.59.04	50.7N	135.8E	NCP	4.6	S	
KUR/001/18N	01/01/72	18.13.54	49.4N	156.5E	50	4.0	S	
KUR/002/05N	01/02/72	05.27.29	46.1N	146.2E	NCP	4.0	S	
GRF/002/09N	01/02/72	09.17.53	27.9N	20.7E	NCP	4.2	S	
SIN/002/10N	01/02/72	10.27.25	41.8N	84.5E	10	5.2	S	
KAM/003/06N	01/03/72	06.26.28	51.6N	150.4E	NCP	4.8	P	
KAM/003/19N	01/03/72	19.26.42	52.0N	159.0E	NCP	4.9	N	MRN
KAM/004/02N	01/04/72	02.29.19	55.6N	161.2E	NCP	4.3	S	
KAM/004/10N	01/04/72	10.42.31	55.6N	163.8E	NCP	4.4	S	
TAI/004/12N	01/04/72	12.15.17	22.4N	122.2E	NCP	4.3	P	
KUR/005/02N	01/05/72	02.16.10	43.8N	147.2E	NCP	4.5	P	
AUS/005/04N	01/05/72	04.57.41	47.8N	16.2E	11	4.0	P	
TAC/005/12N	01/05/72	12.02.54	27.8N	73.1E	NCP	4.5	S	
KOM/005/14N	01/05/72	14.26.48	56.6N	169.4E	NCP	4.0	S	ND
KAM/005/16N	01/05/72	16.09.50	57.3N	160.5E	05	2.9	S	
KIR/006/06N	01/06/72	06.30.36	40.7N	72.4E	NCP	4.7	P	
TAI/006/06N	01/06/72	06.33.24	23.2N	123.4E	NCP	4.7	P	MRN
IRA/006/09N	01/06/72	09.41.32	20.3N	50.5E	NCP	5.2	P	
SWP/007/20N	01/07/72	20.37.32	44.1N	45.1E	NCP	4.2	S	
KOM/009/03N	01/09/72	03.23.06	54.4N	164.4E	NCP	2.6	S	ND
KAM/009/14N	01/09/72	14.00.50	55.7N	163.6E	NCP	4.3	S	
KUR/009/14N	01/09/72	14.47.46	45.1N	148.4E	NCP	2.9	S	ND
PHI/010/05N	01/10/72	05.22.52	20.9N	120.4E	NCP	5.0	S	
KOM/011/08N	01/11/72	08.54.24	54.7N	168.2E	28	2.9	S	
CFE/012/13N	01/12/72	13.51.20	35.0N	24.5E	NCP	4.0	P	MRN
KAM/012/20N	01/12/72	20.20.15	55.6N	163.8E	NCP	4.5	S	
SIP/013/17N	01/13/72	17.24.07	61.9N	147.1E	NCP	5.3	S	

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EVENT PARAMETERS  
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EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LCN	DEPTH	MR	SOURCE PLTN	COMMENT
SIR/014/03N	01/14/72	03.20.20	67.5N	171.5E	NOR	3.0	P	MBN
IPA/014/22N	01/14/72	22.10.04	22.2N	46.9E	NOR	5.1	P	MBN
KUR/015/00N	01/15/72	00.58.33	49.6N	155.0E	NOR	3.9	S	NE
FRS/015/18N	01/15/72	18.07.58	57.4N	120.7E	13	4.7	P	
S11/015/20N	01/15/72	20.21.50	40.3N	79.0E	NOR	5.4	S	
S12/015/20N	01/15/72	20.45.22	39.3N	79.0E	NOR	4.6	P	
KAM/016/04N	01/16/72	04.38.16	55.6N	162.5E	NOR	3.8	S	
KAM/016/11N	01/16/72	11.00.49	55.6N	163.2E	25	3.0	S	
IRA/018/21N	01/18/72	21.12.02	37.5N	48.7E	NOR	4.0	P	MBN
ITA/018/23N	01/18/72	23.16.12	44.2N	3.2E	25	4.1	P	
OOD/020/02N	01/20/72	02.15.07	36.6N	27.1E	NOR	4.8	S	
KUR/022/01N	01/22/72	01.41.24	50.0N	152.0E	NOR	4.2	P	MBN
TUR/022/17N	01/22/72	17.17.21	37.6N	29.0E	12	4.4	P	
KAM/025/10N	01/25/72	10.02.40	53.9N	160.0E	NOR	4.6	P	
ITA/025/20N	01/25/72	20.24.30	43.8N	14.4E	35	4.5	P	
CRF/026/12N	01/26/72	12.54.30	34.5N	25.5E	NOR	4.0	S	
KAM/027/20N	01/27/72	20.37.28	55.7N	162.3E	40	3.9	S	
FCS/028/04N	01/28/72	04.22.28	27.5N	126.5E	NOR	4.4	S	
PAK/028/10N	01/28/72	10.26.54	26.6N	66.3E	NOR	4.0	N	
