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7.4 Extensions of the Northern Europe Regional Array Network -- a new three-component station at Apatity, USSR, and a planned array at Spitsbergen

The Northern Europe Regional Array Network currently comprises the high-frequency arrays NORESS and ARCESS in Norway, FINESA in Finland and GERESS in Germany, as well as the two three-component stations KSP and SFP in Poland. The locations of these stations are shown in Fig. 7.4.1 Data from all of these installations are transmitted continuously and in real time to the NORSAR Data Processing Center at Kjeller, Norway, where the data are processed jointly by the Intelligent Monitoring System (IMS). Current prospects for extending this network and, if possible, integrating new data sources into IMS, are described in this contribution.

The establishment of the FINESA array in Finland was made possible through joint efforts between NORSAR and the University of Helsinki, based on a bilateral cooperative agreement. A similar arrangement has recently been made with the Kola Science Center of the USSR Academy of Sciences, and as first result of this cooperation, a high-quality three-component station was installed by NORSAR personnel in Apatity (see Fig. 7.4.1) in June 1991. The following paragraph gives a description of the system installed in Apatity and contains material related to analysis of data from this new station.

According to current plans, a 9-element array with a 1-kilometer aperture will be installed on the island of Spitsbergen in the Arctic (see Fig. 7.4.1) in the summer of 1992. A short description of these plans are given in this contribution.

A new 3-component station at Apatity, USSR

In mid-June 1991, a high-quality three-component station was installed in Apatity, on the Kola Peninsula of the USSR. The station was installed and is operated under an agreement on scientific cooperation within seismology between the Kola Science Center of the USSR Academy of Sciences and NORSAR.

The three-component station installed in Apatity comprises S-13 seismometers, a Nanometrics RD3 digitizing/synchronization/multiplexing unit, an Omega clock and a PC-based system for data acquisition, analysis and archiving. The amplitude response of the system is shown in Fig. 7.4.2. The PC system has a 25 MHz 386 processor, 4 Mbyte RAM, a 300 Mbyte ESDI disk, and a cartridge tape drive. The system was installed in the basement of the building of the Seismological Laboratory of the Kola Science Center, in the town of Apatity. The S-13 seismometers were placed on the same pad as the seismometers of the analog APA station (established in 1956). Data are recorded continuously on magnetic disk in Apatity and copied to cartridge tapes, which are sent to NORSAR. An archive of continuous data from the new station in Apatity is thus maintained both at Apatity and at NORSAR.

Analysis of data recorded at the new Apatity station -- noise levels

Fig. 7.4.3a shows six noise spectra for the new Apatity station. All noise samples are taken during daytime (2 pm to 5 pm local time), with the exception of the sample corresponding to the dashed curve, which is taken around midnight, local time. The trend of the curves strongly indicates cultural origin for the noise above 2 Hz. Also, one must keep in mind that the station is located within the town of Apatity, which has approximately 100,000 inhabitants. The very heavy mining activities in the nearby (20 km) Khibiny Massif is supposedly also contributing to the noise level. A distinct and consistent peak at 4 Hz indicates a localized source. This 4 Hz wave can be clearly seen in the noise preceding the onset in the recording of the shot in Mine II in Fig. 7.4.5. All spectra except one also exhibit a pronounced peak at 2.5 Hz. The origin of these peaks in the noise spectra are as yet unknown. There is an indication of a slightly lower noise level above 7-8 Hz at nighttime.

Compared to the NORESS noise model (superimposed on Fig. 7.4.3a), the noise level at the new Apatity station stands out as being very high above 2 Hz. For lower frequencies, the noise levels at NORESS and Apatity are similar. This is also to be expected on the basis of usual assumptions about noise generating mechanisms for frequencies below 2 Hz.

On 12 June, prior to installing the station at the Seismological Laboratory in Apatity, the entire system was deployed for an hour at a location approximately 15 km to the west of Apatity (denoted PROF in Fig. 7.4.4). This is a candidate location for a possible future deployment of a small array in Apatity. While the noise level is still high relative to the NORESS noise model, the level is clearly lower than in the town of Apatity, as can be seen by comparing Figs. 7.4.3a and 7.4.3b.

Analysis of data recorded at the new Apatity station -- P-wave signals

The map of Fig. 7.4.4 shows the location of the new Apatity station and the nearby mining area of the Khibiny Massif. The lateral extent of the mining area is approximately 15 km, and there is information available that allows the assignment of each individual explosion since early 1991 to one of the five subareas indicated in Fig. 7.4.4. Fig. 7.4.5 shows three-component records for the new Apatity station for five such explosions, one from each of the five mines. Detailed information on these shots is given in Table 7.4.1. From Fig. 7.4.5, it is clearly seen that there is a large variation among the shots with respect to amplitude and frequency content of P, S and Rg waves, and this variation cannot be explained by differences in epicentral distance and shot size alone. Hence, other factors like propagation path effects and specific conditions pertaining to the individual shots are important. For example, information on shot geometry and ripple firing delay times is not currently available.

