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VI.2 A processing package for on-line analysis of data from small-aperture arrays

A Regional 'ON-line' Array Processing Package (RONAPP) has been developed and tested on off-line data from the small-aperture NORESS array at NORSAR. This array consists of 12 sensors spaced with distances up to about 2 km, and the processing package automatically detects and locates regional seismic events in the distance range from a few kilometers to the maximum propagation range of regional S-type waves (Sn or Lg). The package consists of a conventional STA/LTA detector, a phase identification procedure based on phase velocity, and a location procedure based on observed travel time differences and a common azimuth between the observed primary and secondary phases. In the following we give some details on the detection and detection processing procedures and a description is given of the phase association scheme adopted. Finally some processing results are shown and discussed.

Detection and detection processing

In the present version, the detector works on either a vertical beam or a single channel and with a number of filters. For each filter, STA/LTA is computed and compared successively against two different thresholds. Three blocks of data (presently with 4 sec in each) are always kept in memory, with the detection performed in the middle block. If no detection is declared, the first block is dropped, a new one is brought in, and the procedure is repeated. In case of one or more detections in the current block, data within a certain time window around each detection are written on disk, estimates of refined arrival time and signal frequency are obtained, and a wavenumber analysis is performed following a proper prefiltering. This gives estimates of phase velocity, azimuth and power for each detection, which together with arrival time and frequency constitutes the essential part of a detection record. The detection procedure is continuous and not dependent on the block structure. A block diagram outlining the detection and detection processing procedures is shown in Fig. VI.2.1.

Phase association and event location

Following each processed detection, an event location is performed if the last detection is identified as an S-type wave (phase velocity below 6 km/s), and also a P-wave (phase velocity above 6 km/s) has been detected within an appropriate azimuth range. Distance is taken from an S-P travel time table. An intricate procedure is developed to allow for several detections within the P and S coda, to keep track of 'used' and 'unused' detections, and to identify locations that override previous ones.

The identification of phase type according to phase velocity being above or below 6 km/sec is justified from 'manual' wavenumber analysis of NORESS data from well-identified phases (Mykkeltveit & Ringdal, 1981).

The automatic phase association and location procedure assumes in its present version that the largest secondary arrival detected is an Lg phase. The block diagram in Fig. VI.2.2 gives the details.

The main problem in the location procedure, however, is the correct identification of the type of secondary arrival (in practice Sn or Lg) which is associated with P. It is not possible from our wavenumber analysis to distinguish between Sn and Lg on the basis of phase velocities alone. Unless other objective criteria can be found, it will be necessary to invoke region-dependent information on the general occurrence of secondary seismic phases. Regional events within 12-15^{o} recorded by NORESS are dominated by strong Lg waves, propagating at a fairly constant group velocity of 3.5 km/sec. Exceptions are events in Central Europe, England, Scotland and western part of the North Sea, from which Sn is the dominating phase and Lg is very weak if at all seen. The strong attenuation of Lg is probably an effect of larterally varying structures along paths to NORESS from these regions. Events from or close to the North Atlantic Ridge show the same characteristics. A detailed investigation of regional propagation characteristics within 15^{o} of NORSAR and correlation with gross geological features is in progress.

Experience with the processing package

The processing package has been tested on a number of data intervals from the 12-sensor NORESS array. Our experience so far can be summarized as follows: The on-line automatic processing package provides location results as good as those previously reported by Mykkeltveit and Ringdal (1981) for manual analysis of NORESS data, provided:

a) proper positioning of time window for f-k analysis
b) the automatically determined frequency for the f-k analysis must correspond to peak in signal spectrum
c) data to be subjected to f-k analysis must be properly prefiltered
d) assumptions inherent in the automatic phase association are valid.

Points b) and c) above ensure reliable phase velocity and azimuth results from the f-k analysis, while d) is an obvious requirement for proper location. Fig. VI.2.3 serves as an illustration of the importance of the positioning of the time window for f-k analysis. This figure gives the results from a sliding window analysis, where phase velocity and azimuth results are plotted for windows of length 2.5 sec shifted 0.6 sec at a time. Each time window has been subjected to f-k analysis for 9 frequencies in the range 3-5 Hz and results plotted (at the time interval midpoint) correspond to the frequency with maximum power.

