Seismicity of Norway and surrounding areas

for the period

January 1st to June 30th, 1997

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

e-mail: seismo@ifjf.uib.no
Phone: (+47) 55 58 34 20
Fax: (+47) 55 58 96 69

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1. Introduction

This semi-annual report on the seismicity of Norway and the surrounding areas encompasses the time period January 1st to June 30th, 1997. The seismicity has been compiled from all available seismic stations operating on Norwegian territory including the Arctic islands of Spitsbergen, Bjørnøya and Jan Mayen. In addition, stations from neighbouring countries have been included for large or well recorded events.

In Norway, the University of Bergen (UiB) and the Norwegian Seismic Array (NORSAR) operate seismic stations (Figure 3). These stations are sponsored by different organisations. The UiB operates the Norwegian National Seismic Network (NNSN) which comprises 14 stations and includes the Svalbard array (SVAESS) operated by NORSAR. In addition, there are 10 other seismic stations which are operated by UiB (including two IRIS i.e. Incorporated Research Institutions for Seismology stations), and two seismic arrays (NORESS and ARCESS) in Norway operated by NORSAR. Phase data from arrays in Russia (Apatity), Finland (Finess), Sweden (Hagfors) and from stations operated by the British Geological Survey (BGS) are also included when available. All phase data collected are submitted to UiB, 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.

All local and regional events with magnitude larger than 1.5 and all teleseismic events that are detected by the Bergen network are included. The merging of data between NORSAR and Bergen is done on the following principles:

i) All local and regional events recorded by NORSAR that are also detected by the Bergen network are included,

ii) in addition all local and regional events with local magnitude larger than 2.0 detected by NORSAR and not recorded by the Bergen network are included.

iii) All teleseismic events recorded by NORSAR and also detected by the Bergen network are included

iv) In addition all teleseismic events with NORSAR magnitude $M_b \geq 5.0$ are included.

Macroseismic data for all felt earthquakes in Norway are also collected, and macroseismic maps are presented.

The seismic events in this report include both earthquakes and explosions, and it is likely that more than 70 %, based on statistics for a period of 10 years, of the onshore events are explosions. Events recognized as probably explotions and which are recorded on less than three stations are not prosessed (as of January 1st, 1997). This results in a decrease in the number of single station recordings (see Table 1) compared to earlier reports. Since the beginning of August 1995 the updated version of the explosion filter (Ottemöller, 1995) has been used to identify probable explosions.

2. Velocity models and magnitude relations

The velocity model used for locating all local and regional events, except for the local Jan Mayen events, is shown on the table below (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, 1997).

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):

$$M_L = 1.0 * \log(A) + 0.91 * \log(D) + 0.00087 * D - 1.67$$

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 to layer interface (km)
3.14	0
6.33	3
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 teleseismic 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):

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

here h is the hypocentre depth (km), A is the amplitude (microns), T is period in seconds and Q(D,h) iws the correction for 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 in degrees.

3. Events recorded by the Norwegian stations

A total of 1807 local and regional events, based on the criteria mentioned in section 1, were detected by the Norwegian seismic stations during the first half of 1997. Compared to the previous half year this is a decrease of 10%. Of the local and regional events analyzed during the first six months of 1997, 47% were located. The number of local/regional and teleseismic events, analyzed per month in this period is shown in Figure 1. The average number of local and regional events analyzed per month is 301.

A total of 531 teleseismic events were analyzed during the first half of 1997, of which 72% were located. The monthly average is 88 teleseismic events.

All events (teleseismic, regional and local) analyzed from January to June 1997 with $M \geq 3$ are plotted in Figure 2. The number of events is 428. The large increase in located events with $M \geq 3$ (from 282 in the previous report) is caused by the new processing routine of including teleseismic earthquakes recorded and located by NORSAR. For 225 of these 428 earthquakes, NORSAR is set as the reporting agency, i.e. the earthquakes are not recorded by enough NNSN stations to be relocated.

The station recording statistics for each month from January to June and in total for the first half year of 1997 are given in Table 1. This table gives for each station the number of local events that were recorded only at one station, local events that were recorded on more than one station and teleseismic events that were recorded. The number of events recorded only at one station is for some stations reduced. This reduction is due to that less confirmed and assumed explosions are analyzed.