KIP/028/20N	01/28/72	20.25.19	42.0N	72.0E	NOR	4.4	P	MBN
EPS/028/21N	01/28/72	21.50.00	45.0N	126.0E	NOR	4.0	N	
KUR/028/23N	01/28/72	23.42.51	49.2N	157.3E	NOR	3.8	S	
IRA/029/09N	01/29/72	09.50.58	29.0N	62.0E	NOR	3.9	N	
KAM/032/10N	02/01/72	10.16.09	55.8N	162.8E	NOR	4.1	S	
KAM/033/04N	02/02/72	04.26.59	55.7N	162.0E	NOR	3.7	S	
KUR/033/09N	02/02/72	09.58.51	46.8N	146.4E	NOR	3.6	S	
KUR/033/17N	02/02/72	17.56.30	50.7N	160.1E	NOR	3.6	S	
YUN/034/07N	02/03/72	07.22.49	22.4N	102.4E	NOR	4.5	P	
ITA/035/02N	02/04/72	02.42.19	43.2N	13.2E	25	4.8	P	
PAI/035/03N	02/04/72	03.24.56	51.4N	118.0E	NOR	4.2	S	
ITA/035/04N	02/04/72	04.40.55	42.9N	13.2E	NOR	4.9	P	NE
ITA/035/09N	02/04/72	09.18.22	43.9N	13.2E	23	4.4	P	
ITA/035/17N	02/04/72	17.19.52	43.8N	13.2E	23	4.4	P	
ITA/035/19N	02/04/72	19.02.56	43.9N	13.2E	NOR	4.8	P	
ITA/036/01N	02/05/72	01.26.23	43.8N	13.3E	NOR	4.8	P	
ITA/036/03N	02/05/72	03.49.45	43.2N	13.7E	NOR	4.4	P	
ITA/036/05N	02/05/72	05.05.51	43.7N	13.5E	NOR	4.6	P	
ITA/036/07N	02/05/72	07.08.13	43.9N	13.2E	NOR	4.7	P	
ADR/037/01N	02/06/72	01.24.22	44.0N	13.2E	NOR	4.9	P	
KAZ/037/08N	02/06/72	08.03.42	46.0N	90.0E	NOR	4.2	N	
ITA/037/21N	02/06/72	21.44.29	43.8N	13.2E	NOR	4.4	P	
ITA/039/12N	02/08/72	12.19.15	43.8N	13.3E	NOR	4.6	P	
EKZ/041/05N	02/10/72	05.02.57	50.0N	78.9E	0	5.5	P	
IRA/041/09N	02/10/72	09.04.09	29.6N	50.9E	NOR	3.0	P	
IRA/041/16N	02/10/72	16.40.16	29.5N	50.9E	40	4.1	P	

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EVENT PARAMETERS  
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EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LON	DEPTH	MP	SOURCE	
							PLTN	COMMENT
SIN/042/05N	02/11/72	05.55.46	39.9N	77.4E	23	4.9	P	
TIR/042/12N	02/11/72	12.20.42	29.0N	87.0E	NCR	4.3	M	
KAM/042/21N	02/11/72	21.36.17	56.1N	162.9E	44	4.6	P	
KUR/044/05N	02/13/72	05.24.57	43.5N	147.0E	NCR	3.8	S	
GRF/044/13N	02/13/72	13.07.11	37.1N	24.0E	27	4.5	P	
KOM/044/22N	02/13/72	22.36.54	55.2N	165.5E	NCR	3.9	S	
KUR/046/16N	02/15/72	16.45.22	45.0N	153.0E	NCR	4.1	S	
GRF/047/00N	02/16/72	00.42.24	36.9N	24.2E	NCR	4.5	P	
SIN/047/23N	02/16/72	23.19.20	41.7N	80.7E	20	4.9	P	
KUR/049/19N	02/18/72	18.02.34	43.6N	147.8E	36	4.7	S	
SIN/051/10N	02/20/72	10.22.46	38.5N	90.5E	16	3.9	I	MPN
OKH/051/10N	02/20/72	10.08.46	47.9N	145.9E	97	4.2	I	
KAM/051/20N	02/20/72	20.06.11	50.8N	141.5E	NCR	4.1	I	
KAM/052/22N	02/21/72	22.00.59	54.4N	161.3E	NCR	4.8	I	
YUG/052/23N	02/21/72	23.02.55	41.0N	22.3E	NCR	4.0	I	
MON/053/01N	02/22/72	01.53.36	49.0N	115.0E	NCR	4.1	I	
HIN/053/08N	02/22/72	08.14.26	36.6N	68.6E	NCR	4.0	I	MPN
KUR/054/03N	02/23/72	03.42.41	43.9N	148.3E	30	4.9	I	
KAM/054/19N	02/23/72	19.37.29	55.0N	163.0E	NCR	3.7	I	ND
KUR/055/10N	02/24/72	10.15.37	48.8N	155.7E	NCR	5.0	I	