As a check on the performance and integrity of the new three-component Apatity station, we used the data for the five shots in Fig. 7.4.5 to derive the apparent arrival azimuth for the P wave onset using the broad band slowness estimation technique of Kværna and Doornbos (1986). The results are given in Table 7.4.1, along with the true azimuths, which are given in terms of intervals, due to the spatial extent of each of the five mines. The calculations were made for four different frequency bands, as shown in the table. The length of the time windows used were 1.0 s for the 8-16 Hz band, 1.5 s for the 5-10 Hz and 3-5 Hz bands, and 2.0 s for the 1-3 Hz band. The start time for all windows was 0.1 s prior to the P arrival time. The table shows reasonable figures with an average deviation of 5.5 degrees from the midpoint of the interval for the true azimuth, when disregarding the low SNR event from mine II. We take this result to indicate that the new Apatity station performs well from a technical point of view.

As a further illustration of the new data now available from Apatity, recordings at Apatity, ARCESS and FINESA of a probable earthquake approximately 200 km due south of Apatity are shown in Fig. 7.4.6. The bulletin of the University of Helsinki, Finland, gives an epicenter of 65.71°N, 33.24°E, based on altogether 41 readings of P and S phases. The magnitude is M_L 3.7 and the depth is estimated at 8.8 km (standard deviation 4.5 km) in the Helsinki bulletin. The arrival azimuths of the first P wave at the new Apatity station were estimated as was done for the five mining shots, and results are also given in Table 7.4.1. Again, the results are reasonable, with an average deviation from the true azimuth of about 6 degrees. A feature of special interest in Fig. 7.4.6 is the Rg wave seen in the Apatity and FINESA data. Especially surprising is the presence of an Rg phase at FINESA, at a distance of 593 km. The strong Rg waves also point toward a shallow-focus event, and maybe shallower than 8.8 km, as given in the Helsinki bulletin.

We think that the new data now available from Apatity will prove to be very valuable. It is of special interest that we are now able to obtain near-field recordings of the mining shots in the Khibiny Massif. All of these shots are well recorded at ARCESS (distance 480 km), and the majority of the larger ones also at FINESA (distance 780 km) and NORESS (distance 1315 km). Plans including a computer-to-computer link between NORSAR and the Kola Science Center and possible deployment of additional stations are now being discussed.

Plans for a small-aperture array at Spitsbergen

Companies taking part in oil exploration and production on the Norwegian Continental Shelf have earlier sponsored the establishment of a network of seismic stations onshore northern Norway. As a further development of this network, NORSAR will establish, under the sponsorship of the same oil companies, a small-aperture array near Longyearbyen on the island of Spitsbergen during the summer of 1992.

A site survey was conducted in August 1991. A suitable location was found approximately 20 km from Longyearbyen, which is the largest Norwegian settlement and also administrative center on the island. The plan is to install a 9-element 1-kilometer aperture array of vertical sensors. The array will have two concentric rings with 3 and 5 elements, respectively, plus one sensor at the center. The rocks at the site are of Cretaceous age, covered by thin moraine of variable depth. The sensors will be placed in boreholes, drilled either to the Cretaceous rock or to a depth where stable permafrost conditions are obtained (depths of the order of 6 meters are considered to be sufficient in this regard). All necessary permissions to deploy the array have been granted by the appropriate authorities.

The site survey included noise measurements at the selected site. A noise spectrum is shown in Fig. 7.4.7. Even if the noise level is seen to be higher than the average noise level at NORESS, we consider the noise level at the Spitsbergen site to be quite satisfactory for an array installation. For example, there are no specific peaks in the spectrum. There is mining activity in the area, with mines located at distances between 10 and 20 km from the site.

The system to be established at Spitsbergen will have an on-site recording capability only. We do, however, consider that the data from this new array would be of great value to the IMS. This requires continuous transmission via satellite of data from Spitsbergen to Kjeller. The annual lease of such a link is estimated at approximately USD 30,000.

S. Mykkeltveit A. Dahle J. Fyen T. Kværna
P.W. Larsen R. Paulsen F. Ringdal
E.O. Kremenetskaya, Kola Science Center

References

Fyen, J. (1990): Diurnal and seasonal variations in the microseismic noise level observed at the NORESS array. *Phys. Earth Planet. Inter.*, 63, 252-268.

