Progress Report No 7

for the project

Norwegian National Seismic Network

For the period July 1 to December 31, 1995

Sponsored by

Oljeindustriens Landsforening

Institute of Solid Earth Physics
University of Bergen
Allegaten 41, N-5007 Bergen

and

NORSAR
Boks 51, N-2007 Kjeller

Introduction

This seventh progress report, under the project Norwegian National Seismic Network (NNSN), covers the last half of 1995. The purpose of this report is to describe the current technical operation of the stations, data recorded and the cost and budget of the project for the reporting period. A separate report is given on the seismicity of Norway and surrounding areas in which the data recorded is presented (Appendix 1).

Operation

All of the 11 three-component stations, except Bjørnøya (BJO), functioned satisfactorily with no major breaks for the entire six-month period. The average downtime for all 11 stations is 8.9% which is larger than in the previous six-month period when the downtime was 5.8% (Table 1). The large downtime on MOR and HYA was caused by a combination of lack of spare parts and technicians unavailable at the time (Helge Johnsen was at Bjørnøya during this period).

Table 1. Downtime in % for the time period July to December, 1995 for each station in the NNSN.

Station	Downtime in %
Bjørnøya (BJO)	69
Florø (FOO)	0
Høyanger (HYA)	16.8
Karmøy (KMY)	0
Lofoten (LOF)	0
Mo i Rana (MOR8)	13
Molde (MOL)	0
Namsos (NSS)	0
Odda (ODD1)	0
Sulen (SUE)	0
Tromsø (TRO)	0

New developments for field computers

The current Motorola VME computers used at the field stations are now becoming obsolete. They can still be bought, however, in a couple of years it might be difficult and expensive to get spare parts. A new development was therefore started in 1995 to replace the VME computers with standard IBM PC's. This has been possible because of the developments of faster PC's and the availability of the PC based real time operating system QNX. The fist two QNX systems have now been placed on Bjørøya and Mo i Rana. The intention is to gradually replace the current VME systems as they fail and use the money for spare parts in the budget for this purpose. In the long run this will lower the costs since a VME computer cost about 45 000 kr while a PC with QNX has a price of about 20 000 kr.

Field stations and technical service

The work carried out at the different stations during the last six months of 1995 is summarized below.

Bjørnøya (BJO)

04/11-95: The station has been down in the period March 20th to November 4th. A QNX system with tape deck and a ED 24 digitizer was installed. The station has from this date continous recordings. This has improved the event detection substantially (see Appendix 1).

Florø (FOO)

No visit or technical changes.

Høyanger (HYA)

04/07-95: The vertical component has been inoperational due to a defect sensor. The sensor recording east-west was installed as a new vertical-component.

23/11-95: The station was down in the period from October 24th to November 23rd due to a defect serial-line interphase. A new EW-component sensor was installed.

Karmøy (KMY)

No visit or technical changes.

Lofoten (LOF)

16/8-95: New Seislog software (version 5.1) was installed.

Mo i Rana (MOR8)

24/10-95: The station was down in the period October 1st - 24th, due to defect OS9 system. A QNX system was installed.

Molde (MOL)

A new GPS clock was installed to replace a malfunctioning GPS clock and a

temporarily installed Omega clock. Installed new Seislog (version 5.1).

Namsos (NSS)

No visit or technical changes.

Odda (ODD1)

24/10-95: New Seislog software (version 5.1) was installed.

Sulen (SUE)

5/7-95: A defect GPS clock was replaced.

Tromsø (TRO):

9/11-95: The NS-sensor was inoperational due to a minor mechanical problem, which was fixed.

Svalbard array (SVAESS)

See Appendix 2.

Data recorded

An overview of the seismic activity in Norway and surrounding areas for the last half of 1995 is given in a separate report (Appendix 1). The data recorded by the seismic stations were collected and monthly bulletins were prepared and distributed. Since there was no event in Norway of magnitude larger than 5.0 during the last half of 1995, no special report has been written.

The performance of, and data recorded by the Svalbard array, are described in Appendix 2.

Costs

Accounts for the time period July 1st to December 31st, 1995

Costs at the University of Bergen and NORSAR (NOK 1000)

	Budget for all of 1995	Spent 1995	Rest	Budget for all of 1996	Spent until Apr.1st 1996
Communication	130	103	27	130	14
Travel to field stations	180	112	68	180	10
Local costs at field stations	90	92	-2	90	62
Spare parts	180	268	-88	180	97
Central processing	130	135	-5	130	20
NORSAR	210	210	0	210	0
TOTAL	920	920	0	920	203

Other matters

NNSN data used

At the IUGG meeting in Boulder, Colorado, USA in July, a presentation was given about the network (as was mentioned in the previous report).

A study called: Depth determination through syntetic modelling using the WKBJ-method, was made by Sylvia Sundquist in January 1996. Technical report no. 5, IFJ, UiB.

G. A. Ryzhikov, M. S. Biryulina & E. S. Husebye. A Novel Approach to Automatic Monitoring of Regional Seismic Events. IRIS Newsletter, Vol. XV, No. 1, Spring 1996.

The four following papers were submitted as a Dr. scient thesis by Cenk Deniz Mendi, Institute of Solid Earth Physics, University of Bergen, February 1996:

* C. D. Mendi & E. S. Husebye, Automatic event location for local networks based on seismogram envelopes.
* C. D. Mendi & E. S. Husebye, June 1994. Near real time estimation of magnitudes and moments for local seismic events. Annali di Geofisica, Vol.XXXVII, N. 3.
* C. D. Mendi & E. S. Husebye, 1995. Near real time estimation of seismic event magnitude and moment via P and L_g phases. NATO ASI Series, Partnership Sub-Series, 2. Environment - Vol. 4.
* C. D. Mendi, B. O. Ruud & E. S. Husebye. The North Sea L_g blockage puzzle.

Appendix 1

Seismicity of Norway and surrounding areas

for the period

July 1st to December 31st, 1995

Institute of Solid Earth Physics
University of Bergen
Allegt 41
N-5007 Bergen

e-mail: seismo@ifjf.uib.no
Phone: +47-55 21 34 20
Fax: +47-55 32 00 09

April 1996

Introduction

This semi-annual summary of the seismicity of Norway and the surrounding areas encompasses the time period July 1st to December 31st, 1995. The seismicity has been compiled from all available seismic stations operating on Norwegian territory including the Arctic islands of Svalbard, Bjørnøya and Jan Mayen. In addition, for large or special events, stations from neighbouring countries have also been included.

In Norway, the University of Bergen and the Norwegian Seismic Array (NORSAR) operate seismic stations. These stations are sponsored by different organizations. The University of Bergen operates the Norwegian National Seismic Network (NNSN) which comprises ten stations and includes the Svalbard array (SVAESS) operated by NORSAR. In addition, there are 12 other seismic stations which are operated by the University of Bergen, and two seismic arrays (NORESS and ARCESS) in southern and northern Norway and one in Apatity, Russia operated by NORSAR. All seismic data collected from the seismic stations and a selection of data recorded with the seismic arrays, are submitted to the University of Bergen, and a monthly bulletin is prepared and distributed. A brief overview of the events published in the monthly bulletins is given in this semi-annual report. The merging of data between NORSAR and Bergen is done based on the following principles: i) all local and regional events both recorded on stations operated by UiB and on minimum two of the arrays operated by NORSAR are included, ii) all events with local magnitude $\geq$ 2.0 detected by a minimum of two NORSAR arrays and not recorded by any Bergen stations are included in the monthly bulletin. For all felt events in Norway macroseismic data are collected, and macroseismic maps are presented. No distant events from NORSAR are included in the bulletin

2. Velocity models and magnitude relations

The model used for locating all local and regional events, except for the local Jan Mayen events, is published by Havskov and Bungum (1987). Event locations are performed using the HYPOCENTER program (Lienert and Havskov, 1995) and all processing is performed using the SEISAN data analysis software (Havskov, 1995).

P-wave velocity (km/sec)	Depth to layer interface (km)
6.2	0.0
6.6	12.0
7.1	23.0
8.05	31.0
8.25	50.0
8.5	80.0

Magnitudes are calculated from coda duration and/or amplitudes. The coda wave magnitude scale (M_C) is estimated by Engell-Sørensen (pers. comm., 1987):

$$M_C = -3.0 + 2.6 * \log10(T) + 0.001 * D.$$

where T is the coda length in seconds and D is the epicentral distance in km. When instrument corrected maximum ground amplitudes A (nm) are available, local magnitude M_L is calculated using the equation given by Alsaker et al. (1991):

$$M_L = 0.925*\log(A) + 0.91*\log(D) + 0.00087*D - 1.31$$

where D is the hypocentral distance in km.

For the Jan Mayen area, a local model and coda magnitude scale are used (Sørnes and Navrestad, 1975)

P-wave velocity (km/sec)	Depth interval (km)
3.14	0-3
6.33	3-18
8.27	≥18

The coda magnitude for Jan Mayen is given by Westre (1975):

$$M_C = 3.27\log(T) - 3.24 + 0.001*D$$

where T is the coda duration and D is the epicentral distance in km.

The regional and distant events recorded by the network are located using the global velocity model IASPEI91 (Kennett and Engdahl, 1991).

Body wave magnitude is calculated using the following equation (Veith and Clawson, 1972):

$$mb = \log(A/T) + Q(D,h)$$

where h is the hypocenter depth (km), A is the amplitude (microns), T is period in seconds and Q(D,h) is the correction for epicentral distance and depth.

Surface wave magnitude Ms is calculated using the equation (Karnik et al., 1962):

$$Ms = \log(A/T) + 1.66\log(D) + 3.3$$

where A is the amplitude (microns), T is period in seconds and D is the hypocentral distance (km).

In the seismic monthly bulletin published by UiB, probable explosions are identifyed either by the operator or by passing the data through an explosion filter. Using the explosion filter, an event is marked "probable explosion" if it occours in a particular time interval and has a magnitude below a threshold value (Ottemöller, 1995; see also NNSN report, October 1995). Both the time interval and the magnitude threshold values are region dependent. Events identified by the explosion filter, as "probable explosion" are not relocated using zero depth.The explosion filter has been used since August 1995.

3. Events recorded by the Norwegian stations

There are some limitations in the statistical information presented below, because of the merging routines between the data recorded at NORSAR and UiB. The data presented are based on the Bergen database and therefore the following events are not included;

* distant events recorded on arrays operated by NORSAR
* regional/local events only recorded by NORSAR arrays and with a magnitude below 2.0.
* local events recorded only by one NORSAR array

The last point especially affects the events located in the Spitsbergen area, since many only are recorded by the NORSAR array, SVAESS.

Figure 1 displays the total number of local and distant events for each month, detected by the Norwegian seismic stations, during the last half of 1995. A total of 1392 local and regional events were detected during the last six months of 1995, which is comparable to the previous six-month period when the number was 1391. It was possible to locate around 50% of these events, or a total of 700 events.

Figure 2 shows all located events with $M \geq 3.0$, both distant, regional and local. In total, 152 events with $M \geq 3.0$ were recorded by the Norwegian seismic stations from July through December 1995.

A total of 341 distant events were recorded by the Norwegian seismic stations during the last half of 1995. Out of these, we were able to locate 116 events, or 34%. Table 1 shows all local, regional and distant events detected, by various seismic stations, for each month from July to December, 1995.

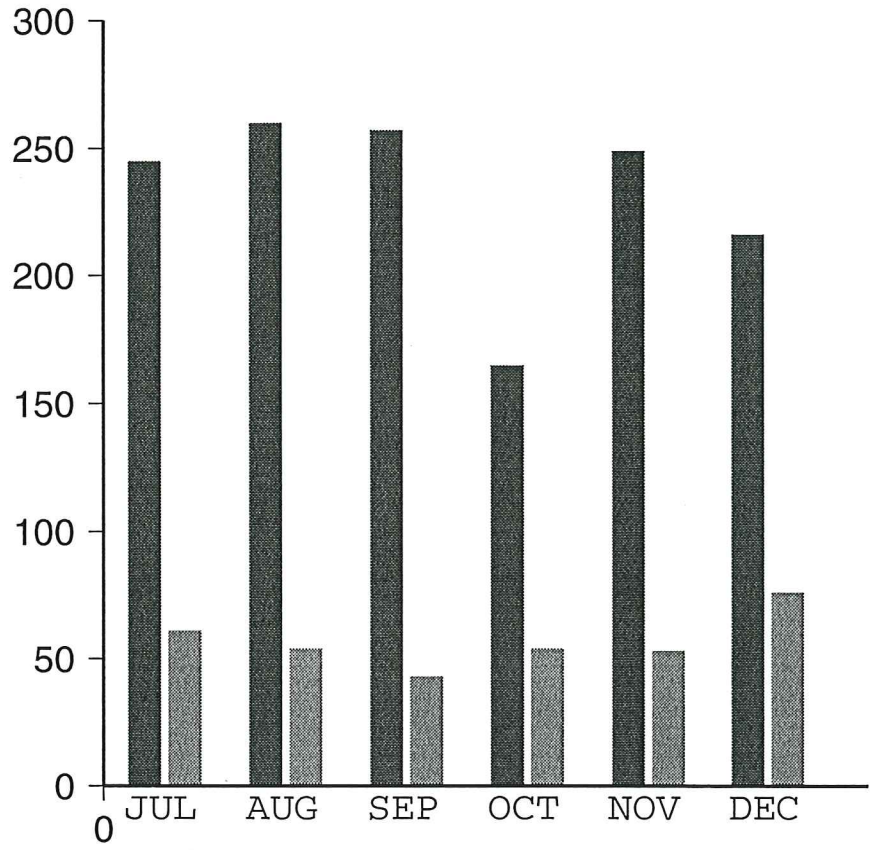


Figure 1. Local and regional (black bars) and distant (grey bars) events recorded by the Norwegian seismic stations, per month, during the last six months of 1995. (See text for limitations.)

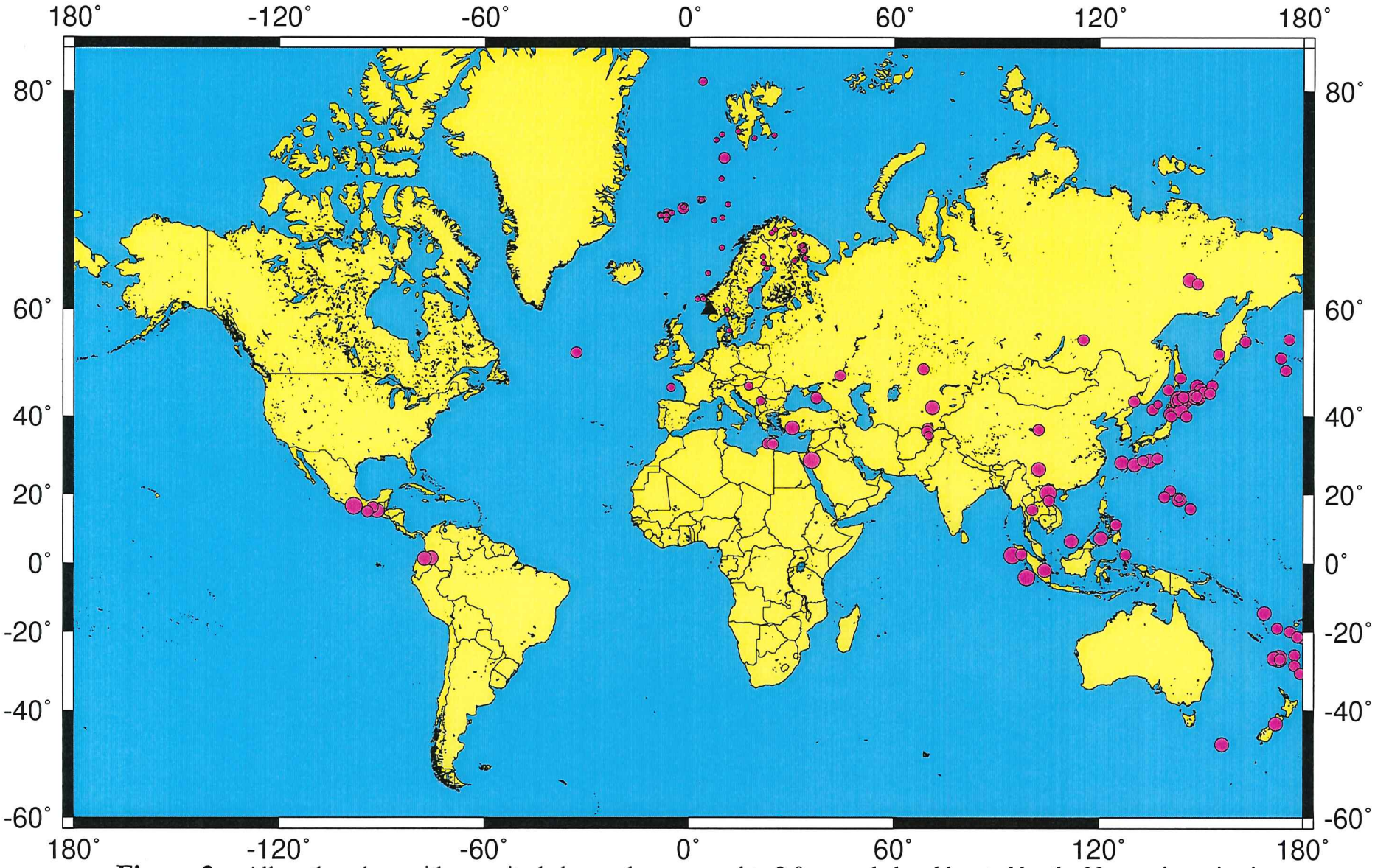


Figure 2. All earthquakes, with magnitude larger than or equal to 3.0, recorded and located by the Norwegian seismic stations during the time period July to December, 1995. The triangle indicates the location of Bergen.
Magnitudes: • M=3.0-3.9 • M=4.0-4.9 • M=5.0-5.9 • M=6.0-6.9 • M=7.0-7.9 • M=

Table 1. Number of local + regional / distant events respectively, for each seismic station, for the time period July to December, 1995. For the array stations (NRA0 and SPA0) no distant events are included in the database in Bergen and therefore no numbers are presented. If a station has been down due to technical problems for (i) a whole month, the cell is left blank, (ii) parts of the month, the numbers are presented in brackets. The station abbreviations are BLS=Blåsjø, KMY=Karmøy, ODD1=Odda, ASK=Askøy, OSG=Oseberg, HYA=Høyanger, SUE=Sulen, FOO=Florø, MOL=Molde, KONO=Kongsberg, NSS=Namsos, MOR=Mo i Rana, LOF=Lofoten, TRO=Tromsø, KTK=Kautokeino, BJO=Bjornøya, KBS=Kings Bay, JMI=Jan Mayen, NRA0=Noress and SPA0=Svaess.