KUR/055/18N	02/24/72	18.17.34	49.0N	158.0E	NCR	3.5	I	ND
KUR/056/19N	02/25/72	19.59.29	46.0N	147.0E	NCR	3.8	I	
WRS/056/22N	02/25/72	22.34.49	50.0N	38.0E	NCR	3.7	I	
KUR/056/22N	02/25/72	22.43.07	49.2N	156.0E	NCR	4.0	I	
KUR/057/05N	02/26/72	05.58.22	46.8N	152.6E	NCR	4.2	I	
KAM/057/09N	02/26/72	09.04.32	55.0N	162.0E	NCR	3.3	I	ND
ERS/057/15N	02/26/72	15.06.42	53.3N	138.7E	NCR	3.8	I	MPN
YUN/057/18N	02/26/72	18.56.13	27.1N	100.2E	NCR	4.7	I	
LOI/058/08N	02/27/72	08.42.59	88.0N	74.0W	NCR	3.3	I	ND
LOI/058/10N	02/27/72	10.03.03	87.0N	53.5W	NCR	4.9	I	
LOM/058/11N	02/27/72	11.03.19	90.0N	95.0W	NCR	3.5	I	
LOM/058/17N	02/27/72	17.50.25	86.2N	77.2W	NCR	4.4	I	
RAI/058/22N	02/27/72	22.15.03	55.0N	93.2E	NCR	4.5	I	
KUR/059/01N	02/28/72	01.04.22	46.0N	148.0E	NCR	4.2	I	ND
PAK/059/05N	02/28/72	05.18.56	36.7N	71.4E	NCR	4.2	I	MPN
KAM/059/11N	02/28/72	11.35.31	56.0N	163.0E	NCR	4.1	I	ND
AFG/059/18N	02/28/72	18.12.35	35.0N	68.7E	NCR	4.4	I	MPN
KAM/059/20N	02/28/72	20.04.00	56.1N	164.2E	NCR	3.6	I	ND
IRQ/060/08N	02/29/72	08.02.51	32.8N	46.6E	NCR	4.0	I	MPN
TPA/062/14N	03/02/72	14.10.13	31.6N	42.1E	NCR	4.0	I	MPN
ALM/062/19N	03/02/72	19.57.42	43.0N	76.0E	NCR	3.5	I	MPN
KAM/063/00N	03/03/72	00.39.23	53.0N	159.2E	NCR	4.1	I	MPN
NSI/063/05N	03/03/72	05.26.53	77.8N	116.7E	NCR	3.8	I	
KOM/063/08N	03/03/72	08.13.55	55.8N	163.9E	NCR	4.1	I	
YUG/063/21N	03/03/72	21.26.51	44.7N	18.4E	22	4.9	I	

TABLE A-1  
EVENT PARAMETERS  
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EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LON	DEPTH	MP	SOURCE	
							RLTN	COMMENT
KUR/063/23N	03/03/72	23.10.41	50.2N	155.7E	NDR	4.5	I	
SIN/064/04N	03/04/72	04.00.09	40.2N	79.0E	NDR	4.5	I	
KAM/066/06N	03/06/72	06.05.08	53.5N	160.9E	NDR	3.9	I	ND
KUR/066/09N	03/06/72	09.59.09	45.0N	150.0E	NDR	3.7	I	
OKH/066/19N	03/06/72	19.13.25	56.0N	140.0E	NDR	4.2	I	
CHI/066/23N	03/06/72	23.17.53	40.0N	103.0E	NDR	4.5	I	ND
YUG/067/05N	03/07/72	05.21.21	43.0N	21.0E	NDR	2.7	I	MRN
OKH/068/02N	03/08/72	02.38.11	51.2N	151.9E	NDR	4.2	I	
IRA/068/21N	03/08/72	21.49.11	27.6N	56.7E	45	4.0	I	
RUL/068/22N	03/08/72	22.04.02	40.8N	22.8E	NDR	3.5	I	MRN
KAZ/070/04N	03/10/72	04.56.57	49.8N	78.2E	0	5.5	I	F
KUR/070/06N	03/10/72	06.50.18	45.1N	149.5E	NDR	3.7	I	
ARC/071/06N	03/11/72	06.47.07	81.0N	157.0E	NDR	4.3	I	ND
KAS/071/13N	03/11/72	13.31.39	35.0N	76.0E	NDR	4.1	I	MRN
KUR/073/02N	03/13/72	02.11.05	49.0N	158.0E	NDR	3.8	I	
AFG/073/05N	03/13/72	05.49.13	37.0N	70.0E	NDR	4.0	I	MRN
TIP/073/18N	03/13/72	18.27.07	34.0N	93.0E	NDR	4.1	I	MRN
TIB/075/06N	03/15/72	06.00.33	30.4N	84.5E	NDR	5.3	I	MRN
KUR/077/07N	03/17/72	07.49.02	49.0N	154.2E	NDR	5.2	I	
TAD/077/09N	03/17/72	09.17.11	40.1N	69.7E	26	5.2	I	
IRA/077/17N	03/17/72	17.11.22	28.0N	54.0E	NDR	3.2	I	MRN