Fig. VI.2.3 shows that azimuth and phase velocity estimates for this high signal-to-noise-ratio event are comparatively stable around the onset times for the main phases. Azimuth values derived from time intervals in the codas, on the other hand, fluctuate around the expected value. For this event, however, all P and Lg coda detections (two for each phase) are associated with lower power than the phase onset detections, which are marked in the figure. Consequently, our association and location procedures work well in this case.

Epicentral distance is determined from the first P and the strongest Lg-type detection via the time difference between these two detections. A good estimate of distance relies upon the assumption that the amplitude maximum in the Lg wave train can be associated with a constant group velocity of 3.5 km/s. This assumption has been justified by the testing performed so far.

Fig. VI.2.4 shows the data for the 12 NORESS channels and the vertical beam for a presumed mining explosion located by the Finnish network to the Finland-U.S.S.R. border at a latitutde of about 61°N. The arrows indicate the four detections by our processing package and results from f-k analysis. Besides the P and Sn detections, there are two Lg detections; the f-k plot shown corresponds to the strongest one. This example shows that our detection and location procedure works also for a fairly modest signal-to-noise-ratio event.

Although more refinement and testing are still needed, we have finalized the basic design for a package that, when finished, should be suitable for implementation within the framework of a low-power, microcomputer-based system.

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References

Mykkeltveit, S. and F. Ringdal (1981): Phase identification and event location at regional distance using small-aperture array data. In: Identification of Seismic Sources - Earthquake or Underground Explosion (eds. E.S. Husebye and S. Mykkeltveit). Reidel Publ. Co., Dordrecht.

