# SUMMARY REPORT OF EURASIAN SHORT PERIOD DISCRIMINATION STUDIES

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This report is a summary of some of the short-period seismological discrimination work done during the past few years using data recorded at the Yellowknife array for events located in the Eurasian area. All of the significant results of this work are to be found in the notes and reports that have been published (see appendix). This report complements these previous publications in that it contains a listing of the unpublished data base and the methods of calculation of the multivariate short period discriminants.

The original Eurasian data base was derived from the YKA analogue tapes, the digitizing and editing of these tapes being done on the in-house analogue and digital DDP-124 system. Due to the present memory requirements of the multivariant discriminant algorithm, the discrimination calculations were done on the larger departmental computer system.

No further data sets have been studied since the International Seismic Month (ISM) program. The few events that have been analyzed after the ISM were processed at the request of the Swedes and these data are not quoted in this report. Should there be a need for any events to be studied using the digital data from the new CANSAM system, a new editing program and possibly a special filter program will have to be designed for the division's PDP-11/40 system. As well, the input subroutines for the discrimination program will require modifications. As mentioned later, to make such a re-programming effort worthwhile, more optimum discrimination functions should be derived through the use of the BMD07M program.

What follows is a chronological summary of the results obtained from our discrimination studies.

Short period signal complexity (C) had been examined by the United Kingdom group and was thought to be a useful parameter until a complex explosion from Novaya Zembya was observed. A concise summary of the U.K. results are to be found in the SIPRI reports.

Subsequent to the U.K. studies, Whitham, Basham and Hasegawa published the first Canadian discrimination work which was done with YKA short period data. They used the correlogram as derived from the processed YKA data to define rise times, quarter widths and coda-peak ratios. Their study included a large suite (35 explosions and approximately 700 earthquakes) in the third zone from Yellowknife, but did not go as far as calculating the probability of classification of each individual event. (appendix A-1)

Weichert then took a suite of Eurasian events and designed a discrimination technique which used a third moment of frequency (TMF). When this parameter was expressed as a function of $m_b$, some overlap between the population of 31 explosions and 42 earthquakes was found. (appendix A-2)

These parameters C and TMF which had been studied previously were then modified. A very significant improvement was obtained when a complexity was combined with a third moment of frequency, the complex

explosions in general being found to have more high frequency energy than the earthquakes and simple earthquakes had less high frequency energy than explosions. These results were reported in a note to Nature. (appendix A-3)

An expanded data base was then formed to include a wider suite of Eurasian events and it was found that some of the larger explosions fell into the parameter space that was associated with the earthquake population. The discrimination method was the same as that used above and the results using this expanded data base were reported in a paper given at the Norsar symposium. (appendix A-4).

At this meeting, a multivariate technique was described in a Swedish paper by Israelson (1972). This method also used the information in the time and frequency domains but applied a more rigorous statistical method to the discrimination problem. As similar results had been obtained using Canadian and Swedish data, a comparison was made using events common to both data bases. In terms of classification, very similar results were obtained which were used in a joint Canadian-Swedish Working paper for the 1972 CCD meeting, (Appendix A-5). and in a note to BSSA (Appendix A-6).

As the complexity-third moment of frequency (C-TMF) method of short period discrimination has been superceded by the multivariate method, the following notes will only contain passing references to the earlier work. There is sufficient information in the appendices A-2, A-3, on the previous C-TMF results.

Basham made a comparison of the $M_s$:$m_b$ discrimination method

and the short period method using the multivariate method for an Eurasian set of data where the probability of classification had been computed. It was found that the methods complemented each other, and the results were reported in a paper presented at the SSA meeting 1973. (Appendix A-7).

Manchee experimented with the S.P. method using a suite of Nevada events and found that these second zone Nevada events were of sufficiently different character so as to make discrimination impractical. His study emphasized the fact that short period method had to be defined on a regional basis. (Appendices A8-9)

With the ISM project, a well defined set of events, up to then the most inclusive, became available. (see Appendix B-3). Using short period YKA data, this data base was exhaustively tested using the SP techniques which were then compared to the $M_s$:$m_b$ results, the previously defined Eurasian data base being used as the design set. The results which were obtained were then used to define thresholds of application and are contained in a CCD working paper. (Appendix A-10) The Canadian and Swedish studies of the ISM data base were also used for a working paper to this CCD meeting held in 1973. Here the data were used over a wider geographical area, in the third zone to Yellowknife, than had been used previously to define the short period discriminant. However, the earthquakes from this wider area still tended to separate from the explosions.

