Royal Norwegian Council
for Scientific and Industrial Research
(NTNF)

NORSAR

NORSAR Scientific Report No. 2-87/88

Semiannual Technical Summary

1 October 1987 – 31 March 1988

L.B. Loughran (ed.)

Kjeller, June 1988

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

VII.5 Seismicity of northern Norway and adjacent areas as inferred from ARCESS and SEISNOR data

Over the last years the seismic instrumentation in Norway and surrounding areas has been improved through the installation of regional and local networks. The increased number of stations has resulted in developing more detailed seismicity patterns and improved focal mechanisms (e.g., Havskov and Bungum, 1987), which in turn can be correlated with similarly detailed information from geological investigations.

This paper will concentrate on the analysis of the combined data from two such recently installed sets of seismic instruments. One is a regional network termed SEISNOR (Surveillance of Earthquake Activity Offshore Northern Norway, Bungum et al, 1988), and the other is the Arctic Regional Seismic Array (ARCESS), which is a 39-element seismic array very similar to the NORESS array (Norwegian Regional Seismic Array, Mykkeltveit, 1985). The SEISNOR regional network stations and the ARCESS array are shown in Fig. VII.5.1, together with the main geological structures off northern Norway.

As an introduction, Fig. VII.5.2 illustrates the previously known seismicity patterns in northern Fennoscandia and the Norwegian and Barents Seas. These data are taken from a NORSAR data base and cover the period from 1955 through 1987 (Bungum, 1988). To maintain a compromise between location precision and magnitude completeness in this figure, only events recorded on at least eight stations have been included. The figure shows, in addition to the seismicity zones in northern Finland and the eastern coast of Sweden, the following main characteristics:

- The mid-oceanic ridge, with the Knipovich Ridge west of Svalbard and the Mohn's Ridge further south and west.

- An extended seismicity zone between the Mohn's Ridge and northern Norway, limited by the Senja Fracture Zone and covering large parts of eastern Lofoten Basin.

- A seismicity zone along the coast of northern Norway (Rana Fault Complex) as well as one offshore zone (following the Kristiansund-Bodø Fault Complex).

- Some earthquake activity near the intersection between the Vøring Plateau Escarpment and the eastern part of the Jan Mayen Fracture Zone.

Data analysis

As outlined above, the monitoring of seismic events in northern Norway has improved significantly following the installation of new seismic stations in 1987. In this report we therefore will concentrate on the time period from April 1987 through April 1988, analyzing events recorded by the SEISNOR network and the ARCESS array.

The SEISNOR network is a regional seismic network consisting of six seismographic stations distributed from 62.6°N to 69.0°N within Norway (see Fig. VII.5.1). The sites contain a mixture of single component, three-component and vertical component mini-array stations with the primary purpose of recording offshore events. The unique features of this network are two-fold. First, this is a computer-controlled network of field stations capable of detecting and storing events locally at each field station and transferring desired data in near real time as instructed by a central processing computer. Detections from all the remote field stations can be processed automatically at the central computer or manually extracted for particular events of interest. Secondly, the northernmost station, KTK, and the centrally located station, MOR, are small mini-arrays with horizontal dimensions of about

450 meters. With this distribution of sensors, estimates of the slowness vectors of the incoming wave field for local and regional seismic events can be used for better identification of seismic phases and calculation of event locations. The network has been operational since April 1987 (Bungum et al, 1988).

The Arctic Regional Array, ARCESS, is an almost circular array of sensors with an aperture of 3 km comprising a total of 39 sensors including single component short period, three-component, broadband and long period instruments. This array, which is very powerful both in terms of detection threshold and location capability, began operation near the end of October 1987 (Mykkeltveit et al, 1987).

The analysis of the data obtained from these two sets of seismic instruments consists of various filtering and wave separation algorithms for phase identification and estimation. The real value of incorporating mini-arrays and the ARCESS array into the SEISNOR network centers around the use of frequency-wavenumber (F-K) analyses (e.g., Capon, 1969).