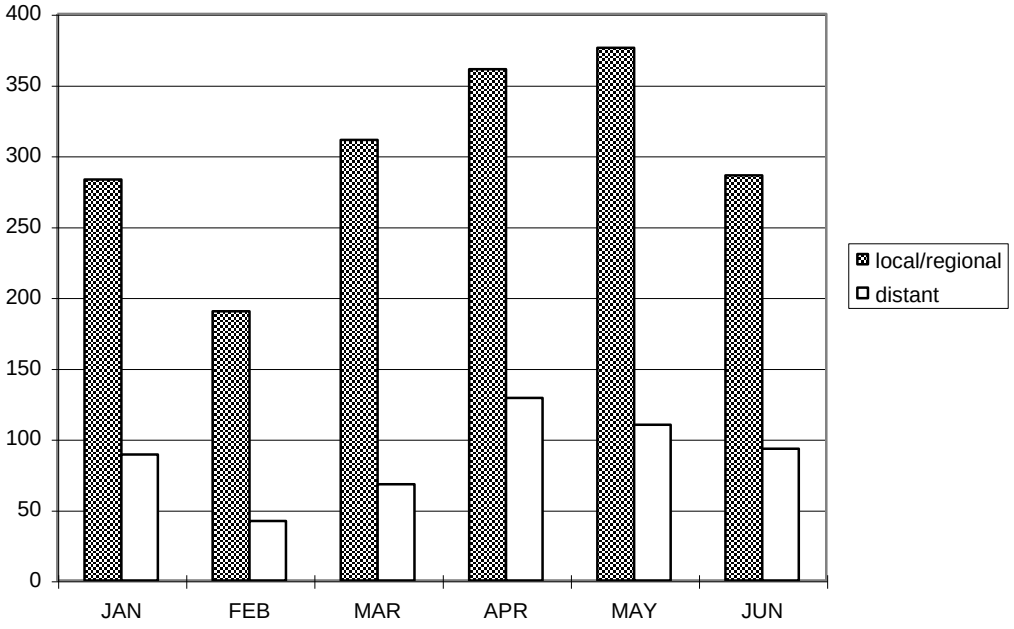

Figure 1. Monthly distribution of local and teleseismic events, analyzed during the first six months of 1997.

Figure 2. Epicentre distribution of earthquakes with M ≥ 3.0, located by the Norwegian seismic stations from January to June 1997. The triangle indicates the location of Bergen. Teleseismic events recorded only by NORSAR have M≥5.0.

Table 1 Monthly statistics of events recorded at each station for the first half of 1997
Abbreviations are:
Event types: **LM**=Number of local events recorded at more than one station, **LS**=local events recorded at only one station and **D**=teleseismic events per month in the time period January to June, 1997.
Stations: ASK=Askøy, BER=Bergen, BJO=Bjørnøya, BLS=Blåsjø, EGD=Espegrend, FOO=Florø, HYA=Høyanger, JMI,JNE,JNW=Jan Mayen, KBS=Kings Bay, KMY=Karmøy, KONO=Kongsberg, KTK=Kautokeino, LOF=Lofoten, MOL=Molde, MOR=Mo i Rana, NSS=Namsos, ODD=Odda, OSG=Oseberg, SUE=Sulen, TRO=Tromsø

