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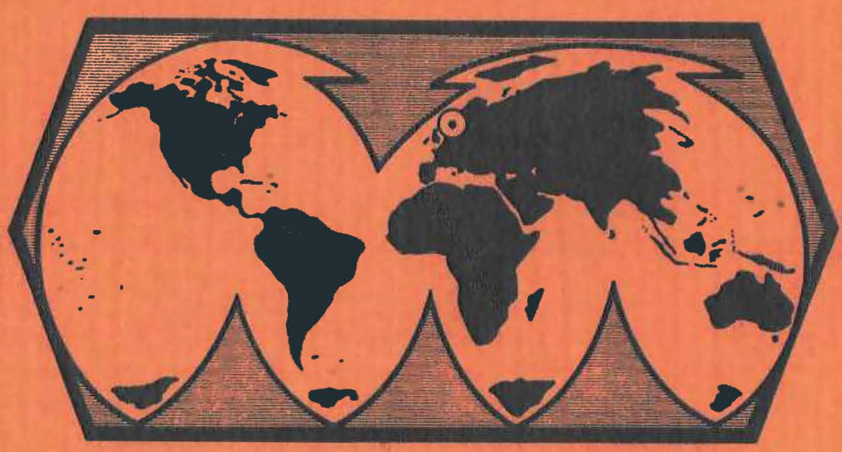

VI.6 Location of Regional Events using Travel Time Differentials between P Arrival Branches

This study was undertaken to investigate the potential of obtaining very precise relative epicentral distance estimates of events in the range 15-30°, using information from the strong secondary P arrival branches observed on NORSAR recordings of Eurasian events at these distances. The present paper discusses the application of such techniques to a limited epicentral region north of the Caspian Sea, from which several presumed explosions have been recorded.

Earlier studies (Massé and Alexander (1974), King and Calcagnile (1975)) have discussed the strong secondary P phases that are observed on NORSAR recordings of presumed explosions in the distance range 15-30°. These can be associated with discontinuities in the upper mantle underneath Eurasia at depths near 420 and 690 km. Massé (1974) showed that arrival time differentials between such phases may give potentially very accurate constraints on epicentral distance estimates.

In this study, we examine the use of regional phases to obtain precise relative distance estimates within a limited epicentral region. We have chosen to study the area north of the Caspian Sea, from where several presumed explosions have been recorded by NORSAR (Table VI.6.1). NORSAR's detection capability for this region is very good, partly as a result of signal focusing effects which give a significant positive magnitude (m_b) bias at NORSAR relative to NEIS m_b. From Table VI.6.1, it is seen that the bias is about 0.5 m_b units on the average. Fig. VI.6.1 shows the NORSAR array deployment, and in Fig. VI.6.2, filtered traces from subarray 02B are displayed for the lowest magnitude event in the data set. This event, 12 September 1978, had a NORSAR m_b of 4.0, corresponding to a NEIS equivalent m_b of 3.5. The signal-to-noise ratio at the best sensor (02B05) is about 1.0 m_b units above the detection threshold, thus indicating that NORSAR is able to detect events down to about m_b=2.5 for this region. The large variation in signal strength across 02B is noteworthy, and shows the importance of taking advantage of signal focusing effects for detection purposes.

A subset of the single sensor traces for event 4 is displayed in Fig. VI.6.3. The relative strength of the first P phase and the second one (with onset some 7 seconds later) is highly variable between sensors. This is again due to signal focusing effects, and shows that an array of wide aperture is necessary to ensure that both phases are detected on at least some sensors.

Fig. VI.6.4 shows measured phase differentials for two events (nos. 4 and 5). The six subarrays with the clearest secondary phase have been selected for this figure, thus providing 48 measurements per event. For both events, the distances refer to a nominal event location of 48.0°N, 48.0°E. The distances are of importance mainly to indicate relative distances between sensors. (If a different location within the test region had been chosen, it would have resulted in essentially unchanged relative distances).

