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SEISMIC IDENTIFICATION USING SHORT PERIOD HAGFORS DATA

HANS ISRAELSON
Hagfors Observatory
Research Institute of the National Defense
Stockholm, Sweden

SUMMARY

A large population seismic discrimination experiment has been performed using short period data recorded at the Hagfors Observatory in Sweden. Altogether 32 presumed underground nuclear explosions in five different areas in the Sino-Soviet region and 177 earthquakes in widely separated seismic regions on the Eurasian continent have been examined.

When used individually, discriminants like complexity, spectral ratio and third moment of frequency tend to give overlapping distributions at low magnitudes even if the data are treated on a regional basis. Multivariate use of complexity and third moment of frequency however almost completely separates shallow earthquakes from presumed explosions in Eastern Kazakh.

For the presumed explosions the discriminants are seen to differ significantly from place to place. There is, however, no striking and simple difference between the large scale tectonic belts. The focal depth seems to have a rather strong influence on the discriminants and earthquakes having a depth greater than 100 km tend to be explosionlike.

Discriminants utilizing detailed information of the waveform and of the amplitude spectrum have been developed. They seem to provide a somewhat better separation than do the simple discriminants mentioned above. Classification experiments with the total event population have been conducted using these discriminants. In general around 90% of the explosions are correctly identified as such whereas a few per cent of the earthquakes give false alarms, most of which are deep focus events.

INTRODUCTION

The performance of various criteria for discriminating between underground nuclear explosions and earthquakes using seismic data recorded at the Hagfors Observatory in Sweden have previously been tentatively studied by Dahlman et al (1971). The $m_b(M_s)$ method comparing the relative excitation of body and surface waves appeared to provide the most efficient separation. At present, however, this method is, for positive identification, severely limited by the difficulty of detecting the long period surface waves from events in the low magnitude range.

For Central Asian events short period body wave discriminants like complexity and spectral ratio were found to operate well using the Hagfors data. This study was undertaken to evaluate more confident estimates of the performance of these discriminants using a more extensive data set. The study also comprised a search for new discriminants properly tailored to the receiving conditions at the Hagfors Observatory and the multivariate use of such discriminants. In addition the objective was to outline the relative importance of magnitude, focal depth and regional variability on discrimination. This report gives a brief summary of some of the results of this study.

THE DATA

The detailed source characteristics of the events analyzed in this study are summarized in the Table 1-3. The vast majority of the focal parameter data are taken from NOAA bulletins. The 40 events which are marked by an asterisk in the tables have not been reported by NOAA, but located at the Observatory using bulletin data from Nordic and Canadian Seismograph stations (Dahlman et al, 1971). The epicenters of these non-NOAA events as given in the tables are preliminary and subject to minor changes.

In all 32 presumed underground explosions (Table 1) have been studied. They are distributed in five separate areas as follows:

Eastern Kazakh	17
Ural Mountains	10
Caspian Sea	3
Novaya Zemlya	1
Sinkiang	1

The earthquakes, amounting to 177, have been restricted to entirely continental ones. With the dividing focal depth at 50 km, the earthquakes are defined as shallow (Table 2) and deep (Table 3) giving the following distributions:

<u>Shallow</u>	
Depth < 50 km	51
Restricted depth	50
Non-NOAA	39
<u>Deep</u>	
Depth ≥ 50 km	37

The apparently shallow earthquakes include really three different types of events: those having a depth determined to be less than 50 km, focal depth restricted to 33 km and events not reported by NOAA. The latter ones are assigned zero focal depth.

The magnitudes, m_b(HFS), (according to the Gutenberg-Richter standard formula) are given in the Tables 1-3 and are in the range 4.2-6.6 and 4.0-6.4 for the explosions and earthquakes respectively. The epicentral distances range from 20^o to 75^o except for two of the presumed Ural explosions being at distances of about 15^o.

The data used in this study are the short period signals from the sub-station HFS of the Observatory (Ericsson, 1969). The signals are sampled ten times a second and recorded digitally. In Fig 1 some selected P-signals are displayed.

The explosion traces in the figure, which are quite typical, reflect the dramatic variation between different areas. The two Eastern Kazakh traces show the variation between closely