An earthquake location program capable of using the azimuth data for both initial starting locations and in the formal inverse problem (Bratt and Bache, 1988) has been used for the present study, and all the seismic phases possible have been analyzed from SEISNOR and ARCESS as well as any other available stations within Norway. A careful identification and timing of the seismic phases has been combined with the azimuth information already obtained from a broadband F-K analysis (Kværna and Doornbos, 1986) of array data and three-component sites in order to obtain a high quality data set for the earthquake locations.

Spatial distribution of seismicity

During its first year of operation, the SEISNOR network has recorded 163 locatable seismic events. Additionally, the ARCESS array has detected 36 offshore events between November 1987 and April 1988. The magnitudes (M_L) range from about 1.5 to 4.0, with almost complete coverage for events above M_L 2.5. Fig. VII.5.3 shows the locatable seismicity between 60° and 80°N, recorded on at least one of the stations in the networks for a one-year period. If we compare Fig. VII.5.3 with Fig. VII.5.2 showing more than 30 years of seismicity we can see a quite consistent pattern. The earthquakes, even for such a short time period as one year, seem to line up along the main fault and fracture systems and known regions of higher seismicity.

Shortly after the SEISNOR network began operation, several earthquakes appeared near 64°N and 12°E. These events were also felt by people in the area, and with magnitudes in the range 2.2-2.7 they appeared in a region that has been relatively quiet earlier. The events lie on the northern part of the Møre-Trøndelag Fault Zone, where the southern part is known to exhibit a relatively high seismicity.

Along the Nordland coast, the Rana Fault Complex separates the coastal areas from the seismically less active Trøndelag Platform. Events recorded around this fault complex during the last year may indicate a larger seismic activity here than earlier known, extending northwards to the intersection with Kristiansund-Bodø Fault Complex, which is one of the most active areas along the Norwegian coast.

In addition to the seismicity along the coast from Møre to Lofoten, there is a noticeable level of activity also offshore along the Kristiansund-Bodø Fault Complex west of the Trøndelag Platform as well as further north along and on the continental side of the Vøring Plateau Escarpment.

Further north, events have been located along the Senja Fracture Zone and eastwards to the Ringvassøy-Loppa Fault Complex. The Senja Fracture Zone has been known for a long time as a very active area (Bungum, 1988), separating the oceanic crust to the west from the continental crust to the east.

The western Barents Sea, i.e., the region east of the Senja Fracture Zone, contains the Ringvassøy-Loppa Fault Complex. This area was until recently assumed to be more or less aseismic, but several earthquakes have been located here, especially after ARCESS was set in operation in late 1987. Since the magnitude threshold for locatable events east of the Senja Fracture Zone is below M_L 2.0 north to 75^{o}N, the Barents Sea may be divided into two different parts with respect to seismicity. The western Barents Sea includes the Ringvassøy-Loppa Fault Complex, which is a system of deep listric faults accompanied by a moderate seismicity dropping smoothly eastwards away from the Senja Fracture Zone. This region has shown very little seismic activity before, with very few events reported the last 30 years (Fig. VII.5.2). When considering the level of seismicity now recorded, with events in the magnitude range of M_L 1.7 - 3.1, this illustrates very clearly the recent significant improvement in detectability for these areas. The seismicity seems to extend more or less continually north to the more active southern part of Svalbard. It should be noted that the onshore seismicity in Fig. VII.5.3 possibly contains some explosions, in particular close to the MOR station, in northern Sweden and within the Kola peninsula.

In order to illustrate the effects the various types of geologic structures have on the propagation of seismic waves through the crust and upper mantle, a suite of seismograms are shown for comparison in Figs. VII.5.4 and VII.5.5. By comparing seismograms at the ARCESS array from earthquakes occurring at many different locations, particular characteristics can be correlated with the gross features of the known lateral variations in the crustal structure of the area in this study. Figs. VII.5.4 and VII.5.5 show panels with six pairs of seismograms from earthquakes located in different areas in the region studied. It turns out that few of the events show very clear Lg phases, which are often seen for events with continental type propagation paths (Kennett et al, 1985). However, Lg phases are seen on the event from Lofoten (LOF), and perhaps also on the event from southern Ringvassøy-Loppa Fault Complex. These events are located closer to the coast than the other two offshore (SFZ and BARNT), which appear to have no Lg phase. The Lg phase is also missing for events from the Viking Graben area, where the graben structure is instrumental in the blocking of Lg energy (Kennett et al, 1985). Since most of the offshore events in the present case lack Lg phases even when located in essentially continental type crust (the Barents Sea), this might be a result of stronger attenuation in the upper crust.