Several observations are made from Fig. VI.6.4:

- Event 5 has consistently greater phase differentials than event 4. Therefore event 5 is located further away from NORSAR than event 4.

- There are significant deviations from a straight-line fit to the data for both events.

- These deviations are apparently not due to inaccurate measurements, since they are very similar for both events. The similarity of the patterns is high both between subarrays and within subarrays.

The measurements of Fig. VI.6.4 were made by cross-correlating each sensor trace with portions of a reference trace. The reference trace was chosen as the record of instrument 03B01 for event 4. Both the reference trace and the other traces were bandpass filtered in the band 1.0-3.0 Hz prior to cross-correlation. The peak of the correlation function was determined by a cubic spline fit in order to obtain a higher precision than the sampling interval (0.05 seconds) of the raw data.

Table VI.6.2 summarizes the measured differences between the two events, averaged over each subarray. The averages range from 0.26 to 0.33 seconds, with a standard deviation of the mean of less than 0.01 seconds within each subarray. Average difference over all 48 instruments is 0.30 seconds.

To transform such time differences into distance differences, one may, as a first approximation, use the time-distance slope in Fig. VI.6.4. Thus 0.30 seconds corresponds to 12.5 km, which would then be the estimated distance difference between event 4 and event 5, in the azimuthal direction of NORSAR. The accuracy is difficult to assess, but appears to be on the order of ± 1-2 km based upon the consistency observed between subarrays.

In order to apply the method to low magnitude events, it is necessary to consider the traces with the best signal-to-noise ratio. Accordingly, we measured the phase differentials at the 'best' sensor 02B05 for all the events in the data set, and the results are given in Table VI.6.4. Note that the results from the largest events are uncertain due to the 'clipping' problem. It is seen that four of the low magnitude events have essentially identical time differences, indicating that their epicentral distance from NORSAR is similar. All of the other measured events appear to be located 10-20 km further away from NORSAR than this group.

There are some differences in the signal spectral contents between the high and low magnitude events in the data set. As an example, Fig. VI.6.5 shows the amplitude spectra at 01A04 for the events 12 and 14. The dominant frequency is around 2 Hz for the high magnitude event (14) and around 3 Hz for the low magnitude event (12). The latter spectrum is typical for all the low magnitude events (No. 4,5,7,8,9,12) while the former is representative for those high magnitude events for which we have been able to estimate the spectrum (No. 10,13,14,15).

In conclusion, the main advantage of the method is to obtain precise relative distance estimates (probably accurate to within 2 km) even for low magnitude events. To assess the accuracy and achieve further improvement, calibration of the delay/distance relation is necessary. This would require knowledge of the accurate location of a subset of events, distributed across the epicentral region in question.

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References

Massé, R.P. (1974): A technique for reducing epicenter coverage regions for explosions, Earthquake Notes Vol XLV, No. 4, 3-12.

Massé, R.P. and S.S. Alexander (1974): Compressional velocity distribution beneath Scandinavia and western Russia, Geophys. J.R. astr. Soc., 39, 587-602.

King, D.W. and G. Calcagnile (1975): P-wave velocities in the upper mantle beneath Fenoscandia and western Russia, Geophys. J.R. astr. Soc., 46, 407-432.