KAS/077/23N	03/17/72	23.33.37	32.0N	75.0E	NDR	3.5	I	MRN
KAZ/078/07N	03/18/72	07.11.55	47.0N	81.0E	NDR	3.6	I	MRN
KAM/078/13N	03/18/72	13.52.14	57.0N	163.0E	NDR	3.6	I	
KAM/078/18N	03/18/72	18.29.37	50.6N	156.7E	NDR	4.7	I	
OKH/078/19N	03/18/72	19.17.25	54.0N	150.0E	NDR	3.7	I	
KIR/078/19N	03/18/72	19.54.18	41.0N	72.0E	NDR	3.2	I	MRN
CAU/079/03N	03/19/72	03.34.31	42.7N	29.1E	NDR	3.9	I	
KUR/080/14N	03/20/72	14.08.12	47.0N	154.0E	NDR	4.0	I	MRN
SIN/080/21N	03/20/72	21.47.55	40.0N	80.0E	NDR	3.4	I	MRN
CK7/153/01N	06/01/72	01.23.28	52.0N	70.0E	NDR	3.6	S	ND
MON/153/11N	06/01/72	11.22.15	44.0N	103.0E	NDR	3.7	N	
GPE/153/13N	06/01/72	13.44.11	39.0N	24.0E	NDR	4.1	S	
KOM/153/21N	06/01/72	21.42.49	55.0N	144.0E	NDR	3.2	S	
IRA/154/00N	06/02/72	00.12.12	30.0N	53.0E	NDR	4.1	N	
KUR/154/01N	06/02/72	01.53.07	50.0N	152.0E	NDR	3.2	S	ND
SI1/154/04N	06/02/72	04.21.49	42.0N	82.0E	NDR	3.8	N	
SI2/154/04N	06/02/72	04.22.16	42.0N	82.0E	NDR	3.7	N	
SIN/154/05N	06/02/72	05.11.12	42.0N	81.0E	NDR	3.5	N	
SIN/154/06N	06/02/72	06.30.49	42.0N	81.0E	NDR	3.0	N	
TSI/154/16N	06/02/72	16.49.22	36.0N	92.0E	NDR	3.7	N	
CHI/154/20N	06/02/72	20.32.55	28.4N	95.9E	NDR	4.3	D	
RYU/155/02N	06/03/72	02.16.51	23.5N	125.5E	NDR	5.2	D	
IRA/155/08N	06/03/72	03.21.30	29.0N	53.0E	NDR	4.2	N	
IRA/156/03N	06/04/72	03.27.49	30.0N	54.0E	NDR	4.2	N	

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EVENT PARAMETERS  
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EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LCN	DEPTH	MR	SOURCE PLTN	COMMENT
KAM/156/07N	06/04/72	07.52.38	53.0N	158.0E	NDR	4.0	S	
KOM/156/12N	06/04/72	12.57.33	53.0N	159.0E	NDR	3.4	S	
KOM/156/13N	06/04/72	13.02.07	54.0N	165.0E	NDR	3.5	S	ND
TUR/156/16N	06/04/72	16.29.34	39.4N	26.2E	17	4.1	P	
TSI/156/23N	06/04/72	23.22.18	33.0N	97.0E	NDR	3.5	N	
KAM/157/04N	06/05/72	04.12.54	56.2N	163.1E	NDR	4.3	P	
GRF/157/10N	06/05/72	10.44.59	37.8N	21.4E	69	4.2	P	
IRA/157/11N	06/05/72	11.17.57	34.0N	46.0E	NDR	3.0	N	
PAK/157/11N	06/05/72	11.52.53	29.8N	70.3E	27	4.8	P	
NFJ/157/19N	06/05/72	19.00.12	86.5N	78.9E	NDR	4.5	S	
KUR/158/02N	06/06/72	02.04.44	44.0N	148.0E	NDR	3.4	S	
KUR/158/06N	06/06/72	06.32.10	49.0N	155.0E	NDR	3.6	S	ND
KAM/159/10N	06/06/72	10.43.33	55.9N	163.8E	NDR	4.7	P	
FK7/159/01N	06/07/72	01.27.57	49.8N	79.2E	0	5.5	P	F
KOM/159/06N	06/07/72	06.00.20	56.0N	166.0E	NDR	3.8	S	
TAI/160/09N	06/08/72	09.14.09	21.1N	120.2E	NDR	5.4	P	
IRA/160/09N	06/08/72	09.39.21	34.1N	46.2E	18	4.9	P	
TAI/160/10N	06/08/72	10.17.44	21.0N	120.2E	NDR	4.9	P	
TUR/160/12N	06/08/72	12.46.15	41.0N	44.0E	NDR	4.1	S	
MUR/160/16N	06/08/72	16.08.06	19.0N	94.0E	NDR	4.3	N	
TAI/160/16N	06/08/72	16.44.24	21.0N	120.2E	NDR	4.7	P	
CAU/160/17N	06/08/72	17.25.52	43.2N	47.2E	NDR	4.5	P	