Conclusion

The data from recently installed seismographic stations have shown that several regions in the northern part of the Norwegian coastline are exposed to a greater rate of seismicity than reflected in earlier seismicity maps. Even though the seismic networks have only been in operation for one year, they have unveiled new and important information about a large number of earthquakes. These have been found in general to follow the main fault systems, with increasing activity along the coast from Møre to Lofoten, and northwards along the continental margin to the Svalbard Islands. The area around the Vøring Plateau and where the Kristiansund-Bodø Fault Complex intersects with the Rana Fault Complex shows an activity that may be as large as the activity off Møre.

The seismic activity is also relatively high along the escarpment and associated fault zones. Since the data used in this analysis only reflects one year of operation (only six months for ARCESS), it is not known to which extent the apparent clustering of events could be related to temporal variations in seismicity.

The Senja Fracture Zone and Western Barents Sea are exposed to a greater rate of seismicity than earlier known. Especially interesting are the events in the Western Barents Sea which occur in a region with traditionally very low seismicity.

The southern and eastern Barents Sea still appear to be seismically quiet. Even during the last year there have been no events detected east of 30°E or in the basin just north of the northern part of mainland Norway. In these areas the detection threshold for earthquakes should be slightly below magnitude 1.5 due to the continental type crustal structure and assumed mild lateral heterogeneity. This suggests that the area has indeed very low seismic activity; however, a longer time period of monitoring is necessary before drawing any firmer conclusions on this.

In general, it turns out that ARCESS has a very good detectability eastwards and northwards. The detection threshold in these directions is below magnitude M_L 1.5 up to distances of at least 600 km. However, the rather complicated geological structures to the west, with events along and beyond the continental margin, may lead to phase identification problems for the detection algorithm at the ARCESS array.

L.B. Kvamme
R.A. Hansen, Univ. of Bergen

References

Bratt, S.R. and T.C. Bache (1988): Locating events with a sparse network of regional arrays. Bull. Seism. Soc. Am., 78, 780-798.

Bungum, H. (1988): Earthquake occurrence and seismotectonics in Norway and surrounding areas. In: S. Gregersen and P. Basham (eds.): Causes and Effects of Earthquakes at Passive Margins and Areas with Postglacial Rebound on both Sides of the North Atlantic, NATO Advanced Research Workshop Proceedings (in press).

Bungum, H., R.A. Hansen, J. Havskov and L.B. Kvamme (1988): An Introduction to SEISNOR: The Northern Norway network. SEISNOR Technical Report.

Bungum, H. and P.B. Selnes (eds.) (1988): ELOCS: Earthquake Loading on the Norwegian Continental Shelf, Summary Report. Norwegian Geotechnical Institute (Oslo), NTNF/NORSAR (Kjeller) and Principia Mechanica Ltd. (London).

Capon, J. (1969): High-resolution frequency-wavenumber spectrum analysis. Proc. IEEE, 57, 1408-1418.