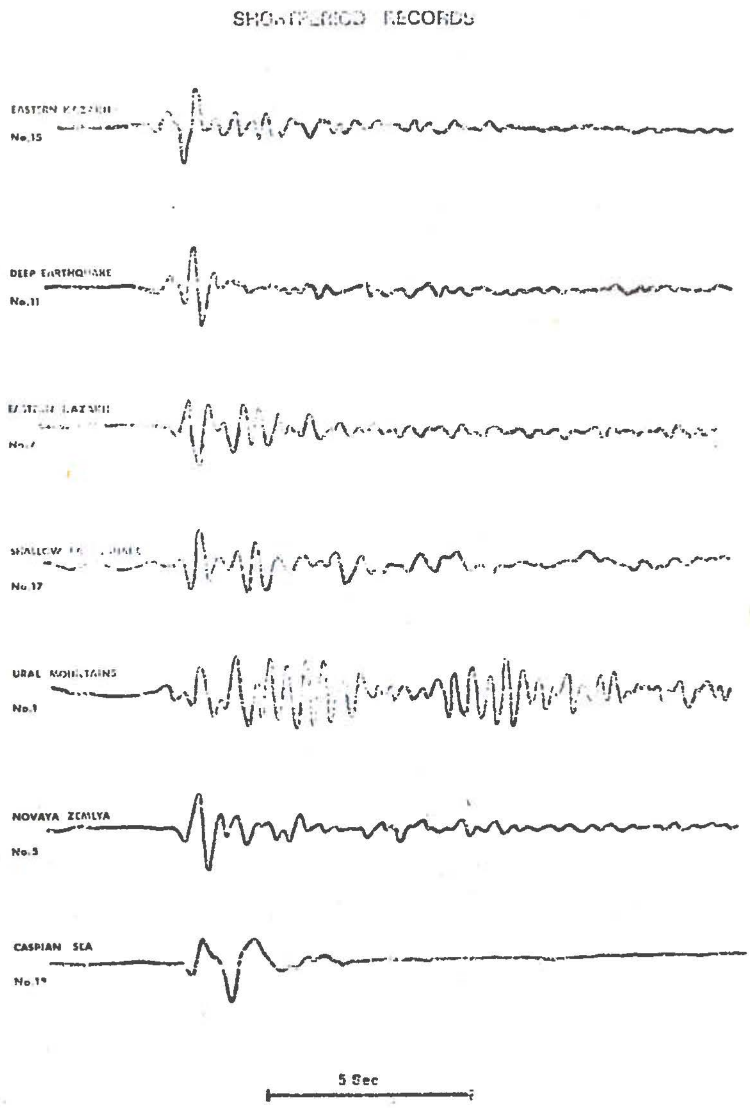

Fig 1. Short Period Records

spaced explosions. The Ural record is visibly very different and is complicated by the ringing coda. That this large coda is probably not merely due to the close distance (20°) can be seen from the character of the Novaya Zemlya explosion being at the same distance from the Observatory as the Ural explosions. This record has a large initial P-amplitude. The record from the Caspian Sea explosion represents still another type having a very low frequent initial pulse. Finally the two strikingly explosionlike records from a shallow and a deep earthquake demonstrate the inherent difficulties with short period discrimination.

SIMPLE DISCRIMINANTS

Three discriminants will be discussed in this section viz. complexity, spectral ratio and third moment of frequency. The calculated values of these discriminants are supplemented in the Tables 1-3 for all the events.

The waveform complexity C is defined by the relation (Dahlman et al, 1970):

$$C = \int_2^{25} |s(t)|dt / \int_0^2 |s(t)|dt$$

where s(t) denotes the signal trace and 0 is at the time of first onset, which has been read visually.

The frequency domain of the signals is represented by the amplitude spectrum in a time window of 12.8 sec after first onset. A spectral ratio, SR, is defined as:

$$SR = \int_{0.63}^{1.09} S(f)\,df / \int_{2.19}^{2.89} S(f)\,df$$

where S(f) is the spectral component at frequency f of the amplitude spectrum.

The third moment of frequency introduced by Weichert (1971) can be written as:

$$TMF = \int_{0}^{5} f^3 S(f) / \int_{0}^{5} S(f)\,df$$

The integration limits of C and SR represent arbitrary but reasonable choices. Optimal limits can easily be developed and such an optimization will be discussed in terms of the detailed study of the waveform and the amplitude spectrum in the next sections.

In assessing the relative efficiency of the discriminants a number of identification curves for different regions and combinations of the discriminants have been calculated (see Ericsson, 1970). In short, these calculations showed that a linear combination of C and TMF generally was the most useful discriminant. Multivariate use of C and TMF has previously been introduced by Anglin (1971). To get some idea how this discriminant works, we have in Fig 2 plotted TMF versus C for explosions and shallow earthquakes. It is interesting to note that the Eastern Kazakh explosions are almost completely separated from the shallow earthquakes. Turning to the Ural Mountains and the Caspain Sea areas, the situation is no longer that favorable. The Sinkiang explosion is embedded in the earthquake population. The large

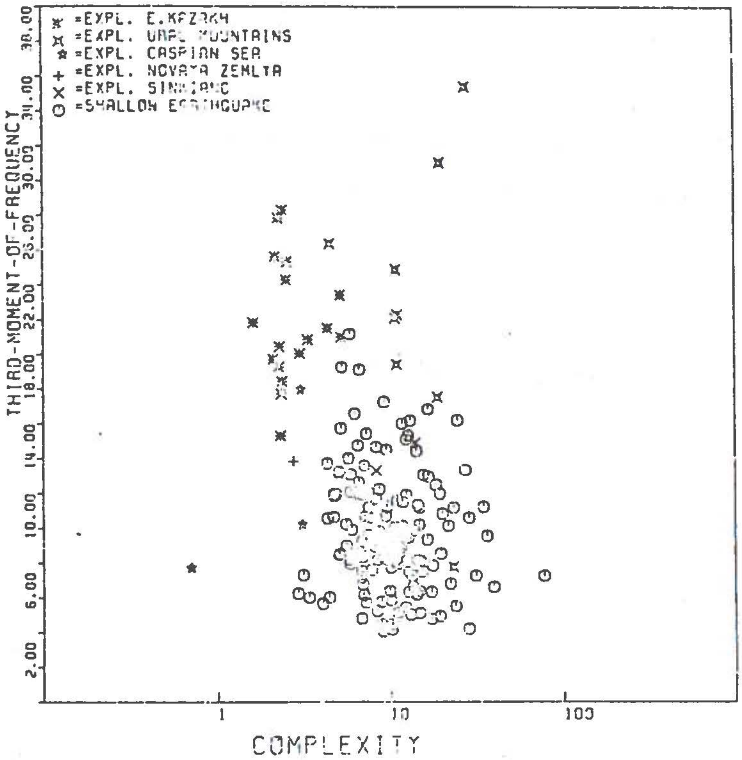

Fig 2. TMF versus Complexity

complexity of this explosion is probably caused by a secondary phase arriving 20 sec after first onset falling inside the second integration interval of C. It can also be seen that the three main explosion areas Eastern Kazakh, Ural and Caspian Sea occupy essentially different parts of the TMF-C plane in agreement with the observations from the seismograms themselves in Fig 1. It might be noted that the spectral ratio is found to have a systematic variation across Eastern Kazakh. The diagram also demonstrates the severe overlap between C and TMF when they are used separately.

A study of various kinds of factors influencing the discriminants gave briefly the following results. The earthquakes generally tend to get more explosionlike with decreasing magnitude. For events having m_b(HFS)$\geq$5.5 the separation between explosions and shallow earthquakes is complete using C and TMF. There appears to be regional differences between events separated by only a few degrees. The regional variations between earthquakes seem to occur primarily within rather than between the large scale tectonic belts. The data also suggest that the deep focus earthquakes appear explosionlike below 100 km.

