

Earthquakes in the Skagerrak recorded at small distances

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During the winter 1977–1978 up to 3 seismographs were temporarily situated in the northern part of Jutland with the aim of recording near earthquakes. 3 seismic events, presumably earthquakes, have been recorded by 1, 2 or 3 of these seismographs. One of the earthquakes was large enough for a special investigation. The location of that earthquake is quite close to the coast of Jutland, while the two smaller earthquakes are located in the Norwegian Channel of the Skagerrak where a number of previous earthquakes are known to have happened. The depth of the largest earthquake is 40 km. The depth estimate is more accurate than any previous estimate because of the near seismic stations, that recorded the earthquake.

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Several times each year an earthquake is reported to have happened in the Skagerrak. Usually only a few seismological stations record these earthquakes because the stations are located quite far away from the earthquakes and the earthquakes are small. With the purpose of recording some of these earthquakes 3 seismological stations were operated in the northern part of Jutland during the winter 1977–1978. All of the stations have been in abandoned limestone quarries. One was in Gøttrup just south of Fjerritslev. The two others were underground, in Mønsted and in Thingbæk (fig. 2). One of the instruments was for a short time operated in Horne near Hirtshals. It was soon moved because we realized that we would obtain less noisy records by moving the instrument from the loose soil at Horne to a more solid limestone foundation at Thingbæk. Not all of the stations have been in operation all winter, because of technical difficulties with the instruments.

On the 26th of April 1978 an earthquake in the Skagerrak was recorded by two of the seismographs in Jutland, in Gøttrup and in Mønsted, and by many seismographs at larger distances. The seismic record from the seismograph near Gøttrup is presented in fig. 1. Such a clear record of a near Danish earthquake is worth noticing. The instrument records vertical earth motion with a magnification of approximately 40.000 for

the frequencies of this signal: If one follows the trace of the pen in fig. 1 from the minute mark at 12 hours 32 minutes one sees that the pen moved only slightly for 52 seconds after the minute mark and then moved vigorously for more than a minute. Two types of waves can be distinguished on this record. A P wave begins at time 12^h32^m52^s. This lasts for a few seconds, and the pen motion is seen to decrease. 9 seconds after the P wave arrival an S wave is seen in the record. A time difference of only 9 seconds between these two wave types is unusual for observations in Denmark. It corresponds to a distance to the earthquake of only 70 kilometers. Longer time differences correspond to longer distances.

Based on seismic records from the surrounding countries the earthquake of APR 26 1978 has been located by the present author at a position closer to the coast of northern Jutland than most of the previous instrumentally located earthquakes in the Skagerrak (table 1, fig. 2). The seismogram readings have been compared for stations that recorded this earthquake in 1978 as well as an earthquake in 1969, which was located by the International Seismological Centre, ISC. Seismogram readings common for the two earthquakes are available at the stations in Copenhagen, Uppsala, Bergen and Moxa in East Germany. The locations based on this limited data, are one degree of longitude apart, the 1978

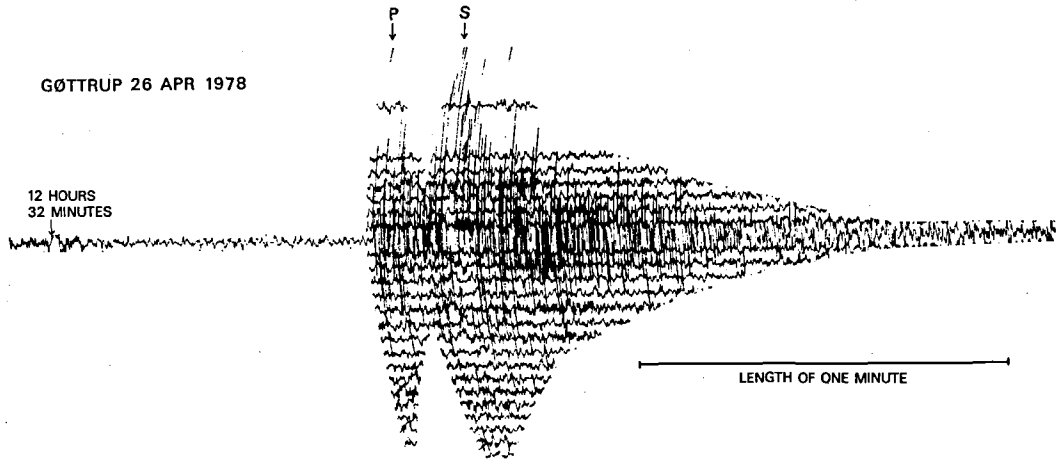


Figure 1. Seismogram from vertical seismograph (S-13 seismometer and MEQ-800 recording) in northern Jutland. P and S waves are distinguished with a time difference of 9.0 seconds.

epicenter being approximately 50 km closer to the coast than the 1969 epicenter. The latter is coincident with a few other earthquake epicenters (fig. 2).

