Notes – *Notiser*

Seismic evidence of complex tectonics in the Meløy earthquake area

SVEIN VAAGE

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A four station seismic network recording three components on analog magnetic tape was operated on an experimental basis and in a few limited time intervals during the microearthquake sequence in Meløy, northern Norway. The experiment resulted in over 100 recorded events. Eight of these have been used to find accurate hypocenters. The hypocenters clustered within a volume of $5 \times 2 \times 1.5$ km^3 and the depth varied from 8.1 to 9.6 km. The first motion data do not fit the previously published composite focal mechanism solution, the difference probably being caused by difference in data quantity and by variation in focal mechanism due to influence of local geological conditions.

S. Vaage, Jordskjelvstasjonen, Universitetet i Bergen, Allégt. 41, N-5014 Bergen-U, Norway.

An earthquake sequence in Meløy, northern Norway. (Fig. 1), starting in November 1978, added a new dimension to the seismic history of Fennoscandia as over 10,000 events were recorded within 10 weeks. The time-history and hypocenter distribution of the Meløy events have been described in considerable detail by Bungum et al. (1979) and Bungum & Husebye (1979). The tectonic implications of this microearthquake sequence have also been discussed by Gabrielsen & Ramberg (1979). More recently Gregersen (1979) and Stein et al. (1979) have drawn attention to the existence of several apparently similar sequences typically occurring near past and present glaciated areas.

During a few limited time intervals of the most active periods of the Meløy earthquake sequence and on an experimental basis Jordskjelvstasjonen, Universitetet i Bergen, operated four seismograph stations with three components recording on analog magnetic tapes. The purpose of this note is to present some preliminary results from the above mentioned four station network, and discuss the findings here compared to those of Bungum et al. (1979). In the latter case the analyses were tied to conventional records from mobile Sprengnether MEQ-800 seismographs.

Field operations

An updated seismicity map of Fennoscandia (after Bungum & Fyen 1980) is shown in Fig. 1 and clearly demonstrates that the Meløy earthquake sequence took place in one of the most active areas of this region. Details of the four station configuration are also shown in Fig. 1 together with the epicenter area as reported by Bungum et al. (1979). The instruments were of the type MARS-66 with four channel frequency modulated recording. In addition to the three seismic channels, timing signals via radio were recorded. The amplitude response of the system is flat (within 3 dB) between 5 and 80 Hz. The instruments are not designed for continuous earthquake monitoring and thus record only two hours of data on each tape. This, combined with a rather poor road network in the Meløy area, made it impossible to operate the network during night time. In fact, the station Enga (ENG) could only be operated for two hours each day. Details of recording intervals and number of recorded events are given in Table 1, while a record of presumed magnitude (M_L) 1.0 earthquake is displayed in Fig. 2.

Data analysis and results

Although the operation intervals of the four station network were rather short, a considerable number of microearthquakes were recorded (Table 1). In comparison, the network of Bungum et al. (1979) maintained an almost continuous monitoring of the whole area from Nov. 18, 1978 until June 1979. On the other hand, the significantly better resolution of our recordings makes it worthwhile to undertake at this stage analysis of a few selected events to check the epicenter location precision and possible con-