MULTIPLE DISCRIMINANTS

In the previous section multivariate use of C and TMF proved to improve substantially upon the discrimination. In the next sections we have pursued this approach using multivariate statistical analysis. In order to take advantage of the detailed information in the signals, the previous discriminants have been changed and we have designed what is felt to be more detailed characterizations of the P-signal in the time and frequency domain. The detailed energy partitioning during the initial ten seconds after first onset of the P-signal is characterized by a ten dimensional vector denoted $\overline{W}$ and subsequently called the signal vector. The components of $\overline{W}$ are defined as:

$$W_i = \int_{i-1}^{i} |s(t)|dt / \int_{0}^{10} |s(t)|dt \qquad i=1,...,10$$

A complementary vector, $\overline{U}$, called spectral vector represents the amplitude spectrum from 0.55 to 3.65 cps. The components of U_i of the spectral vector are given by:

$$U_i = \int_{L(i-1)}^{L(i)} S(f)df / \int_{0.55}^{3.65} S(f)df, \qquad L(i)=0.55+0.31\cdot i \qquad i=1,...,10$$

To get some idea of these vectors we have plotted average values of the individual components of $\overline{U}$ and $\overline{W}$ for deep and shallow earthquakes together with those for explosions in the three main areas of Fig 3. The diagram clearly demonstrates the large variation between the different explosion locations. It can also be seen that the deep earthquakes as compared with the shallow ones tend to resemble the Eastern Kazakh explosion.

To compare the signal and spectral vectors with the previous discriminants we will analyze one case in some detail. Only Eastern Kazakh explosions, the Sinkiang explosion and shallow earthquakes from the general area of Tadzhik - Kirgiz - Sinkiang will then be considered. In fact this is the area where C and TMF were found to operate most successfully.

Fig 4 presents the identification curves for linear combinations of the components of $\overline{U}$, $\overline{W}$, and C, TMF. The coefficients of the linear combinations have been obtained using multivariate statistical analysis (Rao, 1967). The vectors seem to improve the detection probability substantially at low false alarm levels like 0.1 and 1% while the difference is more subtle at larger false alarm rates.