TIR/160/23N	06/08/72	23.10.12	29.5N	92.3E	64	4.7	P	
KUR/161/00N	06/09/72	00.16.42	47.0N	153.0E	NDR	4.4	S	
CRE/161/07N	06/09/72	07.42.20	34.8N	26.5E	NDR	4.9	P	
TUR/161/19N	06/09/72	19.42.27	37.0N	44.0E	NDR	4.0	N	
IRA/162/03N	06/10/72	03.39.33	31.0N	51.0E	NDR	3.6	N	
PAK/162/11N	06/10/72	11.29.11	28.2N	66.5E	NDR	4.5	P	
KAM/163/14N	06/11/72	14.14.01	53.0N	160.0E	NDR	3.3	S	ND
KU1/163/23N	06/11/72	23.23.04	48.0N	152.0E	NDR	4.0	S	
KU2/163/23N	06/11/72	23.33.44	47.0N	152.0E	NDR	4.3	S	
KUP/164/00N	06/12/72	00.19.16	44.0N	148.0E	NDR	3.7	S	
IR1/164/13N	06/12/72	13.34.01	33.1N	46.3E	NDR	5.4	P	
IR2/164/13N	06/12/72	13.39.59	33.1N	46.2E	NDR	5.1	P	
IRA/165/00N	06/13/72	00.55.37	33.1N	46.3E	27	5.1	P	
KAM/165/04N	06/13/72	04.53.30	55.0N	162.0E	NDR	3.8	S	
CAS/166/00N	06/14/72	00.49.54	40.1N	51.9E	47	4.7	P	
IRA/166/04N	06/14/72	04.34.29	33.0N	46.1E	NDR	5.3	P	
IR1/166/12N	06/14/72	12.11.28	31.0N	52.0E	NDR	3.5	N	
IR2/166/12N	06/14/72	12.35.05	27.0N	56.0E	NDR	3.6	N	
ITA/166/18N	06/14/72	18.55.53	43.7N	13.4E	14	4.9	P	
GRF/167/00N	06/15/72	00.32.24	29.3N	22.2E	26	4.9	P	
KOM/167/13N	06/15/72	13.49.13	54.0N	169.0E	NDR	3.5	S	
TUR/167/14N	06/15/72	14.19.02	38.0N	28.0E	NDR	3.3	N	
KAM/168/09N	06/16/72	09.54.41	56.0N	161.0E	NDR	4.1	S	

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EVENT PARAMETERS  
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EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LCN	DEPTH	MR	SOURCE PLTA	COMMENT
HIN/168/18N	06/16/72	18.57.52	36.0N	69.2E	40	4.5	P	
KAM/168/22N	06/16/72	22.12.12	53.0N	157.0E	NCR	2.6	S	ND
IRA/169/23N	06/16/72	23.22.27	34.0N	46.0E	NCR	3.7	N	
AUS/169/09N	06/17/72	09.02.48	48.3N	14.5E	NCR	4.6	P	
KUR/169/19N	06/17/72	19.18.21	44.2N	149.1E	64	4.6	P	
TIR/170/04N	06/18/72	04.30.47	33.0N	83.0E	NCR	4.3	N	
KUP/170/09N	06/18/72	09.10.54	48.0N	154.0E	NCR	3.9	S	
KUP/171/18N	06/19/72	19.07.52	43.8N	151.5E	NCR	4.5	P	
KUP/171/22N	06/19/72	22.41.42	48.0N	157.0E	NCR	4.1	S	ND
IRA/172/05N	06/20/72	05.17.42	29.0N	52.0E	NCR	4.0	N	
FRS/172/09N	06/20/72	09.18.09	52.0N	131.0E	NCR	3.7	S	ND
KAS/172/15N	06/20/72	15.34.37	32.0N	75.0E	NCR	2.6	N	
KAM/173/00N	06/21/72	00.12.58	53.0N	161.0E	NCR	4.3	N	
KM2/173/00N	06/21/72	00.19.02	54.0N	159.0E	NCR	2.7	N	
TUR/173/05N	06/21/72	05.06.17	40.2N	30.0E	NCR	4.1	P	
KAM/173/10N	06/21/72	10.42.45	54.0N	161.0E	NCR	4.3	S	
TUR/173/14N	06/21/72	14.52.09	37.0N	41.0E	NCR	3.8	N	
ITA/173/15N	06/21/72	15.06.53	43.9N	13.3E	4	4.4	P	
KUR/174/02N	06/22/72	02.35.51	49.0N	154.0E	NCR	4.5	N	
TUR/175/04N	06/23/72	04.25.27	41.0N	30.0E	NCR	2.7	S	
GRE/175/07N	06/23/72	07.18.14	37.0N	21.0E	NCR	2.4	N	
TAD/175/16N	06/23/72	16.59.48	37.0N	75.0E	NCR	2.7	N	
IRA/176/06N	06/24/72	06.57.02	28.0N	54.0E	NCR	2.5	N	