The multivariate discrimination studies using short period, $M_s$:$m_b$ focal depth and location data were reported in a note to Nature

(appendix A-11) and as well formed the basis for two papers read at the ISM symposium at the 1974 SSA meeting and the NATO meeting held in Norway (appendix A-12).

The Eurasian design set of shallow earthquakes and explosions for the multivariate vector method is listed in appendix B-1 which also contains the program used to derive the printed data. The table which is made up of 71 Eurasian explosions and 216 shallow Eurasian earthquakes also includes some probabilities of classification as derived from the Swedish data obtained from their Hagfors station. The times listed in this table are the expected times of arrival at YKA as derived from the Gedess program using the PDE data as input. The slowness (SL) and azimuth (Az) are also derived from the Gedess program and are not necessarily the values used for optimum phasing of the P waves. These optimum values can be found in the index listings kept in the DDP-124 computer room.

These data were recorded on the YKA analogue tape at Yellowknife and were replayed at approximately twice the recording speed. To remove some of the noise and also to avoid aliasing, the data were passed through the band pass filters set at 0.5 to 16.0 Hz, resulting in an actual band pass of 0.25 to 8.0 Hz (Fig. 1). Using the division's DDP-124 computer system, these events were digitized at a nominal 20 samples per second using program ARA (see DDP-124 system manual). The mean sampling rate was then determined for each file recorded on digital tape using the same program ARA. The standard analogue output from this program was examined for a first approximation to the optimum values of slowness and azimuth. These digital

files were then examined using program ARACRT where noisy or dead channels were marked and the optimum slowness and azimuth were derived from visual picks of the onset and/or the peaks and troughs of the P phase.

Program PICK was then used on the DDP-124 to pick the exact onset of each event and to form a tape containing the files of data that were to be processed on the department's CDC-6400 system. After being processed by program PICK, each file contains two BCD header records and as many binary records as are necessary to contain the event. The first BCD record contained the information that identified the file while the second BCD record contained the sampling interval, optimum slowness and azimuth, (as derived in ARACRT) and the sample number of the P wave onset.

Using the data derived as described above, for the Eurasian data base the mean rectified signal averages in 20 samples bands (one second) are shown in Figure 2. The vertical scale $\log_{10}(A/\bar{A})$ represents the log of the normalized portion of the signal in each 20 sample interval, where the normalization refers to the total sample length of 140 data samples per channel ( 7 seconds). The horizontal scale defines the components of the discrimination vector in the time domain. This figure simply illustrates that on the average, explosions contain less coda energy than do shallow earthquakes and that they are also less emergent in character. Note that only seven seconds of data are used in comparison to 35 seconds that were used with the

previous complexity calculations. The significance of this is the fact that for small events we are not using a longer section of record that would most likely consist solely of noise. Also, the chance of including other phases such as PcP is diminished.

In the frequency domain, a 128 point Fourier transform starting 10 samples before the picked onset of the signal is shown in fig. 3 as an average of the logs of the normalized spectral amplitudes of the individual ~~the~~ data channels. Note that these spectra are not derived from the phased beam, as the high frequency values are required for efficient discrimination and are attenuated on forming the phased sum due to lack of high frequency coherence. The significant difference between the earthquakes and explosions in spectral amplitudes up to 4.52 Hz should be noted as this is the upper limit that is used in the multivariate discrimination method. The vector components are composed of the spectral amplitudes taken in groups of 4 from 0.31 Hz to 4.52 Hz, i.e., a set of 28 spectral values grouped into 7 vector components in the frequency domain.

To obtain the optimum set of components for purposes of classification, the BMD07M program should be used. However, at the time, not being familiar with this method, the components were subjectively picked after considering figures 2 & 3. When this work was originally done the BMD set of programs were not available on the departmental computer system and so the discrimination study was done using subroutine DISCR of the IBM system/360 scientific subroutine package (which is similar to BMD04M). (appendix A-11) One parameter that this subroutine computes

is the generalized mahalanobis $D^2$ which is a measure of the efficiency of the discriminant. The larger the $D^2$ value the better the discriminant. By a process of trial and error in maximizing $D^2$ a set of components were arrived at, 5 in the time domain and 7 in the frequency domain and these are also shown in Fig. 2 & 3. At a later date BMD07M was run and it was seen that some improvement could be made, but this improved discrmination function has not been used. Using the discrimination function as defined above with 12 components, all of the 71 explosions in the Eurasian data base were correctly classified into the explosion set and for the earthquake set of 216 shallow (h 50 km) events, 13 were classified as being explosion-like.