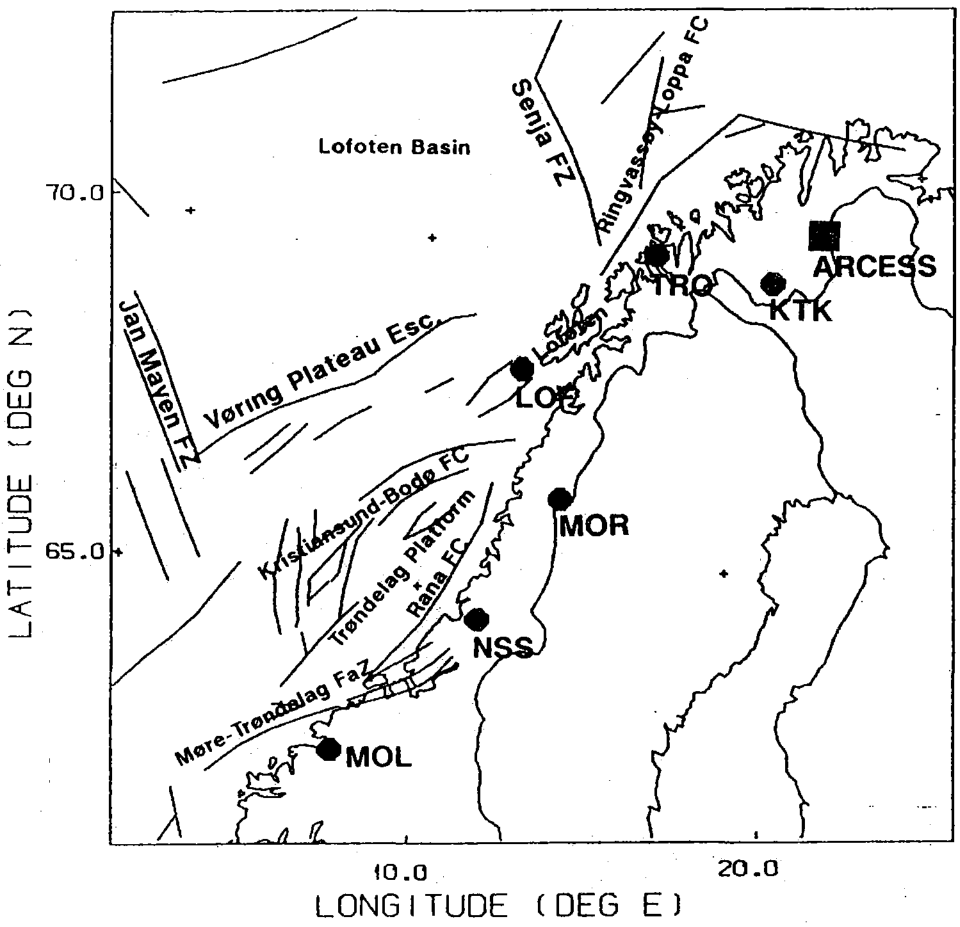
Havskov, J. and H. Bungum (1987): Source parameters for earthquakes in the northern North Sea. Nor. Geol. Tidsskr., 67, 51-58.

Kennett, B.L.N., S. Gregersen, S. Mykkeltveit and R. Newmark (1985): Mapping of crustal heterogeneity in the North Sea basin via the propagation of Lg-waves. Geophys. J.R. astr. Soc., 83, 299-306.

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

Mykkeltveit, S. (1985): A new regional array in Norway. Design work and results from analysis of data from a provisional installation. In: Ann U. Kerr (eds.), The VELA Program. A Twenty-five Year Review of Basic Research, Defense Advanced Research Projects Agency.

Mykkeltveit, S., F. Ringdal, J. Fyen and T. Kværna (1987): Initial results from analysis of data recorded at the new regional array in Finnmark, Norway. NORSAR Semiannual Technical Summary, 1 April - 30 September 1987, NORSAR Sci. Rep. No. 1-87/88, Kjeller, Norway.



<u>Fig. VII.5.1</u> Location of the stations in the SEISNOR regional network, and the ARCESS regional array. The figure also contains the major structural elements as given in Bungum and Selnes (1988).