STATION	July	August	September	October	November	December
BLS	10 / 5	12 / 6	14 / 1	8 / 7	19 / 10	16 / 15
KMY	22 / 7	19 / 9	15 / 2	11 / 10	18 / 3	20 / 8
ODD	6 / 2	9 / 6	17 / 1	5 / 8	19 / 5	17 / 14
ASK	31 / 7	28 / 9	35 / 3	20 / 12	28 / 5	27 / 11
OSG	0 / 0	3 / 0	3 / 0	0 / 0	1 / 0	0 / 0
HYA	41 / 19	21 / 17	26 / 4	(4 / 10)	(1 / 1)	7 / 3
SUE	36 / 12	25 / 9	28 / 2	17 / 8	18 / 6	15 / 8
FOO	18 / 6	11 / 7	23 / 2	11 / 9	10 / 4	11 / 6
MOL	33 / 22	36 / 15	57 / 11	17 / 21	15 / 12	21 / 19
KONO	2 / 47	3 / 37	5 / 29	3 / 41	2 / 33	2 / 35
NSS	31 / 26	36 / 24	51 / 11	25 / 20	21 / 14	19 / 21
MOR	43 / 10	53 / 16	30 / 4	(0 / 0)	11 / 15	4 / 45
LOF	45 / 11	37 / 7	23 / 2	11 / 12	9 / 4	9 / 5
TRO	33 / 23	43 / 24	33 / 16	27 / 24	25 / 16	40 / 37
KTK	(51 / 10)			(9 / 1)	74 / 15	76 / 20
BJO					11 / 8	7 / 7
KBS	10 / 17	10 / 18	9 / 9	8 / 15	11 / 22	15 / 26
JMI	0 / 0	22 / 0	6 / 0	14 / 14	14 / 4	12 / 0
NRA0	51 /	45 /	76 /	59 /	87 /	58 /
SPA0		(7 /)	13 /	15 /	27 /	26 /

4. The seismicity of Norway and surrounding areas

All local and regional events located by the University of Bergen during the last half of 1995 are shown on the map in Figure 3 and in Figure 3a, where probable explosions are filtered away. The number of events located including NORSAR readings, decreased slightly from 377 in the first six months of 1995 to 350 in the last six months of 1995.

Figure 4 and Table 2 show the 48 local and regional events with any of the reported magnitudes ≥3.0. It is likely that almost all of these events are earthquakes. One should however bear in mind that the nature of a ripple explosion causes the coda length and consequently the coda magnitude to be enlarged. It is therefore likely to belive that some events around the Kola Peninsula, Kiruna and Mo i Rana are explosions. The number of events with magnitude≥3.0 are as expected compared to the previous time period when the corresponding number was 50.

The distribution of earthquakes follows the tectonic trends in the region (Figure 3a). Major concentration of earthquakes occur in the northern North Sea, around the Tampen Spur area, and further towards the south along the Viking Graben. Parallell to the continental shelf, there are a number of earthquakes occuring offshore northern Norway. A cluster of earthquakes also occur along the Jan Mayen Fracture Zone with a prominent seismicity following the Mohns Rigde further to the north and along the Senja fracture zone offshore western Svalbard. Sporadic events appear in the southern parts of Spitsbergen.

On mainland Norway, the major concentration is observed in western Norway, south of the Hardanger fjord. Another concentration is found north of Mo i Rana, close to the Meløy area, where a previous well known earthquake swarm was observed in 1978-79 (Bungum et al. 1979). However some of these events may be explosions, since the explosion filter used avoids removing the events falling into this tectonic complex area.

Among the larger earthquakes (M≥3.0), two interesting occurences may be mentioned, one in the Oslo Graben, and one along the Masi Fault in northern Norway.

As a part of the daily prosessing routines, fault plane solutions are also determined for selected events. Because of the varying data quality, it is seldom possible to read first motion on a sufficent number of phases/stations to obtain a reliable fault plane solution. During the last half of 1995, relatively reliable fault plane solutions could be determined for six events, and these are shown in Figure 4a. The details of each focal mechanism are given in Appendix A.

Except for the event in the Oslo region, all focal mechanisms display a dominent reverse displacement with varying amounts of strike-slip components. One of the events in the North Sea shows a pure strike-slip mechanism.

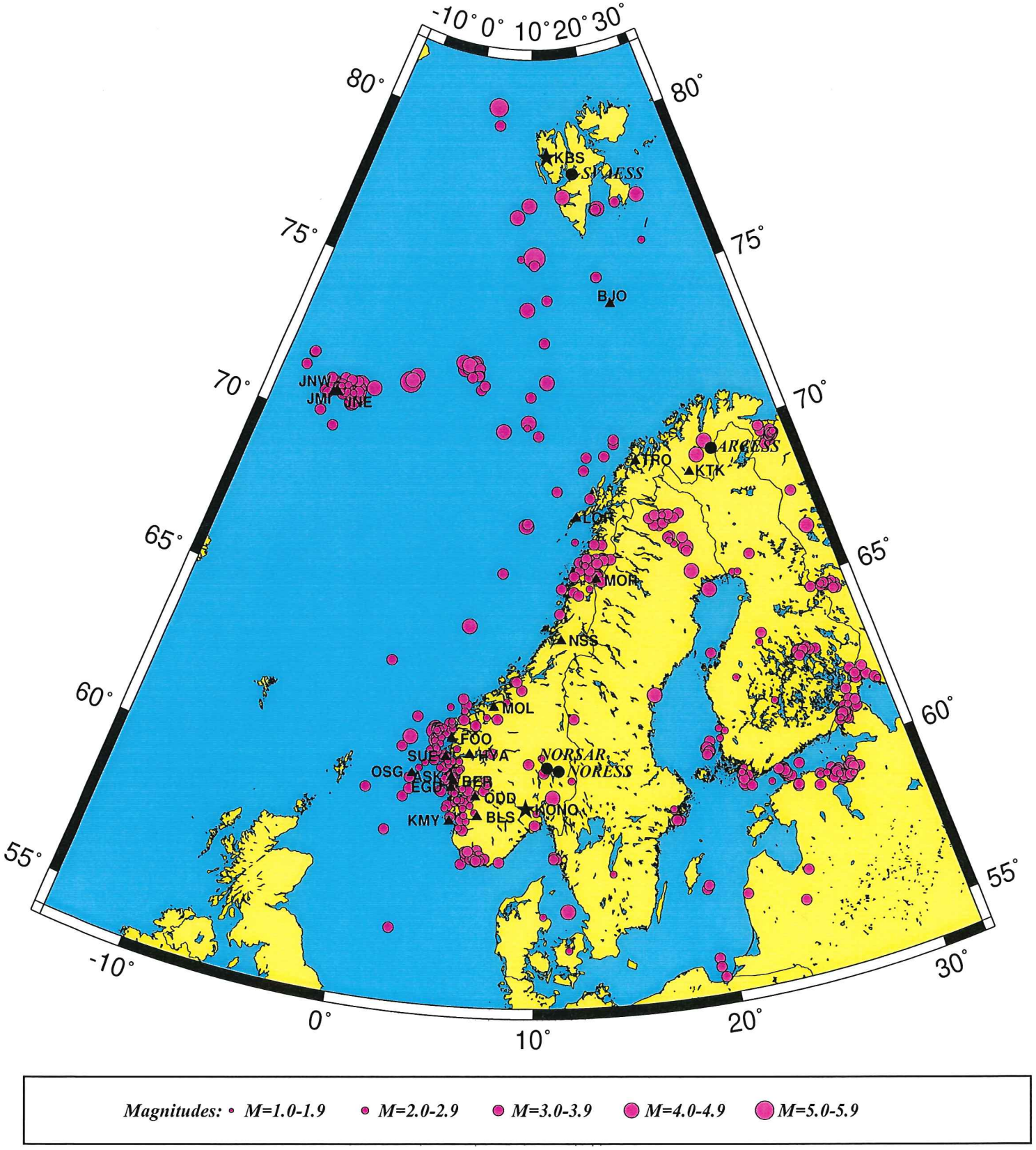


Figure 3. Epicenter distribution of the events registered by the Norwegian seismic stations during July to December, 1995. Note that a number of clusters on the mainland correspond to mining activities. Triangles indicate stations operated by the Institute of Solid Earth Physics, University of Bergen (UiB), black circles indicate array stations operated by NORSAR. The stars indicate the two IRIS stations operated by the UiB.

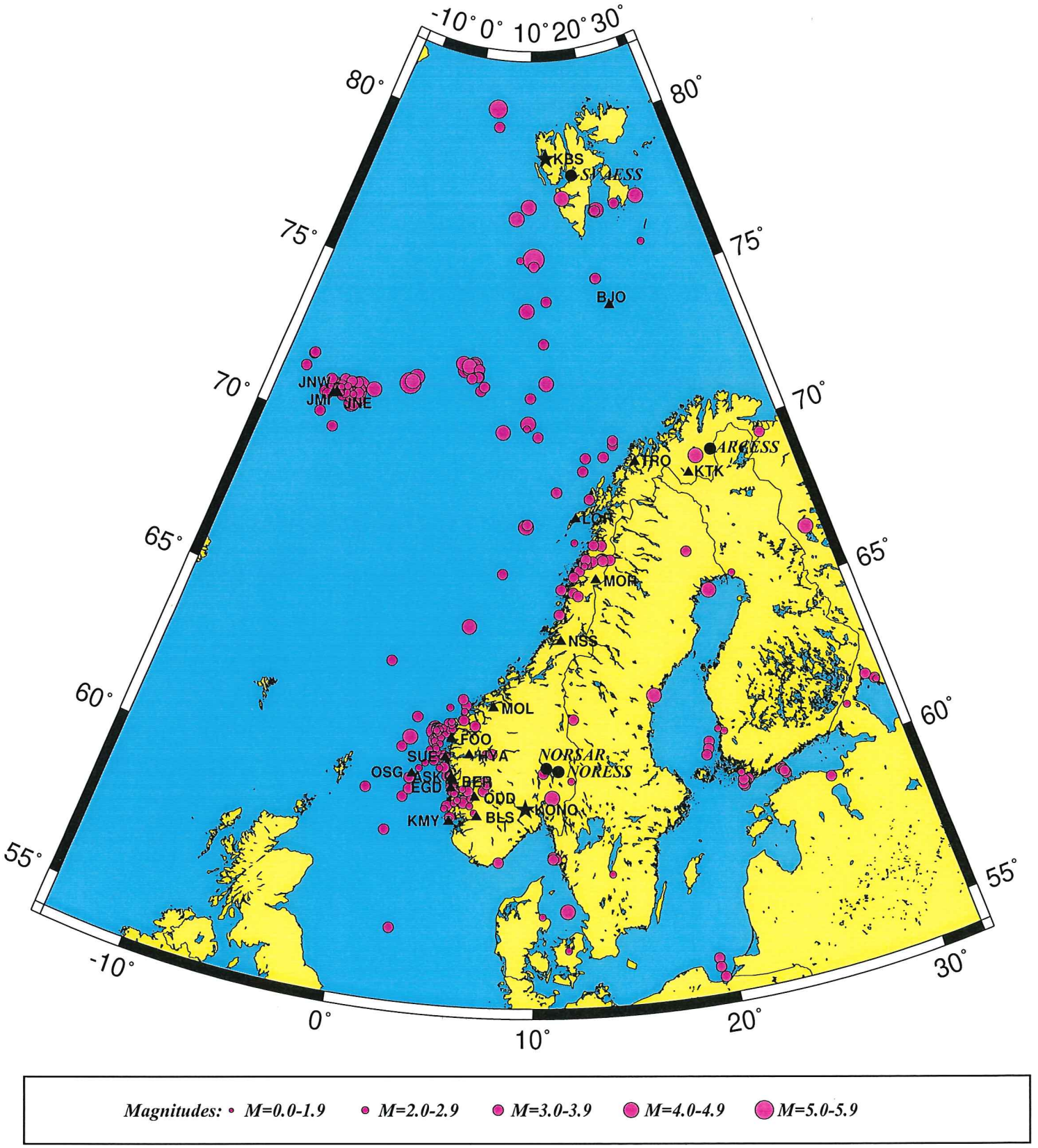


Figure 3a. Epicenter distribution of the events registered by the Norwegian seismic stations during July to December, 1995. Probable explosions are not included.
Triangles indicate stations operated by the Institute of Solid Earth Physics, University of Bergen (UiB), black circles indicate array stations operated by NORSAR. The stars indicate the two IRIS stations operated by the UiB.

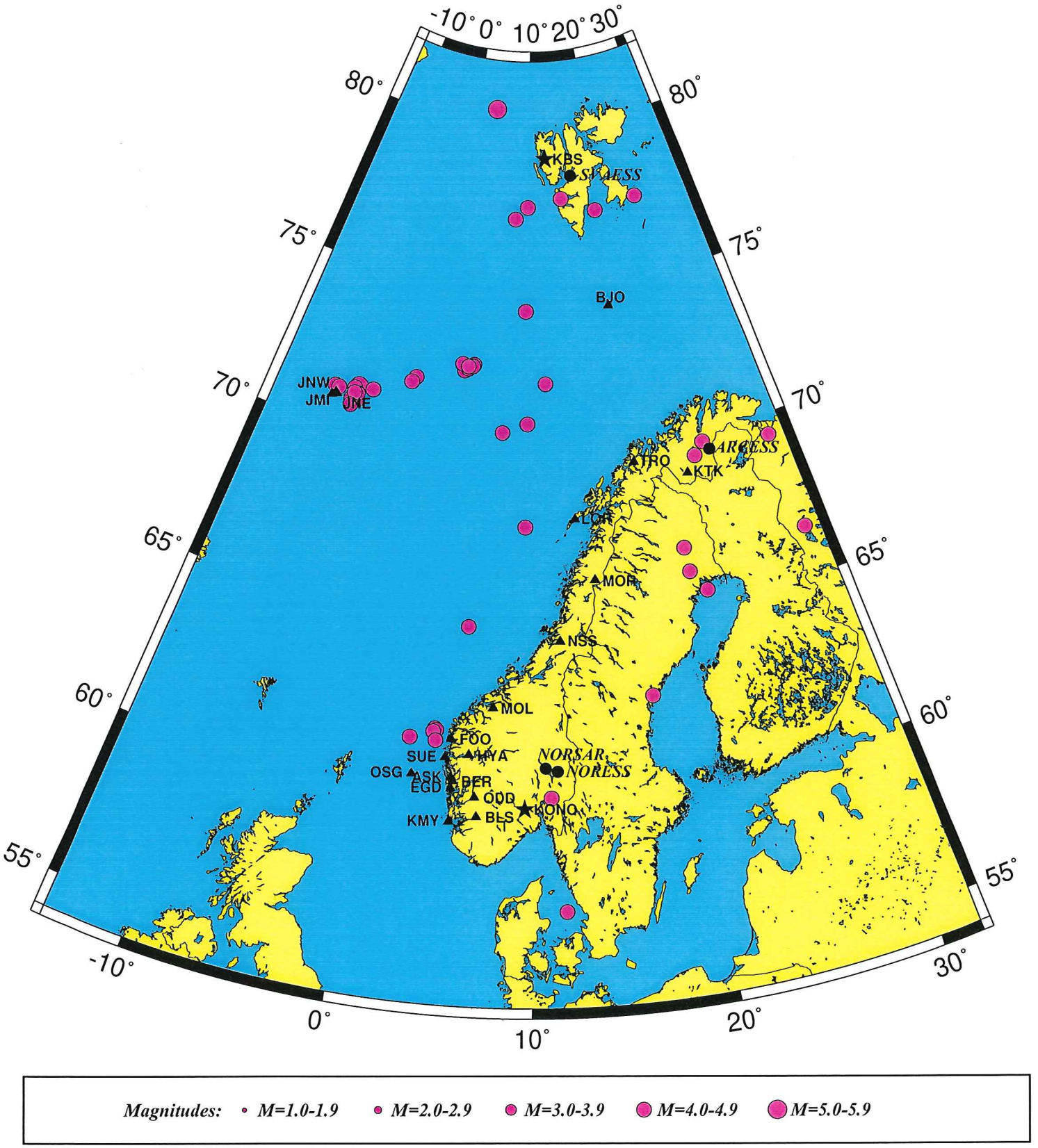


Figure 4. Epicenter distribution of the events registered by the Norwegian seismic stations during January to June, 1995 with M≥3. Triangles indicate stations operated by the Institute of Solid Earth Physics, University of Bergen (UiB), whereas circles indicate array stations operated by NORSAR. The stars indicate the two IRIS stations operated by the UiB.

