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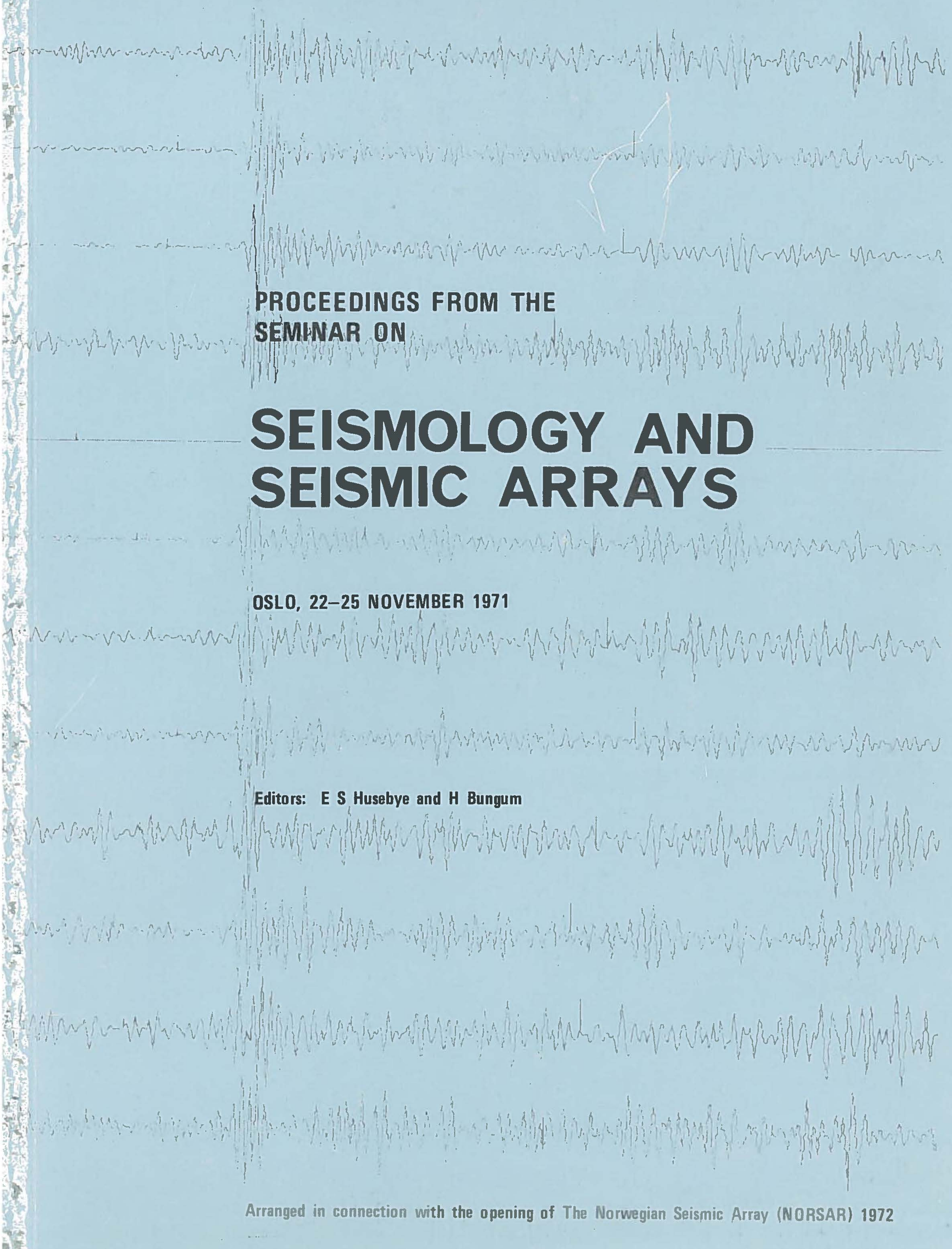

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SHORT PERIOD DISCRIMINATION STUDIES USING THE YELLOWKNIFE SEISMOLOGICAL ARRAY DATA

F.M. ANGLIN

Earth Physics Branch
Dept. Energy, Mines & Resources
Ottawa, Canada

ABSTRACT

Using a population of one hundred shallow Eurasian earthquakes and sixty-five Eurasian explosions, the data from the short period Yellowknife seismological array have been studied in the time and frequency domain in order to find an optimum explosion-earthquake discriminant. It has been found that earthquakes that have a low complexity tend to have a lower value of the third moment of frequency than do the explosions; also, complex explosions have a higher value of the third moment of frequency than do the earthquakes. Various definitions of complexity were studied, the optimum being found to be the ratio of the rectified phased sum over the time interval two to thirty-five seconds to that from zero to two seconds.

INTRODUCTION

Seismological earthquake-explosion discriminants using data from short period seismometer arrays have been studied at various laboratories and have yielded some potentially useful methods of analysis. However, as more data have been accumulated, problems have arisen. For example, complexity seemed a useful discriminant until Novaya Zemlya explosions were added to the data set.