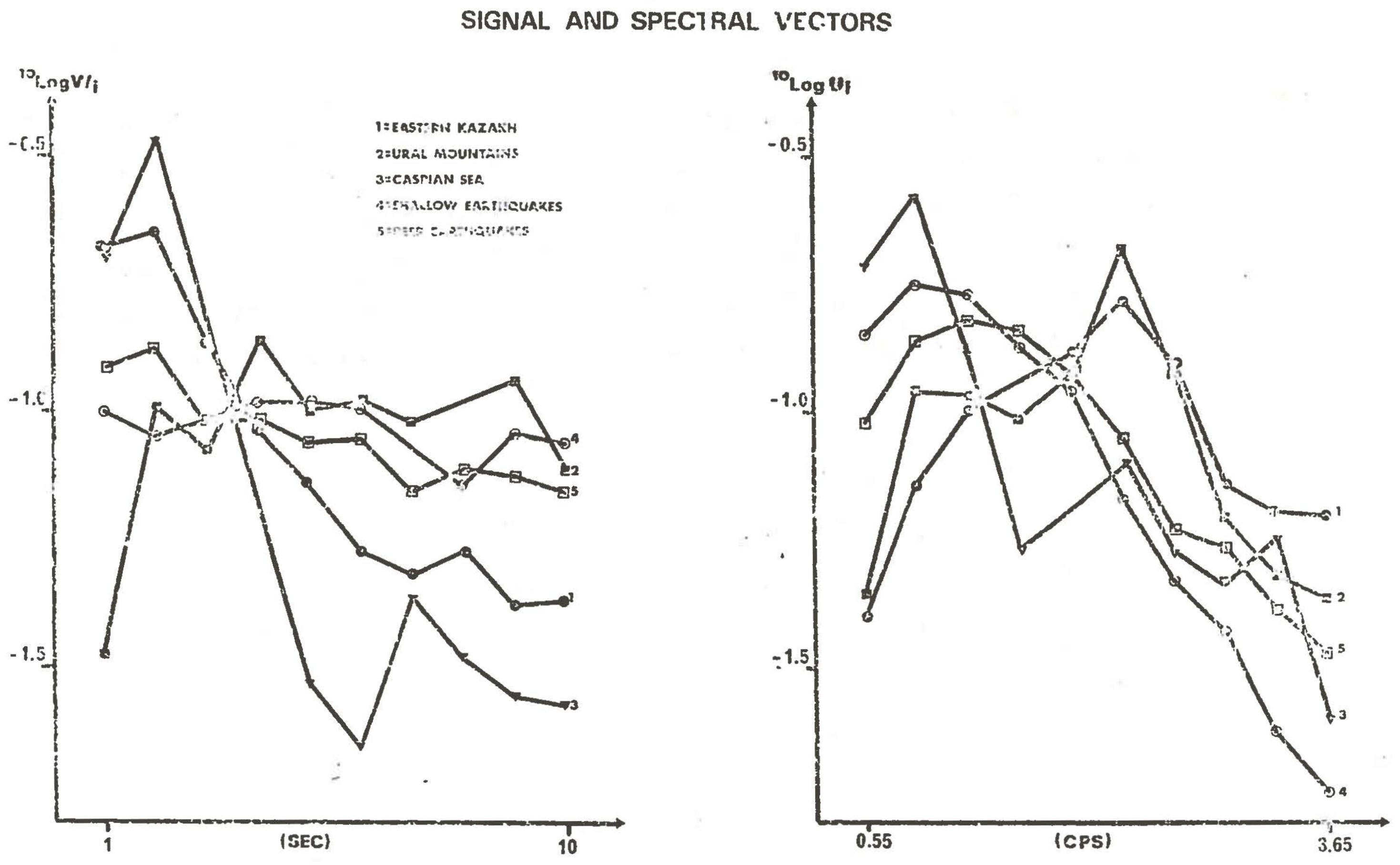

Fig 3. Signal and Spectral Vectors

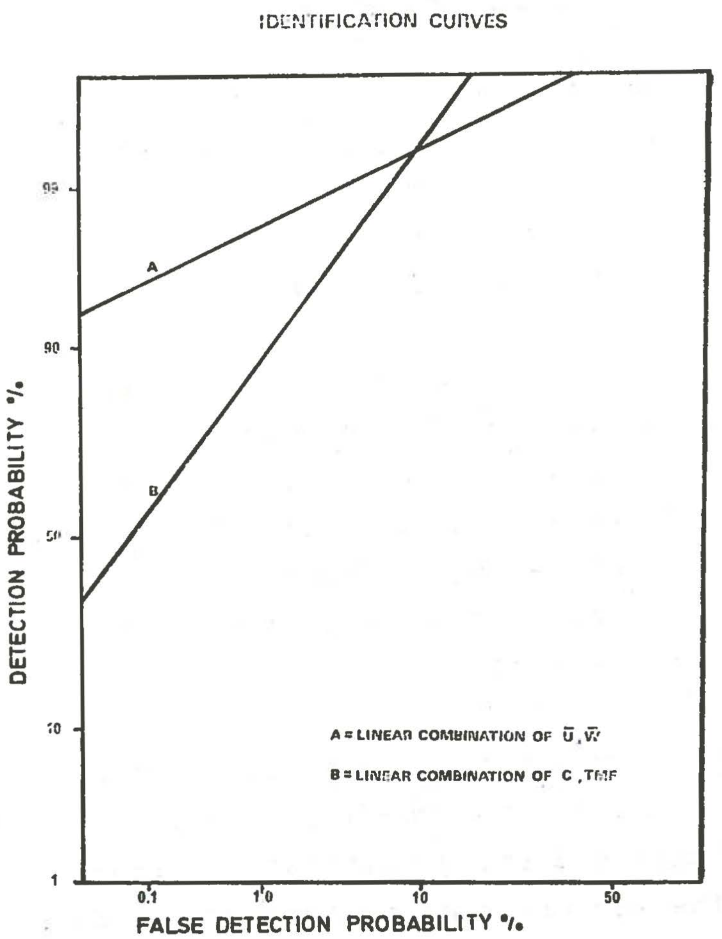

Fig 4. Identification Curves

CLASSIFICATION EXPERIMENTS

From the foregoing discussion it is not unreasonable to assume that the entire sample of events consists of essentially five types: shallow and deep earthquakes and Eastern Kazakh, Ural and Caspian Sea explosions. On this assumption we will now attempt to classify each event into one of these five groups by a special statistical procedure using the $\overline{U}$ and $\overline{W}$ parameters. Theoretically all the calculations are for computational convenience based on multivariate normal distributions for $\overline{U}$, $\overline{W}$ (Rao, 1967). In addition we will assume that the five groups have equal covariance matrices. It is fully realized that these assumptions are not optimum. Even so it is felt that this multivariate procedure can be regarded as a reasonable first approach to define new improved discriminants. All numerical calculations have been carried out with a computer package described by Dixon (1968). By forming linear combinations of $\overline{U}$ and $\overline{W}$ and after appropriate exponentation and normalization, the vectors can be said to have been transformed into five conditional probabilities. Each probability reflects the likelihood for an observation of $\overline{U}$,$\overline{W}$ belonging to the different event groups. Finally we will classify an event into the group having the largest probability.

The classifications will be carried out in three steps:

(1) Learning mode: Small subsamples of each group are selected and used to design the transformation rules taking the original observation of $\overline{U}$,$\overline{W}$ into the five probabilities. The subsample itself will then be tested on these transformation rules.

(2) Recognition mode: A large test sample, which is completely independent of the subsamples in the learning mode, will be run through the classification procedure.

(3) All data: The subsample in (1) together with the test sample in (2) will be run through a new learning mode to design new transformation rules. All the events are then tested on these criteria.

In the last step (3) we get an indication of the stability of the estimates. In real applications the transformation rules are likely to be estimated in an adaptive way. In the selection of events in the first step (1) we have used shallow earthquakes having a depth estimated to be less than 50 km. Otherwise results in terms of classification matrices. To measure the success of the performance, the false alarm and detection probabilities are estimated in the tables as the fractions of misclassified earthquakes and correctly classified explosions respectively. The false alarm remains stable around a few per cent throughout the three steps. The detection probability is roughly 90 per cent except for the recognition mode case. One should not attach too much significance to the low detection probability of this step since only a few explosions are considered. The large number of shallow earthquakes classified as deep in the recognition mode is noteworthy. Many of these are restricted focal depth events and might have occurred at much larger depths. The false alarms occur mostly for the non-Kazakh explosion. The two false alarms for Eastern Kazakh explosions in the third step are one shallow and one deep earthquake, the records of which are shown in Fig 1. For comparison the most closely resembling Eastern Kazakh explosions are given in the same figure. These records give some idea of the efficiency of the classification procedure. From original location data in the NOAA EDR-cards there is visibly no doubt that the two false alarms really are earthquakes.

In addition to the classification experiments presented above, we have run a number of modified experiments and some of these are briefly summarized below. The effect of the size of the events has also been studied by running the classification scheme with $\overline{U},\overline{W}$ in conjunction with m_b(HFS). No dramatic changes were found even if the false alarms generally decline. Runs, where not only the explosion but the earthquakes were regionalized as well, suggest that it is possible to operate on false alarm levels below 1 per cent for certain regions. The number of false alarms can be reduced if events having a maximum probability less than a minimum level are not classified at all. For such events we have to rely on other criteria like the $m_b(M_s)$ method. Such a modified decision procedure attempts to restrict the discrimination to events which can be confidently classified with solely short period data and omitting all marginal events. A 95% minimum decision level implies for the data used in this study that roughly 10% of the earthquakes and the explosions would not be classified.

COMMENTS

The false alarm rates of the simple discriminants discussed in this study are very much the same as the ones obtained from large population studies with data at LASA in US and the Yellowknife array in Canada (Kelly 1968, Anglin 1971).

