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7.6 Accurate location of seismic events in northern Norway using a local network, and implications for regional calibration of IMS stations

Introduction

A seismic network was installed in the Ranafjord area in June 1997 as part of the NEONOR (Neotectonics in Norway) project which is a multidisciplinary research project undertaken in cooperation with several other Norwegian institutions. The purpose of the network was to monitor seismic activity along the potential neotectonic Båsmoen fault. Of the total 260 seismic events located in the first nine months of operation, 180 are probable earthquakes located within the network. Data from the Norwegian national seismic station southeast of Mo i Rana was made available by the University of Bergen and used to improve event locations where possible. The magnitudes of the local events range from M_L 0.1 to 2.8, with depths mainly in the 4-12 km. range. Nine focal mechanism solutions have also been determined, seven of which are tightly clustered in the western part of the network. These solutions show a large, up to 90°, rotation of the direction of maximum horizontal compressive stress (σ_{Hmax}) with regard to the ridge-push dominated regional stress field. Eight of the events within the network were also located by the NORSAR GBF system, and these locations as well as NORSARs analyst reviewed locations have been compared to the local solutions.

Technical installation and data processing

Five of the six stations transmit data via radio links to a central station (the sixth is connected directly to the digitizer), where the data are digitized and sent over a permanent landline to NORSAR. The sampling frequency is 40 Hz, which unfortunately is somewhat low for studying source effects for events with the magnitudes encountered in the region. The station locations are shown in Fig. 7.6.1, along with the location of the Norwegian national station to the east of Mo i Rana, operated by the Institute of Solid Earth Physics, University of Bergen.

Event detection and processing is performed using NORSARs detection and event processing software. Event location, database management, seismic modelling etc. are performed using the Seisan software from the University of Bergen

Historic seismic activity

The offshore and onshore parts of Northern Norway have long been considered an area of elevated seismic activity with regard to the rest of the Baltic shield and margin areas, albeit not particularly high as compared to other passive continental margins globally (Byrkjeland et al., in prep.). The largest known onshore earthquake in Fennoscandia occurred in the Ranafjord area on August 31, 1819, with an estimated magnitude of M_S 5.8-6.2 (Muir Wood, 1989). Although an exact hypocenter location is unavailable, a large number of reports concerning rockfalls, standing waves and difficulties standing exist in the western and parts of the area (Fig. 7.6.2). A landslide was also triggered near Utskarpen by the Rana fjord.

Local seismic activity

Of the 260 events located by the network, 220 are located in the immediate vicinity of the network, 40 of these are explosions and probable explosions, leaving 180 probable earthquakes. Magnitudes range from M_L 0.1 to 2.8, with most events in the M_L 1.0 to 1.5 range. Hypocenter depths are shallow, mainly from 4 to 12 km. This is consistent with other reports of onshore seismic activity in Northern Norway (e.g Bungum et al., 1979; Atakan et al., 1994). Fig. 7.6.3 shows the seismic activity plotted according to magnitude (explosions removed). Four groups of events are visible in the western part of the network, three of these groups have well defined activity periods and hypocenter depths. A time vs. magnitude plot for the local events is shown in Fig. 7.6.4. The largest events within the network occurred within the two westernmost groups, which are also located in the vicinity of many of the reported phenomena concerning the 1819 earthquake (Fig. 7.6.2). The easternmost (red) group has hypocenter depths predominantly around 4-6 km, while the other groups have depths mainly in the 10-12 km range.

Focal mechanism solutions and stress data

Nine earthquake focal mechanism solutions have been determined using data from the network (in combination with data from the University of Bergen where available), shown in Fig. 7.6.5 with corresponding σ_{Hmax} directions. One is a composite solution based on first motion polarities only, the rest are selected on a basis of available first motion polarities combined with full waveform modelling using Herrmann code (Havskov, 1997). A sample synthetic and real trace from the modelling is shown in Fig. 7.6.6.

While seven of the nine solutions are for earthquakes located within the network, there is also one solution around 50 km south of the network, and one offshore to the west. The solutions are mainly oblique-normal to strike-slip. The seven local solutions all show an approximately N-S trending direction of maximum horizontal compression, in contrast to the ridge-push dominated regional stress field which has a WNW-ESE σ_{Hmax} direction (Hicks et al., in prep.). This implicates a strong local stress influence on the seismic activity in the area.