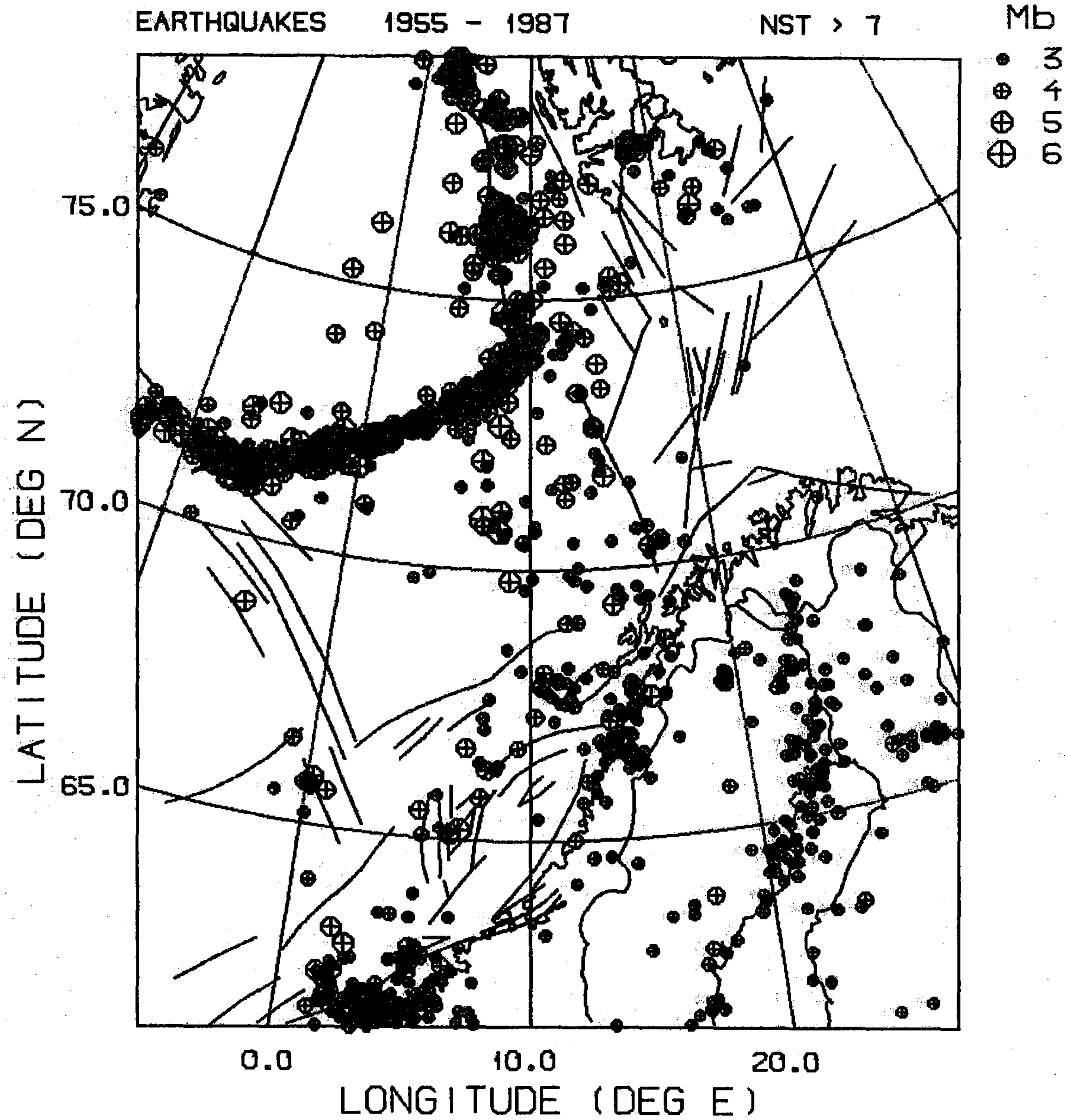


Fig.VII.5.2 Earthquake distribution for the time period 1955 to 1987, reported from at least 8 recording stations (Bungum, 1988). Structural information as for Fig. VII.5.1.