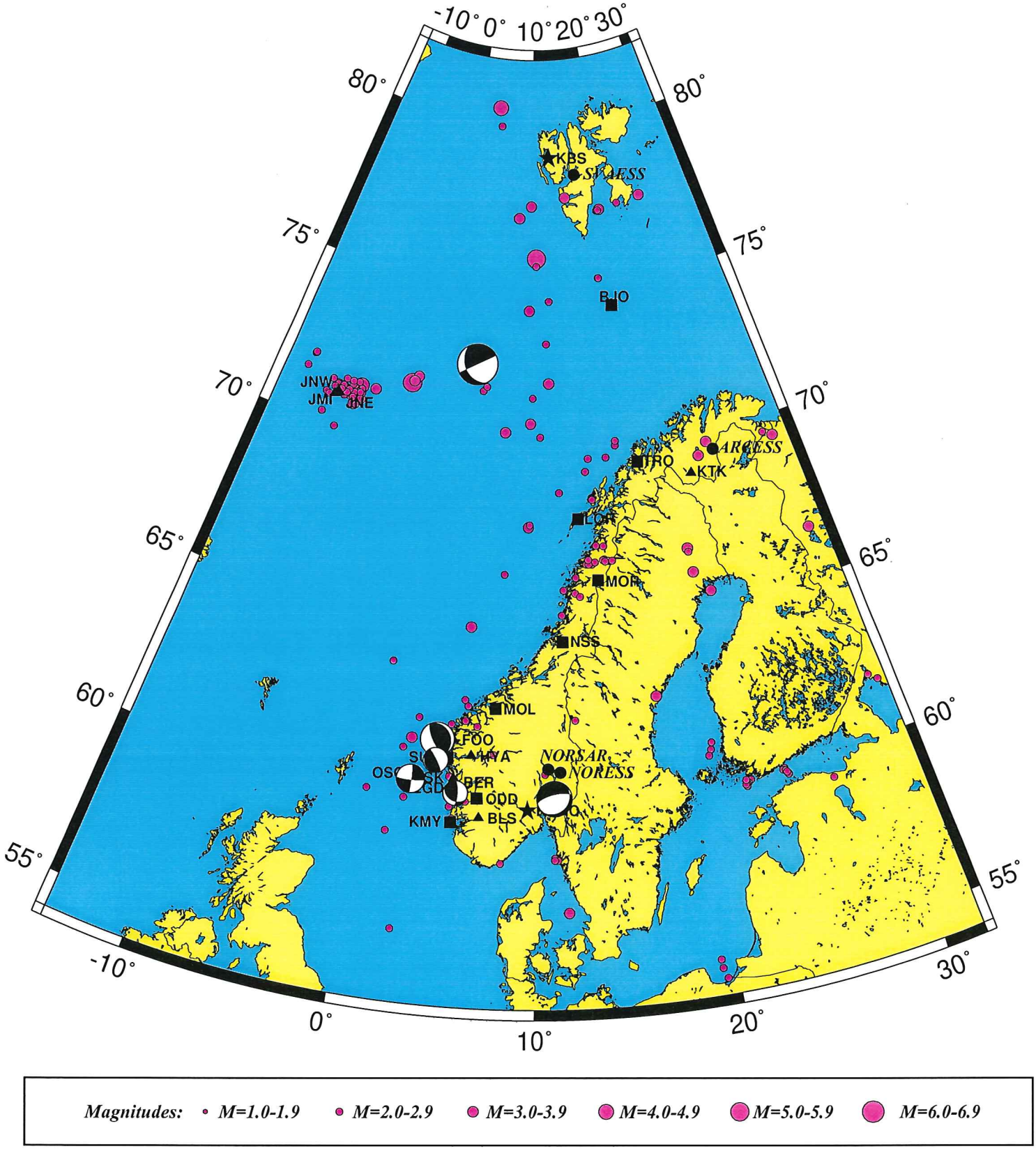


Figure 4a. Fault plane solutions for the six events refered in the text. All magnitudes refer to coda magnitude. Squares indicate stations that are part of the NNSN. Triangles indicate stations operated by the Institute of Solid Earth Physics, University of Bergen (UiB), whereas circles indicate array stations operated by NORSAR. The stars show the two IRIS stations operated by UiB.

Table 2. Earthquakes with magnitude≥3.0 for the time period July to December, 1995.

Columns 1-2: Year, month, day
Columns 3-4: Origin time given in UTC as hour, minutes, seconds
Column 5: Distance identification (L=local, JL= Jan Mayen area, R=regional)
Columns 6-7: Latitude, longitude
Column 8: Focal depth (km)
Column 9: Recording agency
Column 10: Number of stations used for location
Column 11: Root mean square of the travel-time residuals (rms)
Column 12: Coda wave magnitude, Bergen (BER)
Column 13: Local (L) magnitude, Bergen (BER)
Column 14: Local (L) magnitudes provided by NORSAR (NAO)

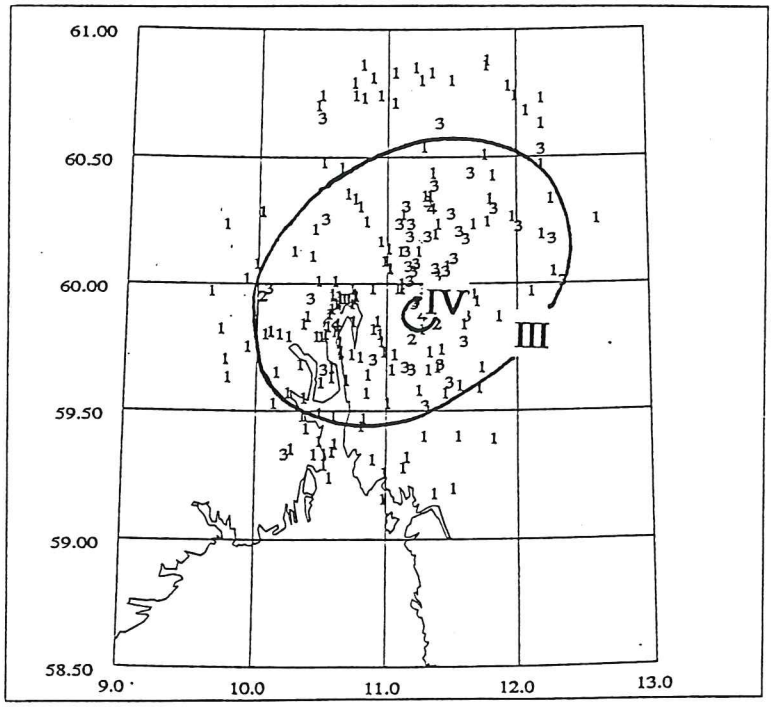
1995	7	3	1249	35.6	L	69.790	25.105	1.7	BER	9	1.4	3.1CBER	3.3LBER	2.8LNAO1
1995	715		1054	21.0	L	71.855	-1.874	10.0F	BER	14	1.3	4.5CBER	4.3LBER	5.3BPDE1
1995	723		1153	12.6	L	62.717	17.824	0.0	BER	9	0.9	3.3CBER	2.5LBER	2.2LNAO1
1995	724		1423	3.6	L	64.908	5.619	10.0F	BER	13	1.5	3.0CBER	2.6LBER	2.1LNAO1
1995	724		1924	33.8	L	72.080	-1.370	10.0F	BER	9	1.2	3.2CBER	3.3LBER	2.6LNAO1
1995	728		0339	23.8	JL	71.400	-6.525	0.0	BER	4	0.5	4.4CBER		1
1995	728		1816	55.5	L	71.327	-6.849	35.7	BER	4	0.8	3.2CBER	3.7LBER	1
1995	8	3	0116	52.5	L	80.497	3.829	15.0	BER	11	1.0	3.6CBER	4.5LBER	1
1995	8	8	0827	1.8	JL	70.998	-6.336	14.9	BER	3	0.1	2.9CBER	3.3LBER	1
1995	811		0802	48.2	JL	71.179	-6.442	11.2	BER	4	0.1	3.1CBER	3.3LBER	1
1995	811		0840	37.2	L	70.716	7.394	12.2	BER	4	0.8	3.3CBER	2.7LBER	1
1995	813		0959	55.9	L	61.530	2.513	15.0F	BER	18	0.8	2.7CBER	2.6LBER	3.0LBGS1
1995	818		1326	34.3	L	61.803	3.971	15.0	BER	21	1.0	3.1CBER	3.2LBER	3.2LBGS1
1995	829		2212	15.2	L	77.495	24.855	15.0	BER	8	0.7	3.8CBER	3.3LBER	3.4LNAO1
1995	830		1104	14.2	JL	71.408	-5.109	15.0	BER	3	0.7	3.1CBER	2.4LBER	1
1995	9	8	1957	23.0	L	61.857	3.996	15.0	BER	22	1.3	3.0CBER	3.0LBER	2.9LNAO1
1995	9	9	1350	36.6	L	61.817	4.076	0.0	BER	23	1.1	3.0CBER	3.2LBER	3.2LNAO1
1995	917		1649	51.2	L	61.770	3.890	15.0	BER	25	1.3	3.1CBER	3.1LBER	2.7LNAO1
1995	918		0326	8.1	L	66.460	30.837	0.1	BER	10	0.8	3.9CBER	2.9LBER	2.9LNAO1
1995	920		0653	48.3	L	71.921	-1.686	10.0F	BER	9	1.3	3.8CBER	3.9LBER	1
1995	924		1827	3.9	L	70.981	9.669	15.0F	BER	11	2.1	3.2CBER	3.0LBER	2.5LNAO1
1995	927		1205	22.8	L	74.380	9.458	10.0F	BER	6	0.9	3.1CBER	3.4LBER	2.8LNAO1
1995	10	2	1957	7.8	JL	71.222	-8.683	0.0	BER	3	0.5	3.2CBER	3.4LBER	1
1995	10	4	0917	32.8	R	75.951	10.284	10.7	BER	11	1.5	4.4LBER		5.3BPDE1
1995	10	4	2049	44.4	L	56.699	11.829	15.0	BER	25	2.2	3.9CBER	3.4LBER	3.4LNAO1
1995	1023		0108	44.1	L	69.443	24.144	0.0	BER	8	1.7	3.2CBER	3.0LBER	2.7LNAO1
1995	1030		1314	25.1	JL	70.975	-6.909	0.0	BER	3	0.1	3.3CBER	3.4LBER	1
1995	11	3	2130	2.6	JL	71.180	-6.754	15.0	BER	4	0.1	3.4CBER	3.6LBER	1
1995	11	3	2134	3.6	JL	70.789	-6.802	7.5	BER	4	0.0	3.4CBER	3.7LBER	1
1995	1113		0122	3.2	L	59.964	11.163	14.8	BER	19	0.8	3.3CBER	3.2LBER	3.2LNAO1
1995	1113		0809	21.7	L	61.515	4.103	12.0F	BER	20	1.1	3.2CBER	3.5LBER	3.2LNAO1
1995	1116		1542	26.2	L	77.170	7.963	10.0F	BER	2	0.2	3.2CBER		1
1995	1116		1630	21.9	LP	66.133	21.755	0.0F	BER	3	1.1	3.1CBER	2.7LBER	1
1995	1117		1232	19.1	L	69.382	30.694	0.1	BER	6	1.1	3.2CBER		2.1LNAO1
1995	1119		1800	11.8	JL	71.210	-8.303	17.9	BER	3	0.0	3.6CBER	3.5LBER	1
1995	1125		1941	30.8	L	77.310	19.009	19.6	BER	9	1.2	3.8CBER	3.5LBER	3.2LNAO1
1995	1127		0501	24.9	L	65.485	22.710	0.0	BER	6	0.9	3.4CBER	2.5LBER	2.2LNAO1
1995	1127		2302	5.7	L	72.489	3.322	3.3	BER	10	0.8	2.9CBER	2.9LBER	3.0LNAO1
1995	12	2	0857	52.5	L	72.182	11.447	10.0F	BER	9	1.3	3.0CBER	2.6LBER	2.7LNAO1
1995	12	8	0741	17.2	L	72.696	4.213	10.0F	BER	20	2.1	3.8CBER	3.9LBER	3.8LNAO1
1995	12	8	0852	27.0	L	72.557	3.701	4.7	BER	11	1.2	3.1CBER		3.0LNAO1
1995	12	8	0936	15.7	L	72.682	3.070	10.0F	BER	6	1.0	3.5CBER		2.5LNAO1
1995	1213		0746	32.6	L	77.534	9.641	10.0F	BER	7	1.3	3.1CBER	3.4LBER	2.7LNAO1
1995	1215		1933	38.2	L	67.920	9.531	15.0F	BER	13	1.7	3.3CBER	2.9LBER	2.4LNAO1
1995	1215		2339	59.1	L	72.642	4.113	10.0FSBER		20	1.6	3.8CBER	3.8LBER	3.4LNAO1
1995	1215		2351	40.4	L	72.622	3.680	11.9	BER	13	1.1	3.5CBER		3.1LNAO1
1995	1221		0257	13.4	L	77.764	14.340	9.0	BER	6	0.7	2.3CBER		3.0LNAO1
1995	1228		1640	40.4	L	66.854	21.683	0.1	BER	3	1.5	3.2CBER	2.2LBER	1

5. Felt events

Six events were reported felt in Norway (not including Jan Mayen and Svalbard) during the last half of 1995 (see Table 3). Four of these events were too small to be felt by a sufficient number of people for questionnaires to be sent out (given max intensity II). Therefore, intensity contour maps were plotted only for the events at 01:22 (UTC) and at 08:09 (UTC) both on November 13th, 1995 (see Figure 5). This interesting ocurrence of two earthquakes on the same day is probably only coincidential because of the differences in the geographical location of the epicenters and their tectonic trends.

Table 3. Earthquakes felt in Norway during the time period July-December, 1995.

Date	Time (UTC)	Max Intensity on (MMI) scale	Magnitude (BER)	Epicentral Location, Area
03.07.95	12:49	II	3.1 (M_C) 3.3 (M_L)	69.79N / 25.11E Finnmark, northern Norway
14.10.95	04:32	II	2.5 (M_C) 2.6 (M_L)	60.23N / 5.24E Sotra, western Norway
23.10.95	01:08	II	3.5 (M_C) 3.1 (M_L)	69.44N / 24.10E Finnmark, northern Norway
13.11.95	01:22	IV	3.3 (M_C) 3.2 (M_L)	59.96N / 11.17E Oslo area, easthern Norway
13.11.95	08:09	IV	3.3 (M_C) 3.5 (M_L)	61.52N / 4.03E Offshore Florø, westhern Norway
20.11.95	04:01	II	2.3 (M_C) 2.2 (M_L)	60.06N / 5.40E Fitjar, Stord, western Norway



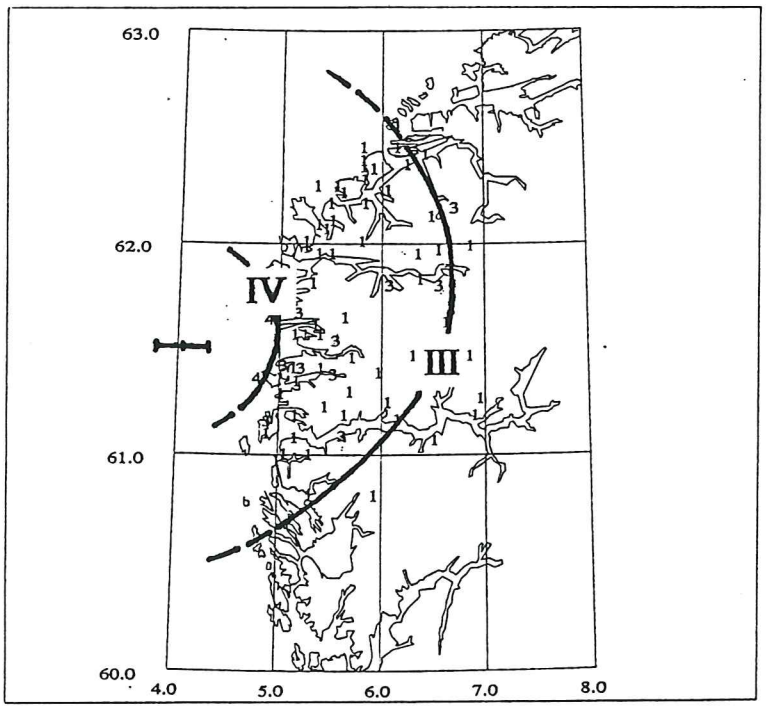


Figure 5. Macroseismic data for **a)** the earthquake felt in the Oslo area, eastern Norway on November 13th, 1995 at 01:22 (UTC) and, **b)** the earthquake offshore Florø, western Norway on November 13th, 1995 at 08:09 (UTC). The intensity map displays Modified Mercalli Intensity (MMI) contours. Each observation point is indicated with a number which gives the intensity. The number 1 indicates that a macroseismic questionnaire was sent in but that the earthquake was not reported felt at that location.