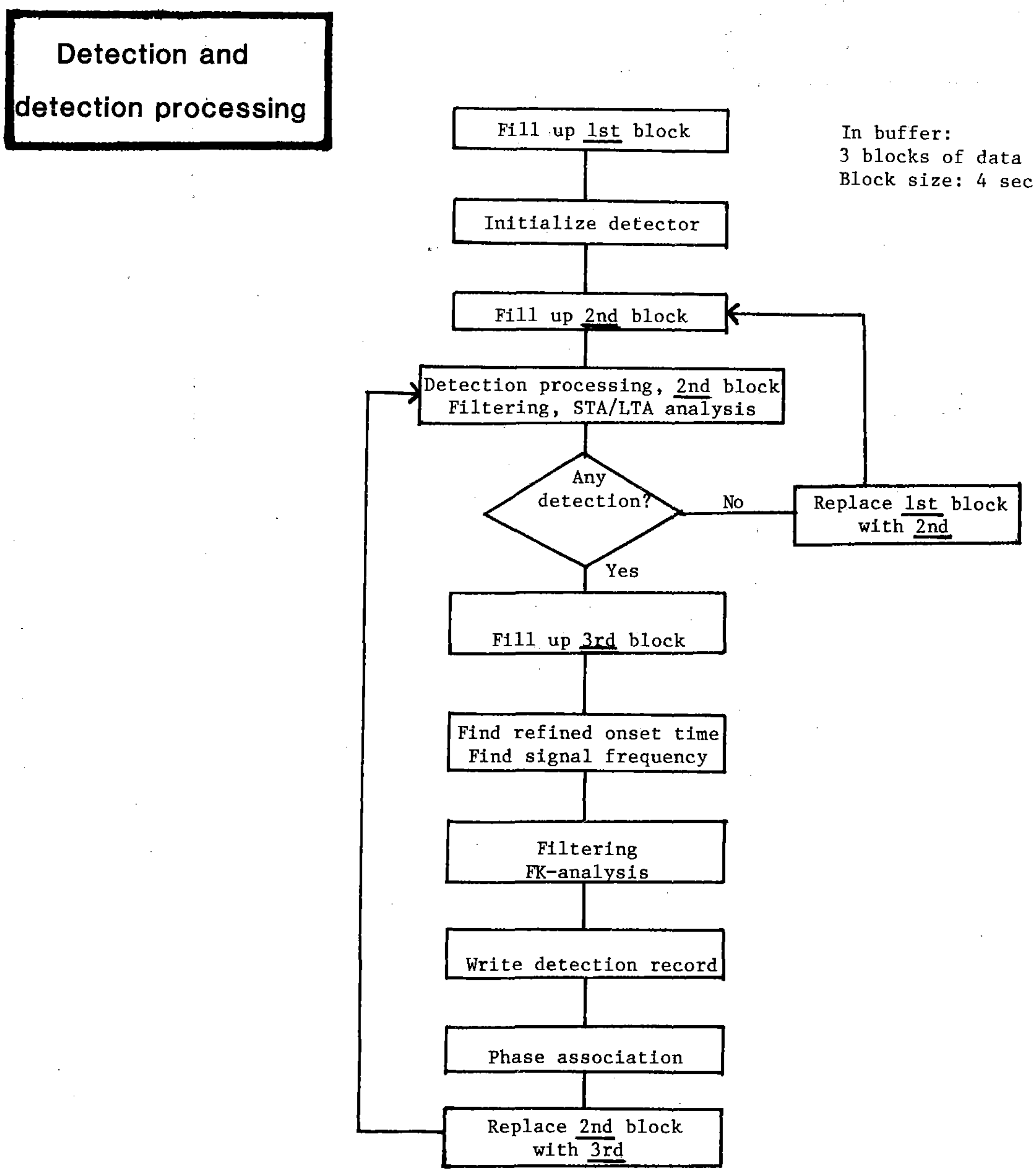

Fig. VI.2.1 Block diagram showing the detection and detection processing in RONAPP.

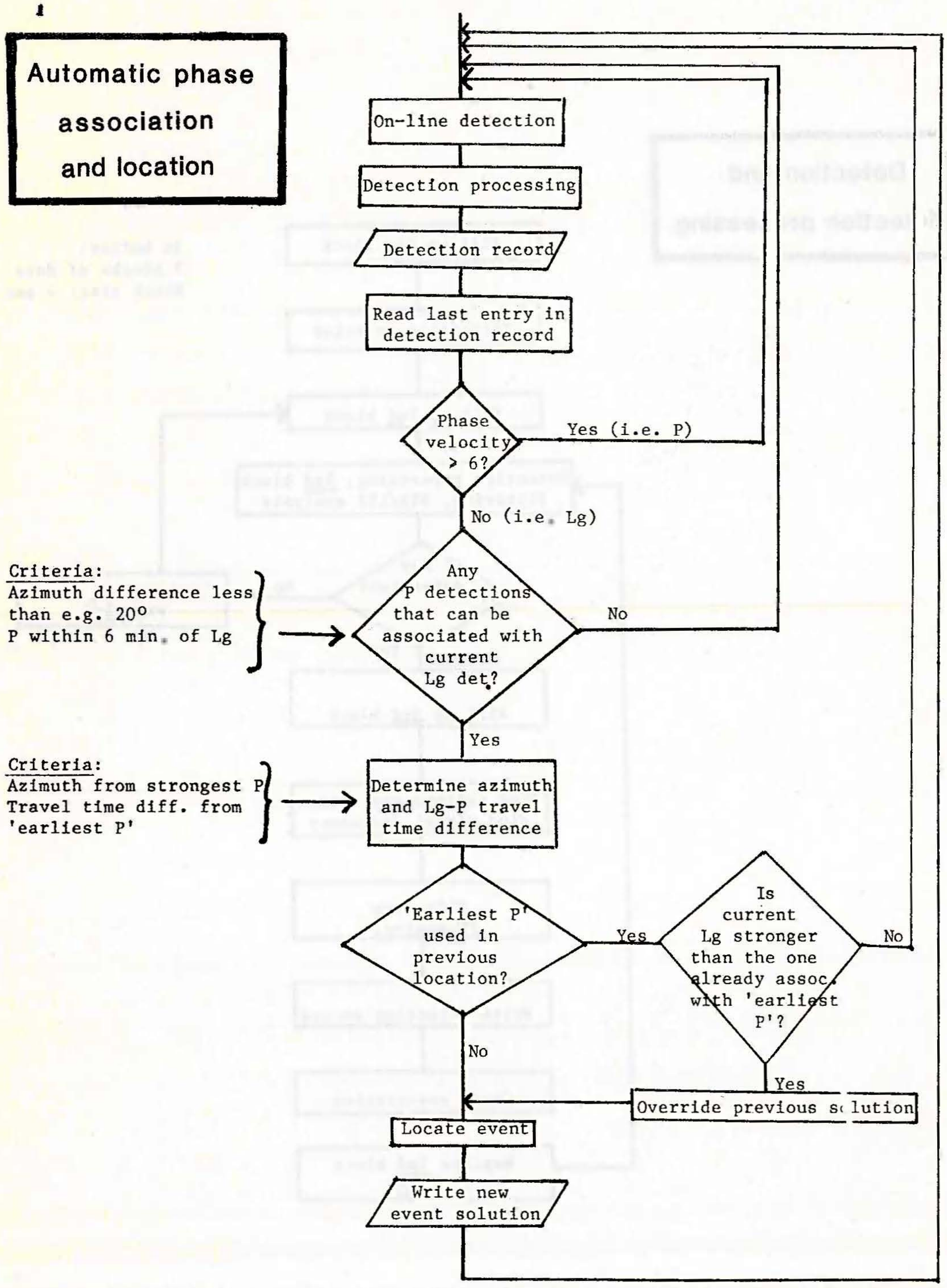

Fig. VI.2.2 Block diagram with details on phase association and location procedure in RONAPP.