	DATE		ORIGIN TIME			EPICENTER			MAGNITUDE(MB)			
NO	YEAR	MM DD	H	MM	SS.D	**LAT**	**LON**	NST	NEIS	NAO	SOURCE	COMMENTS
1	1966	04/22	2	58	03.6	47.900N	47.700E	28	4.7	-	NEIS	NO NORSAR DATA
2	1968	07/01	4	02	01.7	47.900N	47.900E	62	5.5	-	NEIS	NO NORSAR DATA
3	1971	12/22	6	59	56.3	47.900N	48.200E	81	6.0	-	NEIS	CLIPPED (ALL CHANNELS)
4	1975	04/25	5	00	00.0	48.000N	48.000E	0	-	4.7	NORSAR	
5	1976	03/29	7	00	00.0	48.000N	48.000E	0	-	4.5	NORSAR	
6	1976	07/29	4	59	57.7	47.782N	48.120E	203	5.9	-	NEIS	CLIPPED (ALL EXCEPT 14C03)
7	1977	09/30	6	59	55.6	47.800N	48.145E	99	5.1	5.5	NEIS	CLIPPED (SOME CHANNELS)
8	1977	10/14	7	00	00.0	48.000N	48.000E	0	-	4.1	NORSAR	
9	1978	09/12	5	00	00.0	48.000N	48.000E	0	-	4.0	NORSAR	
10	1978	10/17	4	59	56.5	47.818N	48.114E	257	5.8	6.4	NEIS	CLIPPED (ALL EXCEPT 01A04)
11	1978	12/18	7	59	56.3	47.787N	48.192E	254	6.0	6.3	NEIS	NO DIGITAL NORSAR DATA
12	1979	01/10	8	00	00.0	48.000N	48.000E	0	-	4.7	NORSAR	
13	1979	01/17	7	59	55.7	47.883N	48.128E	225	6.0	6.6	NEIS	CLIPPED (ALL EXCEPT 01A04)
14	1979	07/14	4	59	55.1	47.813N	48.097E	227	5.6	6.3	NEIS	CLIPPED (ALL EXCEPT 01A04)
15	1979	10/24	5	59	56.6	47.806N	48.158E	220	5.8	6.4	NEIS	CLIPPED (ALL EXCEPT 01A04)

NOTE:

ALL THE EVENTS OF MB ABOVE 5.5 EXCEED THE DYNAMIC RANGE OF THE NORSAR DIGITAL RECORDING SYSTEM, WITH THE EXCEPTION THAT ONE LOW GAIN CHANNEL HAS BEEN AVAILABLE SINCE 1976.

TABLE VI.6.1

List of events from the area north of the Caspian Sea.

SUBARRAY	NOBS	MEAN DIFF. (S)	ST.DEV	ST.DEV OF MEAN
01B	6	0.3307	0.0210	0.0086
02B	6	0.3018	0.0144	0.0059
03B	6	0.3132	0.0084	0.0034
06B	6	0.3197	0.0116	0.0048
04C	6	0.2563	0.0163	0.0067
05C	6	0.2608	0.0102	0.0042
12C	6	0.3158	0.0157	0.0064
13C	6	0.3090	0.0241	0.0099

TABLE VI.6.2

Time differentials between events 4 and 5, averaged over the 8 subarrays shown in Fig. VI.6.4.

EVENT NO	TIME DIFF SECONDS	DISTANCE(KM) (NEIS LOCATION)
1	-	2729.9
2	-	2740.3
3	-	2755.9
4	7.54	-
5	7.85	-
6	8.0 *	2761.2
7	7.93	2761.0
8	7.53	-
9	7.54	-
10	7.95*	2758.0
11	-	2764.5
12	7.53	-
13	7.8 *	2753.5
14	7.9 *	2757.5
15	8.0 *	2761.2

TABLE VI.6.3

Estimated phase differentials at instrument 02B05 between the first and second recorded P phase.
(Uncertain measurements due to clipping are marked *.)