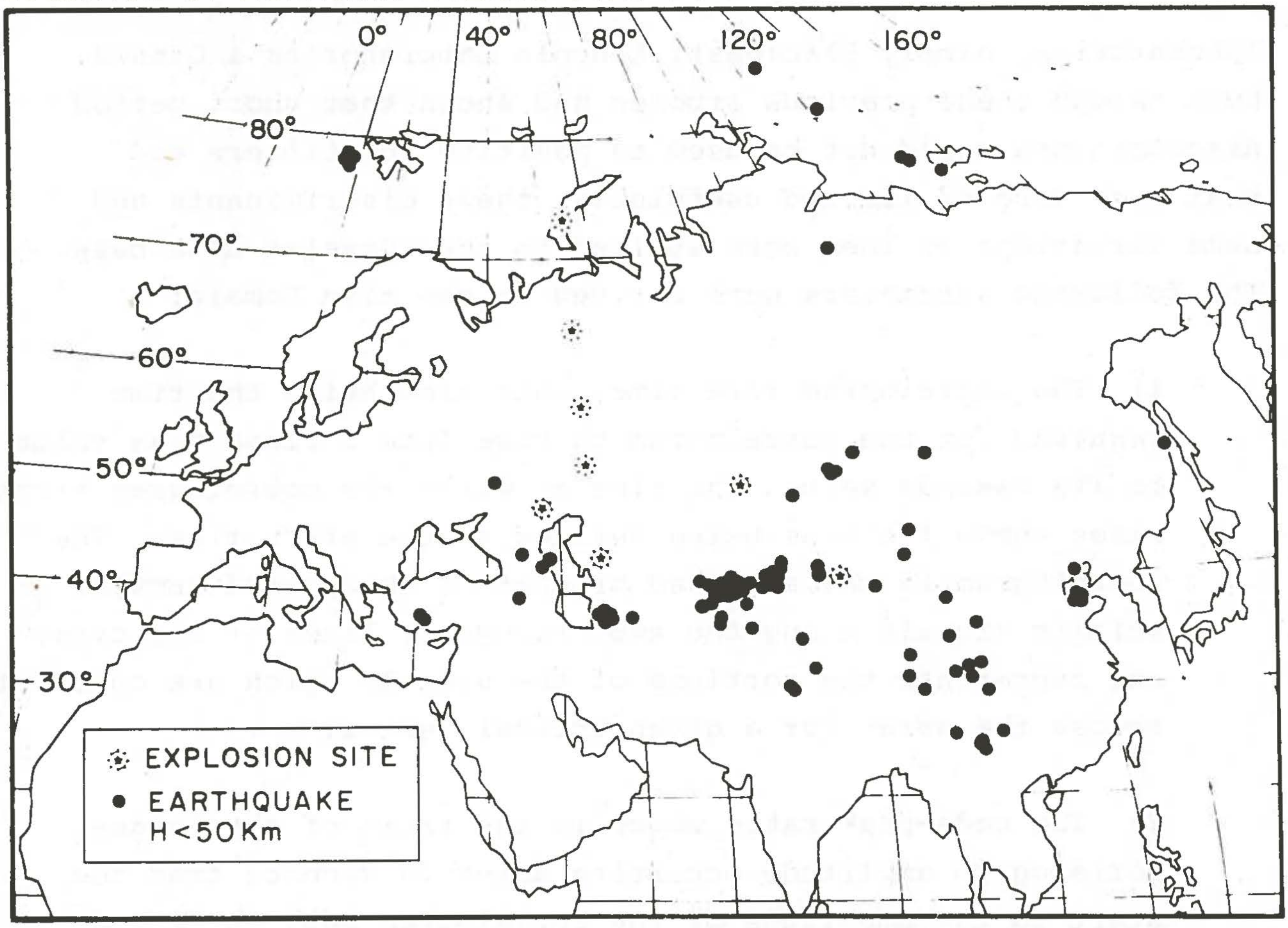
Recently Marshall and Basham (1972) initiated a study of the M_s:m_b discriminant using data from Eurasian seismograph stations for events within Eurasia. As a parallel study, Eurasian data recorded at the

Yellowknife short period seismological array were collected for analysis. The initial data base consisted of those events that had been transcribed to digital tape, as the Yellowknife data which are recorded on analogue tape are only kept in analogue form for about one year. As reported by Anglin in Nature (1971), a short period discriminant was developed that separated a population of Eurasian explosions from shallow Eurasian earthquakes.

This paper contains the results obtained using a larger data sample. A positive identifier using only short period data from one medium aperture array has not been achieved but there is still a possibility that the method can be useful for discriminating low magnitude events. Larger magnitude events are at present discriminated using the $M_s:m_b$ technique.