The whole problem of classifying seismic source types is one of multivariate nature. The multivariate discriminants are shown to be more efficient than simpler ones. It seems therefore that the kind of multidimensional discriminants and discrimination techniques used in this study together with the established $m_b(M_s)$ method is important for discrimination between earthquakes and explosions.

Evidently the deep focus earthquakes tend to be explosionlike. As long as no reliable depth determinations are available one cannot rule out the possibility that earthquakes really being deep will cause false alarms when short period discrimination is restricted to "shallow" earthquakes. The treatment of the deep earthquakes in this study indicates that they could be included in a discrimination system using short period discriminants. The importance of developing accurate depth determination methods must, however, be stressed.

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TABLE 1

PRESUMED EXPLOSIONS

EVENT NO.	DATE	ORIGINTIME (GMT)	EPICENTER LAT(N)	EPICENTER LONG(E)	DEPTH KM	M(B) CGS	M(B) HFS	C	TMF	SR
1	690902	45957.4	57.4	54.9	0	4.9	5.4	10.66	22.1	0.32
2	690908	45956.1	57.4	55.1	0	4.9	5.4	10.98	22.3	0.27
3	690911	40157.1	49.7	78.1	0	5.0	5.5	2.30	15.3	0.43
4	690922	161458.8	41.4	88.3	0	5.1	5.2	8.28	13.3	1.02
5	691014	70006.2	73.4	54.8	0	6.1	6.6	2.72	13.8	0.77
6	691206	70257.4	43.8	54.8	0	5.8	6.2	2.82	17.7	1.38
7	691228	34658.0	50.0	77.8	0	5.7	6.1	3.30	20.8	0.17
8	691229	40158.2	49.7	78.2	0	4.6	5.0	5.14	21.0	0.46
9	700129	70257.5	49.8	78.2	0	5.6	5.9	2.23	27.8	0.23
10	700221	70919.6	59.6	59.2	1	4.3	4.2	23.34	7.8	3.35
11	700327	50256.8	49.8	78.0	0	5.2	5.4	4.28	21.5	0.58
12	700625	45952.4	52.2	55.7	0	4.9	5.3	4.43	26.4	0.30
13	700721	30257.1	50.0	77.8	0	5.4	6.0	2.14	25.6	0.13
14	700724	35657.4	49.8	78.2	0	5.3	5.8	2.35	28.3	0.40
15	700906	40257.4	49.8	78.1	0	5.6	6.0	2.96	20.0	0.36
16	701212	70057.3	43.9	54.8	0	6.1	6.3	2.88	10.0	4.50
17	701217	70057.4	49.7	78.1	0	5.5	5.8	2.27	20.4	0.36
18	701223	70057.3	43.8	54.9	0	6.1	6.4	0.66	7.5	4.19
19	710322	43257.8	49.7	78.2	0	5.8	6.0	2.35	18.4	0.55
20	710323	65956.0	61.3	56.5	0	5.6	6.0	13.98	14.9	0.42
21	710425	33258.0	49.8	78.1	0	5.9	6.4	2.32	17.7	0.48
22	710525	40257.7	49.8	78.2	0	5.2	5.4	2.51	25.3	0.35
23	710606	40257.1	50.0	77.8	0	5.5	5.9	2.08	19.7	0.24
24	710619	40357.6	50.0	77.7	0	5.5	6.1	2.25	19.3	0.18
25	710630	35657.2	50.0	79.1	0	5.4	5.9	1.60	21.8	0.35
26 x)	710702	170001.4	67.5	62.5	0	0.0	4.9	18.92	17.5	1.15
27	710710	165959.3	64.2	55.2	0	5.3	4.8	10.95	19.4	0.42
28	710919	110006.8	57.7	41.1	33	4.5	4.8	26.89	35.2	0.26
29	711004	100002.0	61.6	47.1	13	5.1	4.8	19.70	31.0	0.31
30	711009	60257.1	50.0	77.7	0	5.4	5.7	2.48	24.2	0.19
31	711021	60257.3	50.0	77.6	0	5.6	5.7	5.08	23.4	0.30
32	711022	50000.4	51.6	54.5	6	5.3	5.8	10.81	24.9	0.55

x) = Source data obtained from location with the Nordic seismograph network

Depth restricted to 0 km.