Kværna, T. and D.J. Doornbos (1986): An integrated approach to slowness analysis with arrays and three-component stations, *Semiannual Tech. Summ., 1 October 1985 - 31 March 1986,* NORSAR Sci. Rep. No. 2-85/86, Kjeller, Norway.

Epicenter	Shot size (tons)	P wave arrival time	True azimuth (deg)	Estimated P-wave arrival azimuth (deg) 1-3 Hz	3-5 Hz	5-10 Hz	8-16 Hz
Mine I	120	216/12.49.55.8	36-46	47.1	38.5	44.6	37.0
Mine II	35	259/12.19.27.1	46-53	(55.3)	(99.5)	(78.9)	(34.0)
Mine III	94	187/19.24.01.9	55-60	58.5	57.6	68.2	71.7
Mine IV	430	207/12.31.00.3	60-66	69.2	61.6	74.2	63.7
Mine V	392	193/10.21.22.1	68-74	72.4	64.5	60.1	64.8
65.71°N,33.24°E	-	236/10.57.01.2	180.2	174.3	182.8	185.5	189.4

Table 7.4.1. Apparent arrival azimuths at the new 3-component station at Apatity, as determined from broad band slowness estimation using the method of Kværna and Doornbos (1986). The epicentral information on the earthquake at the bottom of the table is from the Helsinki bulletin. The SNR for the event from Mine II is very low in all frequency bands and the estimated arrival azimuths are given in parenthesis.