YUG/176/07N	06/24/72	07.17.56	43.7N	16.9E	NCR	5.3	P	
HIN/176/16N	06/24/72	16.14.54	36.0N	69.0E	NCR	3.9	N	
TAD/176/18N	06/24/72	18.53.10	39.0N	74.0E	NCR	2.4	N	
YUG/177/04N	06/25/72	04.59.12	44.0N	15.8E	NCR	4.4	P	
HIN/177/07N	06/25/72	07.55.45	34.3N	69.6E	46	4.7	P	
KAM/177/17N	06/25/72	17.35.50	54.0N	160.0E	NCR	4.1	S	ND
TAI/178/08N	06/26/72	08.08.25	21.1N	120.3E	NCR	5.0	P	
KAM/178/17N	06/26/72	17.32.22	56.0N	158.0E	NCR	3.6	S	ND
HIN/178/20N	06/26/72	20.59.02	36.0N	69.0E	NCR	3.7	N	
AFG/179/05N	06/27/72	05.07.42	39.0N	65.0E	NCR	4.0	N	
PAK/179/06N	06/27/72	06.39.44	29.7N	70.3E	12	5.5	P	
KAM/179/06N	06/27/72	06.49.03	54.0N	159.0E	NCR	3.8	S	
BUR/179/09N	06/27/72	09.05.52	26.2N	96.6E	22	4.4	P	
WRS/179/12N	06/27/72	12.20.26	51.0N	47.0E	NCR	3.5	S	
HIN/179/15N	06/27/72	15.59.25	36.3N	69.5E	53	5.1	P	
YUG/180/01N	06/28/72	01.43.56	43.0N	20.5E	NCR	4.9	P	
TSI/180/03N	06/28/72	03.09.59	33.0N	91.0E	NCR	2.6	N	
KOM/180/06N	06/28/72	06.00.22	55.0N	164.0E	NCR	2.4	S	ND
CYP/180/08N	06/28/72	08.16.55	35.0N	32.0E	NCR	4.3	N	
UAR/180/09N	06/28/72	09.49.35	27.6N	23.8E	15	5.6	P	
KAM/180/14N	06/28/72	14.58.49	53.0N	161.0E	NCR	3.9	S	
CKZ/181/00N	06/29/72	00.41.02	54.0N	69.0E	NCR	3.7	S	

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EVENT PARAMETERS  
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EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LONG	DEPTH	MR	SOURCE PLTN	COMMENT
AFG/181/02N	06/29/72	03.32.11	29.9N	71.4E	53	4.9	P	
IRA/182/17N	06/30/72	17.49.32	27.2N	56.8E	NOR	4.6	P	
TAI/182/19N	06/30/72	18.57.42	24.3N	121.1E	NOR	4.9	P	
IRA/182/20N	06/30/72	20.31.33	30.0N	53.0E	NOR	4.0	N	
KGM/183/02N	07/01/72	02.10.18	54.0N	166.0E	NOR	3.4	S	
IRA/184/12N	07/02/72	12.56.07	30.1N	50.8E	31	5.4	P	
IRA/184/14N	07/02/72	14.05.06	30.0N	50.8E	31	4.6	P	
IRA/185/02N	07/03/72	02.10.00	30.1N	50.8E	38	5.0	P	
AFG/185/03N	07/03/72	03.32.50	36.2N	71.1E	128	4.3	P	
IRA/185/12N	07/03/72	12.31.05	30.0N	53.0E	NOR	4.0	N	
IRA/185/19N	07/03/72	19.26.22	32.0N	48.0E	NOR	4.0	N	
IRA/185/21N	07/03/72	21.38.22	30.0N	51.0E	43	5.1	P	
KUR/186/04N	07/04/72	04.42.34	49.0N	156.0E	NOR	3.7	S	NO
TUR/186/06N	07/04/72	06.17.25	41.0N	33.0E	NOR	3.4	S	
IRA/186/09N	07/04/72	09.25.07	28.0N	54.0E	NOR	3.0	N	
KAM/186/13N	07/04/72	13.52.19	55.0N	163.0E	NOR	4.4	S	
KUR/186/21N	07/04/72	21.47.57	49.0N	151.0E	NOR	3.6	S	NO
IRA/187/01N	07/05/72	01.04.44	23.0N	54.0E	NOR	3.8	N	
SIN/187/01N	07/05/72	01.09.53	44.4N	81.1E	NOR	4.6	P	
SIN/187/02N	07/05/72	02.41.54	44.0N	86.0E	NOR	3.5	N	
SIN/187/04N	07/05/72	04.09.49	43.6N	87.9E	NOR	4.3	P	
IRA/187/09N	07/05/72	09.59.09	33.0N	50.0E	NOR	3.4	N	
IRA/187/16N	07/05/72	16.29.27	31.0N	52.0E	NOR	4.0	N	
GRE/187/18N	07/05/72	18.05.00	37.0N	20.0E	NOR	4.4	S	
EK7/188/01N	07/06/72	01.02.58	49.7N	78.0E	0	4.4	P	F