It was also interesting to compare the data of the earthquake APR 26 1978 with that of an earthquake OCT 18 1954, since the old estimate of the epicenter of the 1954 event was close to that of the 1978 event. The 1954 estimate was 56°44'N 08°24'E, in northern Jutland. It was

based on instrumental data from only four stations at distances between 300 and 1400 km. Also taken into account was a report by Saxov (1956) with the macroseismic observations on where the earthquake was felt in northern Jutland. The time differences between the seismogram readings of the S wave in Copenhagen and the P and the S waves in Uppsala are the same for the events in 1978 and in 1954. This indicates that the two events may be very close to each other.

Table 1. Earthquakes in the Skagerrak and along the Norwegian south coast. All ISC locations for the period 1964–1974 and the locations calculated by the present author using a computer program HYPO 71 (Ward and Gregersen 1973) and an average crustal structure for Scandinavia from Noponen et al. (1978).

Year	Date	Time			Latitude N	Longitude E	Depth km	Magnitude	Source
		h	m	s					
1929	23 MAY	18	36	24.6	57°18	6°61	0	—	present author
1929	29 MAY	23	31	11.3	57°30	6°35	11	—	present author
1954	18 OCT	16	44	34.3	56°82	8°26	44	—	present author
1964	14 JUL	05	33	56.7	57°03	7°20	36	4.4	ISC
1966	9 FEB	23	54	08.0	58°20	9°10	0	—	ISC
1966	2 AUG	06	53	35.0	58°20	8°20	0	—	ISC
1967	12 APR	09	09	25.0	58°10	9°10	0	—	ISC
1968	18 JAN	12	54	55.0	58°00	6°60	0	—	ISC
1968	29 APR	21	59	21.0	58°00	8°80	0	—	ISC
1969	5 APR	19	09	48.3	57°13	7°04	33	—	ISC
1969	21 OCT	19	58	40.0	57°30	7°00	0	—	ISC
1970	19 MAR	08	26	20.3	58°52	10°40	0	—	ISC
1970	12 NOV	13	11	21.0	58°40	6°00	0	—	ISC
1972	30 NOV	10	33	24.8	57°06	7°18	0	—	ISC
1974	19 MAY	15	56	49.8	56°44	6°60	0	—	ISC
1974	16 OKT	08	13	21.1	57°13	7°24	0	—	ISC
1974	6 NOV	13	27	59.8	58°35	6°99	0	—	ISC
1978	13 JAN	15	53	24.1	57°95	8°53	27	approx. 3	present author
1978	16 JAN	13	04	36.1	57°63	7°75	34	approx. 3	present author
1978	26 APR	12	32	38.0	56°88	7°80	40	approx. 4	present author