Calibration of IMS stations

Eight of the earthquakes occurring within or close to the network from July 1997 to April 1998 were of sufficient size to also be detected by NORSARs automatic GBF system. The magnitudes for these events range from M_L 2.0 to 2.8 (Table 7.6.2). The detection threshold appears to be around M_L 2.0-2.1 for this area. Two events with magnitudes over 2.0 were not detected by the GBF system, an ML 2.1 on 26.12.97 and an aftershock (M_L 2.0) of the M_L 2.8 event 09.02.98.

The eight GBF events are excellent candidates for a study on calibration with regard to local crustal effects, to verify the NORSAR GBF system as it operates at present, and in general with regard to the capabilities of the international monitoring system. The locations of the eight events are shown in Fig. 7.6.7, with the GBF grid points superimposed. The smallest event has a difference in location of approx. 175 km (based on only four phases), and the westernmost event has a discrepancy of around 75 km (7 phases). The GBF locations for the remaining six events are within 50 km of the local solutions (6 to 11 phases). This is an excellent result for a fully automatic system considering the magnitudes and distances to the stations involved (closest station is ARCESS at ~580 km), but shows that further improvements to the system should be possible.

The seven NORSAR analyst reviewed events are listed in Table 7.6.3 and plotted (along with the corresponding local solutions) in Fig. 7.6.8. The analyst reviewed locations are all within

~25 km of the local solutions, which again is excellent considering the distances involved. The NORSAR solutions do appear to have locations systematically to the east/southeast of the local solutions, which could be an indication of a local crustal anomaly, and should be studied more closely.

E. Hicks

References

Atakan, K., C. D. Lindholm & J. Havskov (1994): Earthquake swarm in Steigen, Northern Norway: an unusual example of intraplate seismicity. *Terra Nova*, 6, 180-194.

Bungum, H., B. K. Hokland, E. S. Husebye & F. Ringdal (1979): An exceptional intraplate earthquake sequence in Meløy, Northern Norway, *Nature*, 280, 32-35.

Byrkjeland, U., H. Bungum & O. Eldholm (in prep): Seismotectonics of the Norwegian margin.

Havskov, J. (ed.)(1997): *The seisan earthquake analysis software for the IBM PC and Sun Version 6.0*, Univ. of Bergen, Norway, 236 pp.

Hicks, E., H. Bungum & C. D. Lindholm (in prep): Crustal stresses in Norway and Surrounding areas as derived from earthquake focal mechanism solutions and in-situ stress measurements.

Muir Wood, R. (1989): The Scandinavian Earthquakes of 22 December 1759 and 31 August 1819, *Disasters*, 12, 223-236.

Date	Lat.	Lon.	Depth	Mag.	P-trn	P-plng	T-trn	T-plng
Comp.1	66.31	13.32	5 km	N/A	167	48	270	11
97.11.21	66.41	13.22	7 km	2.3	208	29	302	7
97.11.25	66.50	12.40	11 km	2.7	77	29	343	7
97.11.28	66.32	13.14	11 km	1.7	74	58	299	23
97.11.28	66.32	13.15	11 km	1.8	74	58	299	23
97.12.26	66.32	13.11	11 km	1.8	176	1	268	67
98.01.08	66.37	13.13	13 km	2.2	27	33	284	19
98.02.09	66.39	13.09	11 km	2.8	351	22	257	11
98.03.09	65.85	13.53	7 km	2.8	115	13	225	57

Table 7.6.1. Earthquake focal mechanism solutions determined using data from the network. The composite solution is determined using first motion polarities only, the remaining eight are determined through a combination of first motion polarities and full waveform modelling

		NEONOR				GBF			
Date	Time	Lat.	Lon.	Mag	Depth	Lat.	Lon.	Mag	Nph
97.11.21	18:00:09	66.41	13.22	2.3	6.3	66.65	12.85	2.2	10
97.11.25	22:24:17	66.50	12.40	2.7	11.0	66.35	14.35	2.4	7
98.01.08	08:04:46	66.37	13.13	2.2	12.8	66.65	12.85	2.0	8
98.01.11	20:01:18	66.37	13.11	2.2	12.3	66.65	12.85	2.1	7
98.02.04	14:31:40	66.38	13.09	2.3	10.6	66.35	14.35	2.2	6
98.02.09	12:59:05	66.39	13.09	2.8	10.7	66.35	14.35	2.7	11
98.02.28	16:53:26	66.70	13.32	2.0	11.6	66.65	17.37	1.6	4
98.03.09	14:19:57	65.85	13.53	2.8	6.6	65.75	14.30	2.9	11

Table 7.6.2. Events located by the local network and at the same time by the NORSAR GBF system. All GBF solutions use at least two stations. Nph refers to number of phases used in the solution.