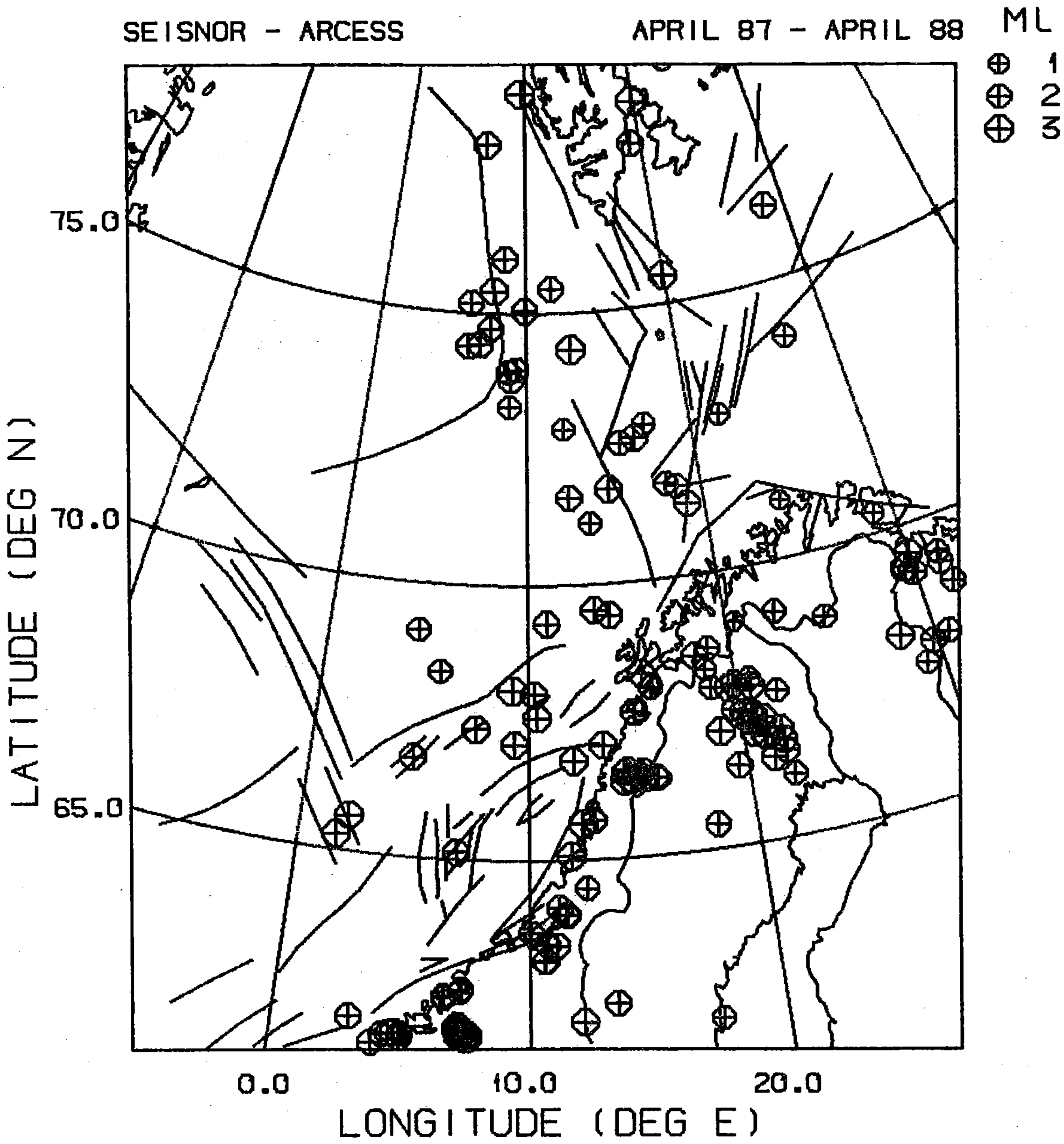


Fig. VII.5.3 Recorded events from April 1987 to April 1988 reported at SEISNOR and ARCESS, where all offshore events are earthquakes. Structural information as for Figs. VII.5.1 and VII.5.2.