SEISMIC EVENT IDENTIFICATION

The data base as used in this paper initially consisted of one hundred shallow earthquakes, depth as reported by the National Oceanic and Atmospheric Administration of the United States (NOAA) being less than 50 kilometers, and all located in the Eurasian area. From the same data reference 65 presumed Eurasian explosions that had been digitally transcribed were examined. This data base was reduced to 92 earthquakes and 56 explosions after those events which had saturated the Yellowknife analogue recording were removed. These events which caused saturation were of magnitude 5.7 or greater as observed at the Yellowknife array. The geographical distribution of the events is shown in Fig 1. The spiked stars are the locations of the presumed explosions while the solid dots are the locations of the shallow earthquakes. The distribution of data is not uniform and perhaps illustrates a weakness of the study. The data were not selected as to quality of recording, all shallow Eurasian earthquakes from 1964 to 1971 that had been transcribed to digital tape were used. For some events a visual examination of the data showed that some of the data channels were not functioning or were excessively noisy. Such data channels were deleted from the analysis. An average of 3 channels were removed from about 7 events, and thus an insignificant amount of data was lost.



LOCATION OF EURASIAN EVENTS USED FOR SHORT PERIOD DISCRIMINANT

Fig 1. Eurasian map showing location of events used in short period discrimination study.

For the Yellowknife array, the 3 db points for the system occur at 0.7 and 8. Hz. Before digitizing at 20 samples per second per channel the data were band pass filtered using analogue filters with 3 db points at 0.25 and 8.0 Hz.

As one of the objectives was to find a discrimination parameter that could later be utilized on a real time data system in automatic mode, only those parameters were studied that would not require the direct intervention by an operator. Automating the system will also decrease the possibility of personal bias. The data as collected on digital files were then studied in the time and frequency domains.

Short period discriminants using the gross characteristics of the data in the time domain have been extensively studied at several laboratories, namely Blacknest, Lincoln Laboratories & Ottawa. Even though these previous studies had shown that short period discriminants could not be used as positive identifiers and that most were of limited usefulness, these discriminants and some variations of them were applied to the Eurasian data base. The following parameters were derived in the time domain:

1) The correlogram rise time, this time being the time required for the correlogram to rise from a fixed bias value to its maximum value. The time at which the correlogram first rises above the bias being defined as the start time. The correlogram is the smoothed product of the phased sums of seismic signals along the two orthogonal lines of the array and represents the portions of the signals which are coherent across the array for a given arrival vector.

2) The coda-peak ratio which is the ratio of the largest correlogram amplitude occurring after 20 seconds from the start to the amplitude of the correlogram peak in 60 s of data.

3) A complexity based on the correlogram and defined as the ratio of the area under the correlogram occurring after 2 s from the start to 35 s, to the area from the start to 2 s after the start.

4) Four complexities based on the phased sum, the phasing being set to maximize the P phase energy. The four complexities differed in that the ratio of the areas under the rectified sum - all were taken at 2, 3, 4 and 5 seconds after the start. As in 3), a signal of 35 s was used.

Since the start time was defined in terms of the correlogram rising above the bias value, this time was always later than the actual onset time, the difference being of the order of a few tenths of a second.

When examined as a percentage cumulative distribution, these parameters gave the following separations of the two populations, 90% of the explosions overlapping Q% of the earthquakes:

		Q
1)	Rise time:	38%
2)	Coda-peak ratio:	12%
3)	Correlogram complexity:	9%
4)	Phased sum complexity, 5 s:	10%
5)	Phased sum complexity, 4 s:	10%
6)	Phased sum complexity, 3 s:	9%
7)	Phased sum complexity, 2 s:	10%

Thus the five complexity definitions were effectively equal in their ability to discriminate and agree with earlier studies.

The same data base was then examined in the frequency domain. Each event was displayed as a phased set of signals on a CRT and a time was selected about 0.5 s before the onset, this being a manual operation that could have been automated. From this time pick, a window of 128 samples long was defined, that is approximately 6.4 s of data per channel. The data were cosine tapered to zero at each end of the time window and then transformed into the frequency domain. In a similar manner two independent noise samples were taken in the 20 s prior to the onset of each event. The length of the data window was set to a maximum of 128 samples as another factor of 2 would have exceeded the memory capacity of the computer being used. For a few events 64 data samples were also transformed but when it became evident that this was giving inferior results it was not continued.

Weichert (1971) has recently published a study of spectral discriminants using Eurasian events recorded at Yellowknife and found that the third moment of frequency was a superior discriminant to lower moments and was also superior to spectral ratios. He used the spectrum of the phased sum with frequency bands running from 0.15 to 3.0 hertz. The phased sum had been chosen as it gave a superior signal to noise ratio, and the upper frequency limit of 3 hertz was used due to the lack of signal coherency across the array above this value. For his data base 90% of the explosions overlapped about 25% of the earthquakes.