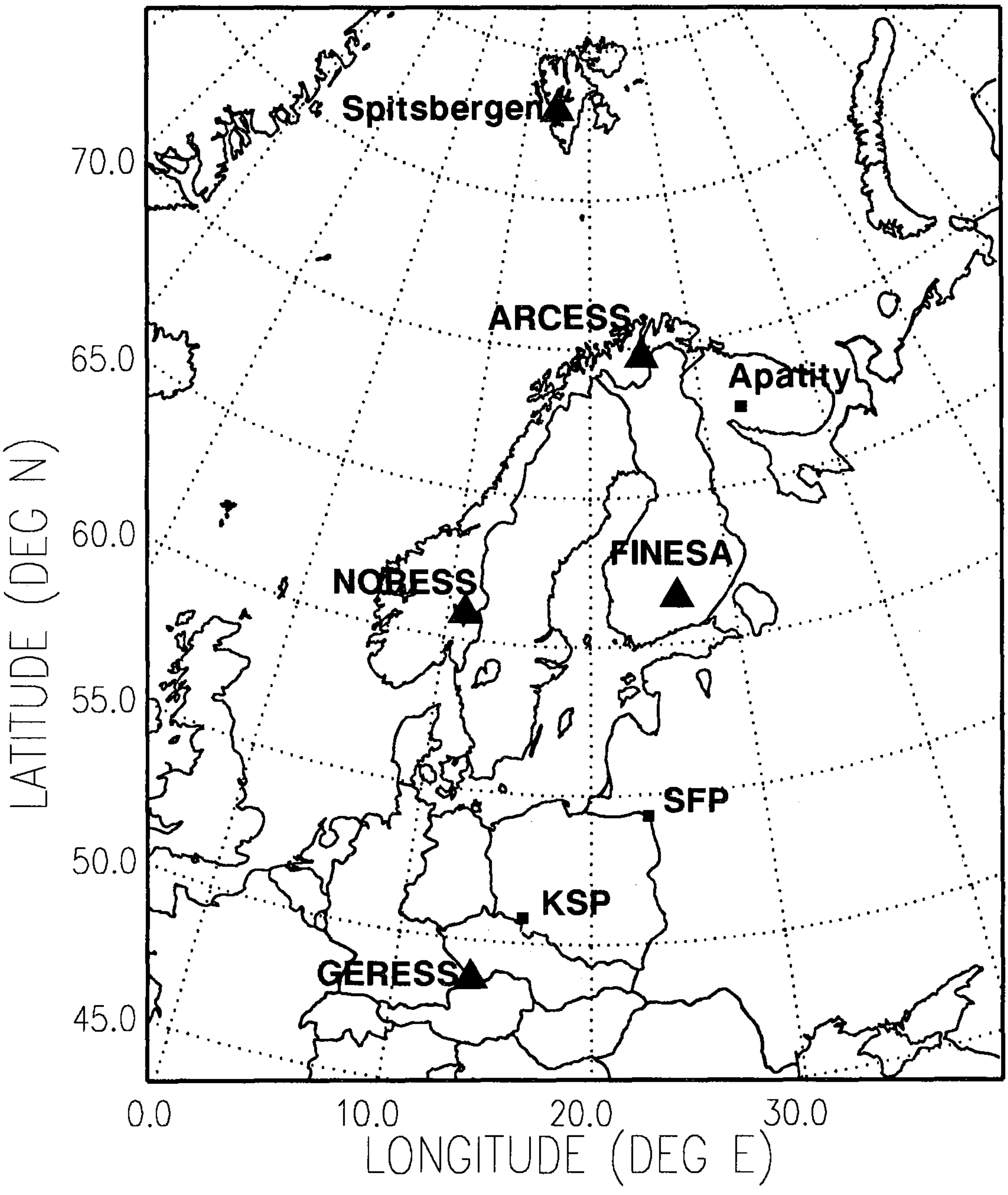


Fig. 7.4.1. The map shows the existing stations of the Northern Europe Regional Array Network as well as the location of the two new stations at Apatity and Spitsbergen, dealt with in this contribution.

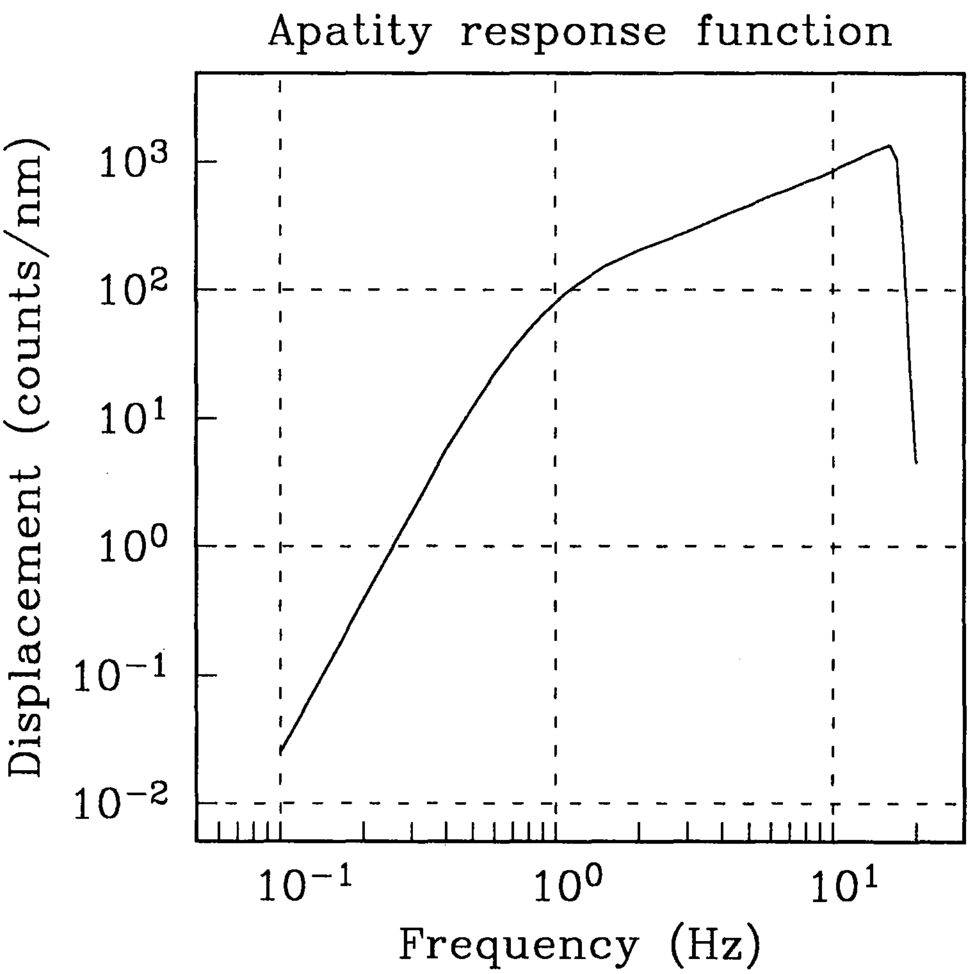
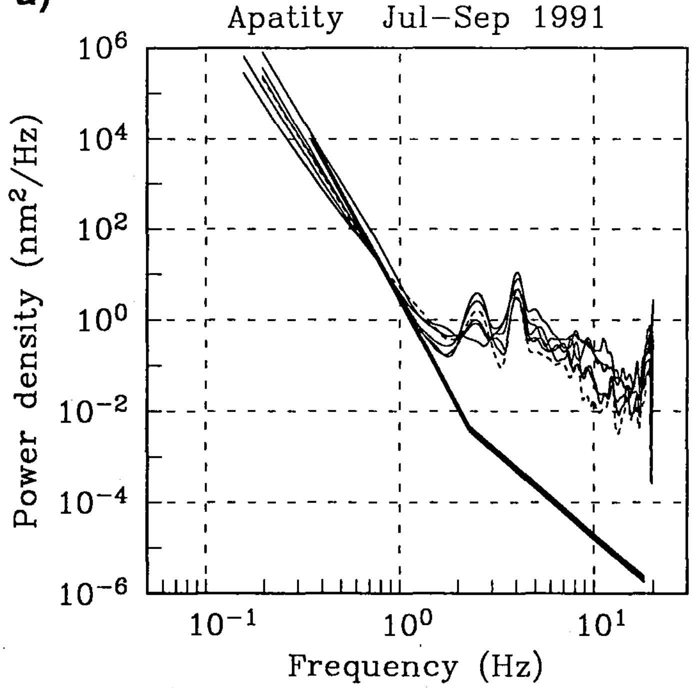