To obtain a discrimination value for an event that has been prepared on the DDP-124, the program SPDISC is run on the departmental CDC-6400 computer using the digital tape prepared by program PICK. This program SPDISC (appendix B-2) also computes the old complexities and third moments from which a classification probability is also derived. However, the significant classification probability is derived from the 12 component vector. The signal to noise ratio (SNR) in the output listing of the ISM data (appendix B-3) represents the SNR in the time domain for each of the time domain components, the noise values having been derived from the data preceding the onset of the event.

It should be noted that SPDISC has not been run on the currently operating Cyber system and thus the control card set up may not now be correct.

The CANSAM digital tapes cannot be used for discrimination with these functions as the pass band is not the same as on the analogue system. Any change in the pass band will probably result in incorrect classification probabilities. Should it become necessary to use the CANSAM digital tapes, a digital filter will have to be derived to approximate the overall response of the old analogue system. As long as we maintain our analogue system and the DDP-124, it will still be a simple matter to obtain discrimination values. However, since this system will be phased out, the possibility of transferring the discrimination analysis to the new PDP 11/40 should be examined. As the PDP system contains disc storage, it might be feasible to do all the computation in house. It might also be feasible to do some on line processing on the CANSAM system.

## References for Appendix A


A-1 Correlogram Discrimination Parameters from Yellowknife Seismic Array Data. K. Whitham, P.W. Basham and H.S. Hasegawa. Seismological Series of the Dom. Obs. 1969.

A-2 Short-Period Spectral Discriminant for Earthquake Explosion Differentiation. D.H. Weichert Zeitschrift fur Geophysik 1971, Vol. 37, p. 147-152.

A-3 Discrmination of Earthquakes and Explosions using Short-Period Seismic Array Data. F.M. Anglin Nature, Vol. 233, p.51-52, Sept. 3, 1971.

A-4 Short-Period Discrmination Studies using the Yellowknife

Seismological Array Data.

Proceedings from the Seminar on Seismology and Seismic Arrays Royal Norwegian Council for Scientific and Industrial Research Oslo 22-25 Nov. 1971, p.49-59.

A-5 An Experiment in International Cooperation: Short-Period Seismological Discrmination of Shallow Earthquakes and Underground Nuclear Explosions.

A Draft Canadian-Swedish Working Paper for the Conference of the Committee on Disarmament.

A-6 Seismological Discrmination of Earthquakes and Explosions Using Multistation Short-Period Data.

F.M. Anglin and H. Israelson

BSSA 63, p.321-323, Feb. 1973.

A-7 Discrmination Characteristics of Eurasian Earthquakes.

P.W. Basham and F.M. Anglin

SSA Annual Meeting, Golden Colorado, May 1973.

A-8 Short-Period Seismic Discrmination.

E.B. Manchee

Nature 239, p.152-153, Sept. 15, 1972

A-9 Short-Period P-wave Discrminants Based on YKA Data.

F.M. Anglin and E.B. Manchee

Earth Physics Branch, EMR Technical Memo 73/2, June 1973.

A-10 The Verification of a Comprehensive Test Ban by Seismological Means. A Working Paper for the Conference of the Committees on Disarmament, submitted by Canada, July 1973.

A-11 Multiple Discrminant Screening Procedure for Test Ban Verification.

P.W. Basham and F.M. Anglin

Nature, 246, p.474-476, Dec. 21/28, 1973

A-12 Explosion Identification and Monitoring

D.H. Weichert, P.W. Basham and F.M. Anglin

Exploitation of Seimograph Networks, KG Beauchamp ed.

Nato Advanced Study Institutes Series

Series E: Applied Sciences - no. 11

Noordhoff - Leiden - 1975.