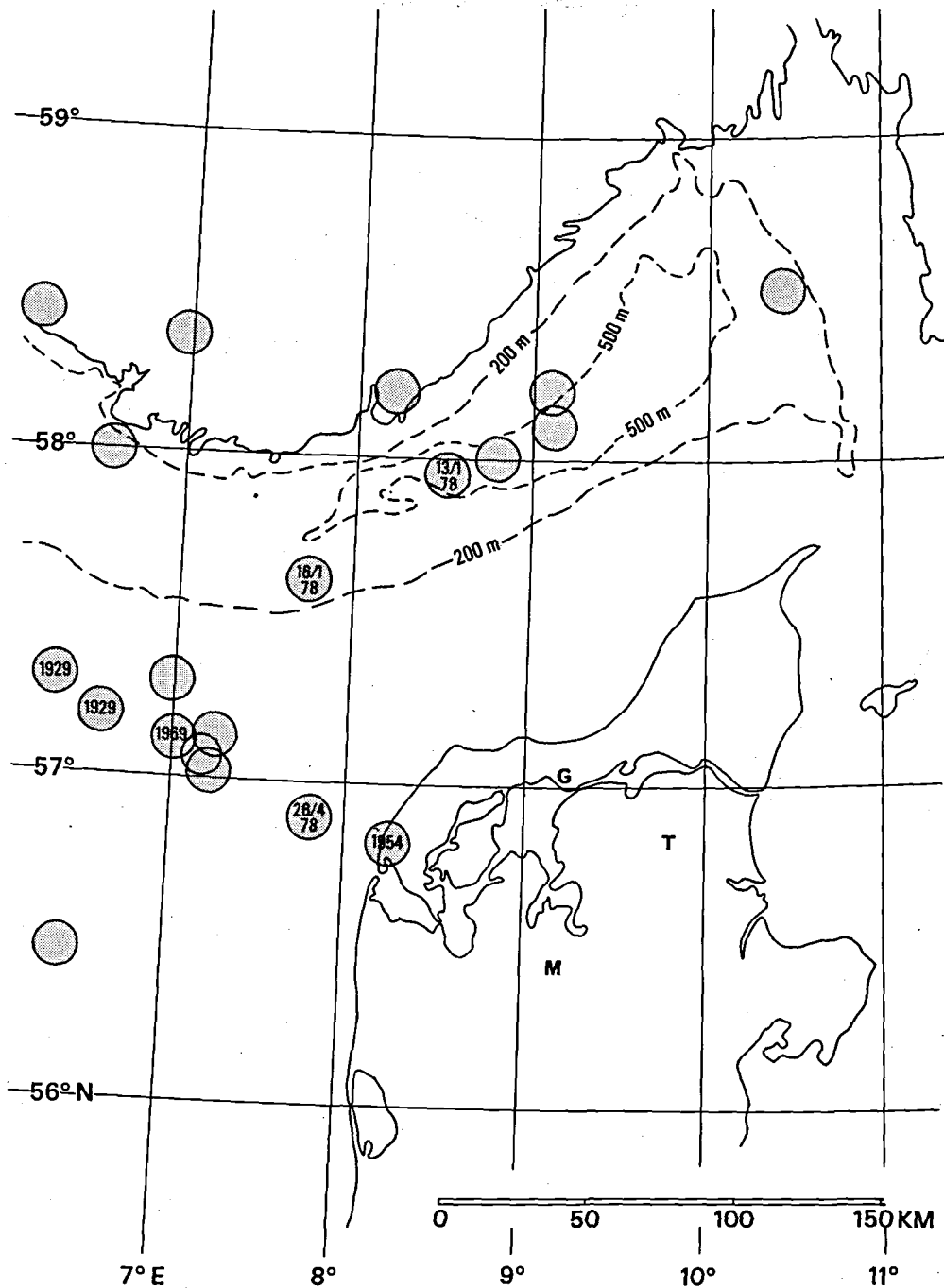


Figure 2. Epicenters for the earthquakes of table 1. All ISC locations for the period 1964–1974 and locations by the present author with date or year. 200 m and 500 m depth contours in the Norwegian Channel of the Skagerrak. G, M, and T indicate the locations of the seismographs in Gøttrup, Mønsted and Thingbæk respectively.

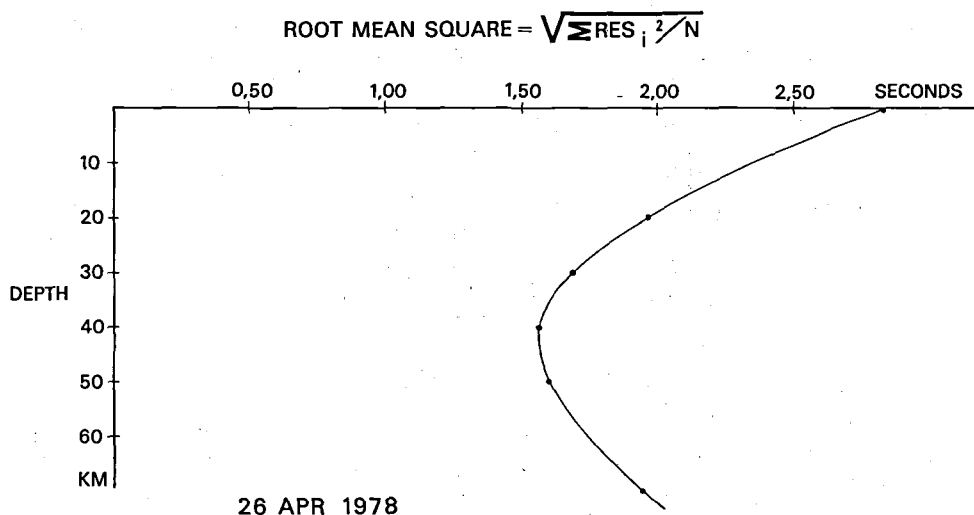


Figure 3. Root mean square for best fitting epicenter as a function of depth for the earthquake of 26 APR 1978. The root mean square is a measure of the misfit of the earthquake location to the data of the seismograms. The sum under the square root is over all i from 1 to N . N is the number of observations.

All of the seismogram readings of the 1954 event have been reevaluated by the present author in the light of the comparison with the recent events. The reevaluated time differences between the seismogram readings at all of the stations that recorded the 1954 event fit quite well to the calculated time differences for the 1978 position. A new epicenter of the 1954 event has been calculated by the present author based on the reevaluated data (table 1, fig. 2). The inaccuracy of the determined epicenter is such that it may be stated that the old and the new estimates of the epicenter of the 1954 event are close to each other, and that the 1954 event happened close to the location of the 1978 event (fig. 2). The 1978 location is one of the most accurate in the Skagerrak area, because of the near Jutland records.