	JANUARY			*FEBRUARY*			*MARCH*			*APRIL*			*MAY*			*JUNE*			*JAN.-JUNE*		
STATION	**LM**	**LS**	**D**	**LM**	**LS**	**D**	**LM**	**LS**	**D**	**LM**	**LS**	**D**	**LM**	**LS**	**D**	**LM**	**LS**	**D**	**LM**	**LS**	**D**
ASK	**22**	**3**	**8**	**10**	**0**	**3**	**10**	**0**	**1**	**25**	**0**	**5**	**43**	**0**	**13**	**30**	**0**	**0**	**140**	**3**	**30**
BER	**3**	**0**	**7**	**0**	**0**	**4**	**2**	**0**	**1**	**0**	**0**	**7**	**2**	**0**	**11**	**0**	**0**	**6**	**7**	**0**	**35**
BJO1	**8**	**3**	**0**	**11**	**1**	**4**	**3**	**3**	**8**	**8**	**0**	**13**	**6**	**2**	**7**	**0**	**2**	**0**	**36**	**11**	**32**
BLS5	**20**	**0**	**10**	**5**	**1**	**1**	**10**	**0**	**3**	**26**	**0**	**7**	**33**	**0**	**20**	**25**	**5**	**7**	**120**	**6**	**47**
EGD	**18**	**0**	**6**	**4**	**0**	**1**	**10**	**0**	**1**	**16**	**0**	**2**	**18**	**0**	**4**	**18**	**0**	**0**	**84**	**0**	**14**
FOO	**10**	**0**	**1**	**11**	**0**	**2**	**1**	**0**	**3**	**7**	**1**	**3**	**15**	**0**	**14**	**19**	**2**	**3**	**73**	**3**	**25**
HYA	**12**	**0**	**8**	**11**	**0**	**7**	**9**	**1**	**6**	**16**	**0**	**8**	**24**	**1**	**11**	**29**	**3**	**7**	**102**	**5**	**46**
JMI	**49**	**1**	**0**	**8**	**0**	**8**	**22**	**0**	**10**	**14**	**0**	**1**	**14**	**0**	**0**	**21**	**0**	**0**	**127**	**1**	**19**
JNE	**53**	**0**	**0**	**9**	**0**	**0**	**25**	**0**	**0**	**19**	**0**	**1**	**30**	**0**	**0**	**32**	**0**	**0**	**167**	**0**	**1**
JNW	**55**	**1**	**2**	**10**	**0**	**0**	**27**	**3**	**0**	**19**	**3**	**2**	**30**	**2**	**6**	**32**	**0**	**0**	**173**	**9**	**9**
KBS	**14**	**9**	**25**	**18**	**14**	**20**	**17**	**21**	**17**	**25**	**14**	**48**	**18**	**12**	**60**	**14**	**14**	**63**	**107**	**84**	**242**
KMY	**20**	**0**	**6**	**3**	**0**	**2**	**9**	**1**	**8**	**31**	**3**	**8**	**28**	**1**	**18**	**25**	**2**	**4**	**117**	**7**	**45**
KONO	**4**	**0**	**25**	**2**	**0**	**13**	**1**	**0**	**17**	**3**	**0**	**25**	**4**	**0**	**60**	**2**	**0**	**59**	**17**	**0**	**198**
KTK1	**32**	**4**	**13**	**33**	**0**	**13**	**44**	**2**	**11**	**39**	**4**	**19**	**41**	**0**	**30**	**23**	**5**	**6**	**213**	**16**	**91**
LOF	**8**	**0**	**2**	**8**	**0**	**5**	**21**	**5**	**8**	**16**	**2**	**8**	**37**	**1**	**21**	**26**	**6**	**5**	**118**	**14**	**48**
MOL	**11**	**3**	**10**	**4**	**1**	**9**	**9**	**0**	**7**	**3**	**0**	**1**	**12**	**0**	**23**	**16**	**4**	**10**	**56**	**8**	**59**
MOR8	**29**	**1**	**18**	**31**	**2**	**19**	**45**	**0**	**21**	**37**	**9**	**31**	**32**	**0**	**32**	**29**	**7**	**15**	**204**	**19**	**136**
NSS	**6**	**0**	**4**	**7**	**3**	**9**	**11**	**1**	**6**	**5**	**5**	**6**	**10**	**6**	**12**	**14**	**8**	**5**	**54**	**23**	**41**
ODD1	**22**	**0**	**9**	**7**	**0**	**6**	**17**	**0**	**6**	**29**	**0**	**11**	**17**	**0**	**11**	**8**	**0**	**2**	**100**	**0**	**45**
SUE	**5**	**0**	**0**	**4**	**0**	**1**	**8**	**0**	**1**	**11**	**0**	**3**	**27**	**0**	**16**	**20**	**0**	**6**	**76**	**0**	**26**
TRO	**14**	**1**	**4**	**15**	**0**	**10**	**14**	**0**	**8**	**7**	**0**	**8**	**1**	**0**	**4**	**0**	**0**	**0**	**52**	**1**	**33**

4. The seismicity of Norway and surrounding areas

Figure 3 show all local and regional events analyzed during the first half of 1997. The number of located events, in the area between 54°N-82°N and 15°W-32°E, including NORSAR readings, decreased from 923 in the last six months of 1996 to 801 in the first six months of 1997. Using the explosion filter (Ottemöller, 1995, Benson et. al., 1992) more than 48% of these events are identified as probable explosions. In Figure 4, confirmed and probable explosions are omitted.

Figure 5 and Table 2 show the 32 local and regional events with any of the reported magnitudes larger than or equal to 3.0. From Figure 5 it is clearly seen that the largest earthquakes are related to the mid oceanic rigde (Mohn and Knipovitch) and to the Jan Mayen island. Also it should be noted that there has not been any large earthquakes offshore Florø, an area which in prior reports has been active.