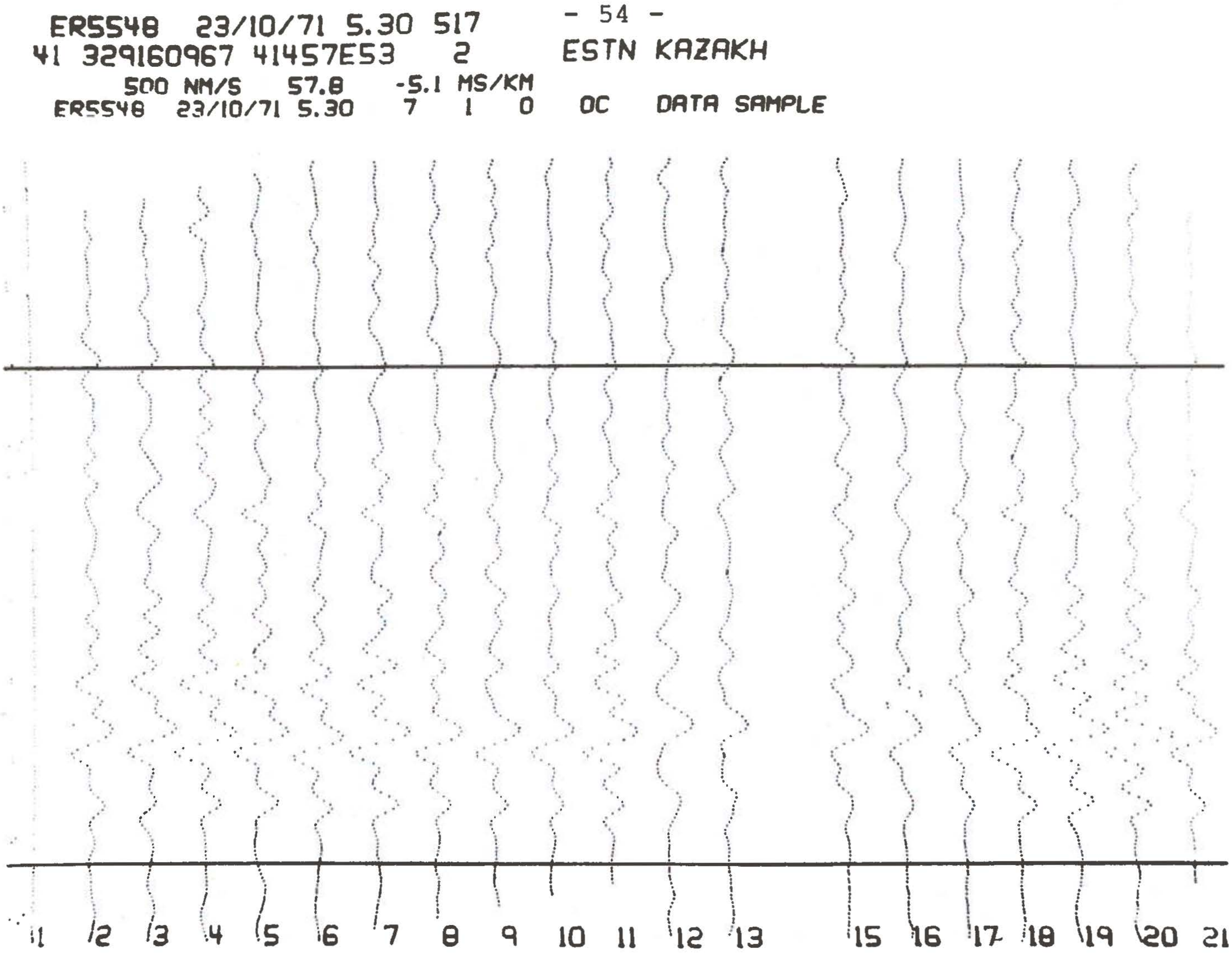


Fig 2. Seismic traces for a presumed Eastern Kazakh explosion Sep 16, 1967. Trace no 2 is from the southernmost seismometer, no 11 from the northernmost, no 12 from the westmost and no 20 from the eastmost. No 14 was dead while no 21 is the phased sum of all channels.