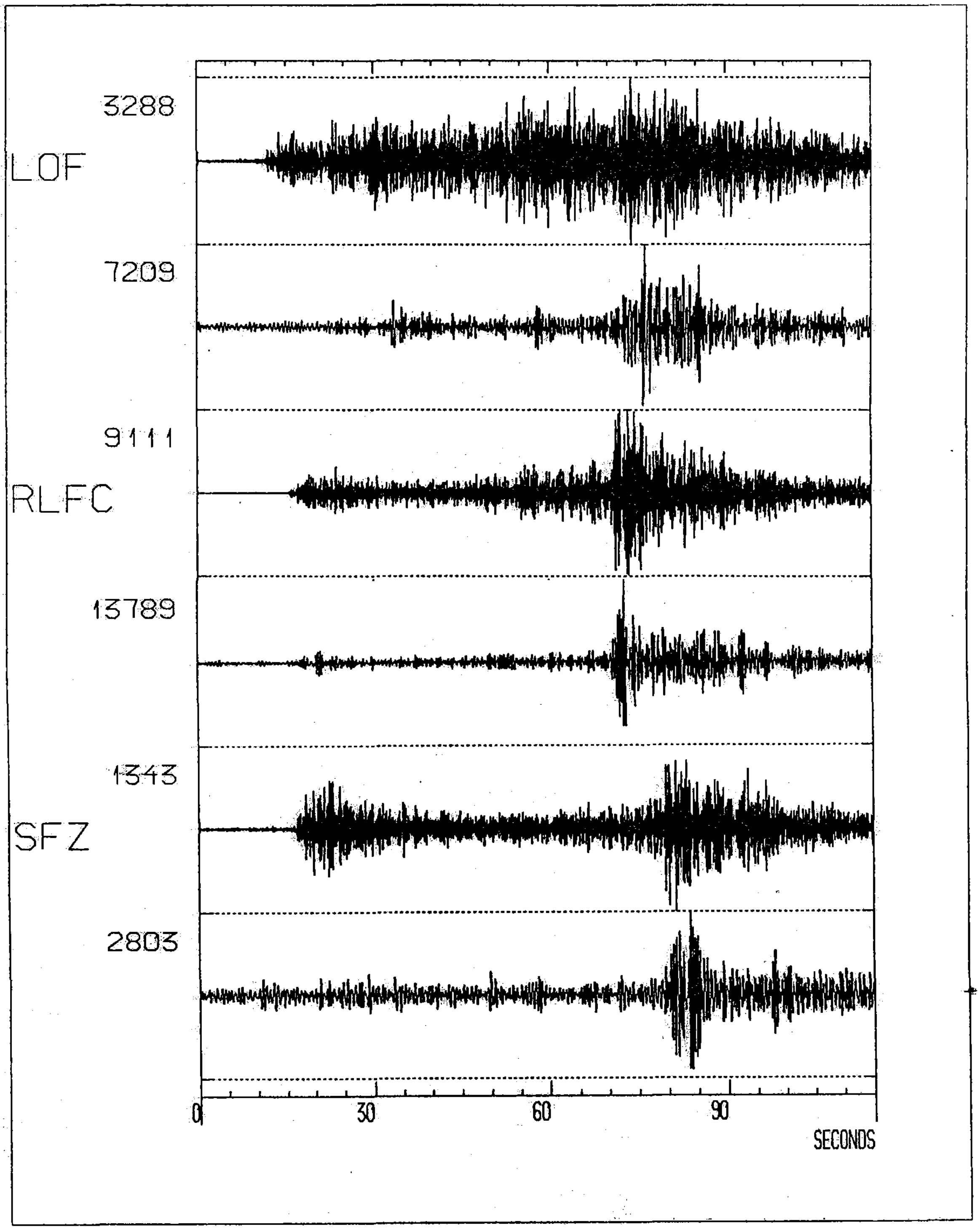


Fig.VII.5.4 Seismograms of three events recorded at ARCESS. The two traces for each event are high-pass filtered (at 6 Hz) and bandpass filtered (1.5 to 3 Hz), respectively. The events are located at LOFOTEN (LOF, 68.1°N, 16.0°E), Ringvassøy-Loppa Fault Complex (RLFC, 72.3°N, 18.7°E), and Senja Fracture Zone (SFZ, 71.6°N, 12.4°E)· Axes are seconds versus amplitude in number of counts, with the maximum number indicated.