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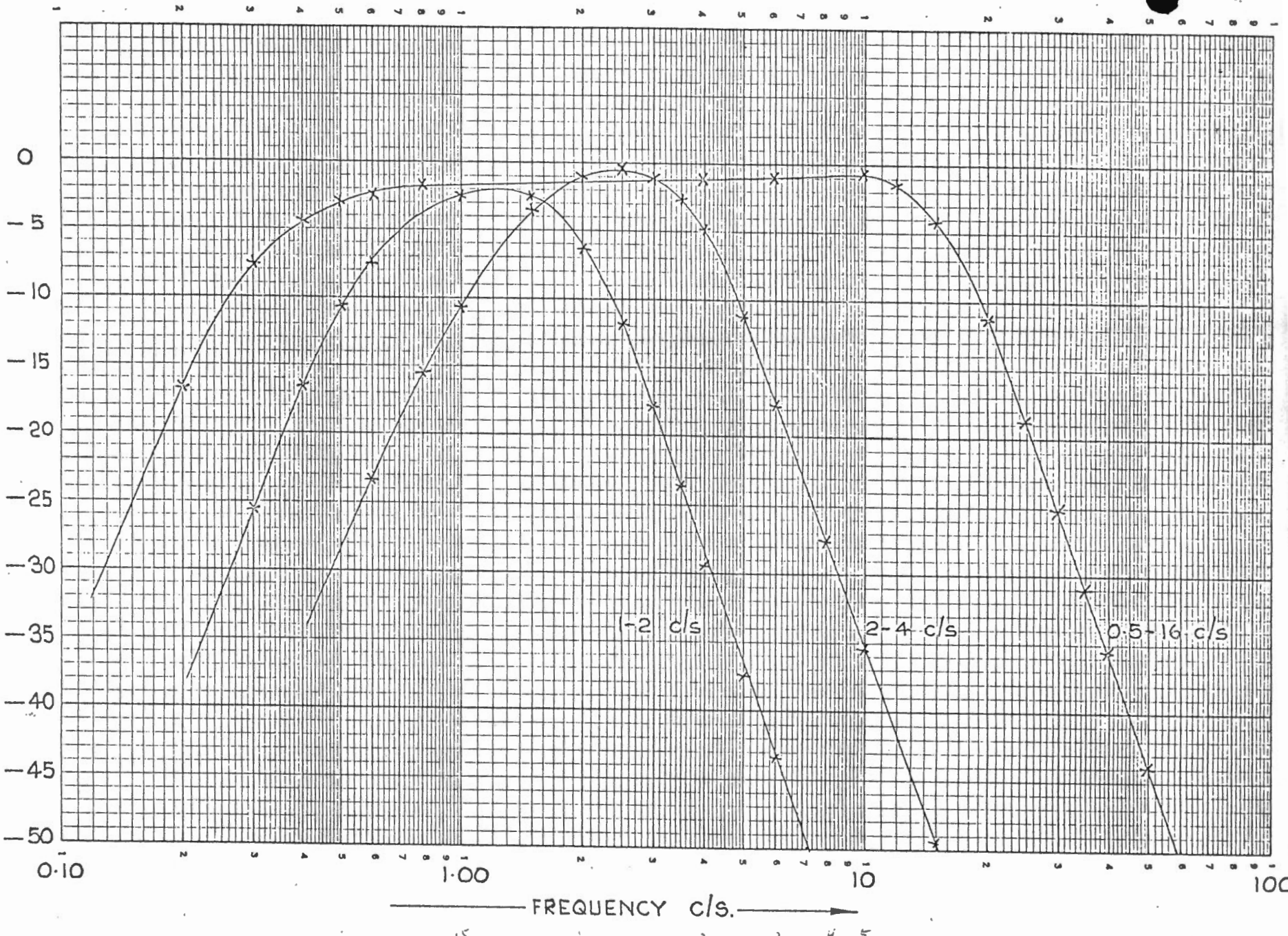
# FREQUENCY RESPONSE OF FILTERS



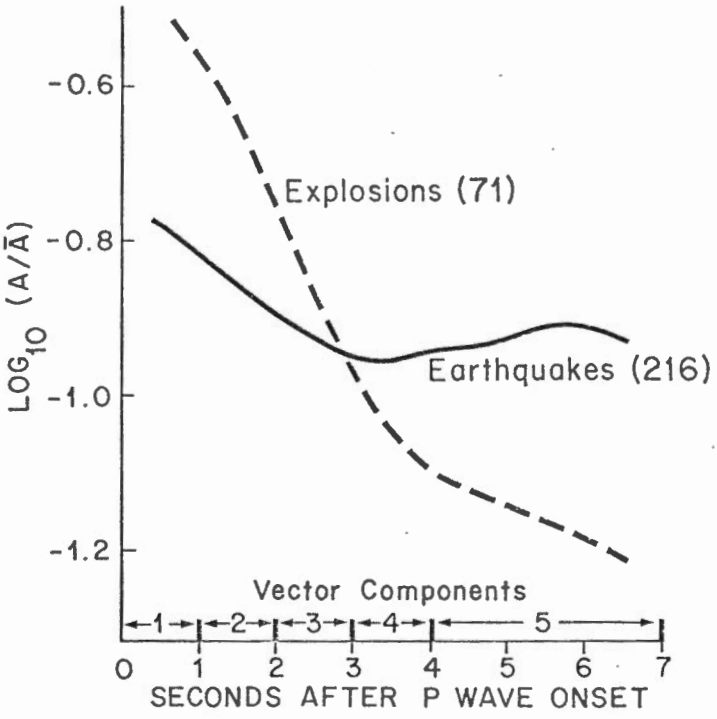



Fig. 2. Eurasian Data Base. Mean signals averaged over 1 second intervals.