The largest earthquake occured on May 16th, at 14:31 (UTC), east of Jan Mayen, with M_L=3.9 . Seismograms for this earthquake are shown in Figure 6. The largest earthquake closer to the Norwegian mainland, was west of Mo i Rana on March 18th at 05:53 (UTC). This earthquake had a magnitude of M_{LBER}=3.2. The second largest earthquake occured in the North Sea on May 17th at 01:28 (UTC) with magnitudes M_{LBER}=3.0.

Figure 3. Epicentre distribution of events analyzed during January to June, 1997. 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.

Figure 4. Epicentre distribution of events analyzed from January to June, 1997. Known and probable explosions are not included. 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.

Figure 5. Epicentre distribution of analyzed events, with M ≥ 3, from January to June, 1997. Squares indicate stations that are part of the NNSN. Triangles indicate stations operated by the Institute of SolidEarth 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. Local and regional events with any magnitude ≥ 3.0 for the time period January to June, 1997, in the area between 54°N-82°N and 15°W-32°E. For depth determination see section 5.

year	moda	hrmi	sec	mde	lat	long	depthFF	ns	rms	magnitudes
1997	1 8	2217	6.3	JL	71.808	-11.901	15.0	3	0.1	3.3CBER 3.3LBER

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1997  111 0717  9.8JL  71.097  -6.235  7.6    3 0.1 2.9CBER 3.1LBER
1997  112 0544 13.5JL  71.059  -7.456 15.0F   3 0.2 2.7CBER 3.2LBER
1997  113 1519  7.9JL  71.279  -5.418 10.0F   9 0.8 3.5CBER 3.4LBER
1997  114 0037  1.9 L  76.223  25.657 15.0F  10 1.4 3.2CBER 3.0LBER 3.0LNAO
1997  118 0909 48.2 L  56.128   3.316 10.0F  15 1.2 2.7CBER 2.5LBER 3.1LBGS
1997  119 0934  2.9JL  71.198  -8.209 17.9    3 0.0 3.1CBER 3.5LBER
1997  120 0303 22.9 L  73.253   7.076 11.3   15 1.5 3.4CBER 3.4LBER 3.2LNAO
1997  2 3 0509 15.0 L  80.395   0.907 31.0    8 1.5 3.4CBER 3.9LBER 4.0BNAO
1997  2 5 2316 20.2JL  71.190  -9.479 10.0F   5 0.5 3.0CBER 3.1LBER
1997  211 0615 18.0 L  80.065  22.497 10.0F   7 0.9 2.9CBER 3.3LBER 2.9LNAO
1997  213 1022 24.6 L  80.545   0.039 15.0   11 1.9 3.5CBER 3.6LBER 3.5LNAO
1997  215 1932 20.8 L  63.902  18.533 10.0F  17 1.4 3.6CBER 3.0LBER 2.9LNAO
1997  3 7 2141 12.5 L  75.096   9.558 19.7    8 0.6 2.6CBER         3.0LNAO
1997  318 0553 52.9 L* 66.382  -2.220 10.0F  38 1.4 3.7CBER 3.2LBER 3.2LNAO
1997  4 3 1415  3.0 L  80.516   1.060 23.0    6 1.0 3.5CBER 3.1LBER 3.6BNAO
1997  4 3 1631 24.2 L  79.967   6.771 10.0F   9 1.5 3.0CBER 2.9LBER 3.0LNAO
1997  413 1857  4.5JL  71.571 -10.047 17.2    3 0.1 2.6CBER 3.2LBER
1997  421 1658 16.5JL  71.999  -9.535 10.0F   3 0.6 2.8CBER 3.1LBER
1997  429 1020  3.4JL  71.054  -7.070 15.2    3 0.0 2.7CBER 3.1LBER
1997  430 0944 13.7JL  71.216  -7.091 15.5    3 0.1 2.5CBER 3.1LBER
1997  430 2124 33.8 L  72.666   5.031 31.2    4 0.3 3.5CBER 2.6LBER
1997  5 1 1653 48.7JL  71.019  -7.000 10.6    3 0.0 2.4CBER 3.0LBER
1997  5 2 0719 30.4JL  71.162  -6.593 15.0    3 0.1 2.6CBER 3.3LBER
1997  5 3 1158 14.3JL  71.407  -6.416  8.2    3 0.2 3.3CBER 3.6LBER
1997  512 0848 21.1JL  71.521 -10.062 15.0    3 0.1 3.1CBER 3.4LBER
1997  513 2207 10.0 L* 60.961   3.736 19.0F  22 1.0 3.0CBER 3.2LBER 2.9LNAO
1997  516 1431 26.6JL  71.786  -1.730 10.0F  20 1.3 3.9LBER 3.9SBER 4.5BPDE
1997  517 0128 28.8 L* 63.120   2.923 15.0F  17 1.2 3.5CBER 3.0LBER 3.1LNAO
1997  622 2118 44.6JL  70.876  -6.639 10.0F   3 0.1 2.9CBER 3.3LBER
1997  625 0209 26.3JL  71.069  -7.526 17.4    3 0.0 2.7CBER 3.1LBER
1997  627 0517 17.6 L  73.323   6.910 21.3    9 1.1 3.6CBER 3.1LBER
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Abbreviations are:

date: **year**, **mo** = month, **da** = day

origin time given in UTC: **hr** = hour, **mi** = minutes, **sec** = seconds

m= model identification (blank=standard model, J=Jan Mayen model, L=only nearest stations used)

d = distance identification (L=local, R=regional, D=teleseismic)

e=event identification (*=well recorded, P=probable explosion, E=known explosion)

location: **lat** = latitude, **long**=longitude

depth = focal depth (km)

FF: first F for fixed depth, second F for fixed location

ns = number of stations

rms = root mean square of the travel-time residuals

magnitudes: magnitude type (C=coda, L=local, B=body wave, W=moment) and magnitude reporting

agency (BER=Bergen, NAO=NORSAR, PDE=Preliminary Determination of Epicenters)

Figure 6. Seismograms for the earthquake on May 16th 1997 at 14:31 (UTC). All seismograms are filtered between 4 and 9 Hz. The station abbreviations are: KTK=Kautokeino, LOF=Lofoten, KBS=Kings Bay, MOL=Molde, FOO=Florø, NSS=Namsos, HYA=Høyanger, KONO=Kongsberg, BLS=Blåsjø and KMY=Karmøy.

5. Well recorded events

Since January, 1995, well recorded earthquakes have been selected during the daily analysis and specially marked in the Bergen data base. The event selection is based on signal to noise ratio and the number of recording stations and this means that both small events near the network and large events further away have been selected. These events are studied in more detail than the remaining events. Additional phase readings and waveform data are collected if available, mainly from NORSAR and BGS. Particularly the location and the depth estimates are checked. For each event the rms-vs-depth plot is checked and if possible the event is located using only the nearest stations (D< 200 km) to see if this gives a better location with a well constrained depth. If this is the case, the depth is fixed and the event is relocated using all stations. If no reasonable depth can be determined, the depth is fixed at 15 km for continental earthquakes and at 10 km for oceanic. The same principles for depth determination is also used for the local and regional events with magnitude equal to or above 3.0.

For this report 13 events have been analysed (see Table 3). The locations of these events are shown in Figure 7.

Fault plane solutions were determined for 3 well recorded events. All three events are located offshore, the largest one falling into the Norway Basin area close to the extinct Eastern Jan Mayen Fracture Zone. All mechanisms are oblique-slip with maximum compressional axis in the WNW-ESE direction. The values of strike, dip and rake are given in Table 3. The fault plane solutions are shown in Figure 8.

Table 3. List of 13 well recorded events in the first half year of 1997 including the values of strike, dip and rake in the line following the event line.