		NEONOR				NORSAR (analyst reviewed)		
Date	Time	Lat.	Lon.	Mag	Depth	Lat.	Lon.	Depth
97.11.21	18:00:09	66.41	13.22	2.3	6.3	66.39	13.24	10.3
97.11.25	22:24:17	66.50	12.40	2.7	11.0	66.43	12.71	20.2
98.01.08	08:04:46	66.37	13.13	2.2	12.8	66.34	13.39	0
98.01.11	20:01:18	66.37	13.11	2.2	12.3	66.34	13.46	0
98.02.04	14:31:40	66.38	13.09	2.3	10.6	66.28	13.41	13.6
98.02.09	12:59:05	66.39	13.09	2.8	10.7	66.30	13.54	8.9
98.03.09	14:19:57	65.85	13.53	2.8	6.6	65.85	13.65	3.4

Table 7.6.3. Events located by the local network and at the same time reviewed and located by the NORSAR regional system. The events are the same as in Table 7.6.2, except for the smallest event (98.02.28) which was not reviewed.

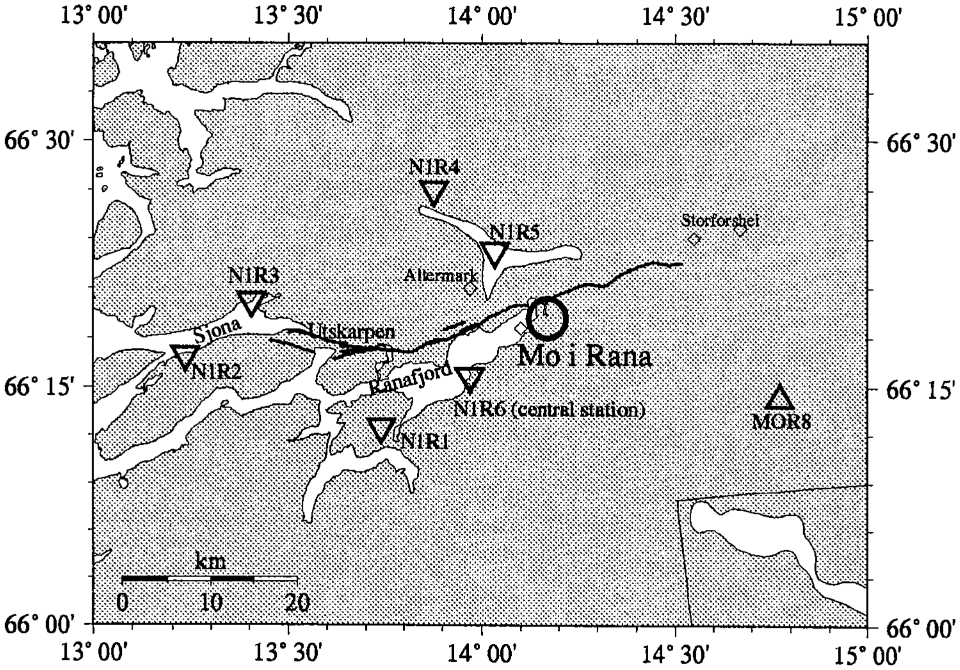

Fig. 7.6.1. The six NEONOR stations (inverted triangles) and the MOR8 station operated by the University of Bergen. The thick black line represents the Båsmoen fault. Diamonds represent mines.