Fig. 7.4.2. Amplitude (displacement) response function for the system installed in Apatity in June 1991.

a)



b)

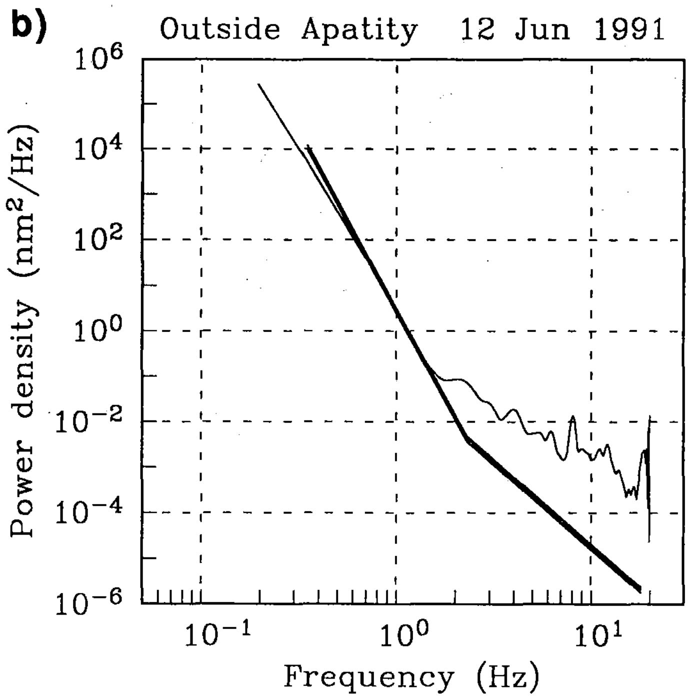


Fig. 7.4.3. a) (top): Six noise spectra for the new Apatity station. b) (bottom): Noise spectrum from the location outside Apatity, denoted PROF in Fig. 7.4.4. The solid line in each of the figures denotes the NORESS noise model of Fyen (1990). All spectra were estimated from partly overlapping 5-second windows, using the indirect covariance method (see Fyen, 1990). The total length of each noise sample was approximately 1 minute.