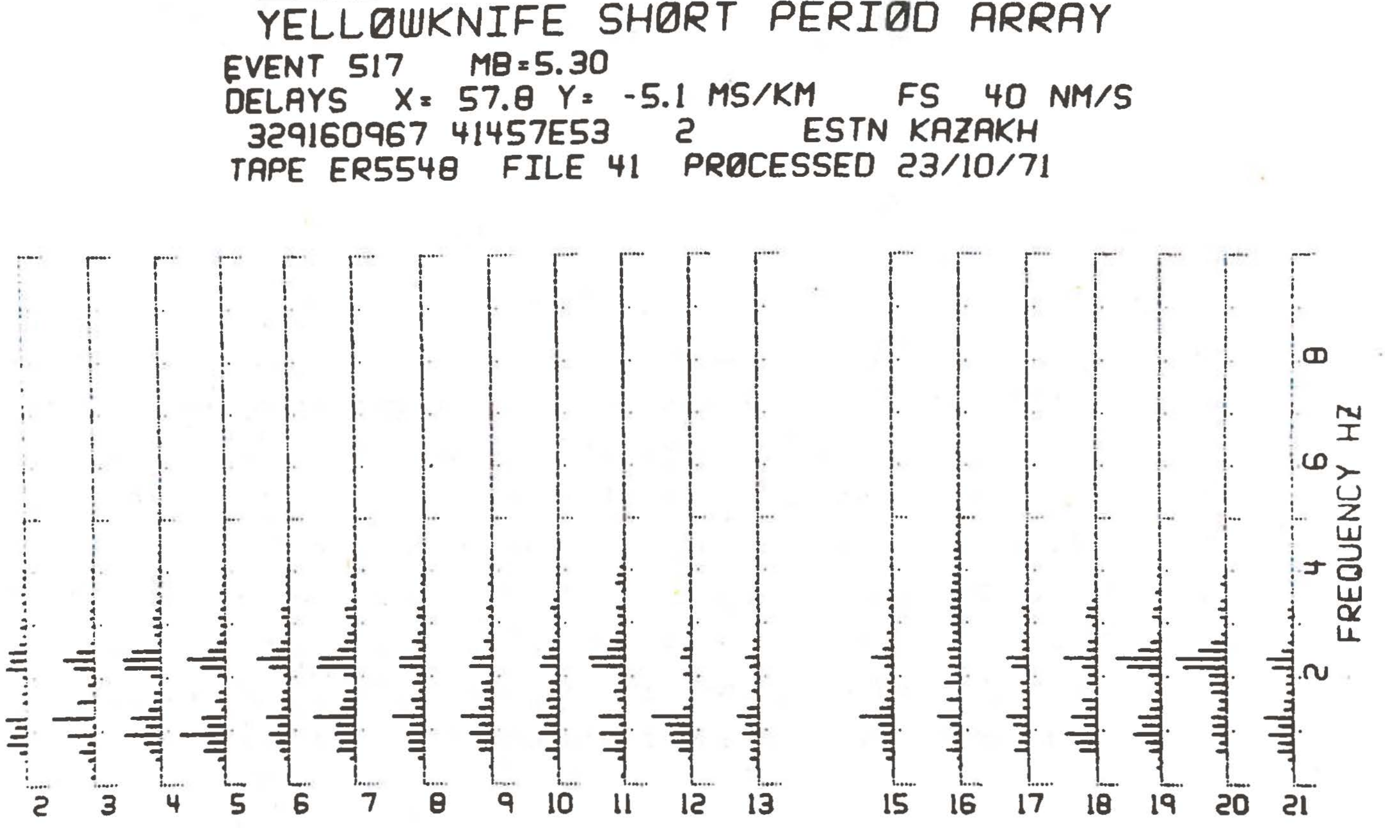


Fig 3. Line spectra of individual channels for the data between the two dashed horizontal lines of Fig 2. The Nyquist

From a visual examination of the explosion spectra it seemed that on the individual channels there was still energy above 3 hertz and thus the analysis of Weichert was re-examined. For each spectral component of frequency on each data channel the average noise spectral component was subtracted from the spectra containing the signal, with the result being set to zero if the noise exceeded the signal. A normalized third moment of frequency was then calculated for each operational channel and the average determined. The third moment of frequency was defined as

$$TMF = \sum_{n=1}^{n=19} \sqrt[3]{\sum_{i=2}^{i=32} (A_n(i)-B_n(i))\cdot i^3 \Bigg/ \sum_{i=2}^{i=32} (A_n(i)-B_n(i))} \Bigg/ 19$$

where $A_n(i)$ is the spectral amplitude of the signal of the i-th frequency component for channel n, and $B_n(i)$ is the average spectral amplitude of two samples of the noise. The nominal sampling rate of 20 samples per second together with the window of 128 samples yields a spacing of 0.156 Hz between components of the frequency spectrum. The frequency limits which are at 0.32 and 5.0 Hz were arrived at from a visual examination of many spectra of signals and noise. Fig 2 shows a signal from a presumed explosion in Eastern Kazakh, the right most trace being the phased sum and the left most being the time track containing coded second marks, while those in between are the traces of the individual channels. The trace separation represents 500 nm/s peak to peak. The left most seismic trace (#2) is from the southern end of the array and trace no 12 is the west end of the array. The two horizontal lines represent the 128 sample time window within which the data are transformed into the frequency domain. The spectra of each channel are shown in Fig 3 with the channel designation being same as in Fig 2. On this particular figure the higher frequencies as well as the noise level are not apparent. Fig 4 shows the spectrum of the phased signal-noise together with the spectrum of the average noise preceeding the onset of the event and Fig 5 shows each spectral component multiplied by the cube of the frequency as used in the definition of TMF. Fig 6 shows the average of the spectra of each channel, modified as before.