PAK/188/16N	07/06/72	16.05.22	30.2N	69.7E	53	4.3	P	
KUR/188/19N	07/06/72	19.02.20	44.0N	146.0E	NOR	3.0	N	
KAM/189/05N	07/07/72	05.13.06	56.0N	163.0E	NOR	3.7	S	NO
PUR/189/12N	07/07/72	12.04.12	20.5N	98.1E	27	5.0	P	
SZE/189/23N	07/07/72	23.43.41	32.0N	102.0E	NOR	3.7	N	
GRE/190/05N	07/08/72	05.46.11	42.0N	24.0E	NOR	4.7	S	
KUR/190/08N	07/08/72	08.29.27	46.1N	154.6E	NOR	4.0	P	
KUR/190/21N	07/08/72	21.07.27	48.0N	151.0E	NOR	4.2	S	
WRS/191/07N	07/09/72	07.00.08	52.0N	31.0E	NOR	4.6	S	F
MED/191/13N	07/09/72	13.21.22	36.0N	19.0E	NOR	4.0	S	
RYU/192/00N	07/10/72	00.41.29	29.0N	131.0E	NOR	3.9	N	
RYU/192/03N	07/10/72	03.02.02	30.0N	129.0E	NOR	3.8	N	
SIN/192/19N	07/10/72	19.03.22	43.4N	98.6E	NOR	4.7	P	
AFG/193/04N	07/11/72	04.20.41	27.0N	72.0E	NOR	4.2	S	
KUR/193/06N	07/11/72	06.58.21	48.4N	154.5E	62	5.2	P	
KAM/193/08N	07/11/72	08.53.49	55.0N	163.0E	NOR	3.6	S	NO
IRA/193/15N	07/11/72	15.33.48	32.0N	60.0E	NOR	3.7	N	
IRA/193/22N	07/11/72	22.49.02	36.1N	45.7E	NOR	4.7	P	
KUR/194/00N	07/12/72	00.14.27	49.3N	155.4E	NOR	5.2	P	
PAK/194/01N	07/12/72	01.21.18	33.0N	73.0E	NOR	3.5	N	

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EVENT PARAMETERS  
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EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LONG	DEPTH	MW	SOURCE RICH	COMMENT
KOM/194/14N	07/12/72	14.25.30	55.0N	149.0E	NDR	4.0	A	
GRF/194/19N	07/12/72	19.41.52	39.0N	21.0E	NDR	3.9	S	
KUR/194/20N	07/12/72	20.14.51	49.0N	154.0E	NDR	3.7	S	ND
TIB/195/05N	07/13/72	05.27.44	31.0N	89.0E	NDR	3.9	N	
KUR/195/15N	07/13/72	15.05.44	44.0N	150.0E	NDR	4.2	N	
PAK/195/18N	07/13/72	18.50.52	28.0N	63.0E	NDR	3.7	A	
ITA/195/22N	07/13/72	22.21.17	43.8N	13.3E	NDR	4.4	D	
TAI/195/23N	07/13/72	23.02.25	22.0N	122.0E	NDR	3.9	A	
TUR/196/04N	07/14/72	04.23.45	36.0N	21.0E	NDR	3.9	N	
IRA/196/13N	07/14/72	13.04.12	30.1N	50.8E	34	4.4	D	
IR2/196/13N	07/14/72	13.18.11	30.0N	51.0E	NDR	3.9	N	
IRA/196/17N	07/14/72	17.49.13	30.0N	51.0E	NDR	3.4	N	
RYU/196/18N	07/14/72	18.50.32	30.0N	122.0E	ADR	3.9	S	
KIR/197/00N	07/15/72	00.35.52	43.0N	78.0E	NDR	3.9	A	
RYU/197/02N	07/15/72	02.15.42	24.2N	125.1E	29	5.1	D	
KUR/197/09N	07/15/72	09.51.51	47.0N	152.0E	NDR	4.4	S	
KUR/197/17N	07/15/72	17.25.37	46.0N	149.0E	NDR	3.5	S	
TIR/198/02N	07/16/72	02.20.24	32.5N	95.0E	ADR	5.2	D	
TUR/198/02N	07/16/72	02.46.37	36.0N	44.0E	NDR	5.5	S	
TIP/198/03N	07/16/72	03.40.00	32.6N	95.8E	NDR	4.7	D	
TAI/198/13N	07/16/72	13.47.52	21.0N	122.0E	ADR	4.5	N	
KUR/198/17N	07/16/72	17.28.03	44.0N	150.0E	NDR	3.7	S	
KAM/198/20N	07/16/72	20.04.04	54.4N	142.9E	NDR	4.2	D	
YUN/198/22N	07/16/72	22.41.59	27.0N	101.0E	ADR	3.0	N	
KAM/199/01N	07/17/72	01.17.26	51.0N	153.0E	NDR	4.2	S	
MED/199/03N	07/17/72	03.14.05	34.0N	20.0E	NDR	3.0	S	