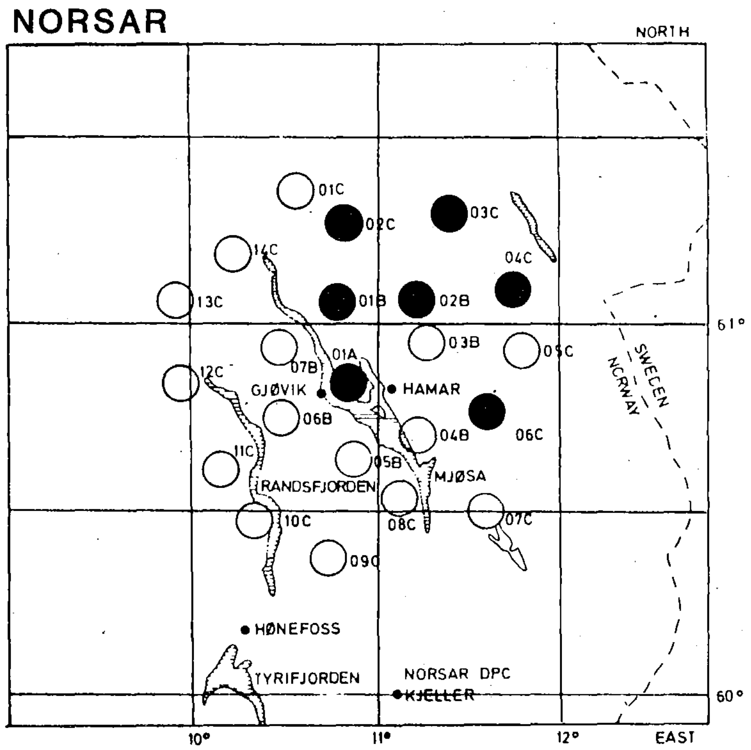


Fig. VI.6.1 Deployment of the original 22 NORSAR subarrays (from 1971 to October 1, 1976). The subset of 7 subarrays in operation since October 1, 1976, are marked as filled circles.

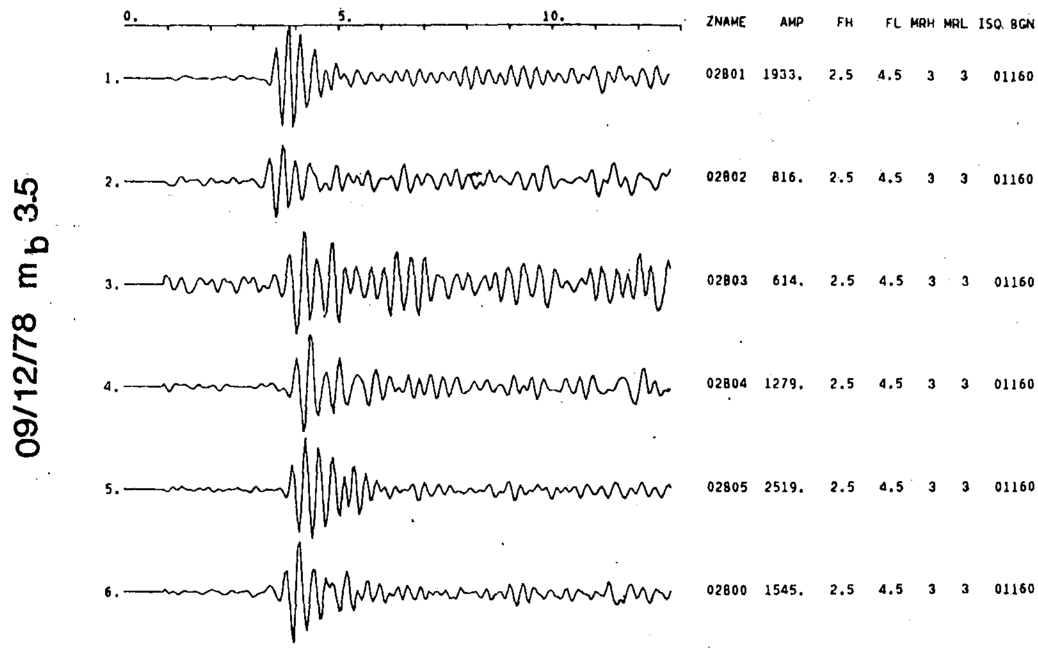
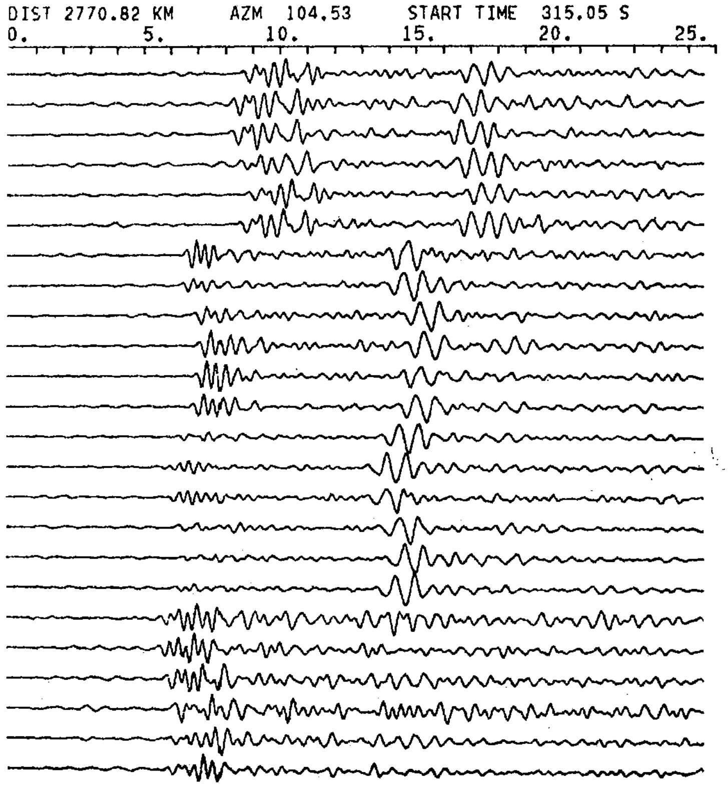