YELLOWKNIFE SHORT PERIOD ARRAY

EVENT 517 MB=5.30
DELAYS X= 57.8 Y= -5.1 MS/KM FS 20 NM/S
329160967 41457E53 2 ESTN KAZAKH
TAPE ER5548 FILE 41 PROCESSED 23/10/71

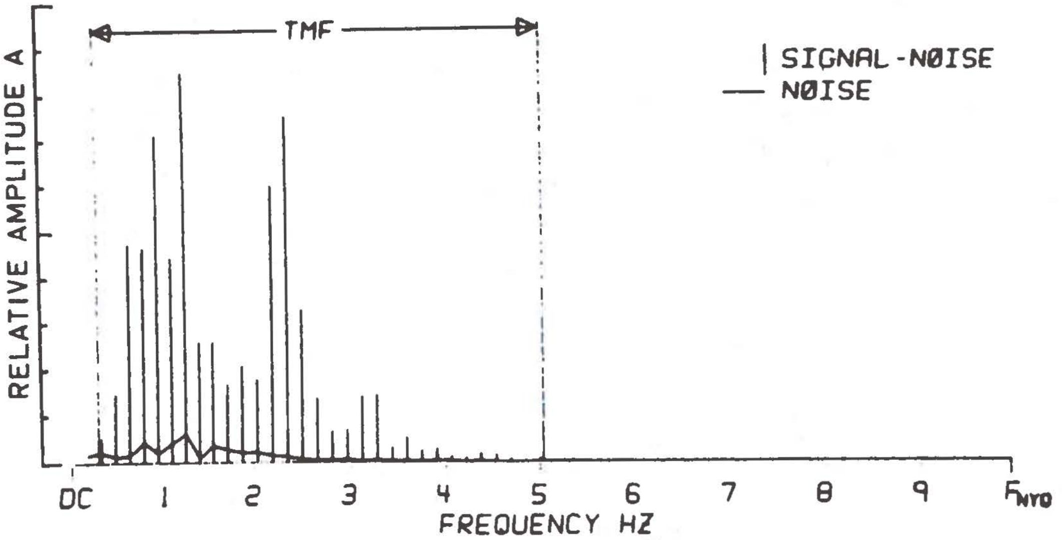


Fig 4. Line spectrum of the phased signal, the average noise values have been subtracted. The noise spectrum is shown as the lower continuous line.

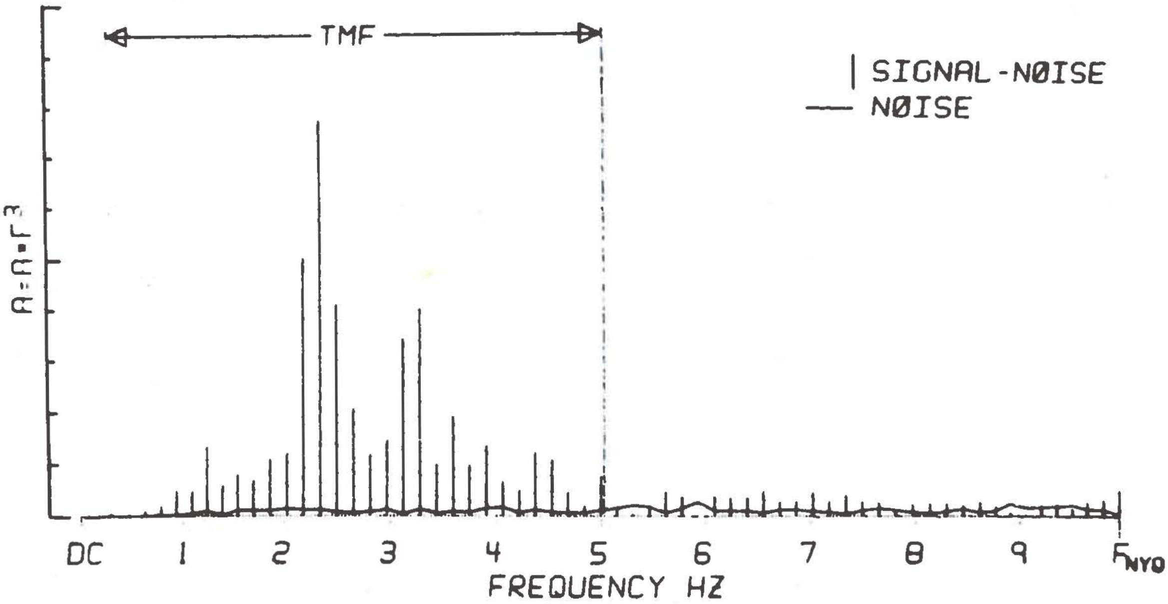


Fig 5. Line spectrum of the phased signal as in Fig 4 except that each frequency component has been multiplied by the cube of the frequency in order to emphasize the higher frequencies.