year	damo	hrmi	sec	mde	lat	long	depthFF	ns	rms	magnitudes	MO	ST	OM	f0	R	AI
•1997	1	1 1151	45.9	L*	62.349	4.865	5.0F	12	1.2	2.6CBER 2.1LBER 2.2WBER	12.3	3.2	0.9	8.05	0.16	-
strike: 153.4		dip: 75.50			rake: 26.6											
•1997	120	2027	23.0	L*	61.322	2.695	15.0F	11	0.7	2.4CBER 2.1LBER 1.8LNAO 2.2WBER	12.4	2.6	2.0	8.04	0.17	+
•1997	126	0035	17.2	L*	61.549	2.610	15.0F	15	1.2	2.5CBER 1.9LBER 1.9LNAO 2.0WBER	12.1	2.5	2.6	9.77	0.13	+
•1997	215	0357	38.1	L*	61.752	3.576	8.0F	8	1.5	2.2CBER 2.2LBER 2.3WBER	12.6	7.8	6.3	9.52	0.13	+
•1997	318	0553	52.9	L*	66.382	-2.220	10.0F	38	1.4	3.7CBER 3.2LBER 3.2LNAO 3.0WBER	13.8	19.1	3.9	5.05	0.29	+
strike: 356.3		dip: 64.3			rake: -16.1											
•1997	322	1413	19.3	L*	60.549	5.965	7.1F	10	0.2	1.8CBER 1.4LBER						
•1997	428	0323	57.3	L*	62.044	5.521	15.0F	12	1.3	2.8CBER 2.3LBER 2.2LNAO 2.3WBER	12.5	8.4	6.7	10.20	0.12	+
•1997	5	2 2024	45.3	L*	61.847	4.959	15.0F	11	1.0	2.7CBER 2.4LBER 2.3LNAO 2.4WBER	12.6	5.3	10.6	8.27	0.15	+
•1997	513	2207	10.0	L*	60.961	3.736	19.0F	22	1.0	3.0CBER 3.2LBER 2.9LNAO 3.1WBER	13.7	58.1	13.2	7.84	0.18	+
strike: 296.0		dip: 71.3			rake: -23.9											
•1997	516	2040	14.8	L*	59.469	5.690	15.0F	9	1.2	2.0CBER 1.9LBER 1.8LNAO						
•1997	517	0128	28.8	L*	63.120	2.923	15.0F	17	1.2	3.5CBER 3.0LBER 3.1LNAO 3.0WBER	13.6	3.4	7.7	3.27	0.40	+
•1997	6	9 0311	36.0	L*	59.888	6.647	7.0F	12	1.0	2.5CBER 1.7LBER 2.1LNAO 1.9WBER	12.0	1.9	18.1	9.35	0.14	+
•1997	619	2302	37.6	L*	61.457	3.891	7.0F	8	0.7	1.8CBER 1.6LBER 1.7WBER	11.6	0.8	36.8	9.72	0.13	+

Abbreviations are:

date: **year mo** = month **da** = day, **origin time given in UTC**: **hr** = hour **mi** = minutes **sec** = seconds, **m**= model identification (blank=standard model, J=Jan Mayen model, L=only nearest stations used); **d** = distance identification (L=local, R=regional, D=teleseismic), **e**=event identification (*=well recorded, P=probable explosion, E=known explosion); **location**: **lat** = latitude, **long**=longitude **depth** = focal depth (km); **FF**: first F for fixed depth, second F for fixed location; **ns** = number of stations; **rms** = root mean square of the travel-time residuals, **magnitudes**: magnitude type (C=coda, L=local, B=body wave, W=moment) and magnitude reporting agency (BER=Bergen, NAO=NORSAR, PDE=Preliminary determination of epicenters), **MO** = log of seismic moment in Nm, **ST** = stress drop in bar, **OM** = log spectral level in nm sec, **f0** = corner frequency in Hz, **R** = source radius in km, **AI** = addidional waveform files has been used (+ = YES, - = NO)

Figure 7. Epicentre distribution of well recorded events in the first half of 1997. 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.