TABLE 2

SHALLOW EARTHQUAKES

EVENT NO.	DATE	ORIGINTIME (GMT)	EPICENTER LAT(N)	LONG(E)	DEPTH KM	M(B) CGS	M(B) HFS	C	TMF	SR
1	690614	32829.6	31.7	94.6	33	5.3	5.0	6.87	6.8	4.55
2	690916	211926.5	39.8	75.1	19	4.9	4.9	5.81	12.1	1.56
3	690927	165625.2	38.6	75.1	33	4.9	5.1	13.44	7.2	3.40
4	691030	121722.3	52.3	95.8	33	4.8	5.4	5.04	13.2	3.41
5	691205	184517.4	29.7	80.8	33	4.9	5.0	6.80	9.2	1.31
6x	700214	53225.8	33.5	74.3	0	0.0	4.7	20.18	10.8	2.26
7	700219	71001.8	27.4	94.0	18	5.5	6.0	9.88	6.4	1.89
8	700305	42330.6	30.6	103.0	33	5.0	4.5	10.08	7.7	3.80
9	700305	183422.5	32.4	76.5	33	4.9	4.8	16.42	9.3	2.36
10	700310	52010.3	26.8	97.0	33	5.4	6.0	3.35	6.0	3.85
11	700314	220622.3	30.6	103.0	42	5.0	4.7	10.02	5.8	3.49
12	700317	231942.3	33.9	59.7	19	5.0	4.9	13.14	5.0	10.00
13	700324	234700.7	26.2	104.9	8	4.9	5.2	8.38	9.2	2.28
14	700328	94457.8	52.2	105.8	33	5.2	4.4	12.36	11.9	1.91
15x	700329	151601.2	34.4	104.3	0	0.0	4.6	13.73	9.8	3.59
16x	700412	181234.9	40.0	79.2	0	0.0	4.4	6.74	7.2	4.11
17	700415	54520.1	39.0	70.7	33	4.6	4.9	4.68	11.8	0.40
18	700419	53346.2	39.0	70.8	33	4.7	4.8	6.56	11.9	0.78
19	700419	84937.3	38.8	75.3	33	4.8	5.0	4.67	10.6	1.12
20	700423	180218.8	37.5	72.6	46	5.1	5.2	6.86	8.3	2.23
21	700424	32912.9	38.4	69.0	31	4.6	4.5	12.86	7.5	1.80
22	700501	34715.7	47.6	82.7	33	4.9	4.9	7.22	15.4	1.03
23x	700509	11135.8	32.8	87.7	0	0.0	4.4	15.12	8.1	4.06
24	700511	31219.7	28.5	52.3	22	5.1	5.3	6.57	19.1	1.50
25	700515	171315.1	50.2	91.3	33	5.9	6.2	28.46	4.2	8.80
26x	700515	172654.5	44.5	100.5	0	0.0	5.3	10.15	4.2	9.76
27x	700515	172846.2	43.3	93.9	0	0.0	5.3	8.97	4.1	5.26
28	700515	175828.3	50.2	91.3	33	5.1	5.5	8.32	5.2	9.17
29	700515	183604.0	50.3	91.3	33	4.5	5.1	6.94	6.1	3.84
30x	700515	184833.0	50.3	91.2	0	0.0	4.3	9.12	9.5	2.94
31	700515	185007.4	50.3	91.2	33	4.6	4.8	8.07	8.9	3.21
32	700515	201216.9	50.2	91.3	33	5.0	5.5	7.13	5.7	4.17
33	700515	205012.7	56.8	117.8	33	4.9	5.5	21.85	10.1	1.55
34	700516	212655.2	43.0	47.0	33	4.8	4.5	16.62	16.8	2.82
35	700517	5648.0	50.2	91.3	33	4.5	4.6	11.23	8.5	2.02
36x	700517	21504.1	48.8	92.9	0	0.0	4.4	6.61	8.5	4.42
37	700517	50217.7	43.0	46.9	33	4.7	4.7	27.38	13.3	3.82
38	700517	64906.1	43.0	46.9	33	5.0	5.8	36.62	9.5	4.35
39	700518	31225.5	42.8	46.9	33	4.4	4.3	9.40	10.7	2.49
40	700518	53644.4	42.6	46.6	33	4.5	4.4	34.98	11.2	3.48
41	700518	65525.7	27.6	52.9	40	4.7	5.0	5.13	15.7	0.53
42	700518	73216.2	50.3	91.3	33	4.8	5.1	2.88	6.2	7.40
43	700518	143640.7	56.9	117.6	33	4.6	5.3	23.45	11.1	1.65
44x	700521	101422.1	39.9	44.7	0	0.0	4.9	6.51	12.6	2.44
45	700523	145134.6	50.1	91.6	43	4.5	5.0	17.38	6.3	6.89
46x	700604	205851.7	44.6	45.2	0	0.0	4.1	12.69	15.3	1.10
47	700605	45306.4	42.5	78.8	20	6.0	6.0	12.20	9.3	1.90
48x	700609	62601.7	43.2	46.3	0	0.0	4.2	15.65	13.0	2.25
49x	700619	184720.9	33.4	113.1	0	0.0	4.8	4.69	12.0	0.82
50x	700621	161304.3	40.9	73.1	0	0.0	4.6	10.87	11.5	3.09