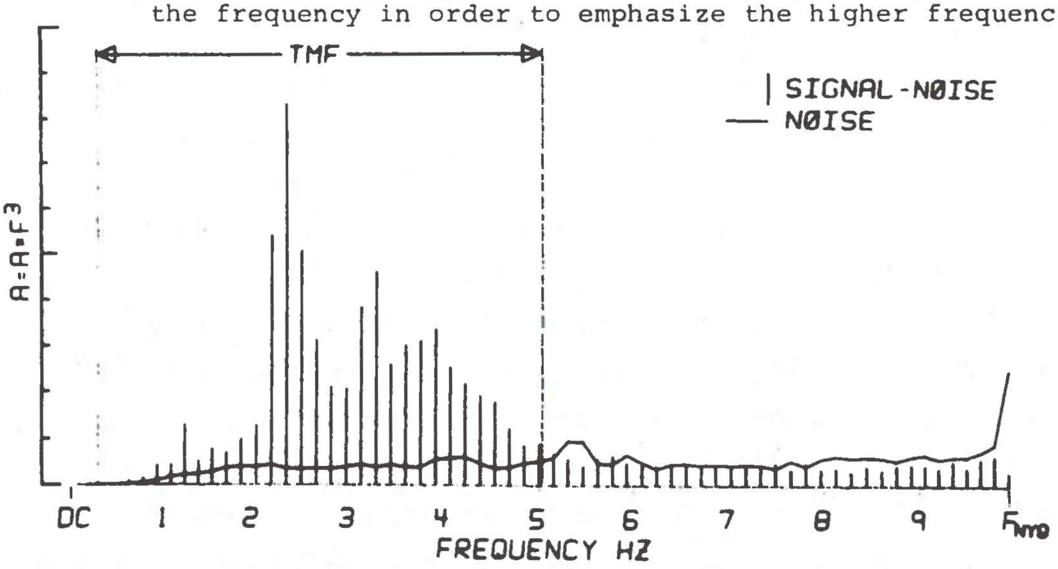


Fig 6. The average spectrum of the 19 data channels displayed as in Fig 5.

Above 3.5 hertz there is more higher frequency energy but as well a higher noise level. Although an objective signal to noise criterion has not been applied to this study, it is a problem that needs to be considered. As mentioned previously only a small amount of visual editing in the time domain had been done.

For the third moment of frequency (TMF) as defined here 90% of the explosions overlapped 10% of the earthquakes, a separation equal to that achieved using complexities.

For earthquakes, the TMF tended to increase as a function of depth for focal depths between about 50 and 200 km and for explosions the TMF tended to increase for decreasing magnitudes although the data were too scattered to see if this agreed with theory.

Using the TMF which was found to be the optimum discriminant in the frequency domain and plotting it as a function of the optimum discriminant in the time domain yielded an even better discriminant as shown in Fig 7. In the initial study, using the smaller data base no overlap of the populations of earthquakes & explosions occurred. However, in extending the data base, two explosions fell below the line that was subjectively drawn as the upper bound of the earthquake population. The explosion with the lowest TMF is a W. Kazakh event of m_b 6.1 (NOAA) and array magnitude of (5.7). This is near the saturation value. The next lowest is an E. Kazakh explosion of m_b 5.4 (5.5). This figure shows that earthquakes with a TMF larger than the average, tend to be more complex than the explosion with similar values of TMF. The explosions tend to have a low complexity but those that are more complex tend to have a higher TMF.

The distance of each data point as a function of m_b from the line of Fig 7 is shown in Fig 8. The explosions nearest the zero line of Fig 8 are one from W. Kazakh, and two from E. Kazakh. The two explosions furthest from the zero line are located in the Urals. The possible trend of the explosion data away from the zero line as m_b decreases was found to be mainly a function of the TMF, that is the lower magnitude events tend to have larger TMF's. However, there was also, but to a lesser degree, an increase in complexity as m_b decreased due to the decrease in signal to noise ratio. Thus