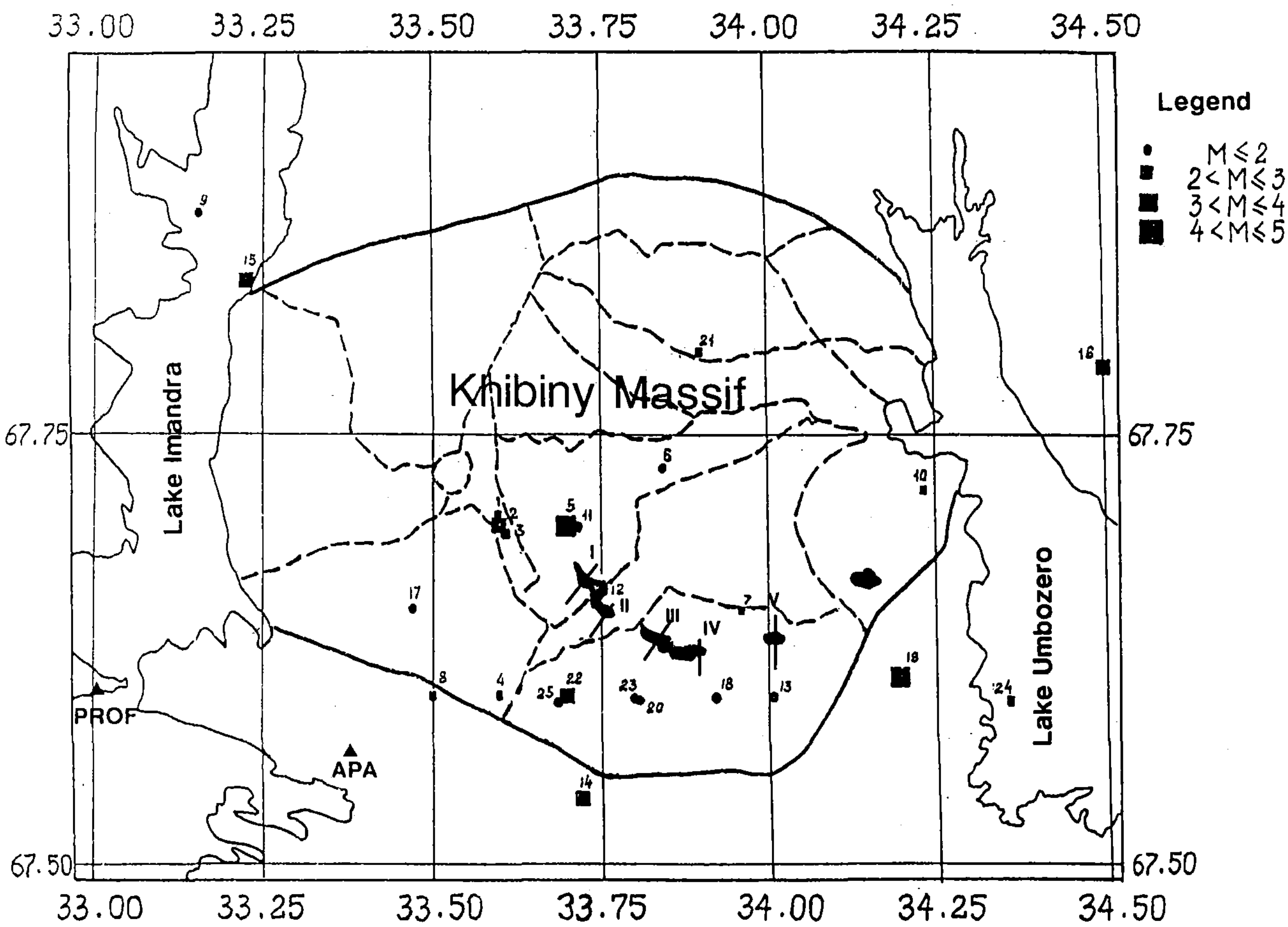


Fig. 7.4.4. Map of the Apatity area, showing the location of the new Apatity station and also the candidate site PROF for a future small array. Also shown is the mining area of the Khibiny Massif, and the division into five (denoted I - V) separate subareas where explosions are currently taking place. Locations for 25 mining induced earthquakes (magnitude range 2-5) are also shown (see also section 7.7, this volume.).