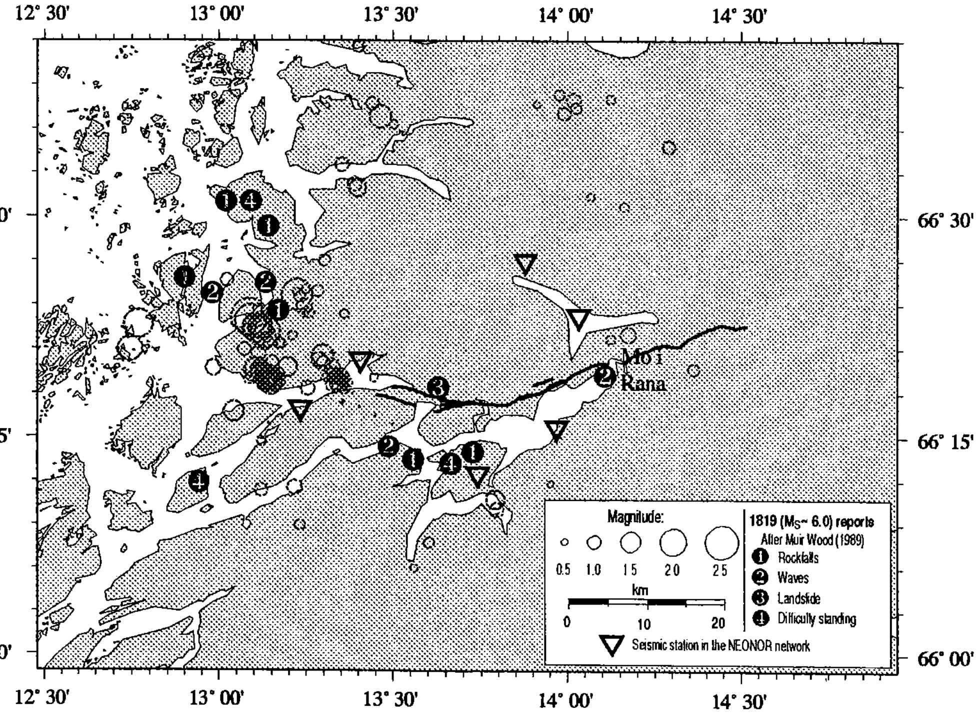

Fig. 7.6.2. Reported effects from the August 31, 1819 M_S 5.8-6.2 earthquake. Earthquakes located by the NEONOR network are plotted according to magnitude as grey circles.

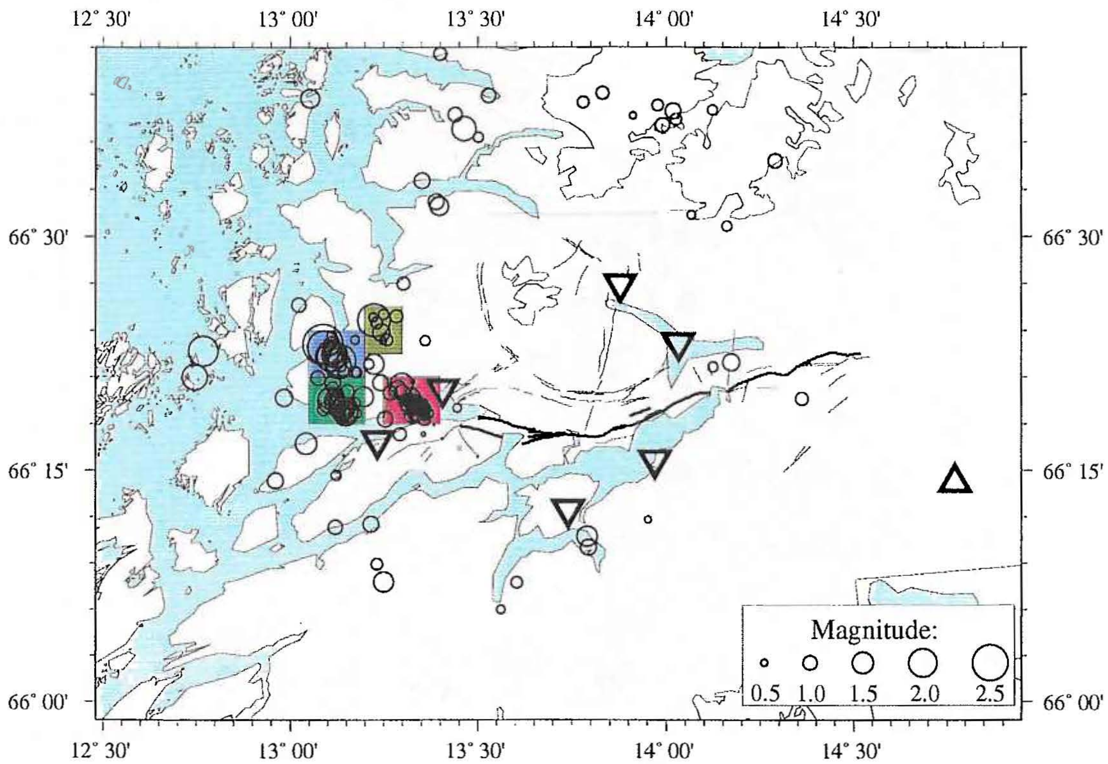

Fig. 7.6.3. Local earthquakes plotted according to magnitude (explosions and probable explosions removed). Events within the colored boxes correspond to the colored bars in Fig.7.6.4.