Fig. VI.6.2 NORSAR-recorded signals (at subarray 02B) for Event 9 in Table VI.6.1. The signals have been bandpass filtered (2.5-4.5 Hz) and are scaled to max. amplitude for each of the six sensors. Note the significant variation in amplitude (a factor of 4) across the subarray, from 614 q.u. at 02B03 to 2519 q.u. at 02B05.

** 25 APR 1975 **

SUBARRAY NOR132 SOURCE WR1

DIST 2770.82 KM AZM 104.53 START TIME 315.05 S



TM(S)	SEIS	AMP	DIST	AZM
1.	01B01	748.3	2780.1	105.0
2.	01B02	564.7	2775.9	105.0
3.	01B03	612.2	2775.9	104.9
4.	01B04	658.2	2780.3	104.8
5.	01B05	700.9	2783.3	104.9
6.	01B00	558.7	2779.6	104.9
7.	02B01	968.9	2753.2	105.5
8.	02B02	1213.8	2752.7	105.4
9.	02B03	1073.2	2758.6	105.3
10.	02B04	1193.3	2760.2	105.4
11.	02B05	1625.0	2758.8	105.5
12.	02B00	1387.8	2757.0	105.4
13.	03B01	1616.1	2751.2	105.3
14.	03B02	1403.0	2747.3	105.3
15.	03B03	1466.0	2747.7	105.2
16.	03B04	1403.6	2752.2	105.1
17.	03B05	1078.7	2753.9	105.2
18.	03B00	1845.9	2750.4	105.2
19.	04B01	467.2	2745.0	104.7
20.	04B02	577.9	2743.9	104.6
21.	04B03	600.3	2747.0	104.5
22.	04B04	474.5	2751.3	104.6
23.	04B05	663.2	2749.3	104.7
24.	04B00	647.2	2747.8	104.6

Fig. VI.6.3 Selected NORSAR recordings (subarrays 01B-04B) of event 4 in Table VI.6.1. The data have been bandpass filtered (1.0-3.0 Hz) and are scaled to max. amplitude for each sensor. (Max. amplitude is specified for each trace.) Note the strong secondary P-phase some 7 seconds after the first P-onset. Also note the strong variability in relative amplitudes between the first and secondary P phases.