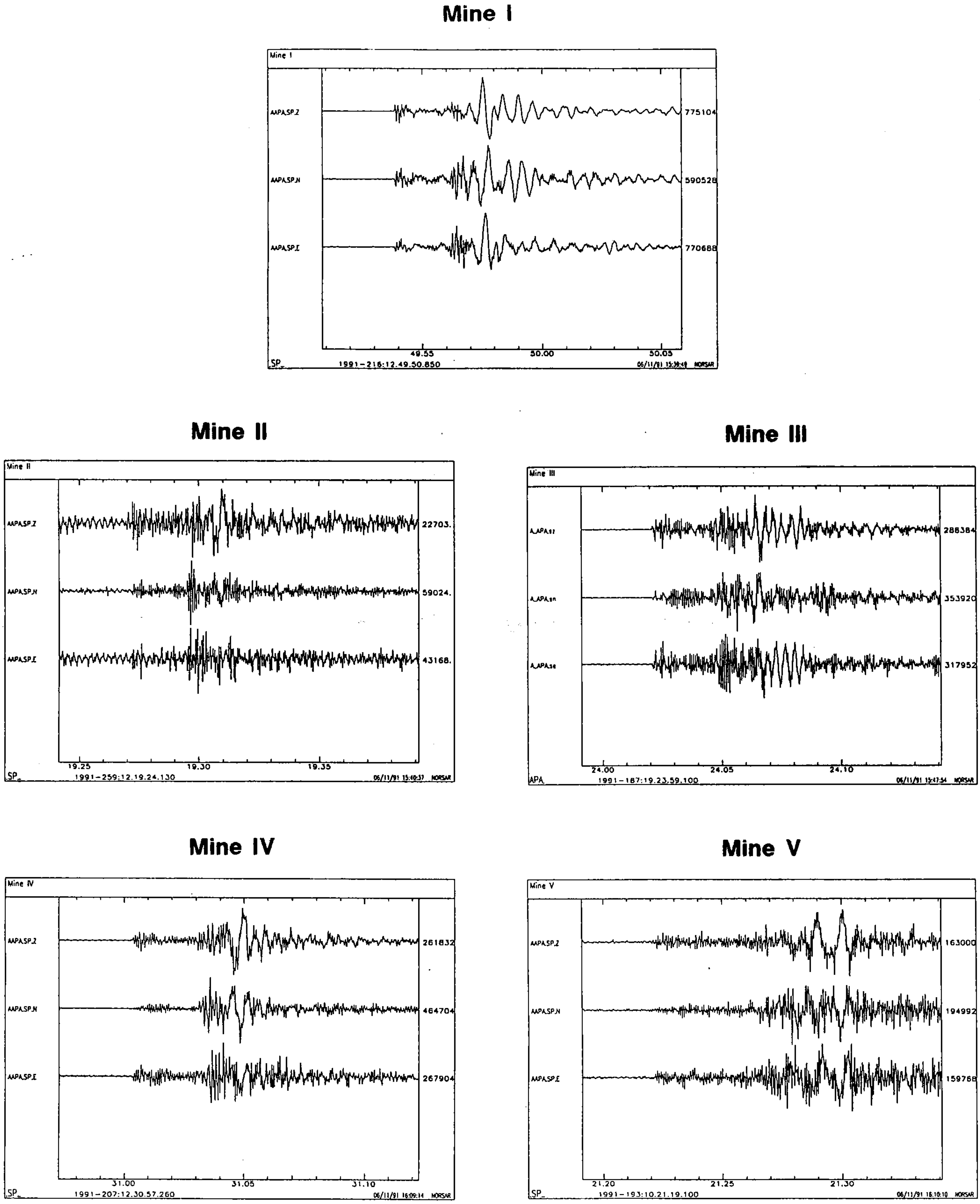


Fig. 7.4.5. Apatity three-component data for five mining shots, one from each of the mines I - V in Fig. 7.4.4.