TABLE 2

SHALLOW EARTHQUAKES

EVENT NO.	DATE	ORIGINTIME (GMT)	EPICENTER LAT(N)	LONG(E)	DEPTH KM	M(B) CGS	M(B) HFS	C	TMF	SR
51	700730	5219.5	37.8	55.9	19	5.7	6.4	14.41	8.1	3.07
52*	700802	144741.1	49.3	91.8	0	0.0	4.4	28.74	10.6	3.49
53	700903	223809.4	40.0	53.6	36	4.4	4.3	14.19	14.4	1.79
54	700908	124507.0	28.6	58.9	21	4.8	4.6	11.01	7.9	2.20
55*	700913	165049.7	35.9	71.2	0	0.0	4.8	4.26	13.7	1.34
56	700914	94333.5	39.9	77.0	33	5.2	5.1	14.29	6.2	5.46
57	700918	200225.0	36.4	68.9	33	5.1	4.5	13.12	16.2	0.88
58	701003	24740.6	34.1	47.3	24	4.5	4.2	12.85	6.3	2.14
59	701005	104249.1	40.2	77.1	33	5.0	4.6	8.54	9.8	3.19
60	701007	22036.7	27.8	56.5	43	5.0	5.1	6.82	11.9	0.99
61	701007	104603.7	43.4	44.0	33	4.5	5.1	5.72	8.2	3.56
62	701009	134852.6	39.1	71.7	46	5.2	5.2	7.59	10.6	2.23
63	701017	53315.2	41.4	79.2	33	5.0	4.8	5.92	9.9	3.41
64	701020	103419.3	27.6	56.7	44	4.9	5.2	4.97	8.4	1.22
65	701025	112218.2	36.8	45.1	19	5.5	5.6	19.40	4.9	5.49
66*	701117	175917.3	25.2	108.2	0	0.0	5.0	12.76	9.4	2.41
67	701129	20337.4	41.6	81.8	33	5.1	5.1	8.37	8.1	2.31
68*	701205	54947.2	29.6	81.3	0	0.0	5.1	5.65	14.0	2.14
69*	701225	41354.6	23.0	97.1	0	0.0	5.1	7.43	12.0	2.24
70	701228	15654.2	41.5	44.0	19	4.8	4.7	11.49	8.9	4.18
71	710128	60927.2	28.5	57.4	34	4.6	4.6	6.16	16.6	2.12
72	710128	155106.6	35.0	47.0	43	4.6	5.0	7.43	11.2	0.94
73	710201	142142.9	42.3	85.3	33	4.8	4.3	9.17	17.2	2.22
74	710202	75957.0	23.8	91.8	48	5.4	6.0	4.00	5.7	5.12
75	710210	233142.9	38.7	70.6	30	4.8	5.1	14.44	11.3	0.84
76	710211	14129.0	38.3	46.9	48	4.1	4.3	8.22	11.7	2.10
77*	710212	142351.0	51.5	86.0	0	0.0	4.6	11.70	16.0	1.40
78	710221	114524.8	40.8	72.6	33	4.2	5.0	5.08	8.5	1.23
79*	710227	153235.1	41.2	78.3	0	0.0	4.3	11.78	9.8	2.31
80	710301	5651.5	34.1	95.8	33	4.6	4.8	14.79	6.3	3.42
81	710311	235946.5	40.1	77.1	33	0.0	4.7	7.42	9.6	2.59
82	710312	52517.2	28.7	94.6	35	0.0	4.6	5.49	10.2	2.41
83	710315	225717.6	33.0	68.1	41	4.3	4.7	6.75	7.5	7.46
84*	710322	84541.4	42.7	45.9	0	0.0	4.6	6.43	14.7	1.88
85	710324	205428.6	41.5	79.5	18	5.3	5.7	8.82	5.8	15.19
86	710324	210154.9	41.4	79.4	25	5.3	5.7	6.74	4.8	11.31
87	710326	211838.9	35.3	46.4	33	4.6	4.7	14.78	10.2	2.29
88	710328	25412.2	19.1	96.3	34	4.4	5.3	10.72	8.2	1.82
89*	710328	104929.3	36.5	80.1	0	0.0	4.1	9.26	8.2	3.87
90*	710328	180237.0	35.0	83.8	0	0.0	4.0	9.34	9.2	3.84
91	710331	81619.6	26.2	96.6	22	5.0	5.1	8.57	12.2	1.34
92	710331	215010.3	34.6	50.3	31	4.4	5.2	8.25	9.5	0.60
93	710403	44903.4	32.3	95.1	33	5.7	5.9	22.43	6.8	4.03
94	710403	45045.6	32.3	95.4	33	5.8	6.0	8.85	4.5	10.02
95	710403	73450.2	32.2	95.1	33	5.1	4.4	10.81	8.2	1.03
96	710404	13523.3	38.4	73.3	33	4.8	4.9	5.51	9.0	2.61
97	710404	61227.5	30.5	67.8	15	0.0	4.9	7.74	7.6	4.65
98	710406	30257.0	39.6	77.8	33	4.5	4.3	15.31	7.5	6.86
99	710406	64952.9	29.8	51.9	10	5.2	5.0	24.66	16.2	1.15
100*	710406	104444.4	32.0	90.0	0	0.0	4.7	10.55	10.0	3.90

TABLE 2

SHALLOW EARTHQUAKES

EVENT NO.	DATE	ORIGINTIME (GMT)	EPICENTER LAT(N)	LONG(E)	DEPTH KM	M(B) CGS	M(B) HFS	C	TMF	SR
101x	710407	62232.1	44.5	103.0	0	0.0	4.8	11.77	10.1	4.0
102	710412	190325.9	28.3	55.6	44	6.0	6.0	31.39	7.2	2.4
103	710413	204300.3	28.2	55.6	44	4.8	4.8	9.47	14.5	1.3
104x	710418	64806.7	37.9	70.6	0	0.0	4.6	9.55	11.2	2.8
105	710418	72414.3	39.1	71.7	33	4.5	4.8	16.74	12.9	0.4
106x	710418	231354.2	41.5	80.6	0	0.0	4.2	14.84	8.1	3.6
107x	710419	203617.7	35.3	74.3	0	0.0	5.0	5.77	21.2	0.6
108	710421	91522.9	26.6	92.2	33	4.3	5.0	18.45	12.5	0.8
109	710421	143953.1	41.5	79.2	40	5.1	4.7	7.08	10.6	4.2
110	710428	151242.2	34.4	73.5	40	4.9	4.9	7.01	13.6	0.6
111	710428	153200.9	22.9	101.0	15	5.6	6.0	39.95	6.6	2.2
112	710503	3322.5	30.8	84.5	16	5.4	5.8	3.09	7.3	2.2
113x	710512	232849.9	25.7	117.1	0	0.0	4.8	8.22	14.6	1.0
114x	710518	1148.3	41.8	44.0	0	0.0	4.8	10.32	8.5	2.9
115x	710518	81919.4	42.0	44.9	0	0.0	4.6	11.08	9.8	5.2
116	710522	140207.5	35.6	58.3	36	4.8	4.8	4.37	6.0	5.0
117	710522	164358.7	38.8	40.5	3	6.0	6.4	77.49	7.2	8.4
118	710522	173229.1	38.9	40.5	33	4.5	4.4	11.05	5.1	5.7
119	710522	173415.1	38.8	40.6	13	4.8	4.8	17.37	4.8	8.4
120	710522	183530.6	39.0	40.7	33	4.7	4.7	14.86	5.1	4.7
121	710522	200332.4	32.4	92.1	33	5.6	5.7	12.23	5.4	7.1
122	710525	43236.9	27.7	55.4	23	5.1	5.1	19.46	12.0	1.0
123	710525	65248.9	27.3	53.4	11	4.8	4.9	5.80	13.1	1.1
124	710526	24146.0	35.5	58.2	26	5.4	5.9	10.22	4.5	6.2
125x	710526	164548.8	40.8	43.7	0	0.0	4.9	14.87	11.2	2.2
126x	710527	30.7	48.2	47.8	0	0.0	4.3	12.37	15.1	1.4
127	710527	3027.7	38.3	69.0	36	4.8	4.9	5.79	7.9	2.2
128x	710527	62044.2	31.9	51.6	0	0.0	4.8	5.20	19.3	1.2
129	710530	115559.9	25.3	96.4	33	4.9	5.2	13.55	6.6	2.4
130	710530	154415.7	25.2	96.4	15	5.8	6.0	23.99	5.5	3.5
131	710530	213900.5	25.3	94.4	33	4.9	5.2	14.25	6.2	6.7
132	710531	51359.7	25.2	96.5	33	5.3	5.8	17.65	7.8	1.9
133x	710531	125655.2	28.3	96.4	0	0.0	5.0	4.97	13.2	2.1
134	710604	204958.3	32.2	92.1	33	5.0	5.0	6.30	8.3	4.7
135	710606	103449.0	28.1	85.6	34	4.9	5.0	4.79	11.9	2.1
136x	710624	175733.8	46.7	78.8	0	0.0	4.6	9.75	9.0	5.3
137x	710626	231153.7	37.9	74.8	0	0.0	4.7	4.29	10.6	1.8
138x	710628	51138.9	35.3	103.7	0	0.0	4.9	11.82	11.5	2.4
139	710628	195345.7	42.4	43.3	34	4.6	5.2	19.65	8.5	3.1
140x	710630	133603.7	42.1	79.5	0	0.0	4.8	9.48	11.2	4.3