6. The largest events during the time period July-December, 1995

The largest regional event recorded during the last half of 1995 was the event on October 4th, 1995 at 20:49 (UTC), with a magnitude of M_C=3.9 (BER), M_L=3.4 (BER) and M_L =3.4 (NAO) (Table 2). This event was located in Kattegatt, and it was felt in parts of south western Sweden.

All local events recorded by the Norwegian seismic stations and in the vicinity of mainland Norway, with M≥3.5, were analysed in detail. For each event, all phase readings and magnitudes were checked and reevaluated, first motions were read in order to determine a fault plane solution, and the focal depths were studied using both synthetic modeling and by analysing the root mean square of the travel-time residuals (rms) versus focal depth. For the synthetic modeling the WKBJ method was used (Chapman et al., 1988).

The event evaluated is the following:
i) November 13th, 1995 at 08:09 (UTC),
magnitudes M_C=3.2 (BER), M_L=3.5 (BER) and M_L =3.2 (NAO), located at 61.513°N and 4.106°E, with a focal depth fixed at 12 km.

The recorded seismograms are shown in Figure 6. Some additional data has been collected from BGS and from NORSAR.

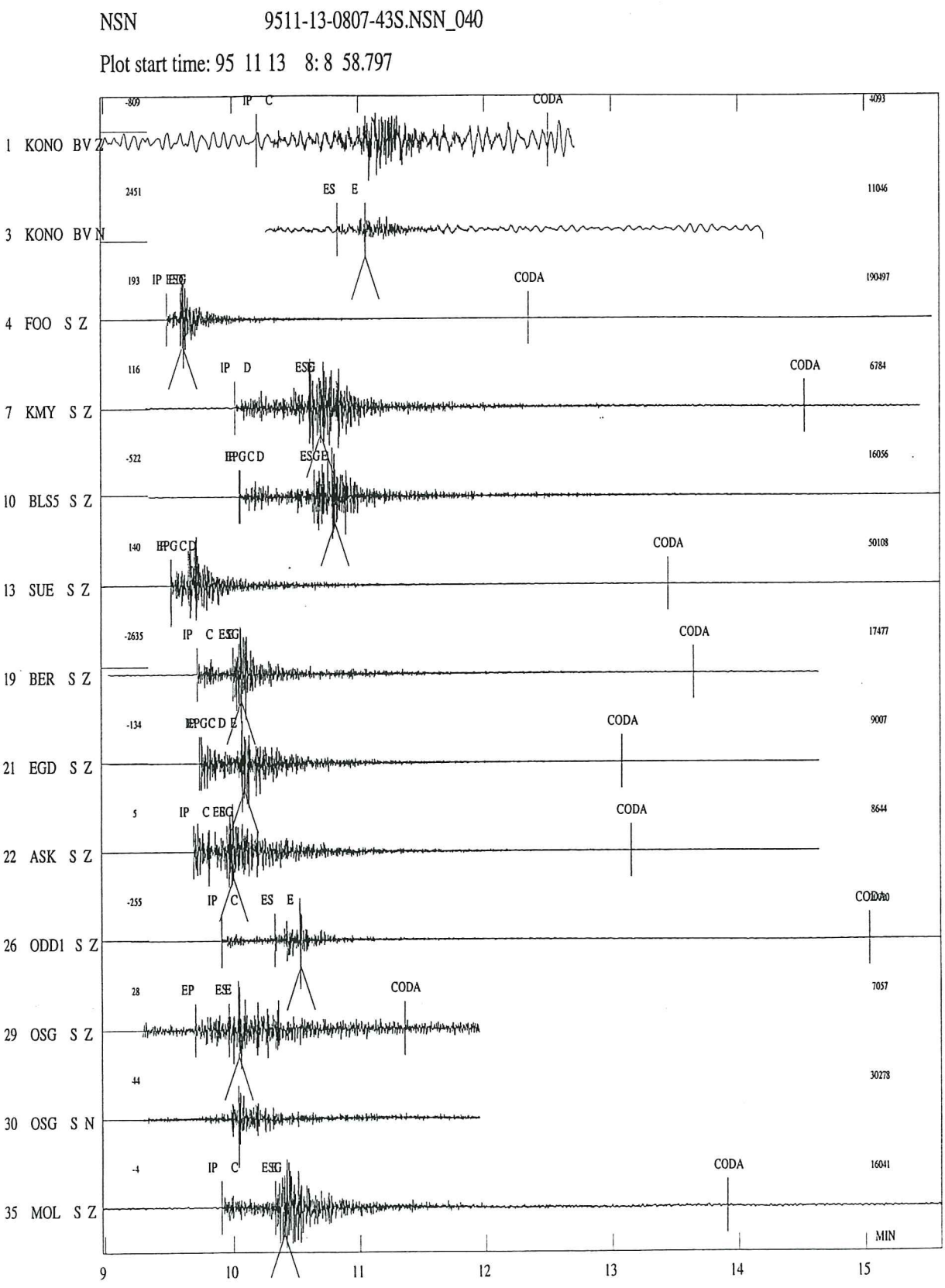
Hypocentral depth: By locating the event with only stations up to 200 km's distance, the depth was estimated to be 13 km. This is in contrast to the depth of 0 km given when all the stations were used. This depth was also checked by synthetic modelling. Tests were made with 5, 10 and 15 km's depth and the modeling showed the depth to be between 10 and 15 km (Figure 7 I, II and III). It can therefore be concluded that the depth of 13km is well constrained.

Fault plane solution: A total of 12 polarities were used. For two stations (EGD and SUE), two polarities were read, one for the first arrival and one for the Pg phase. This can normally not be done, but in this case the phase polarities were very clear. These additional polarities made it possible to obtain a well constrained solution (Figure 8). However, the solution is critically dependent on one or two polarities. The solution is a thrust fault with the compressional axis SW.

Spectral analysis: Amplitude spectra of the S-waves were made for the 3 nearest stations, Sulen, Bergen and Florø. The spectra showed clear corner frequencies (example in Figure 9) and the following average parameters were obtained:

Seismic moment : 3.2 10**13 Nm
Stress drop : 1.9 bars
Source radius : 0.43 km
Moment magnitude: 3.0

Figure 6. Seismograms for the largest local event recorded by the Norwegian natiomal seismic network during the last half of 1995. This event was located offshore Florø with a magnitude of M_C=3.2 (BER), M_L=3.5 (BER) and M_L=3.2 (NAO) (Table 1). The station abbreviations are FOO=Florø, HYA=Høyanger, BER=Bergen, EGD=Espegrend, ASK=Askøy, MOL=Molde, OSG=Oseberg, ODD1=Odda, BLS5=Blåsjø, KMY=Karmøy and NSS=Namsos.



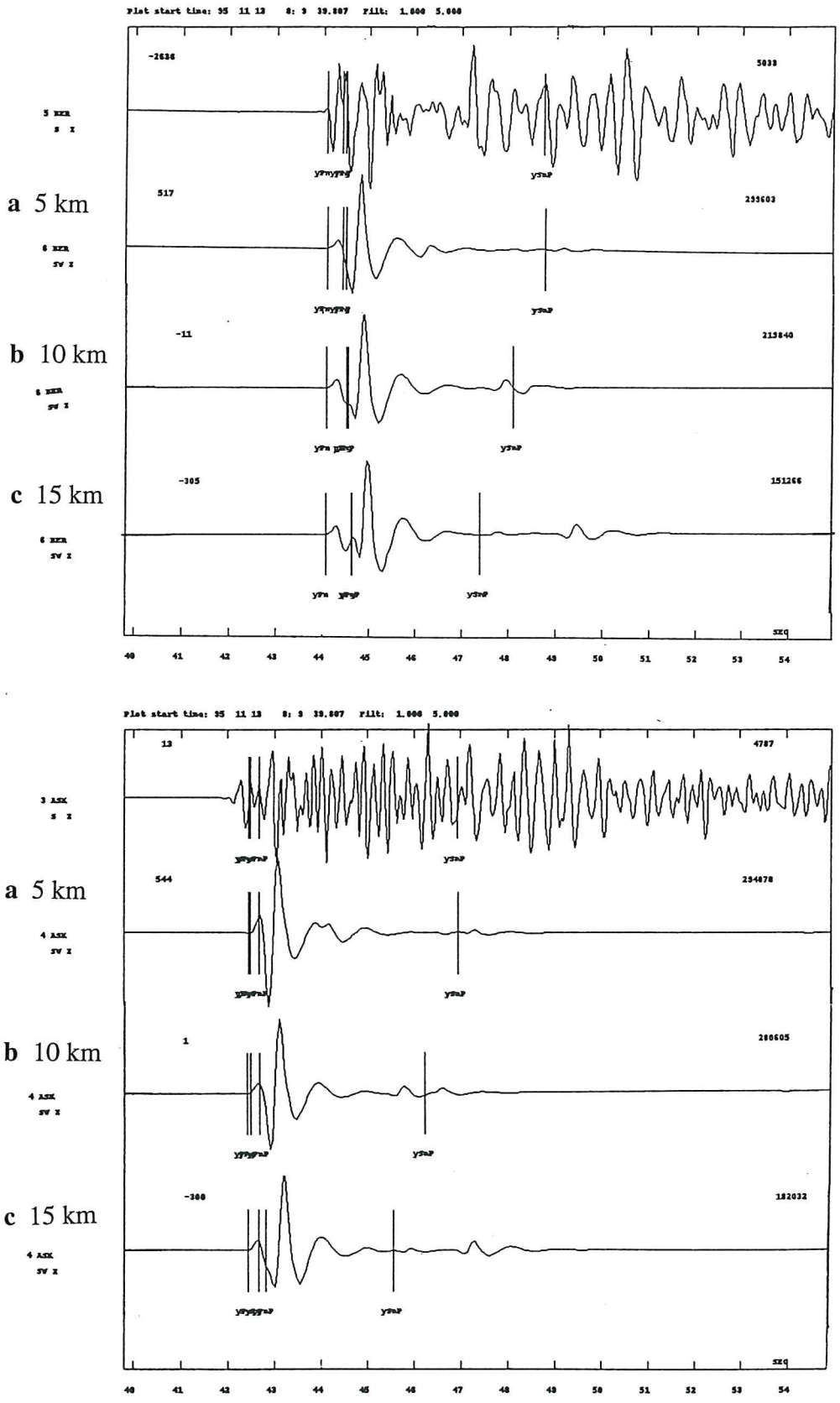


Figure 7 I. Recorded (SZ) and synthetic (SWZ) seismograms for the event on November 13, 1995 at 08:07 (UTC). This figure shows the first part of the trace, for three different depths: (a) 5, (b) 10 and (c) 15 km. The station abbreviations are: BER= Bergen, ASK= Askøy.

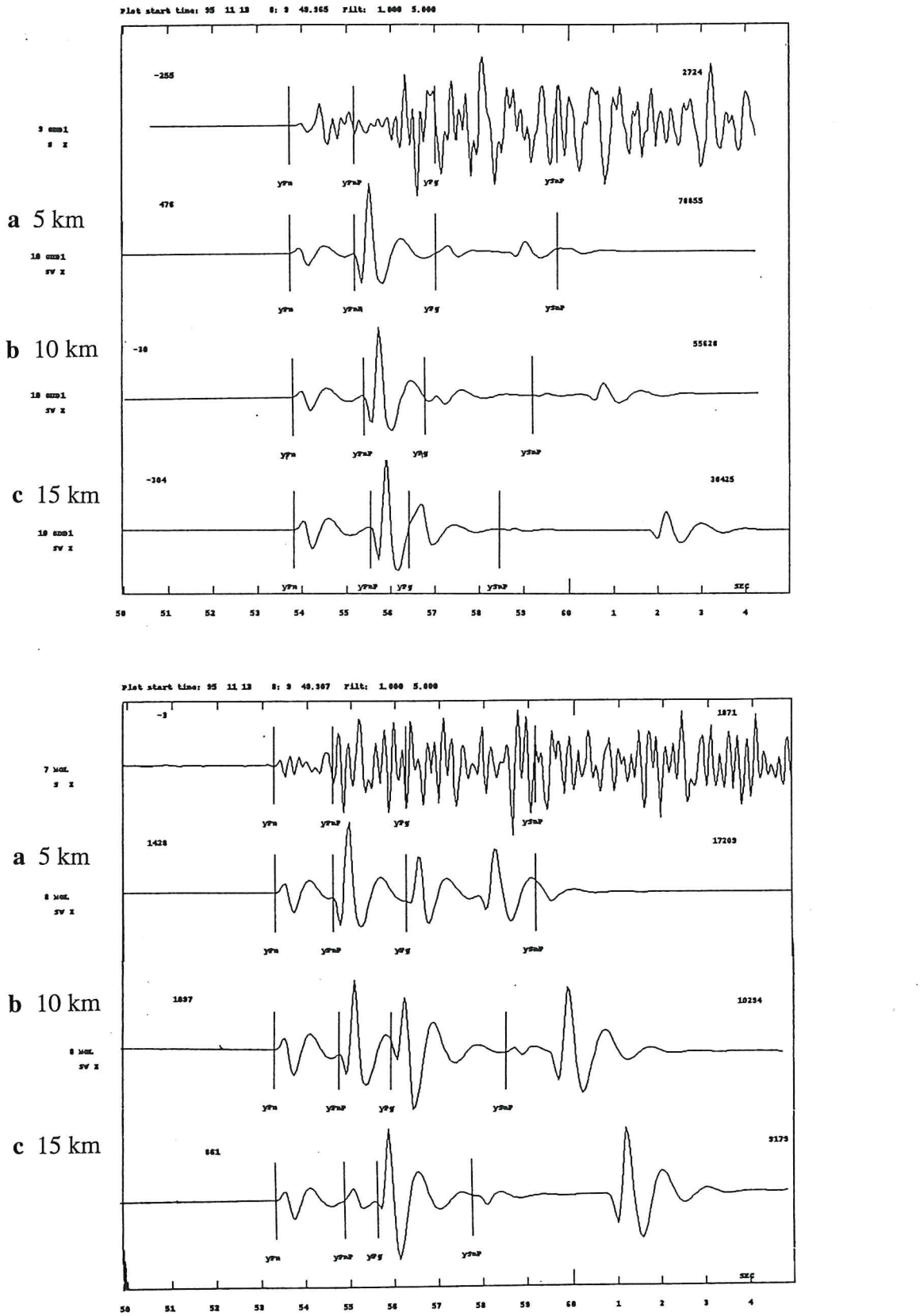


Figure 7 II. Recorded (SZ) and synthetic (SWZ) seismograms for the event on November 13, 1995 at 08:07 (UTC). This figure shows the first part of the trace, for three different depths: (a) 5, (b) 10 and (c) 15 km. The station abbreviations are: ODD1= Odda, MOL= Molde.

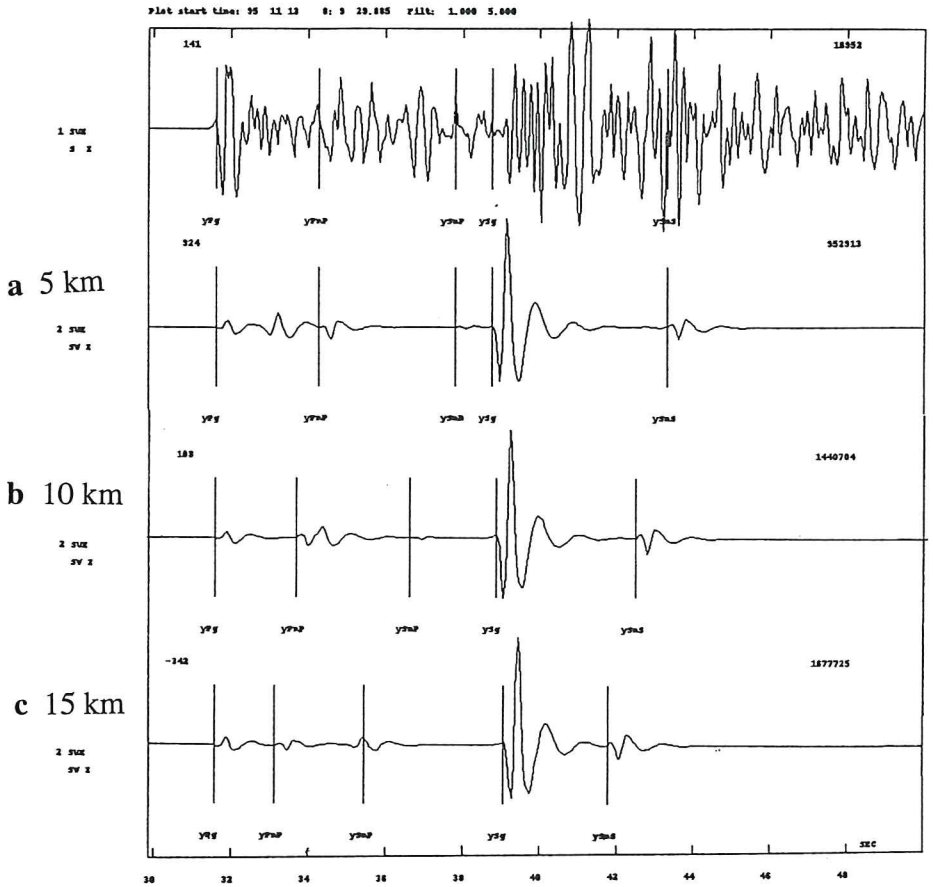


Figure 7 III. Recorded (SZ) and synthetic (SWZ) seismograms for the event on November 13, 1995 at 08:07 II(UTC). This figure shows the first part of the trace, for three different depths: (a) 5, (b) 10 and (c) 15 km. The station abbreviations are: SUE= Sulen.