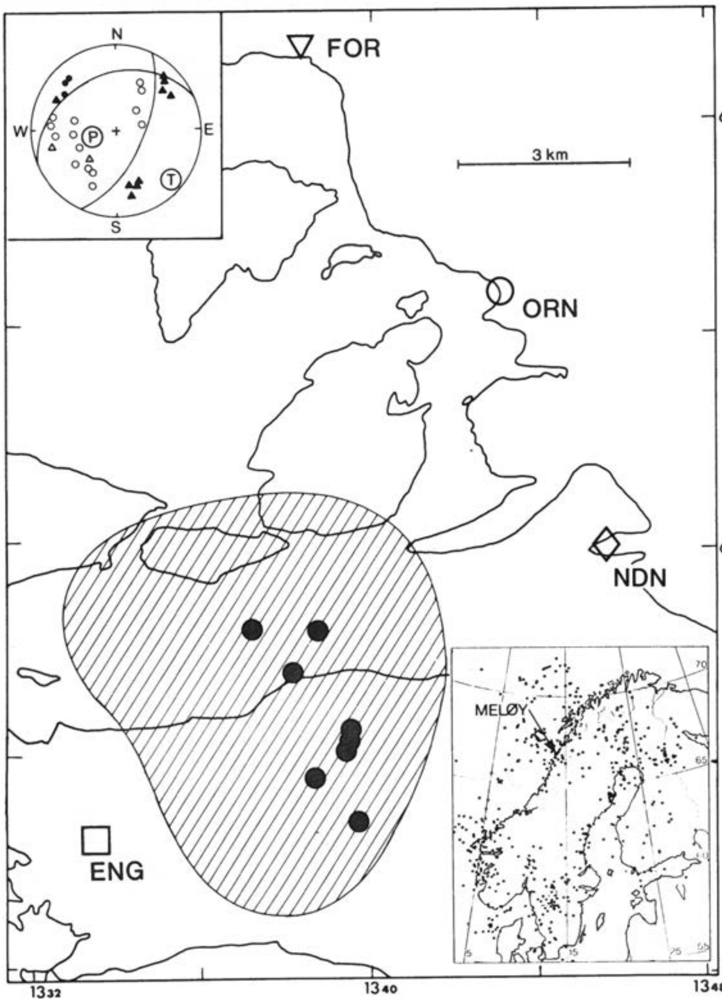

Fig. 1. Map of the Meløy area showing the sites of the three component network (open symbols) and the epicenters of the events in Table 2 (filled symbols). The epicenters of Bungum et al. (1979) lie within the hatched area. *Upper left insert*: Focal mechanism from Bungum et al. (1979). Compressions – solid symbols; dilatations – open symbols. The two nodal planes have strikes/dips of 25°/63°E and 250°/35°N, respectively.
Lower right insert: Seismicity of Fennoscandia 1954–1978. After Bungum & Fyen (1980).

straints on the focal mechanism solution reported by Bungum et al. (1979) (inserted in Fig. 1).

In order to compute accurate hypocenters, records from station ENG are indispensable in the given network configuration, as obvious from Fig. 1. In particular, without data from this station the uncertainties in the depths estimates would increase drastically. Thus, at this stage only eight events recorded at ENG (Table 2) have been subject to detailed analysis.

The hypocenters were computed by minimising the RMS-differences between the observed and calculated travel times of P and S waves. A P to S velocity ratio of 1.78 was used in a simple constant velocity half space ($\alpha = 6.25$ km/s). The S-P times of the recorded events were always less than 1.3 s at any station. This gives a maximum in hypocenter depth of about 11 km in the model. The uncertainties of the readings have been estimated to be in the order of 0.03–0.05 s somewhat dependent on the clarity of the

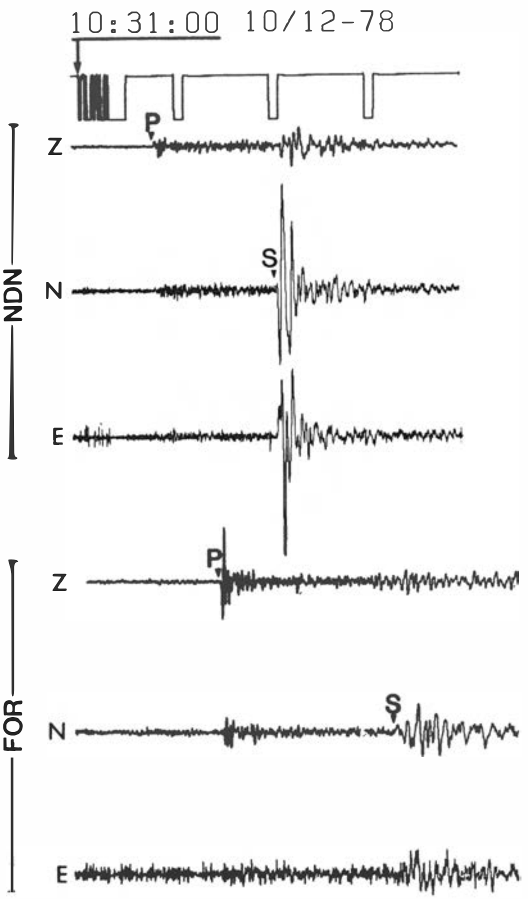

Fig. 2. Examples of three component recordings from NDN (Neverdal) and FOR (Fore) along with the timing signal as received from radio. Time interval between each pulse is 1 sec.

S wave onset. This gives an accuracy in the hypocenter determinations of about 0.5 km. The actual event locations for the eight events considered are shown in Fig. 1 and Table 2.

The first motion data of the events in Table 2 are plotted in Fig. 3 and a very preliminary focal mechanism solution is indicated.

Discussion

The epicenters in Fig. 3 all fall within the epicenter area defined by Bungum et al. (1979). The depths vary between 8.1 and 9.6 km (Table 2) while Bungum et al. found depths in the range 3–9 km. The results are considered consistent in view of the large difference in number of events analysed.

Focal mechanism. – The difference between the two focal mechanisms in Figs. 1 and 3 are interesting. While Bungum et al. (1979) found a composite solution showing near normal dip-slip, our data indicate a strike-slip solution with a normal dip-slip component. Since both focal mechanisms are composite, the differences may reflect non-uniqueness in the respective solutions or alternatively reflect genuine fault pattern differences. To discuss these two possibilities the following points are relevant.

Difference in data base. – In favour of the dip-slip solution, it can be stated that Bungum et al. have used four events separated both in time and space in their solution and thus have the possibility of getting an average solution of the

TABLE 1 Operational intervals of the 3 component network

Station	Date	Hours	No. of recorded events
ORN (Ørnes)	5-13/12-78	8-18	90
NDN (Neverdal)	6-13/12-78	8-18	76
FOR (Fore)	6-10/12-78	10-18	31
ENG (Enga)	7-11/12-78	10-12	8

TABLE 2 Results of hypocenter determinations.