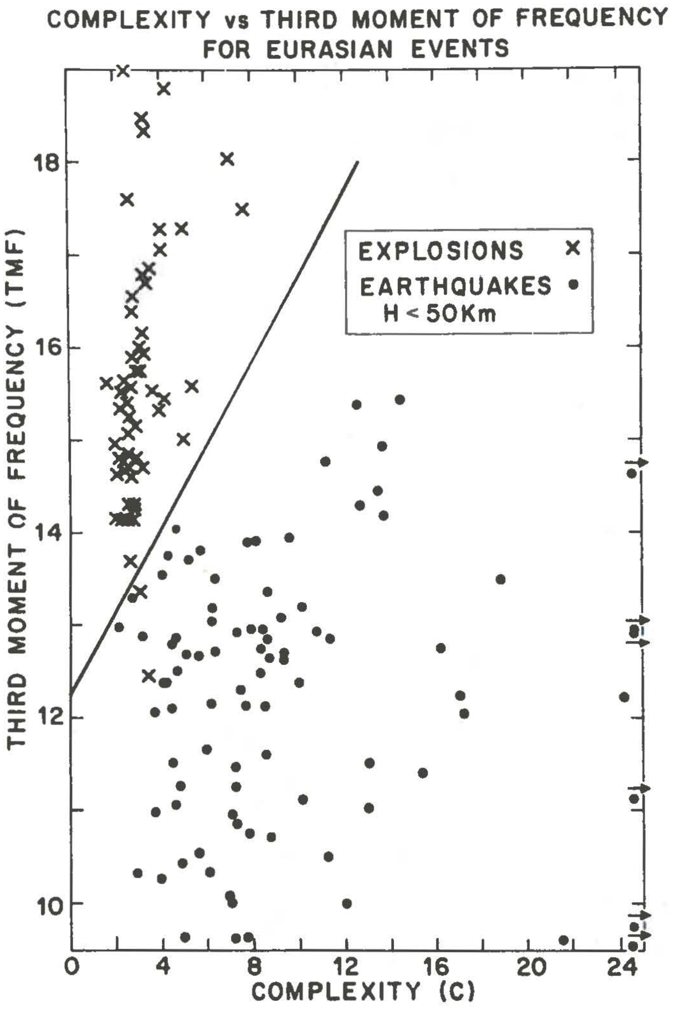


Fig 7. Scatter diagram of the third moment of frequency plotted as a function of complexity.

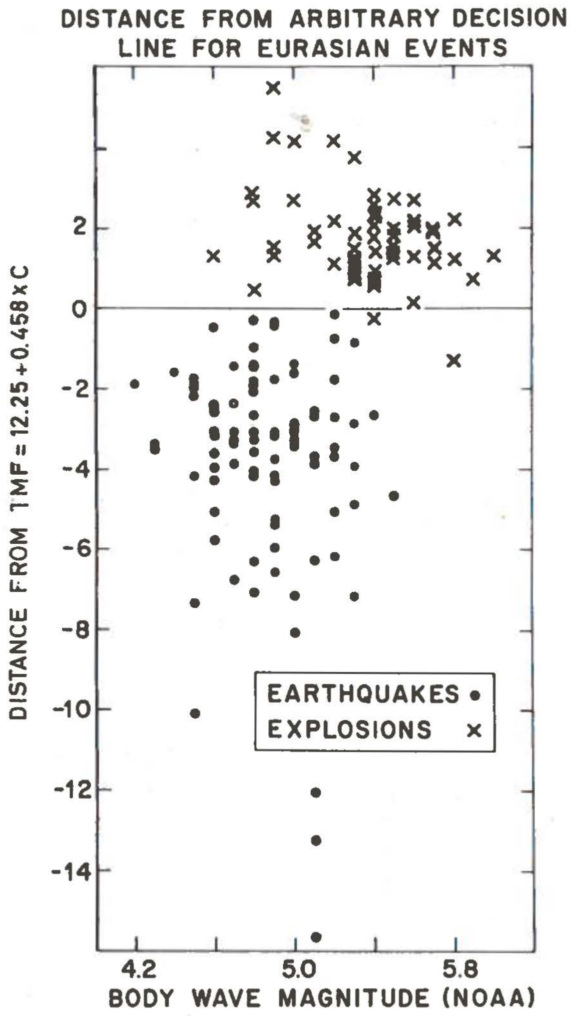


Fig 8. Distance from arbitrary decision line of Fig 7 as a function of body wave magnitude.

it is possibly premature to speculate what success can be achieved below m_b 4.5. A similar multivariant discriminant was tried by Capon and Lande (1969) where the dominant period was used as the frequency domain parameter. Their results are not directly comparable; however, from the Yellowknife data it seems that the TMF is a better parameter to use.

CONCLUSION

In summary, it has been found that using available short period data from a medium aperture array at Yellowknife, Canada, a useful diagnostic aid can be obtained for Eurasia events. It has not been found to be a positive discriminant, but is possibly a useful discriminant for events of magnitude below m_b 5.2. There still remains the problem using a single medium aperture array of uniquely identifying earthquakes with depths greater than 50 km as such events tend to fall into the explosion population. Noise criteria still need to be applied to the data. In as much as the frequency response and noise varies from pit to pit the discriminant might be enhanced by using only selected data channels. The complexity definition might be improved by making the time window a function of observed m_b, the 35 s of data being reduced for smaller events.

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