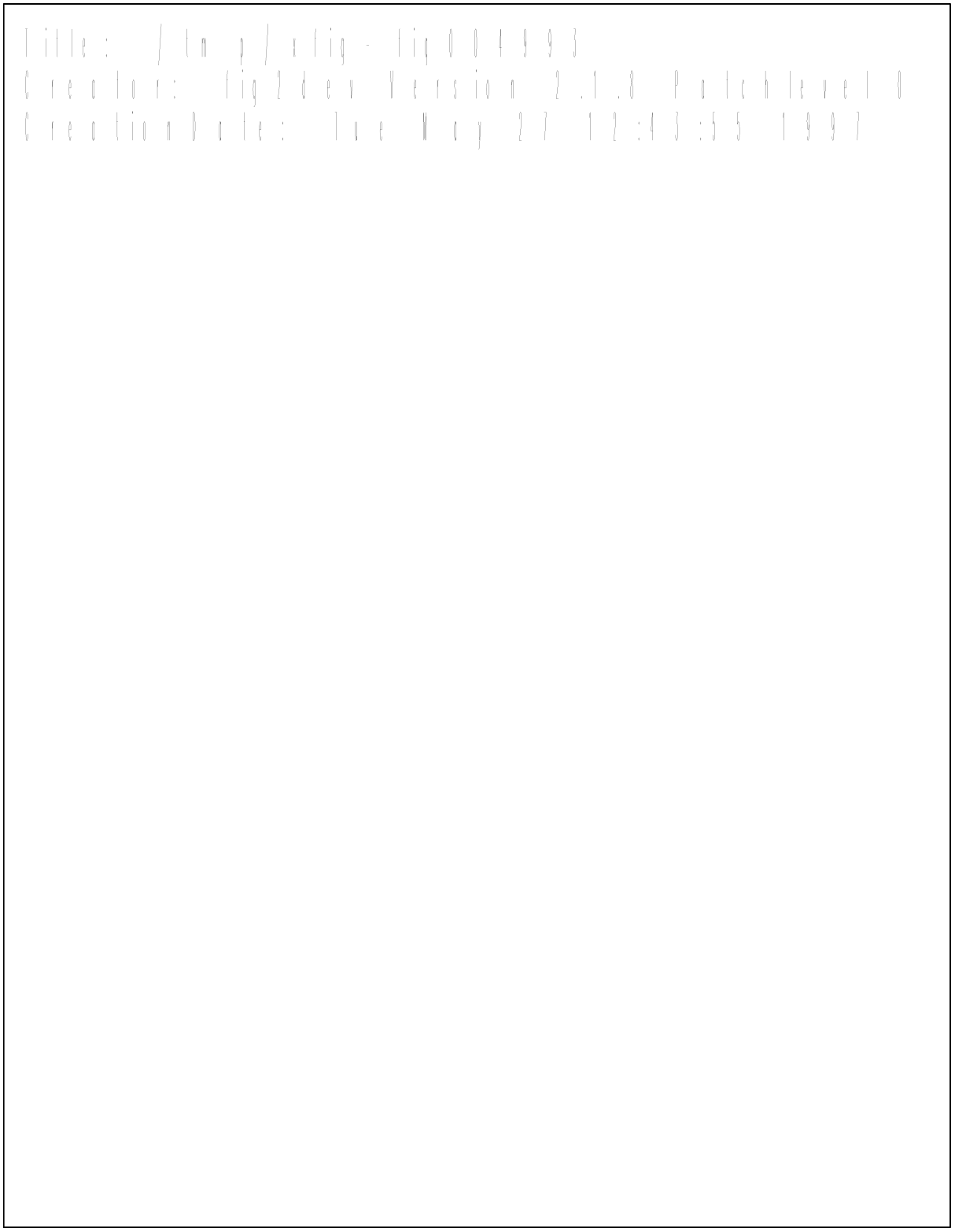

Figure 8. Earthquake focal mechanisms (indicated by stereographic projection) in the first half of 1997. Squares indicate stations operated by the Institute of Solid Earth Physics, University of Bergen (UiB), whereas the star shows the IRIS station KONO. The epicentres are indicated by circles.

6. Felt events

Four events were reported felt during the first half of 1997 (see Table 4). None of these were large enough to be felt by a sufficient number of people so that macroseismic questionnaires could be sent out. Three of these earthquakes are special events which are described below.

- The two earthquakes that occurred on May 12th and June 30th are related to the tunnel construction in connection with the power station at Kvernafjellet south of Lysefjorden in Rogaland. These two events are two of 4 events located in the same area .The NNSN recordings of the strongest of these two felt events can be seen in Figure 9.
- The earthquake on May 13th is located close to the Troll platform in the North Sea, and Figure 10 shows the recorded seismograms. This event was felt by people in Masfjorden, Hordaland and by workers at the Troll Platforms.

Table 4 Earthquakes felt in Norway during the time period January to June, 1997 (excluding Jan Mayen and Spitsbergen).

Date	Time (UTC)	Max Intensity on (MMI) scale	Magnitude (BER)	Epicentral Location, Area
28.04.97	03:23	III	2.8 (M_C) 2.3 (M_L)	61.99N / 5.60E Eidså, Møre og Romsdal
12.05.97	22:45	II	2.0 (M_C) 1.5 (M_L)	59.00N / 6.36E Kvernafjellet, Rogaland
13.05.97	22:07	III	3.0 (M_C) 3.2 (M_L)	60.96N / 3.73E Offshore, close to Troll
30.06.97	11:25	II	1.7 (M_C) 1.3 (M_L)	59.02N / 6.41E Kvernafjellet, Rogaland

7. The events close to Kvernafjellet/Flørlia

In the area Kvernafjellet/ Flørlia, the hydro power company Lyse Kraft, is constructing a tunnel in connection with a power station. May 12th at 22:45 (UTC) a small earthquake was felt by the workers at the construction site. The event was recorded by NNSN stations and it was estimated to M_L=1.5. It is reported that there has been observed damage on the tunnel side walls due to rock deformation. After analysing all triggers recorded that night, it was found that there had also been an event on May 13th at 00:07 (UTC, M_L=1.2) located in the same area. This event was, however, not felt.