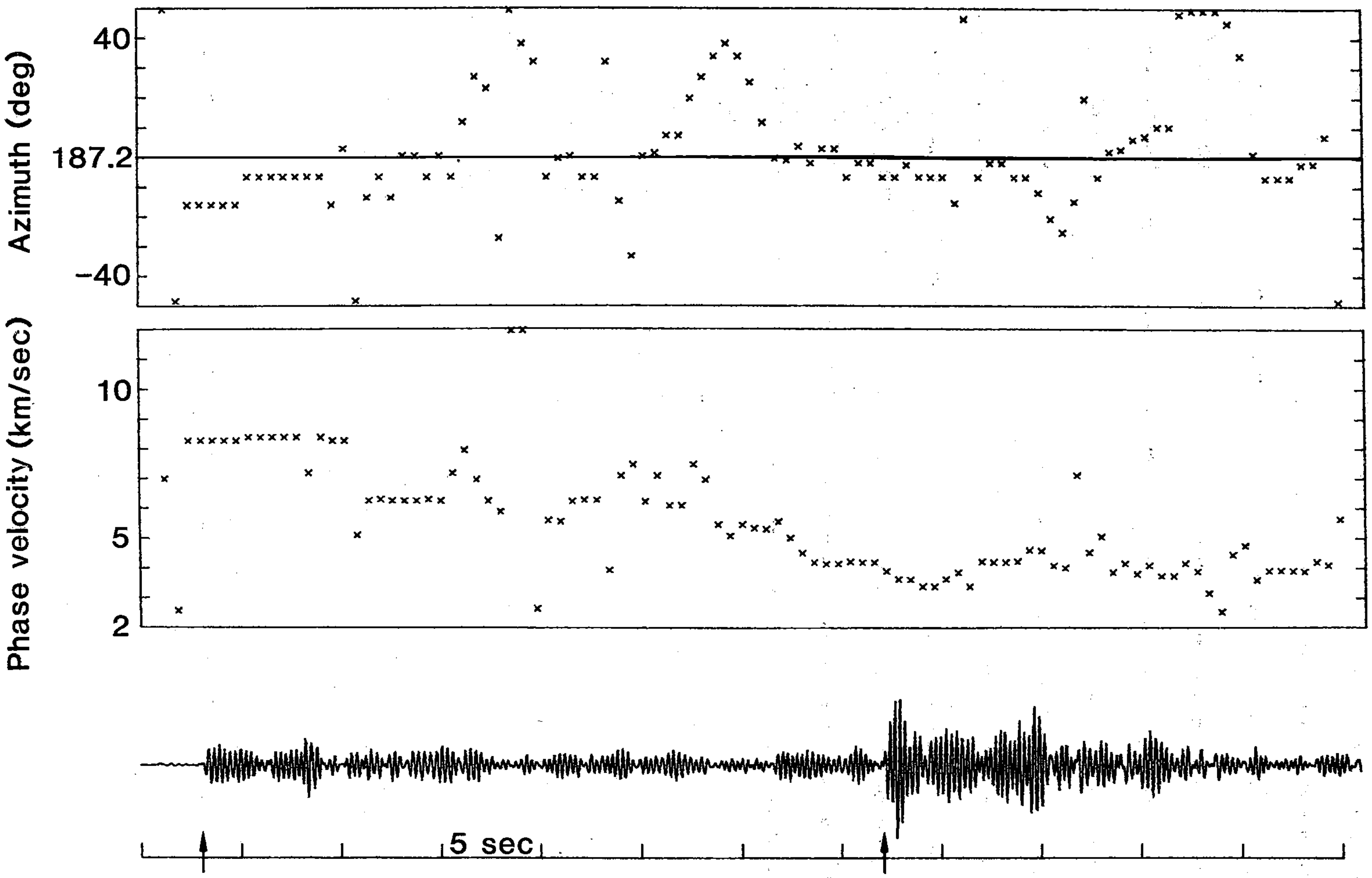

Fig. VI.2.3 Results from sliding window analysis of NORESS data from a presumed explosion in the sea at a distance of 260 km, direction south. Data for one of the NORESS channels are shown, and arrows indicate the detections used in phase association and location. The line in the azimuth diagram shows the azimuth according to the epicenter solution by the Scandinavian network of seismic stations. The uncertainty of this solution in terms of azimuth from NORESS may be as large as 5-10 degrees.