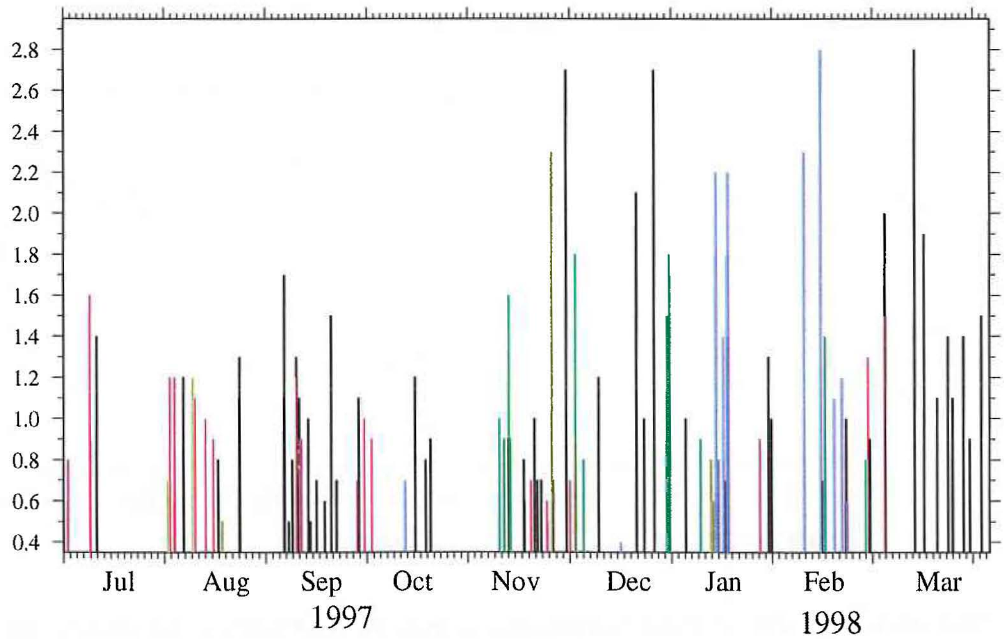

Fig. 7.6.4. Event magnitudes plotted vs. time. The colors indicate events within the colored boxes in Fig. 7.6.3.