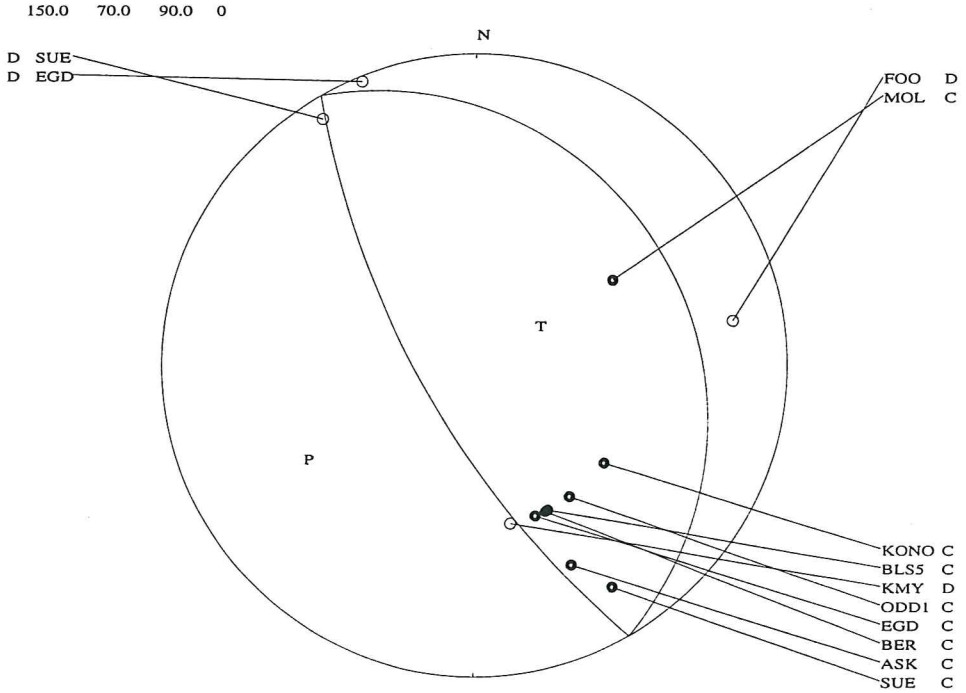


Figure 8. Fault plane solution for the event on November 13th, 1995 at 08:07 (UTC), given by Bergen, with a strike, dip and rake of 150°, 70° and 90°, respectively.

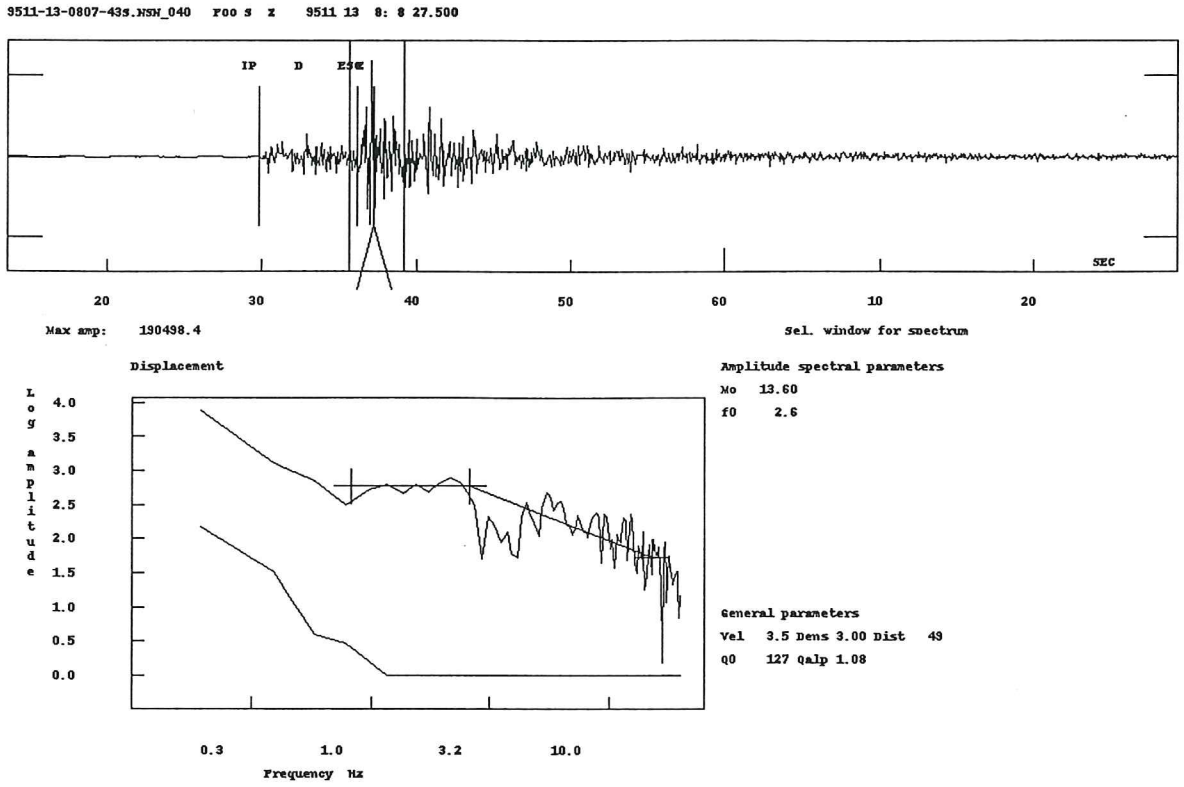


Figure 9. Amplitude spectra of the S-wave recorded at Florø for the event on November 13th, 1995 at 08:07 (UTC). The abbreviations are: FOO= Florø, M0= seismic moment, f0= corner frequency,vel= velocity, Dens= density, dist= distance, Q= Q correction= Q0*f**Qalp and f= frequency.

7. Earthquake swarm offshore Florø

During the last six months of 1995 an increase in the earthquake activity was noticed offshore Florø. When studying the location of earthquakes outside the coast, a consentration of events was found in the area shown in Figure 10. In this Figure also the largest event recorded during this time period, November 13th 1995 at 08:09 (marked **a**), is shown. From the Figure it is clear that a majority of the events are located inside an area limited by latitudes 61.7° - 61.9° N and longitudes 3.8° - 4.4° E. From July through December 1995, 16 earthquakes were located inside this limited area (Figure 11), 4 with magnitude ≥ 3.0. The time distribution of these events show an increased activity in September especially the 8th and 9th (Figure 12). When studying the time versus magnitude distribution of the earthquakes recorded the September 8-9th (Table 4 and Figure 15), it became clear that this cluster of earthquakes did not follow a main shock-aftershock sequence but rather a behavior typical for an earthquake swarm.The occurence of an earthquake swarm deserve special attention. In this respect we have investigated and searched for similar sequences since the first installation of the Western Norway Network in 1984.

All events located offshore Florø, recorded from January 1984 through December 1995 were selected and their time distribution was studied. The events are plotted in Figure 13, and from this figure it is not possible to observe any earthquake clusters. Figure 14 shows the monthly distribution of the 68 earthquakes recorded from January 1984 to December 1995 and located

inside the limited area were the earthquake swarm was found in July - December 1995. It becomes clear that a cluster, as the one in September 1995, has not occured during the last 12 years. It is belived that the earthquake swarm in September 1995 is a unique earthquake sequence since the installation of the seismic station network on the Norwegian west coast in 1984. One should, however, bear in mind that the area studied is small and that the location errors might be larger for the older data. Earthquake swarms lasting several months have previously been observed in in Northern Norway at Meløy in 1978-79 (Bungum et al., 1979) and at Steigen in 1993 (Atakan et al., 1994).

The earthquake sequence offshore Florø falls within a tectonically complex area, where rotation of the maximum horisontal compressional stress axis from a NW-SE orientation to an E-W direction was reported (Lindholm et al., 1995). However, any possible link between the earthquake swarm and the underlying complex structure needs to be studied in more detail, before any conclusion can be drawn. Furthermore, possible implications for future earthquake occurences in the region and the related potential seismic hazard calls for special attention.

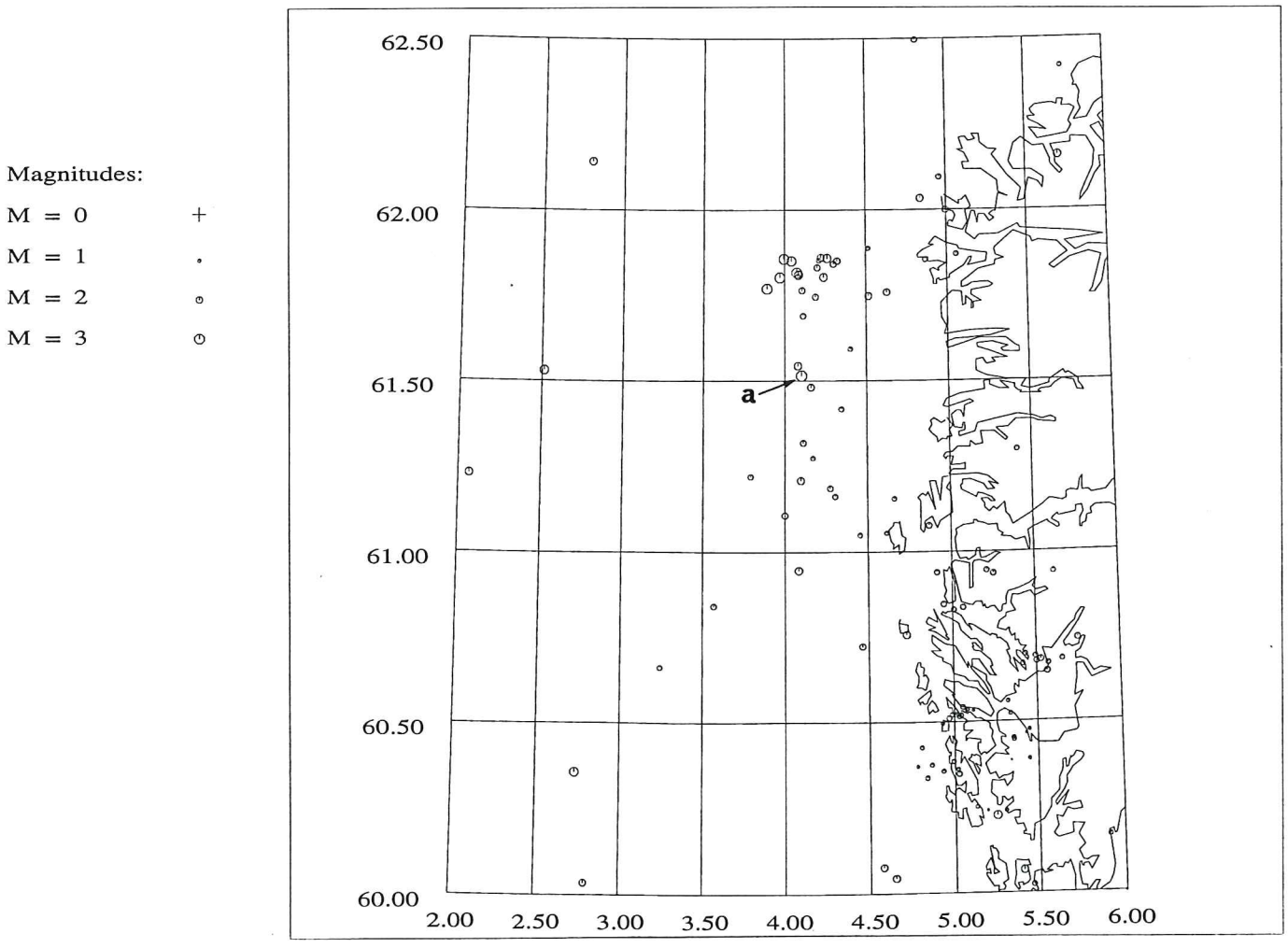


Figure 10. All earthquakes located inside a selected area offshore Florø. The largest earthquake recorded during the last six months of 1995 is marked with an **a**.

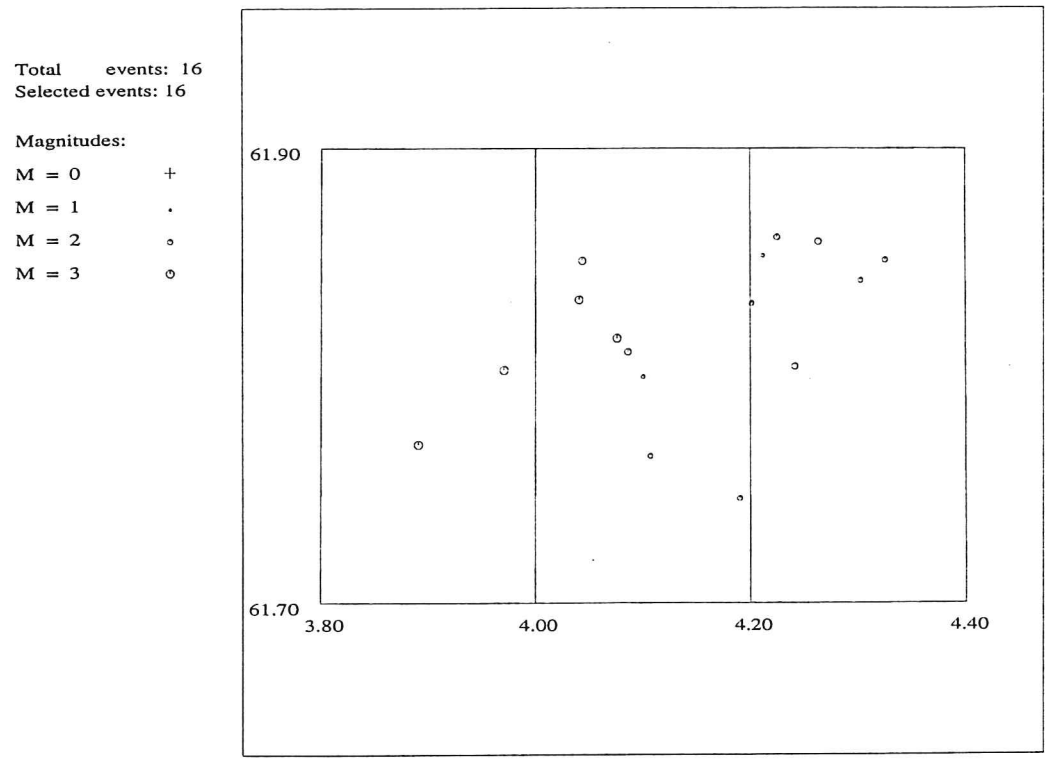


Figure 11. All earthquakes recorded during July-December 1995 located inside a small limited area offshore Florø.

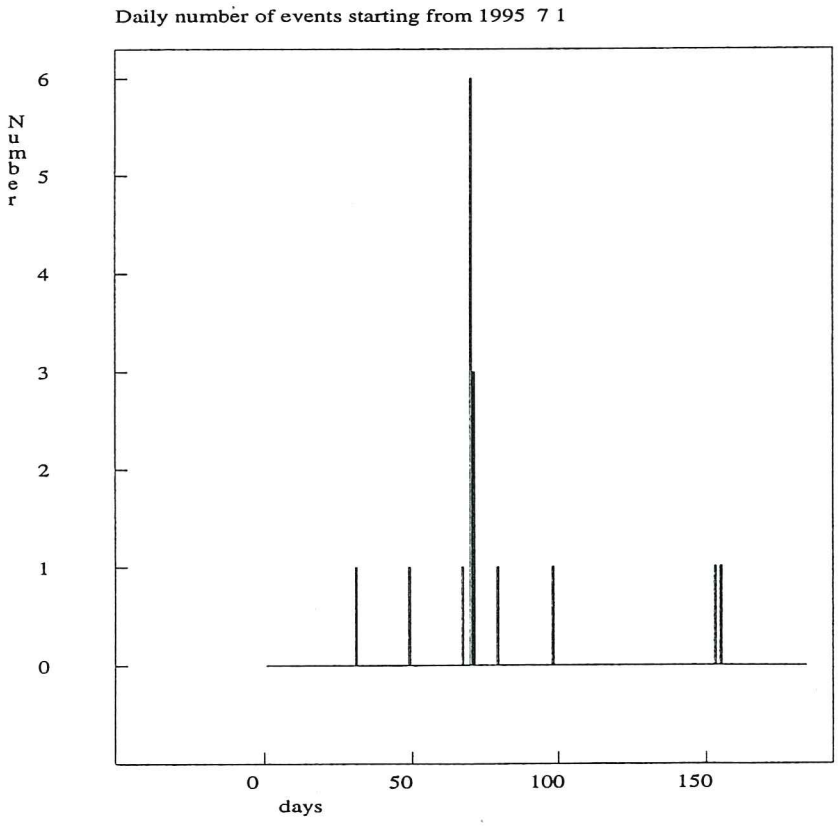


Figure 12. Distribution in time of the 16 earthquakes shown in Figure 11.