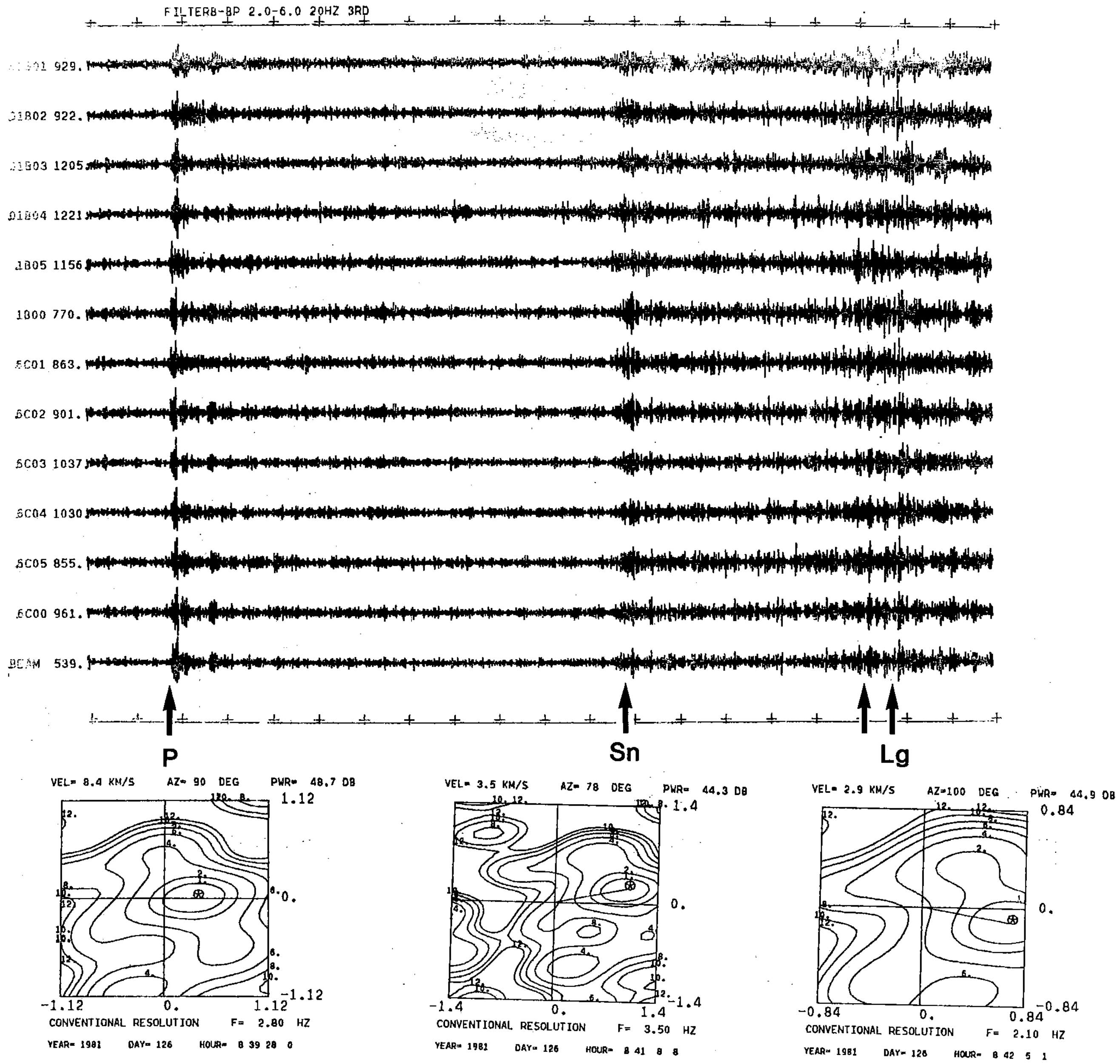

Fig. VI.2.4 NORESS data (and vertical beam) for a presumed mining explosion in the Finland/U.S.S.R. border region. There are four detections and f-k plots for three of them are shown.