KAM/199/08N	07/17/72	08.28.52	55.0N	159.6E	ADR	5.3	D	
KAM/199/11N	07/17/72	11.11.46	57.0N	162.0E	NDR	3.3	S	ND
MED/199/16N	07/17/72	16.15.29	35.0N	22.0E	NDR	3.4	A	
KUR/199/17N	07/17/72	17.02.48	43.0N	149.0E	NDR	4.1	S	
KAM/199/20N	07/17/72	20.50.54	55.1N	152.5E	ADR	4.5	D	
GRF/200/13N	07/18/72	13.45.48	41.6N	23.8E	NDR	4.0	D	
KAM/201/10N	07/19/72	10.26.42	52.0N	162.0E	ADR	4.2	S	
KAM/201/12N	07/19/72	12.02.50	56.0N	157.0E	NDR	4.3	S	
AFG/201/19N	07/19/72	19.43.40	39.0N	70.0E	ADR	3.6	N	
TAC/203/14N	07/21/72	14.07.10	41.0N	72.0E	NDR	3.9	S	
SZF/203/16N	07/21/72	16.11.32	28.8N	102.3E	NDR	4.0	D	
CRI/204/05N	07/22/72	05.10.47	47.0N	26.0E	NDR	4.1	S	
TIR/204/16N	07/22/72	16.41.04	31.4N	91.5E	ADR	5.5	D	
TIR/204/21N	07/22/72	21.00.09	31.4N	91.4E	NDR	4.7	D	
MED/205/18N	07/23/72	18.17.25	32.0N	24.0E	NDR	3.9	S	
TIR/205/23N	07/23/72	23.41.55	31.0N	91.0E	ADR	3.6	N	
KAM/206/10N	07/24/72	10.14.35	58.0N	159.0E	NDR	3.7	S	
TUR/206/10N	07/24/72	10.22.05	36.0N	42.0E	NDR	4.3	S	
KAM/206/13N	07/24/72	13.05.26	58.0N	162.0E	NDR	4.0	S	

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EVENT PARAMETERS  
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EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LONG	DEPTH	MR	SOURCE BLTN	COMMENT
KAS/206/14N	07/24/72	14.58.14	35.8N	90.6E	NOR	4.8	P	
GRF/207/01N	07/25/72	01.56.07	38.7N	21.4E	45	4.5	P	
KUR/208/02N	07/26/72	02.25.57	45.0N	149.0E	NOR	4.5	S	
KUR/209/00N	07/27/72	00.20.55	50.0N	159.1E	NOR	5.1	P	
RYU/209/16N	07/27/72	16.41.24	24.0N	132.0E	NOR	5.1	N	
SIN/210/05N	07/28/72	05.50.29	42.0N	81.0E	NOR	4.3	S	
DOD/211/08N	07/29/72	08.22.17	37.0N	29.0E	NOR	3.8	S	
AFG/211/17N	07/29/72	17.10.35	32.0N	68.0E	NOR	3.8	N	
KUR/211/21N	07/29/72	21.07.16	49.0N	156.0E	NOR	4.5	S	
AFG/212/01N	07/30/72	01.30.09	39.9N	24.2E	NOR	4.4	P	
KUR/212/03N	07/30/72	03.01.11	50.0N	157.0E	NOR	5.0	S	
TAD/212/11N	07/30/72	11.41.01	41.0N	70.0E	NOR	4.0	N	
TAI/212/16N	07/30/72	16.00.03	21.2N	121.2E	NOR	4.9	P	
SFE/212/19N	07/30/72	19.00.54	30.0N	101.0E	NOR	3.5	N	
TUR/212/19N	07/30/72	19.46.24	41.0N	27.0E	NOR	3.6	S	
KAM/213/06N	07/31/72	06.40.28	56.2N	162.9E	NOR	4.8	P	
TAI/213/17N	07/31/72	17.04.47	23.7N	121.6E	24	4.6	P	
IRA/213/21N	07/31/72	21.01.25	31.0N	52.0E	NOR	3.6	N	
EK7/229/03N	08/16/72	03.16.57	49.8N	78.1E	0	5.2	P	F
EK7/239/03N	08/26/72	03.46.57	50.0N	77.8E	0	5.5	P	F
N7M/241/05N	08/28/72	05.59.57	73.3N	55.1E	0	6.3	P	F
EK7/246/08N	09/02/72	08.56.58	50.0N	77.7E	0	5.1	P	F
WRS/248/07N	09/04/72	07.00.04	67.7N	33.4E	7	4.6	P	F
SWP/277/08N	10/03/72	08.59.58	46.8N	45.0E	0	5.8	P	F
EK1/345/04N	12/10/72	04.26.58	49.8N	78.1E	0	5.7	P	F
EK2/345/04N	12/10/72	04.27.08	50.1N	78.8E	0	6.0	P	F
EK7/363/04N	12/28/72	04.26.58	50.0N	78.0E	NOR	4.5	S	F