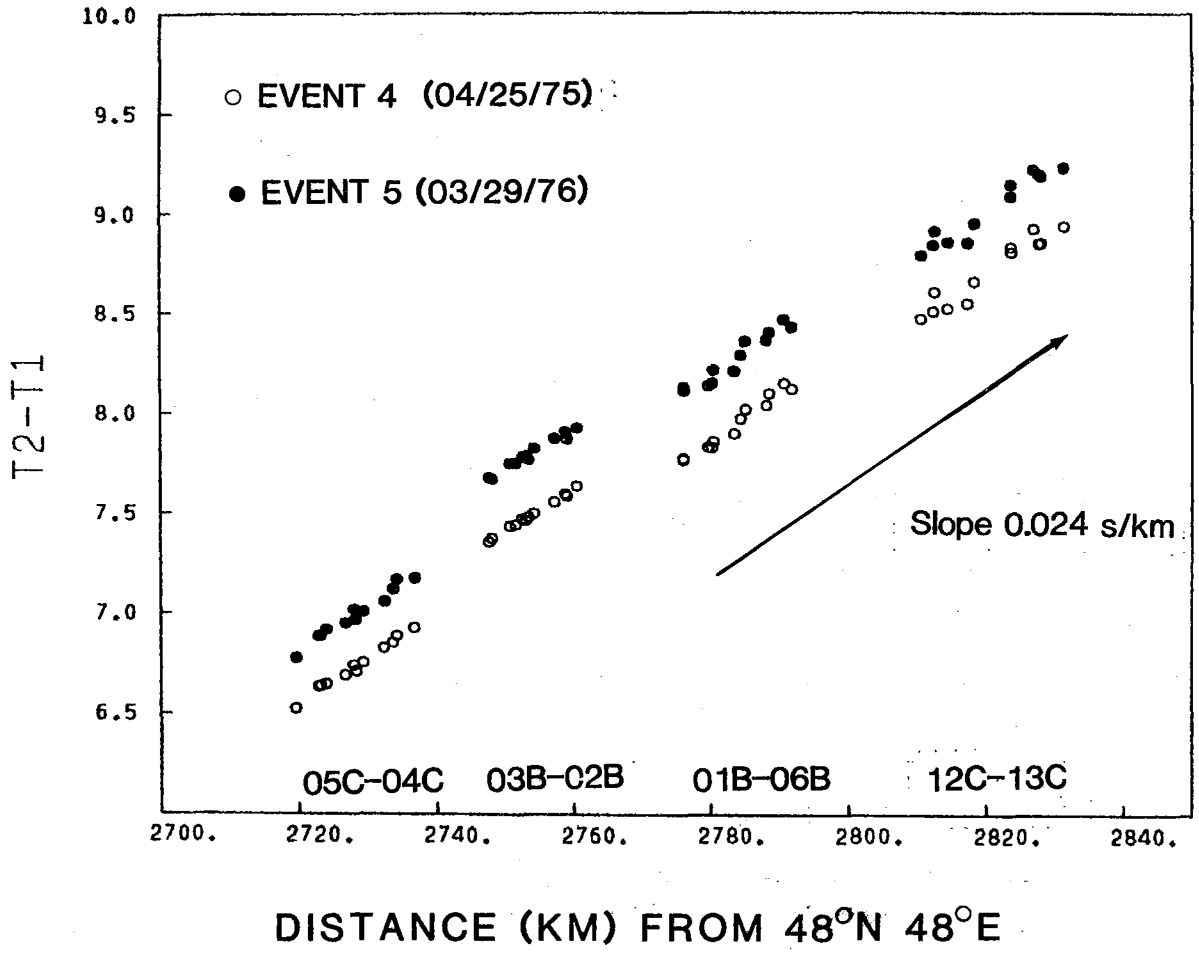


Fig. VI.6.4 Measured time delays for eight subarrays (as marked in the figure) for Event 4 (open circles) and Event 5 (filled circles). The distances are nominal as explained in the text. Note the consistency of the measurements for the two events both between subarrays and within subarrays.