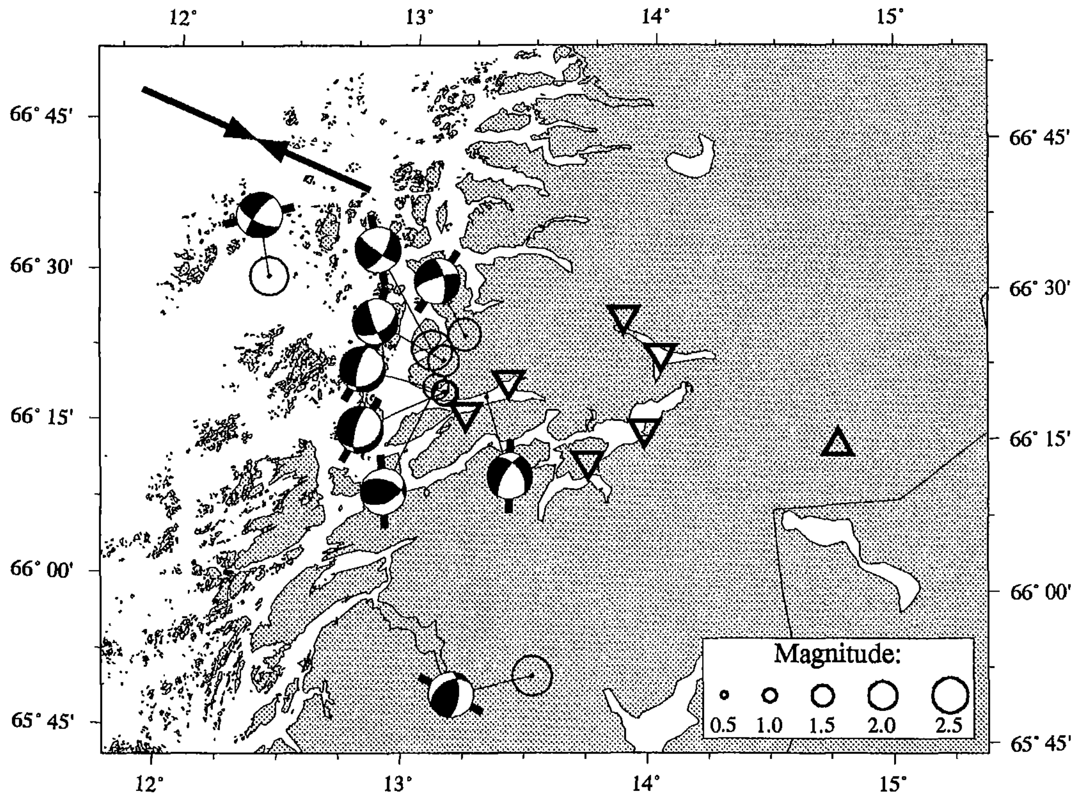

Fig. 7.6.5. Earthquake focal mechanism solutions determined using data from the network. The bars indicate the σ_{Hmax} stress direction for each solution. The large arrows represent the approximate direction of the regional ridge push dominated stress field.

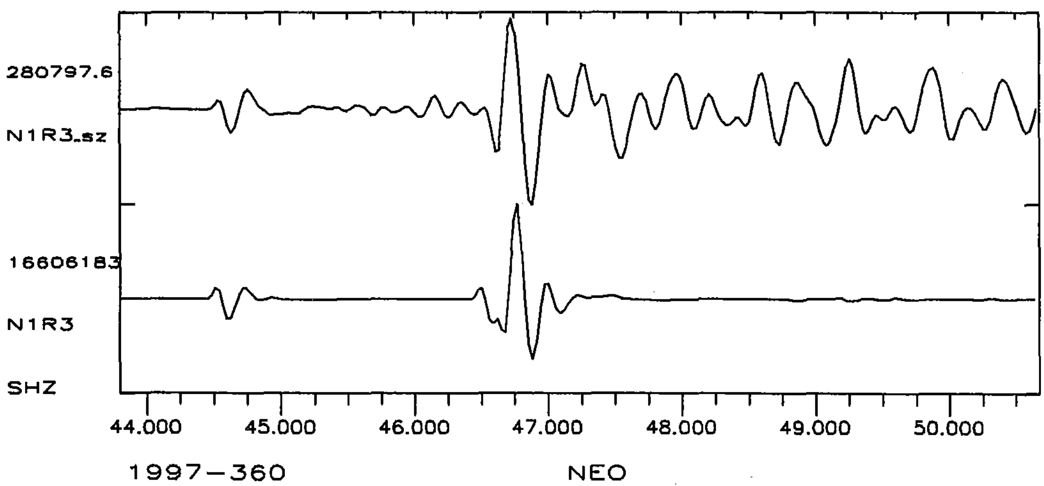

Fig. 7.6.6. Real (top) and synthetic (bottom) traces from the N1R3 station for the selected focal mechanism solution for the 26 December 1997 M_L 1.8 earthquake.