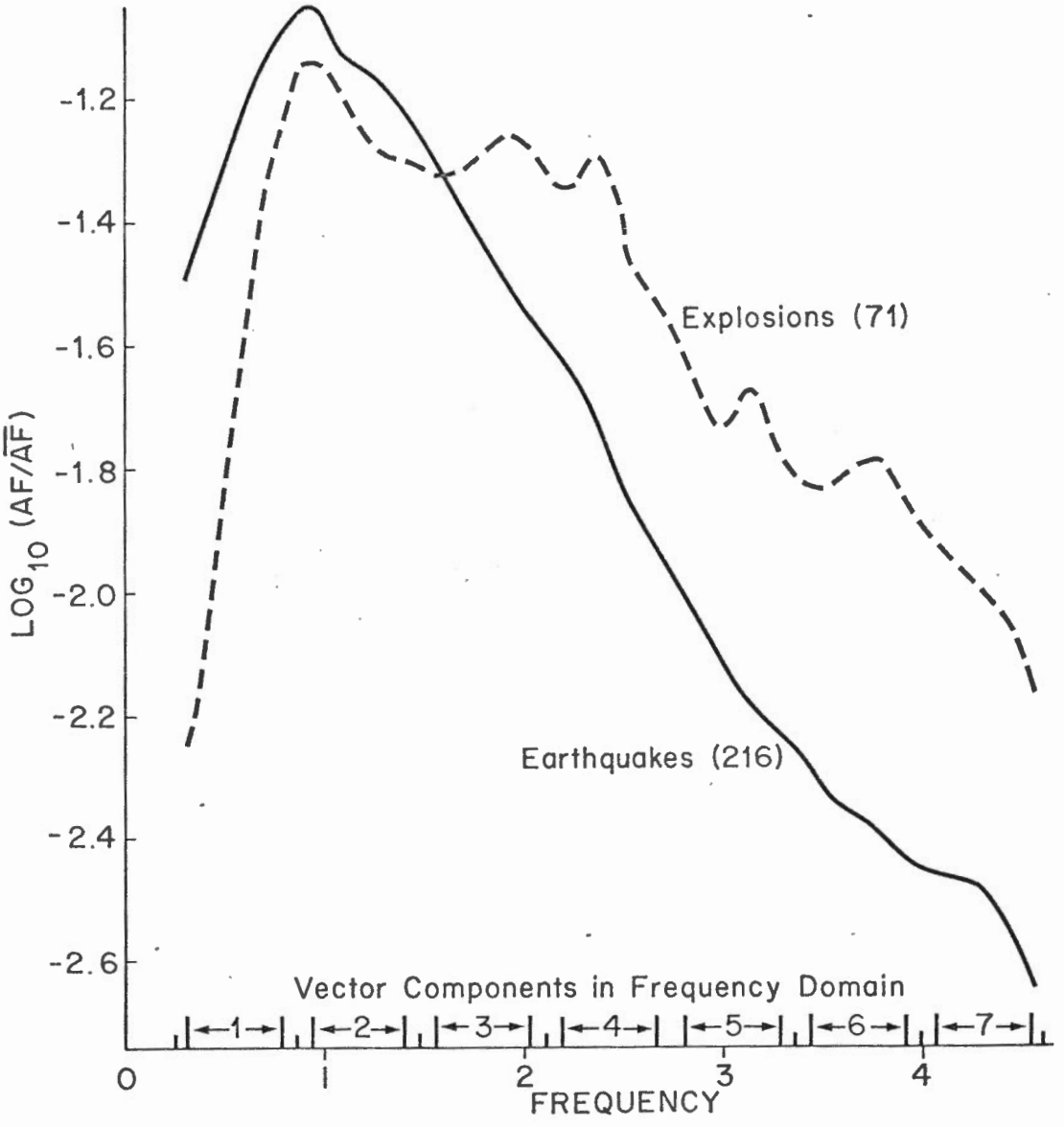



Fig.3. Eurasian Data Base, Mean Spectra.

Dr. Whitham:

Attached is an internal report of the Seis. Services for your files. It is a very brief report by Frank Anglin on his Eurasian Short Period Discrimination Studies. The appendix is useful in that it brings all the references together on the Division's contribution to this subject.

Also referenced - but not included in your copy are

1. 2 program print-outs
2. A complete list of ISM events used in the study.

While the report is not entirely satisfactory it is I believe adequate as a write-up of Anglin's work — should we ever wish to resume it. It is not suitable for publication and it is our view that further publication of this work is now inappropriate — as most of the relevant stuff has now appeared.

Myles