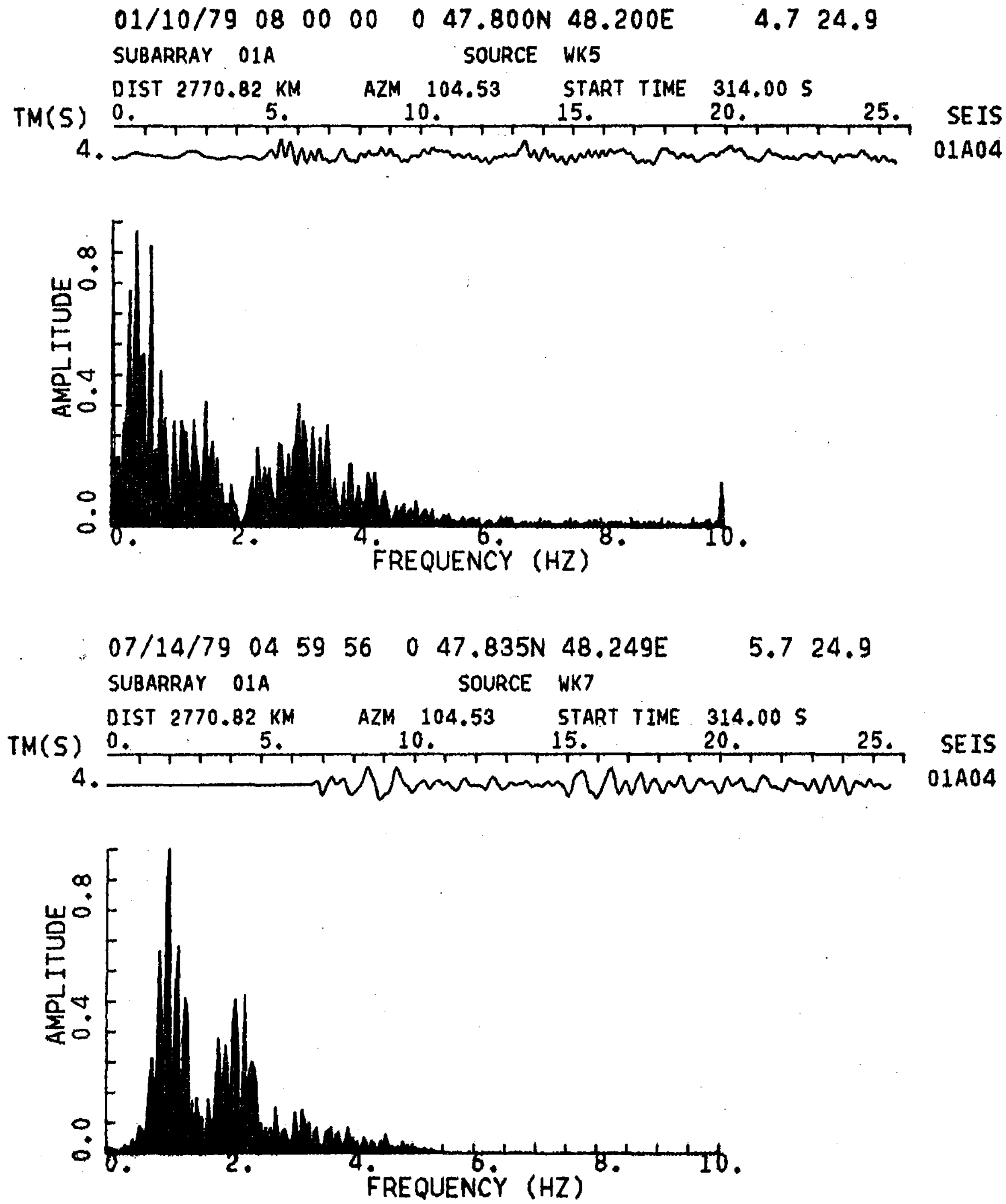


Fig. VI.6.5 Amplitude spectra at instrument 01A04 for Event 12 (top) and Event 14 (bottom). This instrument has an analog low pass filter with upper 3 dB point of 8 Hz. Note the significant difference in spectral shape above 1 Hz.