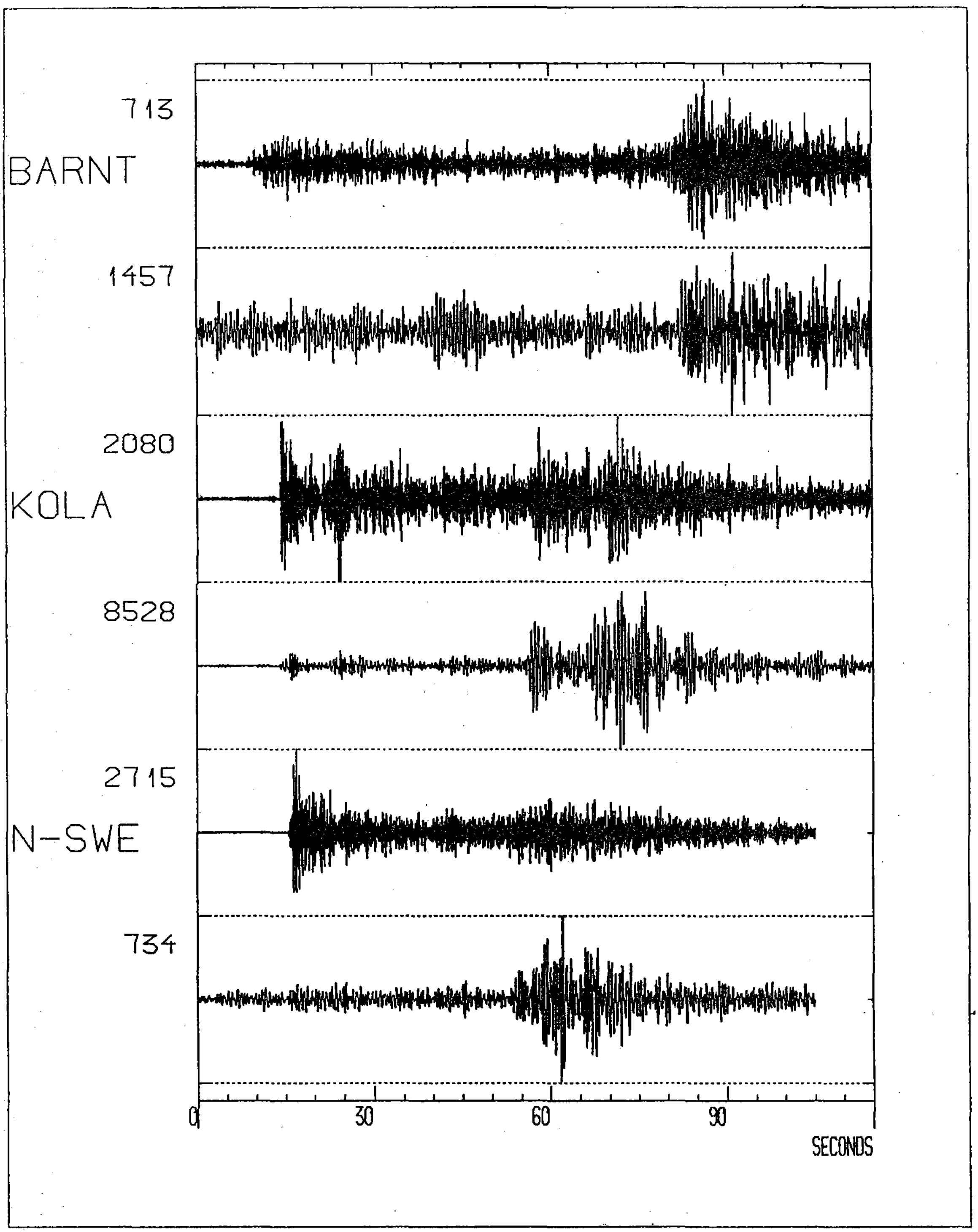


Fig.VII.5.5 Seismograms of three events recorded at ARCESS, where the first in each pair is high-pass filtered (at 6 Hz), while the second is bandpass filtered from 1.5 to 3 Hz. The events are located at Western Barents Sea (BARNT, 73.9°N, 27.1°E), Kola Peninsula (KOLA, 67.6°N, 33.4°E), and northern Sweden (67.3°N, 20.6°E)· Axes are seconds versus amplitude in number of counts, with the maximum number indicated.