x) = Source data obtained from location with the Nordic seismograph network

Depth restricted to 0 Km.

TABLE 3

DEEP EARTHQUAKES

EVENT NO.	DATE	ORIGINTIME (GMT)	EPICENTER LAT(N)	LONG(E)	DEPTH KM	M(B) CGS	M(B) HFS	C	TMF	SR
1	690826	32319.2	37.1	72.7	65	4.7	5.0	11.02	10.5	1.42
2	690928	185328.6	39.3	73.6	62	5.0	5.5	10.91	14.4	0.54
3	700223	223736.8	36.0	70.4	137	5.0	5.5	7.46	17.4	1.89
4	700307	125949.8	36.8	71.2	148	4.7	5.5	3.24	17.3	1.10
5	700313	182454.0	24.9	93.9	62	4.9	5.6	3.41	11.6	0.87
6	700315	151038.9	32.2	49.4	65	0.0	4.1	13.20	9.5	3.05
7	700316	34706.4	33.9	86.3	52	4.9	4.9	6.59	7.1	3.31
8	700401	235405.6	28.0	56.7	62	5.1	5.1	6.18	14.9	1.20
9	700410	82259.6	36.4	71.1	125	4.7	5.2	4.15	18.5	1.09
10	700416	12652.1	38.7	48.6	78	4.9	4.8	14.19	10.2	4.21
11	700510	123233.3	36.1	71.1	121	4.7	5.3	3.08	18.4	0.54
12	700904	131202.2	36.6	70.1	290	4.9	5.1	7.41	17.1	1.05
13	700905	192625.6	37.0	71.4	112	5.1	5.0	8.23	15.8	0.77
14	701006	220626.8	39.1	71.6	68	5.2	5.4	12.50	14.3	0.99
15	701009	11844.1	39.0	71.6	81	5.1	5.2	14.69	12.0	1.74
16	701009	185005.4	35.9	70.4	141	5.1	4.9	4.41	24.0	0.54
17	701109	174142.2	29.5	56.9	106	5.5	6.2	3.45	6.6	3.25
18	701113	173006.7	36.9	71.6	124	5.3	6.3	2.69	14.1	1.23
19	701129	51206.8	36.2	71.4	117	4.9	5.3	4.75	17.3	0.56
20	701129	85320.0	36.6	71.5	177	4.6	5.2	4.44	15.4	1.02
21	701129	173745.9	39.6	54.6	53	4.7	4.9	12.10	10.5	1.32
22	701226	75841.7	36.4	70.9	197	5.1	5.3	2.18	8.5	6.53
23	710113	215235.6	38.9	71.0	72	4.8	5.1	7.38	11.7	0.91
24	710120	213203.0	35.1	46.9	57	5.1	5.8	9.62	9.0	1.40
25	710130	201540.8	30.5	79.1	56	4.6	5.1	6.00	13.3	2.18
26	710206	163410.7	38.1	73.3	171	4.5	5.3	5.49	8.0	1.41
27	710206	221244.8	36.0	69.9	109	5.0	5.3	6.80	19.1	1.37
28	710219	101329.3	36.6	71.5	110	4.8	5.4	3.06	15.0	0.62
29	710316	52811.6	36.6	54.9	56	0.0	4.6	7.89	6.9	4.21
30	710318	191243.0	38.2	73.6	145	4.9	5.7	1.79	12.3	0.95
31	710403	101925.3	33.2	46.5	51	4.1	4.4	8.80	11.4	1.84
32	710408	183338.3	38.4	73.3	129	5.0	4.5	9.87	20.5	0.54
33	710516	172056.7	36.1	77.9	84	4.6	4.5	6.92	18.7	2.60
34	710517	84321.8	24.3	94.7	167	4.7	5.5	4.96	11.2	1.04
35	710531	110555.9	28.9	54.6	60	4.4	4.8	12.60	18.9	0.57
36	710625	110224.9	37.6	72.1	140	4.6	5.0	5.60	13.2	1.40
37	710626	222329.0	36.3	71.4	127	5.0	5.6	2.66	18.0	0.48

<u>TABLE 4</u>

CLASSIFICATION MATRICES

Group		Learning mode: Total no.	Learning mode: Classified as (K)	(U)	(C)	(S)	(D)	Recognition mode: Total no.	Recognition mode: Classified as (K)	(U)	(C)	(S)	(D)	All the data: Total no.	All the data: Classified as (K)	(U)	(C)	(S)	(D)
Kazakh	(K)	15	14	0	0	0	1	2	2	0	0	0	0	17	15	1	0	0	1
Ural	(U)	5	0	5	0	0	0	5	0	2	0	1	2	10	0	9	0	1	0
Caspian	(C)	3	0	0	3	0	0	0	0	0	0	0	0	3	0	0	2	0	1
Shallow	(S)	20	0	0	0	18	2	120	1	4	0	69	46	140	1	1	0	114	24
Deep	(D)	22	1	0	0	1	20	15	1	1	0	3	10	37	1	4	0	9	23
Detection probability		22/23 = 95.6%						4/7 = 57.1%						26/30 = 86.7%					
False alarm probability		1/42 = 2.4%						7/135 = 5.2%						7/177 = 4.0%					