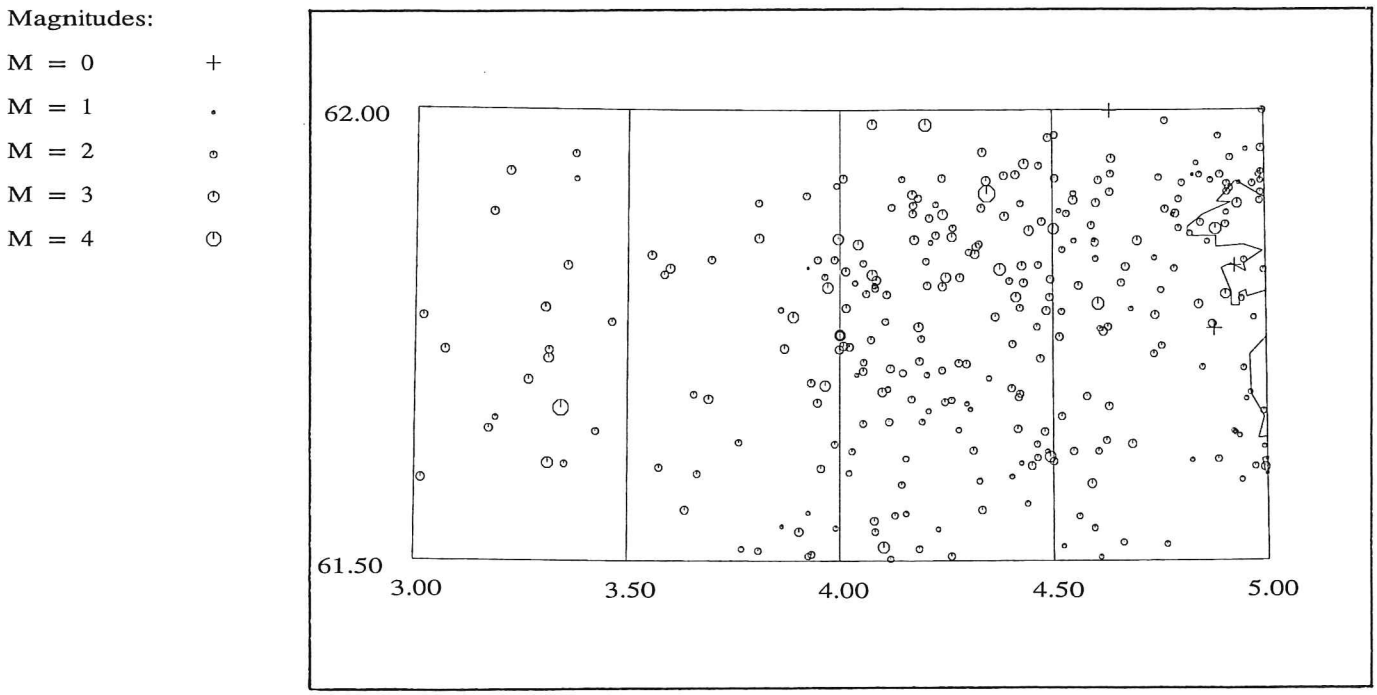


Figure 13. Alle events recorded during January 1984 to December 1995 and located in this selected area offshore Florø.

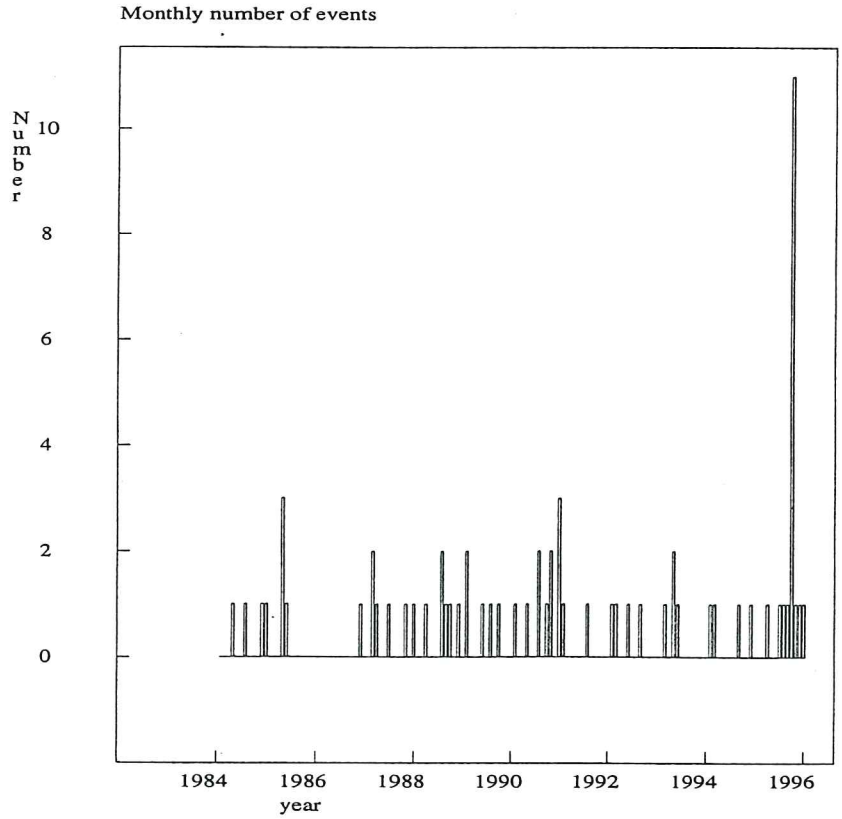


Figure 14. Time distribution of all events recorded during 1984-1995 and located inside the small area shown in Figure 11 (61.7-61.9° N and 3.8-4.4° E).

Table 4. The 16 earthquakes shown in Figures 11 and 12. The abbreviations are:
Columns 1-2: Year, month, day
Columns 3-4: Origin time given in UTC as hour, minutes, seconds
Column 5: Distance identification (L=local, JL= Jan Mayen area, R=regional)
Columns 6-7: Latitude, longitude
Column 8: Focal depth (km)
Column 9: Recording agency
Column 10: Number of stations used for location
Column 11: Root mean square of the travel-time residuals (rms)
Column 12: Coda wave magnitude, Bergen (BER)
Column 13: Local (L) magnitude, Bergen (BER)
Column 14: Local (L) magnitudes provided by NORSAR (NAO)

1995	731	0630	16.9	L	61.765	4.107	0.1	BER	5	0.5	1.9CBER	1.4LBER		1
1995	818	1326	34.3	L*	61.803	3.971	15.0	BER	21	1.0	3.1CBER	3.2LBER	3.2LBGS1	
1995	9 5	2013	14.8	L*	61.804	4.241	10.0F	BER	11	0.8	2.4CBER	2.2LBER	1.8LNAO1	
1995	9 8	0949	19.7	L*	61.851	4.043	11.0F	BER	15	1.1	2.8CBER	2.8LBER	2.6LNAO1	
1995	9 8	1205	26.1	L	61.832	4.201	3.5	BER	5	0.4	1.9CBER	1.7LBER		1
1995	9 8	1725	39.6	L	61.853	4.212	0.0	BER	3	0.6	1.4CBER			1
1995	9 8	1957	23.0	L*	61.857	3.996	15.0	BER	22	1.3	3.0CBER	3.0LBER	2.9LNAO1	
1995	9 8	2051	45.1	L	61.811	4.086	6.9	BER	13	1.0	2.5CBER	2.6LBER	2.2LNAO1	
1995	9 8	2114	27.2	L	61.842	4.302	15.0	BER	6	0.7	1.9CBER	1.9LBER		1
1995	9 9	1214	47.9	L	61.861	4.225	0.1	BER	7	0.5	2.2CBER	2.2LBER		1
1995	9 9	1350	36.6	L	61.817	4.076	0.0	BER	23	1.1	3.0CBER	3.2LBER	3.2LNAO1	
1995	9 9	1530	12.6	L	61.851	4.325	8.0	BER	6	0.6	2.0CBER	1.8LBER		1
1995	917	1649	51.2	L	61.770	3.890	15.0	BER	25	1.3	3.1CBER	3.1LBER	2.7LNAO1	
1995	10 6	0517	37.0	L	61.746	4.190	0.0	BER	3	0.8	1.9CBER	1.6LBER		1
1995	1130	0758	58.7	L	61.805	4.082	12.2	BER	3	0.2	1.6CBER			1
1995	12 2	1621	46.6	L*	61.859	4.263	15.0	BER	9	0.7	2.5CBER	2.3LBER		1

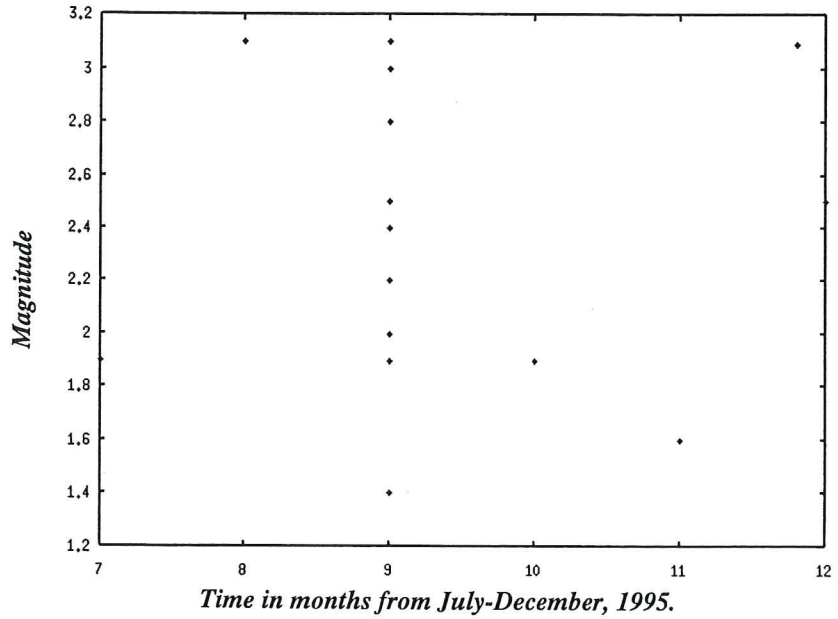


Figure 15. Magnitude distribution of the events listed in Table 4.

References

Alsaker A., Kvamme L. B. , Hansen R. A., Dahle A. and Bungum H. 1991. The ML scale in Norway, *Bull. Seism. Soc. Am.*, Vol. **81**, No. 2, pp.379-398.

Atakan K., Lindholm C D., and Havskov J., 1994. Earthquake swarm in Steigen northern Norway: an unusual example of intraplate seiamicity. *Terra Nova,* Vol. **6**, pp 180-194.

Bungum H. And Husebye E. S., 1979. The Meløy, northern Norway earthquake sequence - a unique intraplate phenomenon. *Norsk Geplogisk Tidskrift,* Vol. **59**, pp 189-193.

Chapman, C.H., Chu Jen-Yi, and Lyness, D.G., 1988. The WKBJ seismogram algorithm, in: D.J. Doornbos (ed), *Seismological algorithms*, Academic Press, London, pp. 47-74.

Havskov J. 1995. The SEISAN earthquake analysis software for the IBM PC and SUN, version 5.0. Manual, Institute of Solid Earth Physics, University of Bergen, Norway.

Havskov J., and Bungum H., 1987. Source parameters for earthquakes in the northern North Sea, *Norsk Geologisk Tidskrift,*Vol.**67**, pp 51-58.

Karnik, V., Kondorskaya, N.V., Yu. V. Riznichenko, Ye. F. Savarensky, S.L. Solovev., N.V. Shebalin, J. Vanek, and A. Zatopek 1962. Standardisation of the earhquake magnitude scales. *Studia Geophys. et Geod.*, Vol. **6**, pp. 41-48.

Kennett, B.L.N. and Engdahl E. R., 1991. Traveltimes for global earthquake location and phase identification, *Geophys. J. Int.*, Vol. **105**, pp. 429-465.

Lienert, B.R. and Havskov, J., 1995. HYPOCENTER 3.2 A computer program for locating earthquakes locally, regionally and globally. *Seismological Research Letters*, Vol. **66**, pp26-36.

Lindholm, C.D., Bungum H., Bratli R. K., Aadnøy B. S., Dahl N., Tørudbakken B. and Atakan K., 1995. Crustal stress in the northern North Sea as inferred from borehole breakouts and earthquake focal mechanisms, *Terra Nova*, Vol. **7**, pp. 51-59.

Ottemöller, L., (1995). *Explosion filtering for Scandinavia.* Technical Report No. 2, Institute of Solid Earth Physics, University of Bergen, Norway.

Sørnes A. and Navrestad T., 1975. Seismic survey of Jan Mayen. Norsk Polarinstitutt, Årbok 37-52.

Veith K.F., and Clawson G. E., 1972. Magnitude from short-period P-wave data. *Bull. Seism. Soc. Am.*, Vol. **62**, pp.435-452.

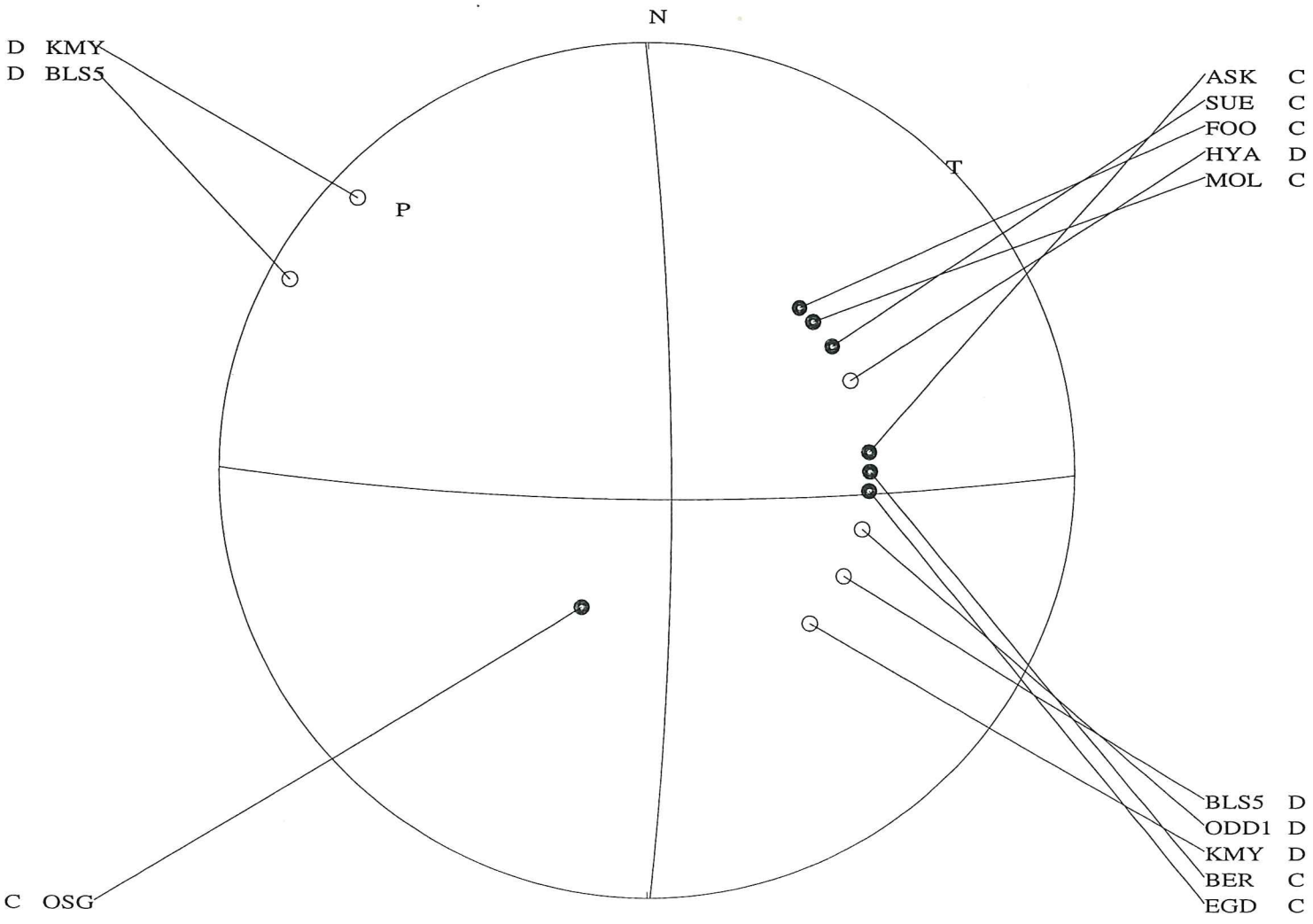
Westre S. 1975. Richter's lokale magnitude og total signal varighet for lokale jordskjelv på Jan Mayen. Cand. real thesis., Seismological Observatory, University of Bergen, Norway.