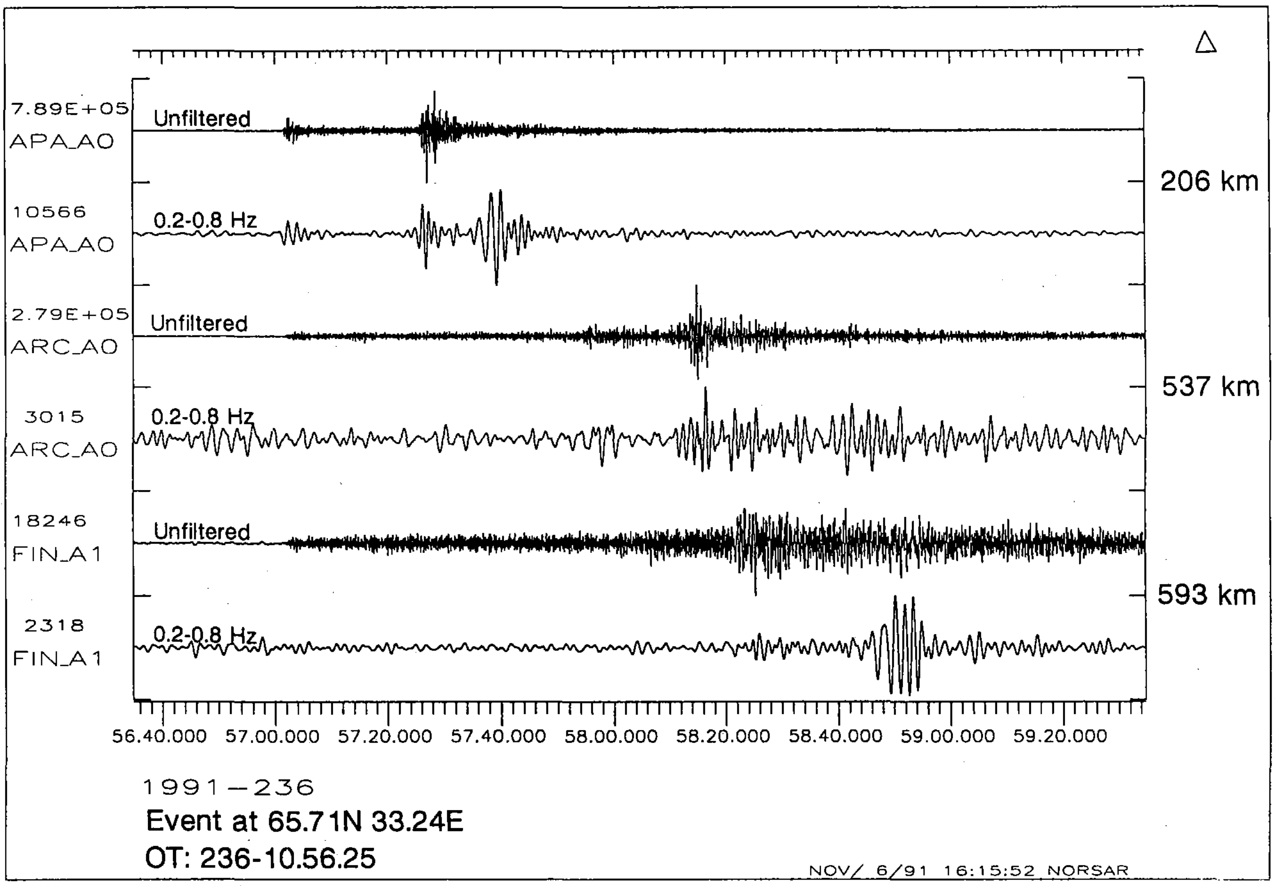


Fig. 7.4.6. Apatity, ARCESS and FINESA single vertical component recordings for a presumed earthquake 200 km south of Apatity. For each station, the plot shows unfiltered data, and data filtered in the band 0.2-0.8 Hz. Note the presence of an Rg phase at FINESA at a distance of nearly 600 km. The time axis refers to the Apatity station on top; ARCESS and FINESA data are aligned with respect to the P onset.

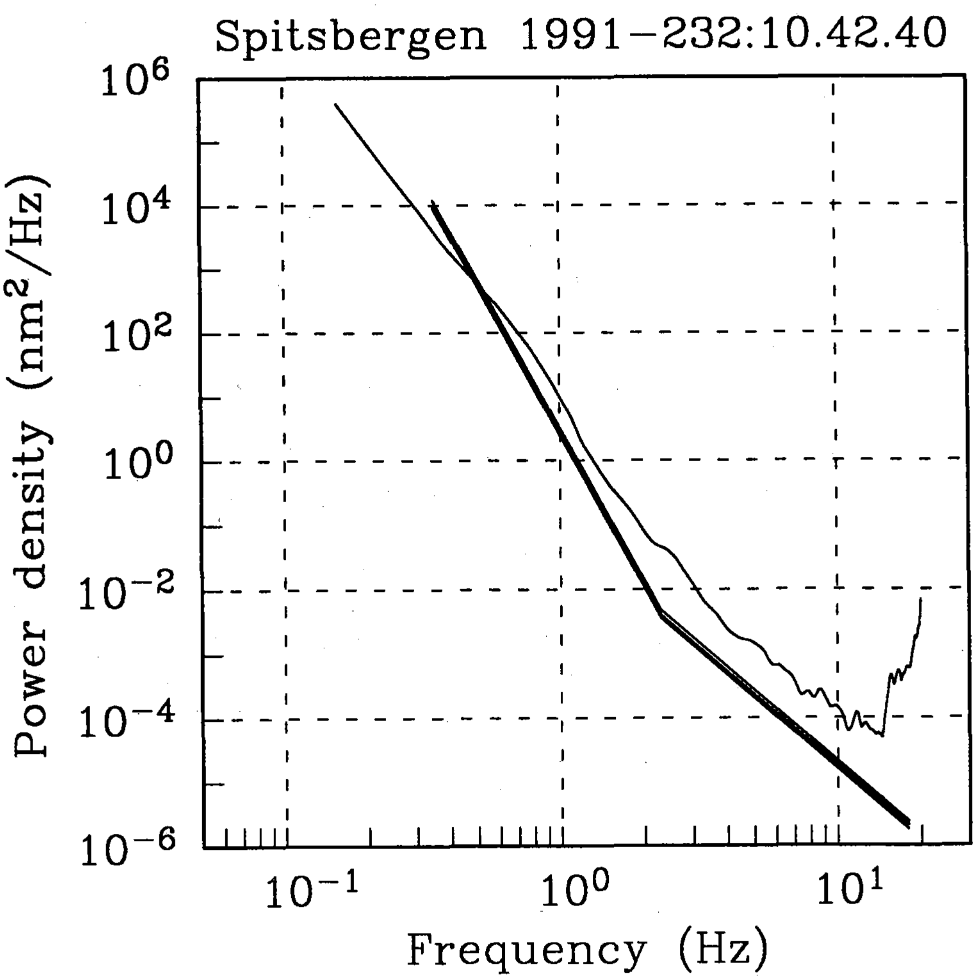


Fig. 7.4.7. Noise spectrum taken at the site for the new small-aperture array to be installed on Spitsbergen in 1992. The solid line denotes the NORESS noise model of Fyen (1990). The spectrum was estimated in the same way as the spectra of Fig. 7.4.3.