During the time period January 1st 1990 to June 30th 1997, 8 events are located in an area around Kvernafjellet, limited by the expected location errors (ca. 15 km), see Figure 11. These events are listed in Table 5. In addition to the event on May 12th 1997 also the event on June 30 1997 at 11:25 (UTC) was felt. Knowing that events number 6 and 8 were felt and confirmed not to be explosions, and studying the waveform signatures, it seems likely that events no. 5-8 in Table 5 and on Figure 11 are related to the same location/source. The location for the earlier events (no. 1-4) as well as the events on August 1996 (no 5) are uncertain since the location are based on fewer stations than for the other events. The spread in the epicentre locations is a direct indication of the errors in location. Note that the best located events (6, 7 and 8) also give the closest location to the tunnel construction site.

It is interesting to note that the construction period in Flørlia/Kvernafjellet started in May 1996 with the building of roads, and that the time of the first event in this series of similar events started in August 1996. Since there is no doubt that event 6 and 8 are shallow earthquakes related to the construction, it is likely that the remaining events (5 and 7) in the series also are related to the construction work. These events are probably the first case of known and documented mining induced earthquakes in Norway.

Table 5. 8 events located to an limited area around Flørlia/Kvernafjellet.

#	year	moda	hrmi	sec	mde	lat	long	depthFF	ns	rms	magnitudes
1	1991	212	1522	54.5	L	58.989	6.484	15.0F	2	2.5	1.7CBER
2	1993	1118	1648	53.0	L	58.906	6.289	15.0F	2	1.3	0.7CBER
3	1993	1129	1607	46.4	L	58.941	6.290	10.0F	2	0.9	1.1CBER
4	1995	514	0556	0.6	L	59.129	6.491	12.0F	5	0.8	1.5CBER 1.3LBER
5	1996	813	2001	28.6	L	59.027	6.746	1.0F	3	0.3	1.4CBER 0.6LBER
6	1997	512	2245	53.3	L	59.022	6.363	1.0F	5	0.7	2.0CBER 1.5LBER 1.6WBER
7	1997	513	0007	19.2	L	59.011	6.446	1.0F	8	0.7	1.9CBER 1.2LBER 1.5LNAO
8	1997	630	1125	31.1	L	58.984	6.396	1.0F	7	1.1	1.7CBER 1.4LBER 1.7LNAO

Abbreviations are:
date: **year**, **mo** = month, **da** = day
origin time given in UTC: **hr** = hour, **mi** = minutes, **sec** = seconds
m= model identification (blank=standard model, J=Jan Mayen model, L=only nearest stations used)
d = distance identification (L=local, R=regional, D=teleseismic)
e=event identification (*=well recorded, P=probable explosion, E=known explosion)
location: **lat** = latitude, **long**=longitude
depth = focal depth (km)
FF: first F for fixed depth, second F for fixed location
ns = number of stations
rms = root mean square of the travel-time residuals
magnitudes: magnitude type (C=coda, L=local, B=body wave, W=moment) and magnitude reporting **agency** (BER=Bergen, NAO=NORSAR, PDE=Preliminary Determination of Epicenters)

Figure 9. Seismograms for the earthquake felt near Kvernafjellet, Rogaland on the 12.05.1997 at 22:45 (UTC). The seismograms are filtered between 5 and 10 Hz.
Abbreviations are: NRA0= NORESS, BLS=Blåsjø and ODD= Odda.

Figure 10. Seismograms for the earthquake felt in Western Norway on the 13.05.1997 at 22:07 (UTC). All seismograms are filtered between 4 and 9 Hz. The station abbreviations are: FOO=Florø, HYA=Høyanger, SUE=Sulen, MOL=Molde, KMY=Karmøy, KONO=Kongsberg, NAO= NORESS. The additional stations are operated by British Geological Survey.

Figure 11. Location of the 8 events located close to the Flørlia/Kvernafjellet construction site. The numbering corresponds to events listed in Table 5.

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