APPENDIX A

```
1995  822 0141   6.5 L* 60.355    2.734 23.0F BER 13 0.8 2.7CBER 2.5LBER 2.2LNAO1
1995 1113 0122   3.4 L* 59.977   11.172 14.0F BER 19 1.0 3.3CBER 3.2LBER 3.2LNAO1
1995 1113 0809  21.8 L* 61.570    4.047 15.0F BER 20 1.2 3.2CBER 3.5LBER 3.2LNAO1
1995 1120 0401  59.5 L* 60.064    5.400  5.0FFBER 12 2.0 2.3CBER 2.2LBER 2.1LNAO1
1995 12 8 0741  17.2 L* 72.696    4.216 10.0F BER 20 2.1 3.8CBER 3.9LBER 3.8LNAO1
1995 1223 0555  18.3 L* 60.944    4.074 11.0F BER 10 1.8 2.3CBER 2.2LBER         1
```

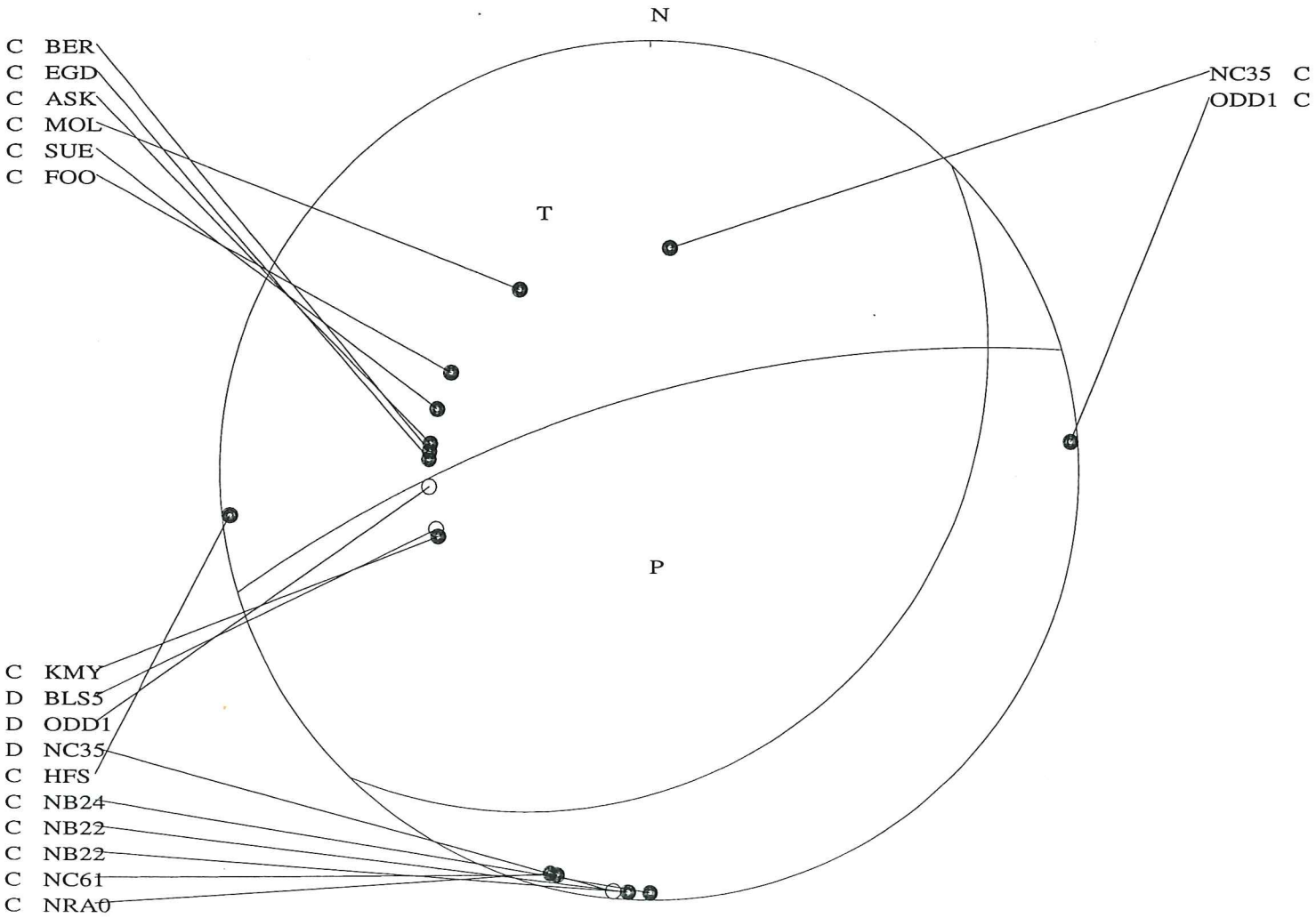
1995 822 0141 6.5 L* 60.355 2.734 23.0F BER 13 0.8 2.7CBER 2.5LBER 2.2LNAO

359.6 83.6 -7.7 1



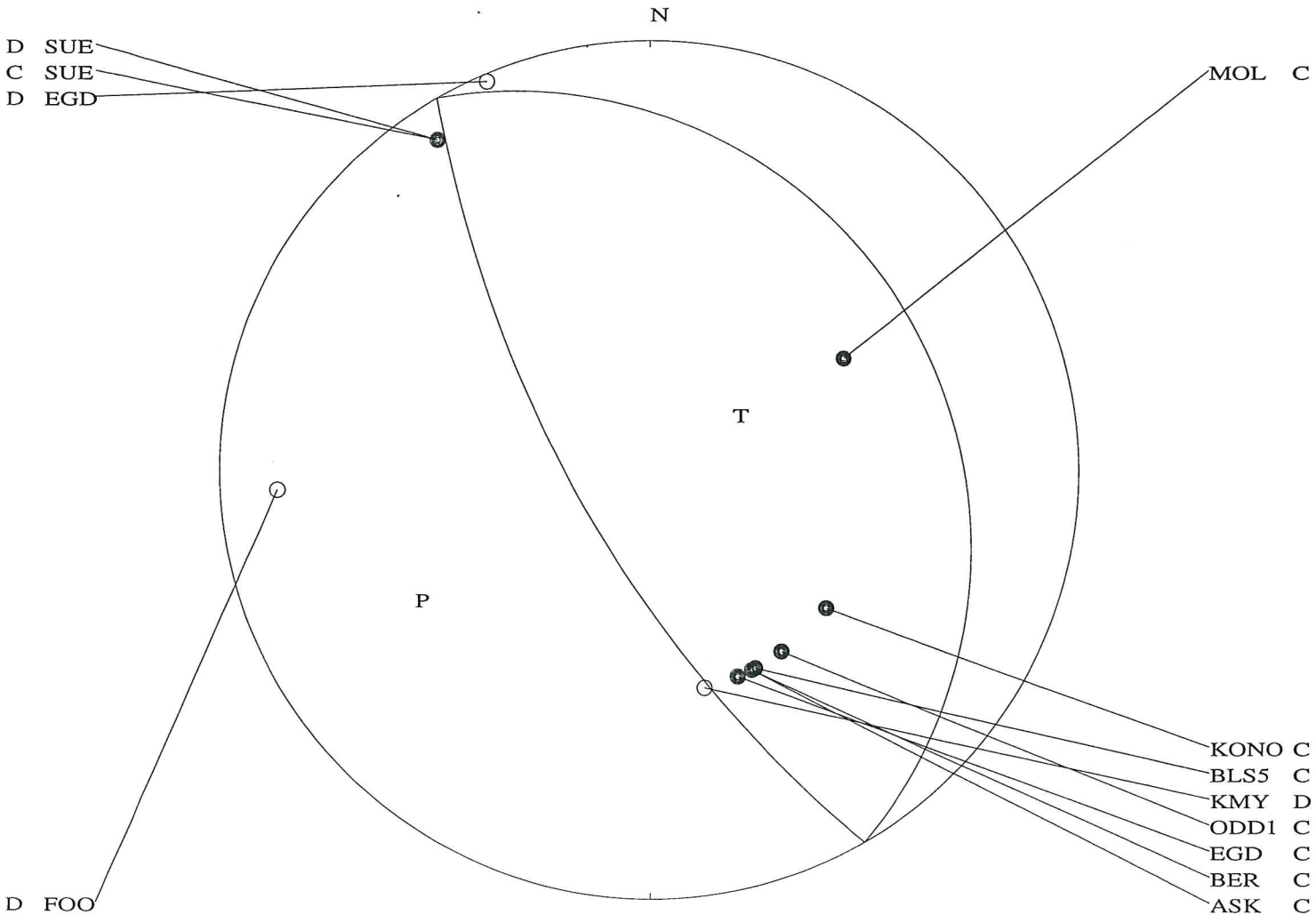
1995 1113 0122 3.4 L* 59.977 11.172 14.0F BER 19 1.0 3.3CBER 3.2LBER 3.2LNAO

253.6 70.3 -79.4 2



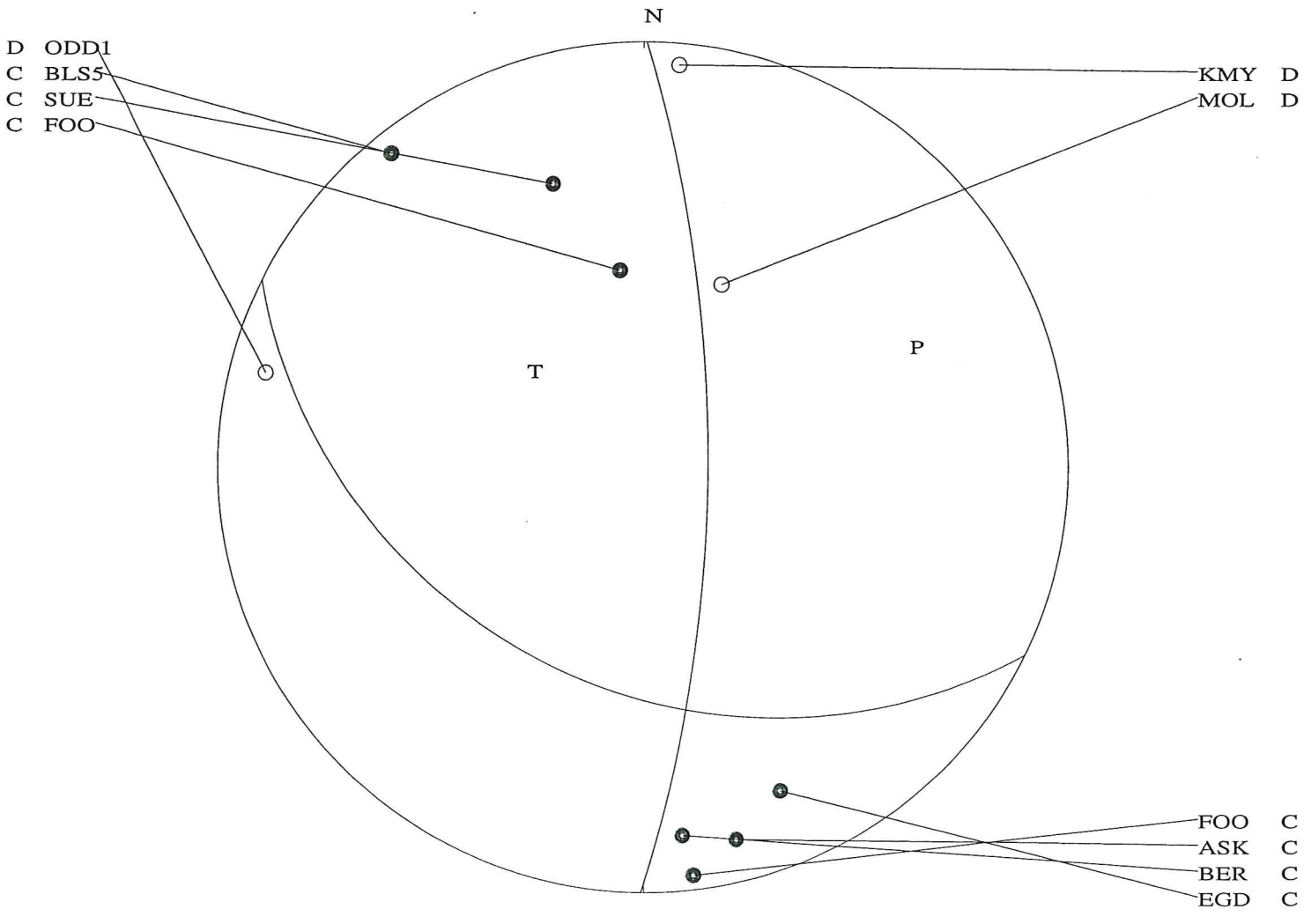
1995 1113 0809 21.8 L* 61.570 4.047 15.0F BER 20 1.2 3.2CBER 3.5LBER 3.2LNAO

150.0 70.0 90.0 0



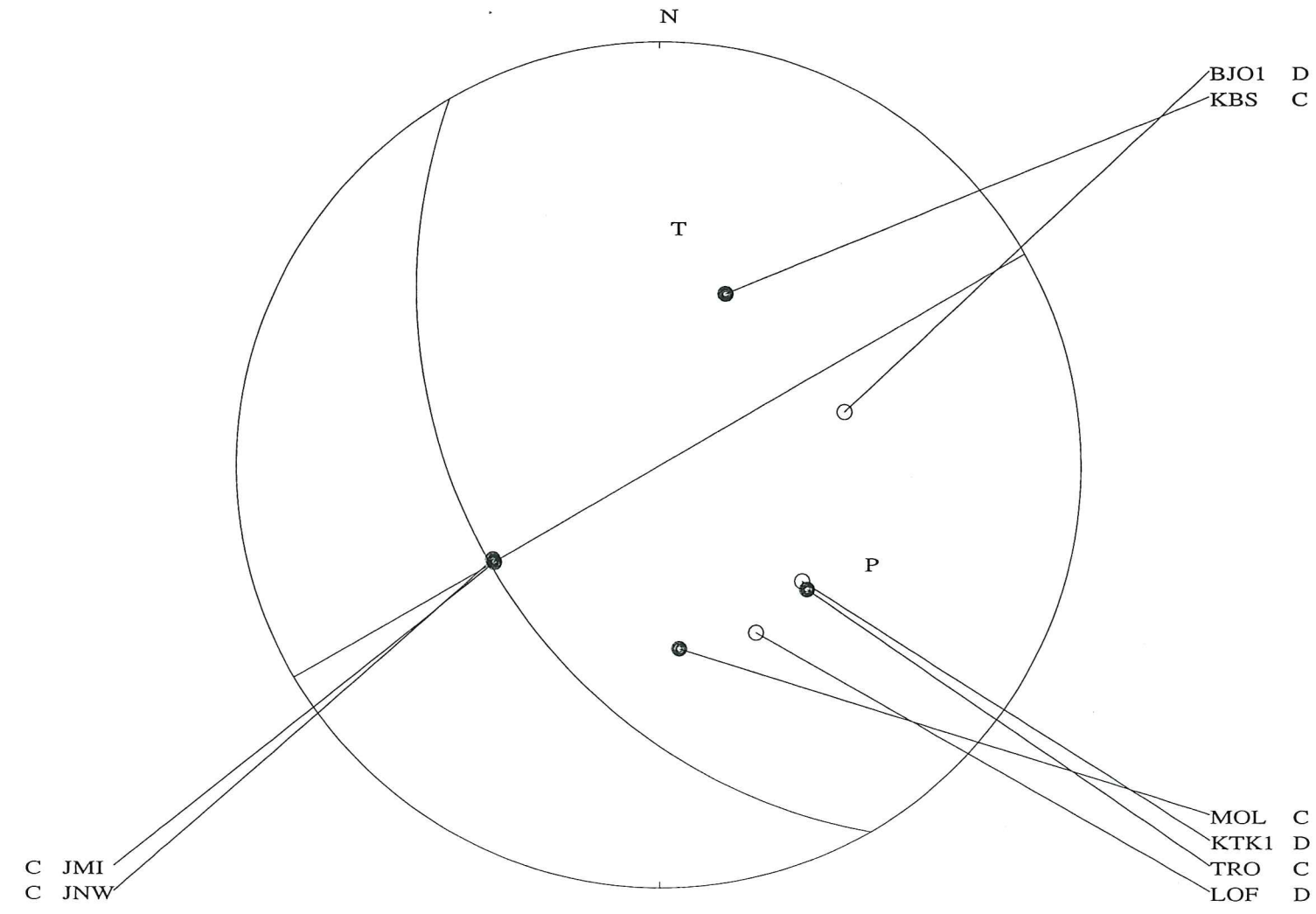
1995 1120 0401 59.5 L* 60.064 5.400 5.0FFBER 12 2.0 2.3CBER 2.2LBER 2.1LNAO