A measure of the misfit between the observations and the calculations for the best fitting earthquake location is the sum of the squared residuals (expressed as root mean square in fig. 3), the residuals being the discrepancies between the observed arrival times of the seismic waves and the calculated arrival times. The depth dependence of the sum of the squared residuals for the 1978 event is illustrated in fig. 3. The curve has a minimum around 40 km depth, so a depth of 40 km is chosen for the earthquake. Fig. 3 is based on the seismogram readings of the near

stations in Jutland, Copenhagen, Norway, Sweden and Scotland. The uncertainty of the 40 km depth of the earthquake probably is 10–20 km.

The body wave magnitude of the 1969 earthquake was determined as 4.5 by the U.S. Coast and Geodetic Survey. The number of stations, on which this magnitude calculation is based, is so small that the International Seismological Centre did not report a magnitude. The presently investigated 1978 earthquake has a magnitude of approximately half a unit less than the 1969 earthquake, i.e. around 4.

Two even smaller earthquakes, of magnitudes around 3, have been recorded in northern Jutland by the temporary stations. The first one happened the 13th of January 1978. It has been plotted in fig. 2. It is seen to conform with the previously known pattern of seismicity. The depth is determined as 30 km. The other small earthquake happened the 16th of January 1978. It was a multiple event, i.e. more than one rupture event took place in a fault zone. Four events can be distinguished in the seismograms within 33 seconds. The main shock is the last and largest of the 4 events. Three aftershocks followed this multiple event, presumably in the same place, approximately 5, 6.5 and 7 minutes after the main shock. The first events of the multiple event were so small that there is doubt whether the more distant stations in Norway and Sweden re-

cord one or the other of the events as the first. As a consequence the uncertainties of the earthquake epicenter and the depth are larger than those of the events of 26 APR and 13 JAN 1978. Also this earthquake conforms with the previously known pattern of seismicity (fig. 2).

The earthquake bulletins of the University of Uppsala contain many more seismic events of small magnitude than those of table 1, that fall in the Skagerrak and near the Norwegian coast. Some events are expected or known explosions others are expected to be earthquakes. The epicenters of those earthquakes are more uncertain than those illustrated in fig. 2, because of the distances from the Swedish stations. The depths of those earthquakes can not be determined, for the same reason. Approximately 90 seismic events within the area of fig. 2 have been reported by the University of Uppsala in the 11 year period from 1964–1974, which are not in table 1 and in fig. 2. In the same period other agencies reported 15 additional events in the area.

Previous to 1964 the International Seismological Centre did not exist and fewer stations were in operation in Scandinavia, so only the largest events, mainly those that were felt by people, have been reported. Lehmann (1956) has published a list of the earthquakes that were known to have happened before 1956 in or close to Denmark. Only three earthquakes before 1964 were large enough so that a sufficient number of seismological stations had recorded signals from them and a location could be recalculated by the present author. Of these three the 1954 event has already been mentioned. The epicenters of two earthquakes which happened in 1929, 23 MAY and 29 MAY, have also been recalculated by the present author. They have been included in table 1 and in fig. 2. The earthquakes were described by Lehmann (1929). The seismogram readings on which the calculations are based are published in the International Seismological Summary. An additional reading on the Copenhagen records of the seismic wave Lg, which comes later than the S wave on the seismograms, has been done by the present author. The computer location program (Ward and Gregersen 1973) has been modified such that the Lg wave is taken into account. The

trend in the seismicity in fig. 2 through the 1929 epicenters SE toward the coast of Jutland may not be real. The 1929 epicenters are more uncertain than the other epicenters so they may coincide with the group of epicenters around the 1969 epicenter, and the 1954 epicenter may not be really different from the 1978 epicenter. It is argued though in this paper that the 1978 and the 1969 epicenters are different.

A seismic trend along the Norwegian Channel suggested previously from the data of the International Seismological Centre and the University of Uppsala is confirmed by the data of this paper. The earthquakes in the Skagerrak seem to happen typically close to the base of the earths crust at depths of 30–40 km.

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Dansk sammendrag

I løbet af vinteren 1977–1978 har op til 3 seismografer været midlertidigt placeret i den nordlige del af Jylland med det formål at registrere nære jordskælv. 3 jordrystelser, formodentlig jordskælv, er blevet registreret af 1, 2 eller 3 af disse seismografer. Et af jordskælvne var stort nok til en speciel undersøgelse. Dette jordskælvs position er ganske nær ved Jyllands kyst, medens de to mindre jordskælvs positioner er i Norskerenden i Skagerrak, hvor et antal tidligere jordskælv vides at være sket. Dybden af det største af jordskælvne er 40 km. Dette dybdeskøn er mere nøjagtigt end noget tidligere skøn på grund af de nære seismiske stationer, der registrerede jordskælvet.

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