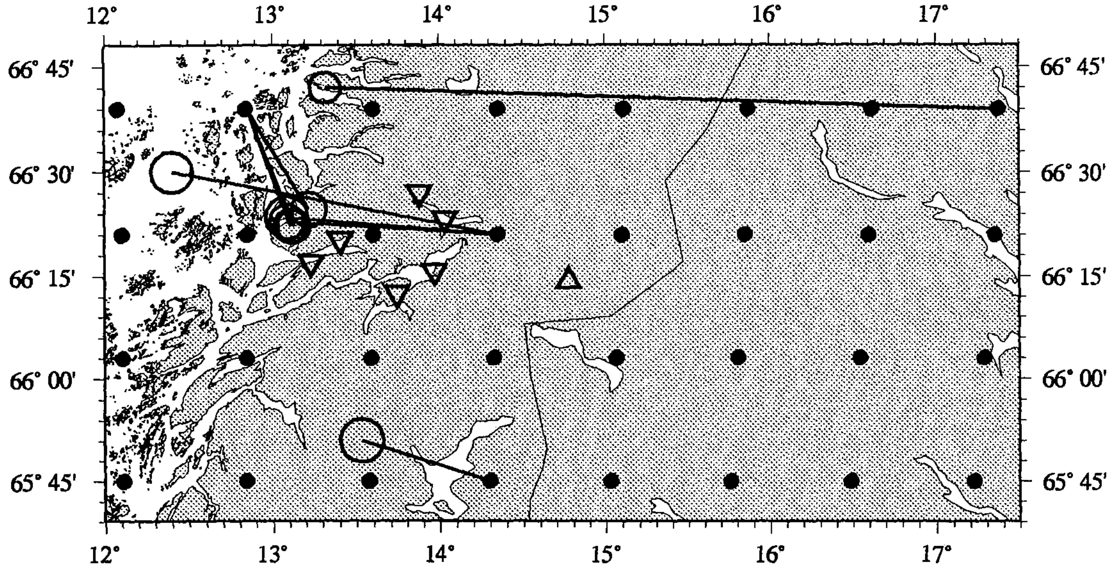

Fig. 7.6.7. Locations of the 8 common detected events (circles).The GBF grid points are represented by dots, the grid interval is 33 km. Lines join the GBF locations to the corresponding local event locations.

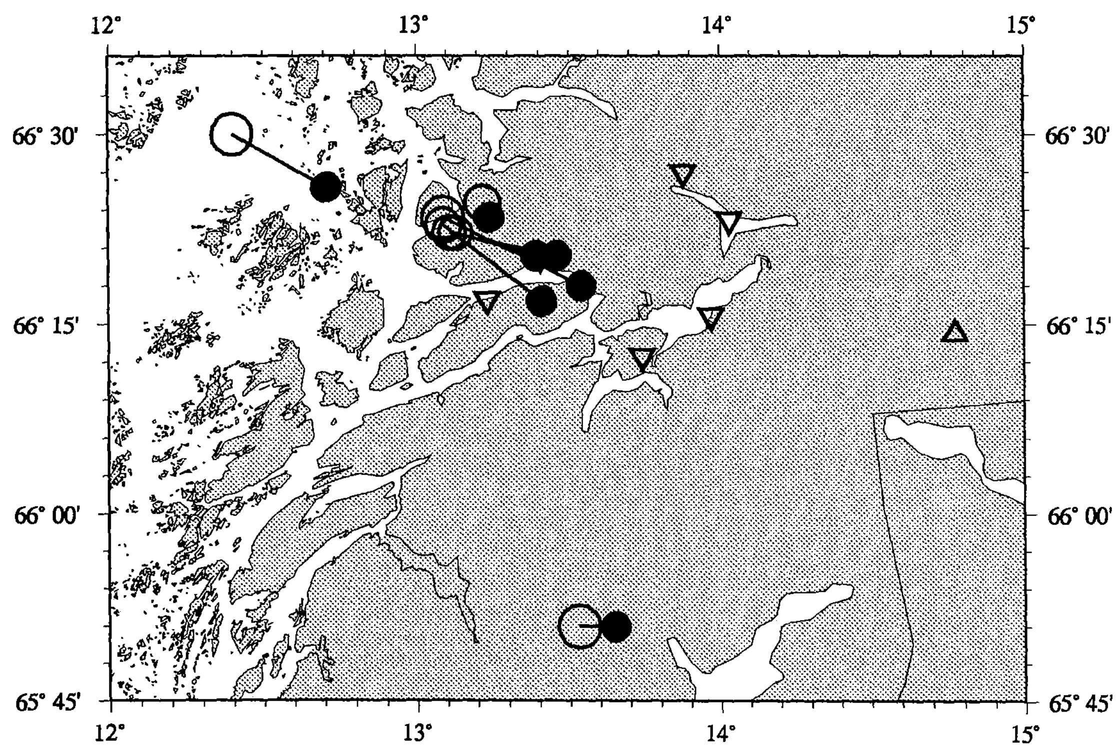

Fig. 7.6.8. Locations of the 7 reviewed events (filled circles) and the corresponding local solutions (open circles).