116.1 35.5 30.6 0



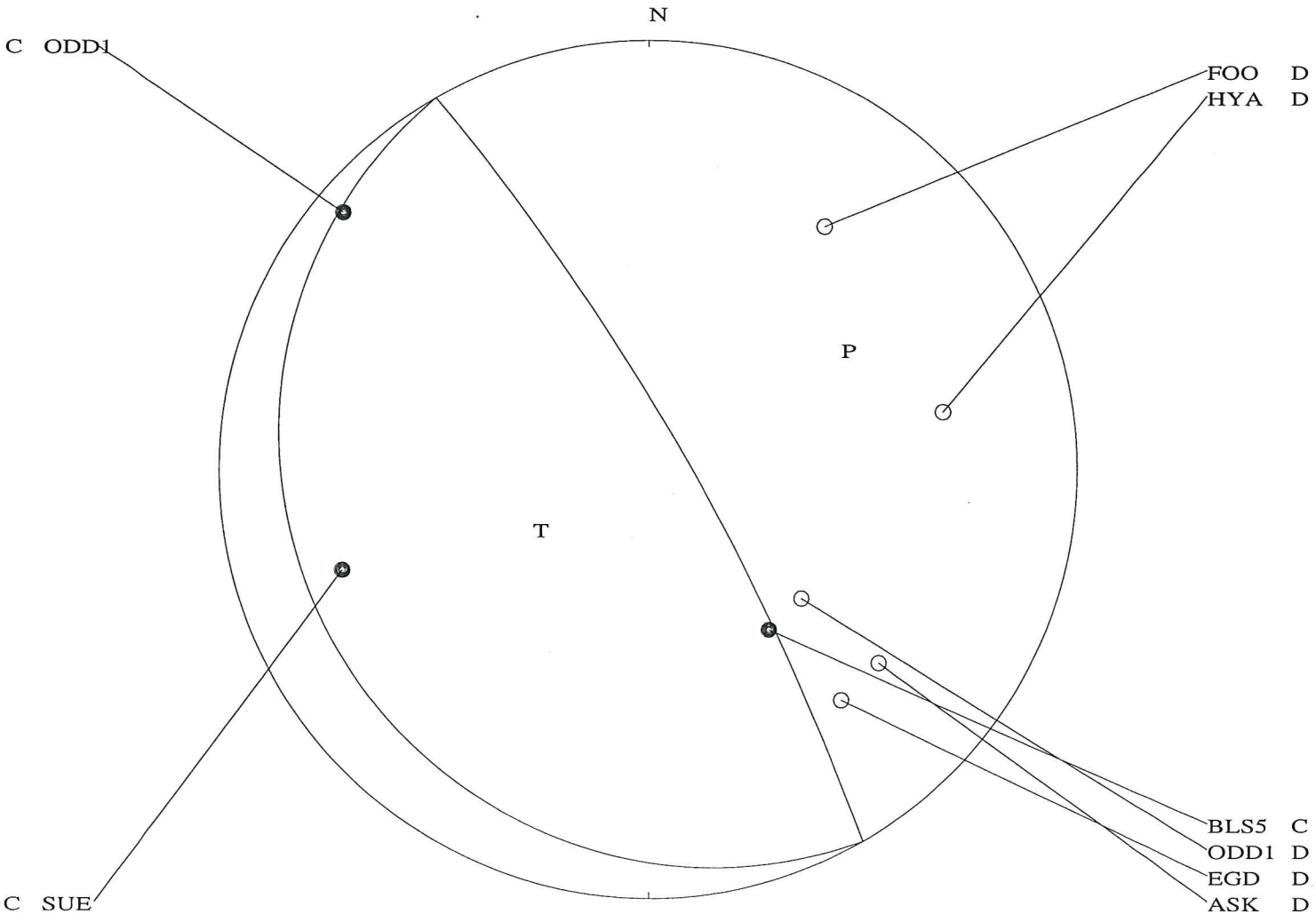
1995 12 8 0741 17.2 L* 72.696 4.216 10.0F BER 20 2.1 3.8CBER 3.9LBER 3.8LNAO

150.0 40.0 0.0 2



1995 1223 0555 18.3 L* 60.944 4.074 11.0F BER 10 1.8 2.3CBER 2.2LBER

150.0 10.0 90.0 0



Appendix 2

Svalbard Array

Introduction

This semiannual report covers the period July-December, 1995, and reviews the array recording performance and the detection and location capability of the array.

Recording Performance

In the previous reporting period, the recording performance was reported to be low in June, 1995. This was caused by hardware failure at Longyearbyen on June 20, when the NORAC array controller broke down. The controller was shipped to the NORSAR maintenance center in Hamar for repair, but due to the heavy seasonal activities at the maintenance center, the controller could not be reinstalled until July 6. When the controller was reinstalled it appeared that there was also a problem with the radio link between Longyearbyen and the site due to low battery voltage at the site. This problem had to be solved by a field visit which could not be arranged until August 3, 1995. Altogether, these operational problems accumulated to more than one month continuous gap in the recording at the Svalbard array as can be seen from Table 1. Also, the December, 1995, uptime is low due to the VSAT (satellite) transmission failure during extreme weather conditions (snow and ice cover on antennas).

July	:	00.00%
August	:	90.27%
September	:	97.07%
October	:	98.20%
November	:	98.27%
December	:	76.92%

Table 1. Monthly uptime in per cent of theoretical for the Svalbard Array on-line data recording in the period July-December, 1995, taking into account all factors (field installations, transmission line, and data center operation)

In August 1995, diodes with a new and better standard (Motorola manufactured) were installed in the windmill generators at the recording site, and this new standard resulted in more stable power supply conditions.

Detections and Locations

The Svalbard array (SVAESS) detects in average 1000 events per day. Of these, about 100 events are located by automatic association of P- and S-wave arrivals. Most of these events are local, low magnitude events, and the source of these events still remains unresolved.

The analyst reviewed events recorded in the area 70-83°N, 10°W-40°E during the reporting period are shown in Fig. 1. Events with magnitude less than 2.0 are all given a symbol size equal to magnitude 2.0 in this map. The largest events located are tied to the Mid-

Atlantic Ridge, however, some earthquakes with magnitude between 3.0 and 4.0 are found also in the Svalbard Archipelago and its immediate vicinity.

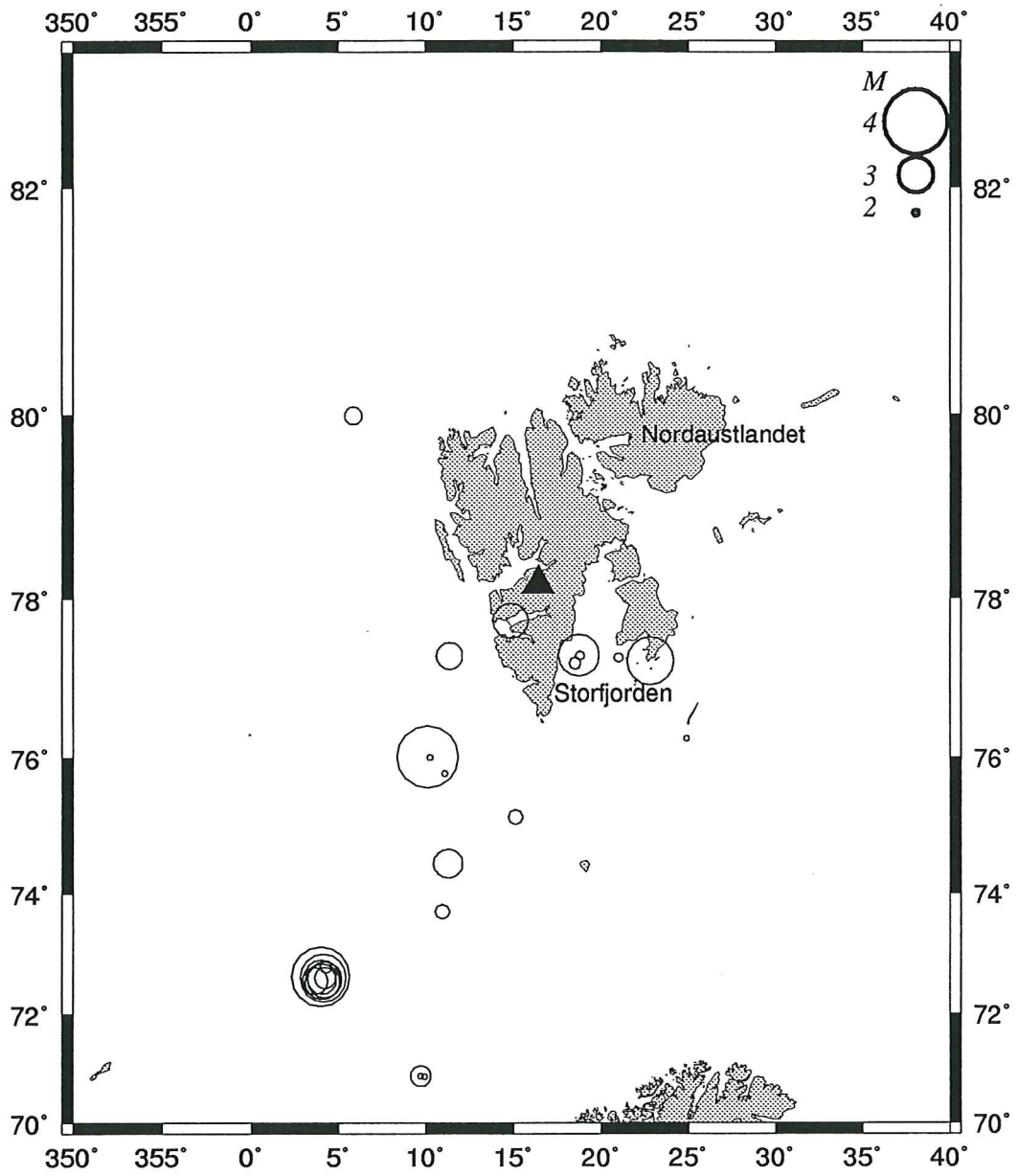


Fig.1. Analyst reviewed events located by readings from the Svalbard array in the period July - December, 1995. Events with magnitude (M) less than 2.0 have been given a symbol size equal to M=2.0.

The majority of the events located in this area are small magnitude events less than magnitude 2.0. Such small magnitude events are plotted in Fig. 2, where the events have been given the same symbol size irrespective of magnitude.

Events with magnitude equal or larger than 2.0 are shown in Fig.3, and by comparing the latter two figures, it is seen that the low magnitude events (Fig. 2) in general coincide in location with the larger more reliable events (Fig.3). This indicates that the small magnitude events are related to seismogenic structures which are capable of producing earthquakes within a wide range of magnitudes.

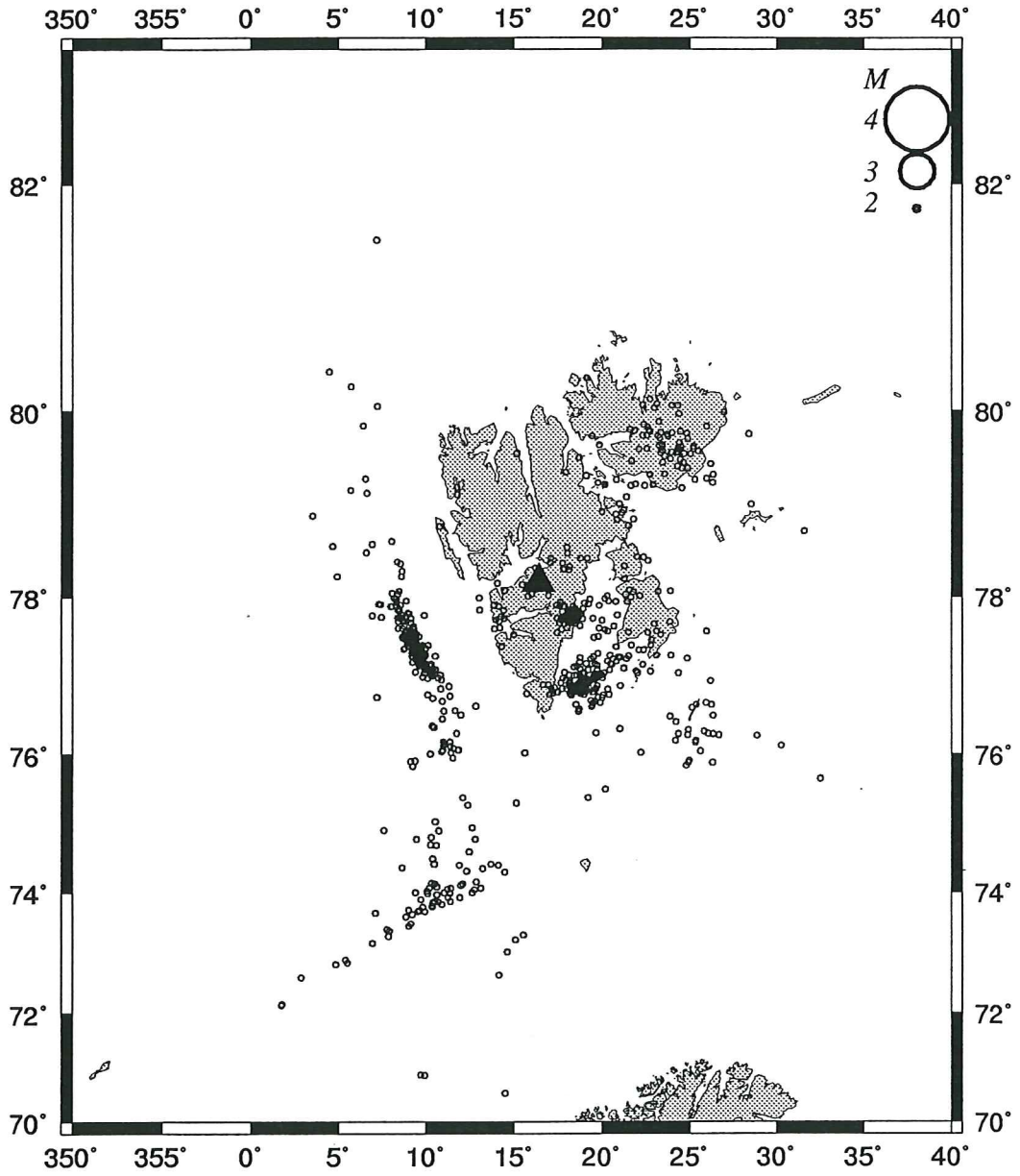


Fig.2. Analyst reviewed events of magnitude less than 2.0 located by readings from the Svalbard array from the start of the operation of NNSN up to end of December, 1995.

Exceptions are found, however, in the southern part of Nordaustlandet and in Storfjorden, where some clusters of small magnitude events are found without any association with larger (above M=2.0) magnitude events.

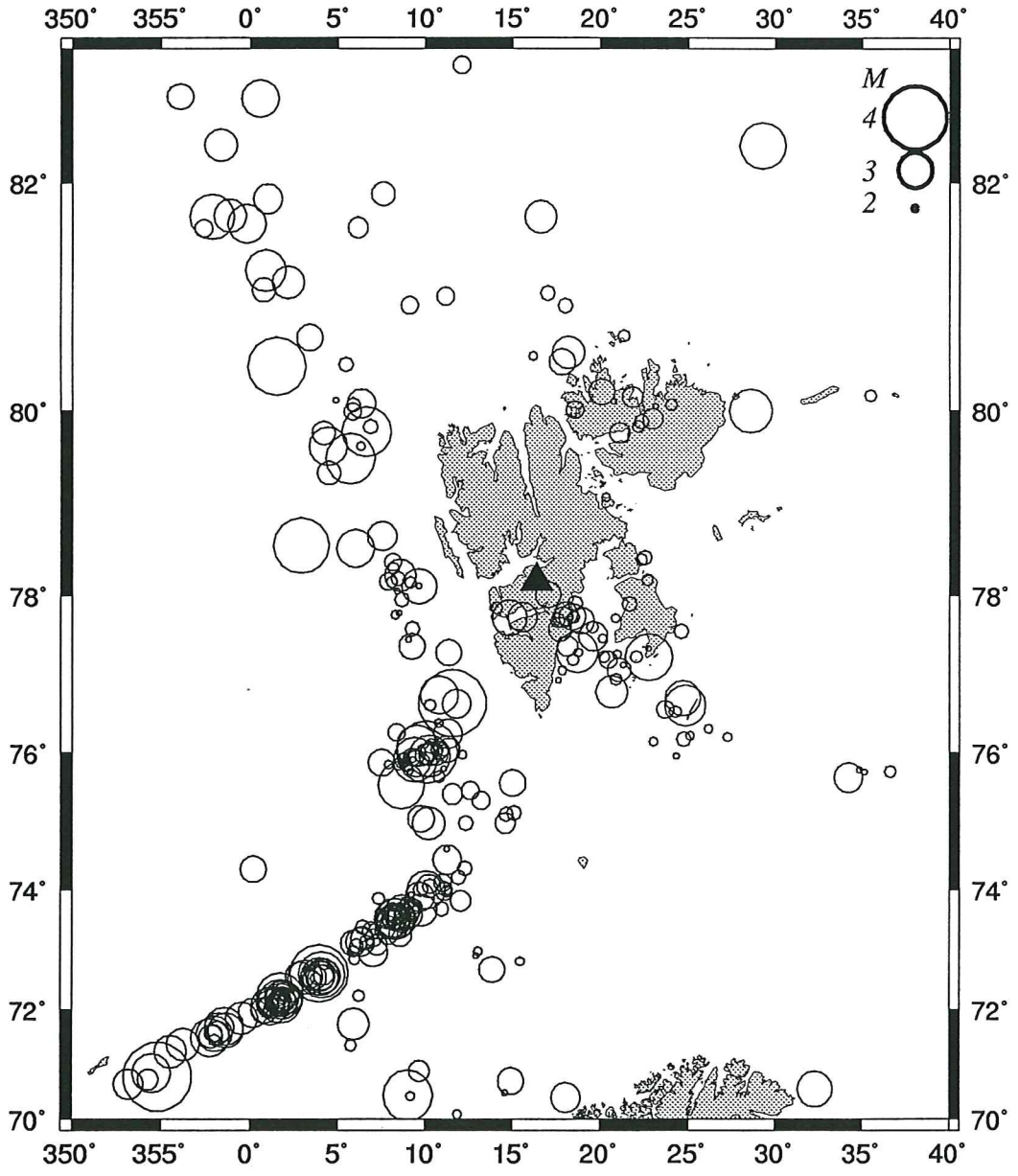


Fig.3. Analyst reviewed events of magnitude equal to or above 2.0 located by readings from the Svalbard array from the start of the operation of NNSN up to end of December, 1995.

Further research

Prof. Hilmar Bungum (NORSAR-UiO) has obtained an allocation of a Cand. Scient student at the Institute for Geology, UiO (Ståle Høgden) for a thesis study on seismotectonics in the Svalbard region.