No.	Date	Or.time	Epicenter		Depth (km)
1	07.12.78	11:15:24.4	66°47.3'N	13°40' E	9.2
2	07.12.78	11:16:19.5	66°49.1'N	13°37.5'E	8.5
3	07.12.78	11:37:26.3	66°47.7'N	13°39' E	8.2
4	07.12.78	11:42:13.9	66°49.1'N	13°39' E	8.1
5	10.12.78	10:30:05.5	66°48.1'N	13°40' E	8.7
6	10.12.78	10:30:59.1	66°48.1'N	13°40' E	9.1
7	10.12.78	10:36:16.8	66°47.9'N	13°39.5'E	9.6
8	10.12.78	11:15:15.8	66°48.7'N	13°38.5'E	8.8

whole activity. The events used in this paper cover only two short time periods (Table 2) and the hypocenters group within a small part of the total activated volume.

Dynamic properties. – The dip-slip solution does not account for the polarity changes of the P wave onset on station NDN (Fig. 3) which

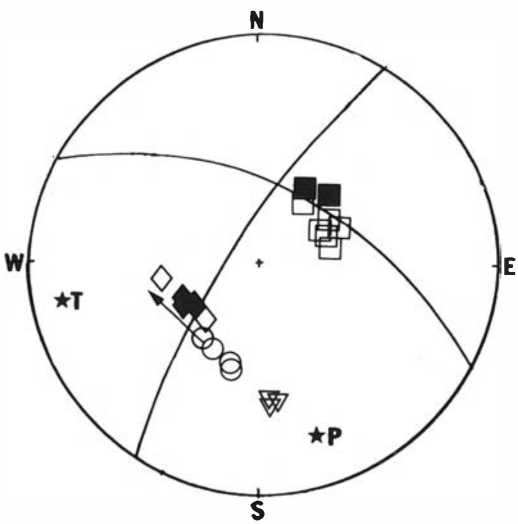

Fig. 3. Composite focal mechanism solution of the Meløy earthquakes listed in Table 2 plotted in a lower hemisphere stereographic projection. Dilatations are marked by open symbols and compressions are marked by solid symbols. The shape of the symbols represent first motion readings from the different stations in Fig. 1. The arrow indicate the direction of the first motion of the S waves on station NDN. P and T are inferred axes of maximum and minimum compressive stress. The two nodal planes have strikes/dips of 32°/80°W and 116°/62°N, respectively.

furthermore exhibit a clear SH arrival with a unidirectional polarity on all records. Finally, records from FOR (Fig. 2) show a clear P wave arrival with relatively large amplitudes compared to both the S waves on FOR and the P waves on NDN. These dynamic properties of the wave trains indicate that the station NDN is located near a nodal plane, while FOR is probably located between the two nodal planes. As can be seen from Fig. 3, the strike-slip solution fits these observational features very well.

Tectonic implications. – The tectonic setting of the Meløy area has been analysed by Gabrielsen & Ramberg (1979), using mapping based on satellite imagery (Landsat). The lineaments have two main directions, one parallel to the fjords (N80–85°E), and another striking NNE (N20–35°E). As can be seen from the focal mechanisms in Figs. 1 and 3, both solutions have one nodal plane striking in the latter lineament direction. In the dip-slip solution this plane also gave the best fit to the hypocenter distribution in space and was chosen as the most probable fault plane by Bungum et al. (1979). The eight hypocenters found in this paper are too clustered to give a reliable plane distribution in space. However, if the source is a ''single couple'' the plane striking N116°E has to be chosen as the fault plane because of the large SH-waves on station NDN (cf. arrow in Fig. 3).

Local geological conditions. – The influence of local geological conditions (pre-existing stress distribution) is likely to cause variation in the focal mechanism of small earthquakes (Richardson & Solomon 1976, Bergman & Solomon 1979, Bungum & Fyen 1980). Since no earthquake with M_L larger than 2.5 has been included in either of the two focal mechanism solutions from the Meløy area, variation in the mechanisms is likely to occur. This is also supported by the fact that both composite solutions have discordant points.

From the above discussion it is concluded that the difference between the two focal mechanisms reflects genuine fault pattern differences, rather than non-uniqueness in the solutions. A possible explanation for this difference is that although the main activity of faulting is confined to near vertical fracture planes striking N 20–35°E, the focal mechanisms of the events show variation according to the local stress pattern and prevailing geological conditions.

The stress generating mechanism associated with the Meløy earthquakes and similar sequences have been discussed by various authors. Glacial rebound and/or post-glacial sediment deposition on the continental shelf have been suggested as possible causes (Bungum et al. 1979, Stein et al. 1979, Bungum & Fyen 1980). The available data from the Meløy earthquakes seem too incomprehensive to be conclusive regarding the stress generating mechanism of the sequence.

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