

OTA KULHÁNEK AND RUTGER WAHLSTRÖM

MACROSEISMIC OBSERVATIONS
IN SWEDEN
1984–1990



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ABSTRACT

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Macroseismic data from 33 earthquakes in Sweden in the period 1984–1990 were collected and analysed. Maximum intensity is given in all cases but two; where the data so permit radius of perceptibility, focal depth and macroseismic magnitude are given, and isoseismal maps are drawn. The period is characterized by high seismicity, with two of the largest earthquakes in Sweden in the current century: in Kattegat on June 15, 1985, $M_L(\text{UPP})=4.6$, $I_0=\text{VII}$, and near Skövde, province of Västergötland, on July 14, 1986, $M_L(\text{UPP})=4.5$, $I_0=\text{V-VI}$. The peak ground acceleration for the former event is estimated at 15% g.

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INTRODUCTION

During the currently investigated 7-year period, 1984–1990, 33 instrumentally recorded earthquakes in Sweden were reported felt, not counting aftershocks connected with at least two of the events. This number is slightly higher than that for the previous 7-year period, 1977–1983, namely 28 (Kulhánek and Wahlström 1981, 1985), not counting a series of small earthquakes in southeastern Dalarna in 1981. The average annual number of felt earthquakes during the past few decades is smaller, about three (Båth 1979), and the increase in the last years may in part be an effect of improved systematic compilation of macroseismic data (see Kulhánek and Wahlström 1985). However, the instrumental data also show exceptionally high seismicity lately, e.g., two of the largest earthquakes in Sweden during the current century: in Kattegat on June 15, 1985, magnitude, $M_L(\text{UPP})=4.6$ and Skövde on July 14, 1986, $M_L(\text{UPP})=4.5$; a third event exceeding magnitude 4 – Kattegat on April 1, 1986; and four events with magnitude 3.6–3.7. The Kattegat and Skövde earthquakes were studied specially (Arvidsson et al. 1991a, b). The estimated maximum intensity of the largest Kattegat earthquake corresponds to peak ground accelerations of 0.8 m/s² vertically and 1.3 m/s² horizontally (Trifunac and Brady 1975), i.e., a total acceleration of about 15% g. Seismometer networks were installed and temporarily operated in the epicentral area after several of the earthquakes, but except for the Skövde earthquake (Holmqvist and Wahlström 1987) no or only minor aftershock activity was recorded during the field campaigns.

From the maximum intensity, I_0 (MM – Modified Mercalli 1956 scale), and radius of perceptibility, r_p (km), the focal depth, h (km), and macroseismic magnitude, $M_M(\text{UPP})$, are computed according the equations used by Kulhánek and Wahlström (1985):

$$I_0 - 2.5 = 4 \log \frac{\sqrt{r_p^2 + h^2}}{h} \quad (1)$$

$$M_M(\text{UPP}) = 0.38 + 1.14 \log r_p + 0.23I_0 \quad (2)$$

where $M_M(\text{UPP})$ is calibrated with the regional instrumental scale for Fennoscandia, $M_L(\text{UPP})$. Table 1 summarizes instrumental and macroseismic parameters for the 33 earthquakes. Epicentre locations are mapped in Fig. 1.

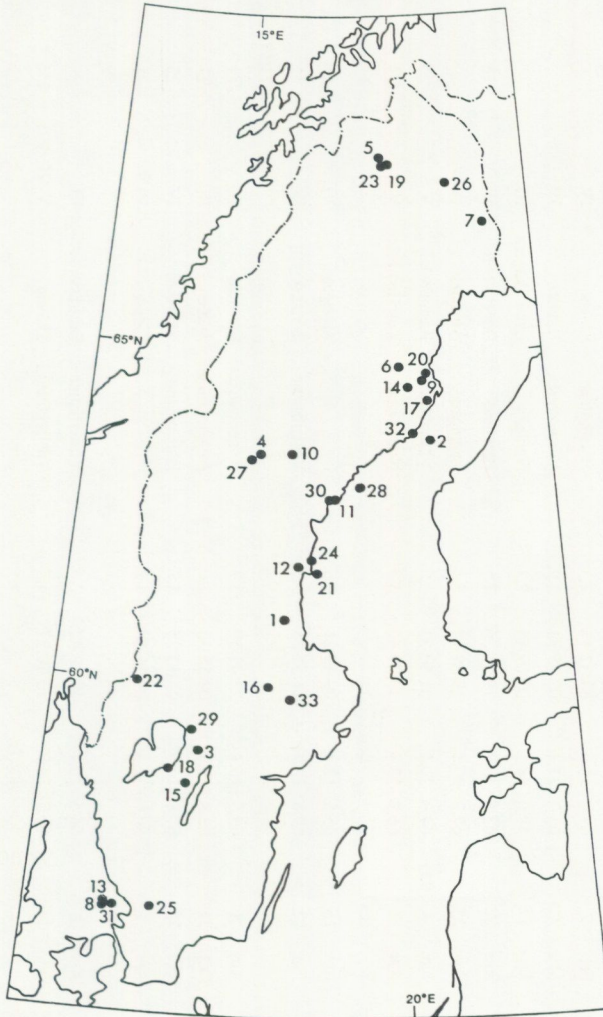


Fig. 1. Epicentres of earthquakes felt in Sweden 1984-1990. Enumeration follows Table 1.

TABLE 1. Instrumental and macroseismic parameters of earthquakes in Sweden recorded and felt in 1984-1990

Event No.	Date	Instrumental parameters				Macroseismic parameters						
		Epicentral coordinates °N °E		Origin time GMT	Magnitude M_L (UPP)	Province	Location	Max felt intensity MM, 1956	Radius ¹⁾ Km	Focal depth Km	Magnitude M_M (UPP)	Isoseismal map
1	Feb. 2, 1984	61.0	16.6	03 32 16	2.1	Hälsingland	Lingbo	IV				
2	Mar. 2	63.7	21.1	02 25 31	2.9	Västerbotten	Holmön	IV				
3	Mar. 17	59.0	14.3	00 09 15	2.1	Närke	Lake Skagern	III				
4	Apr. 27	63.5	15.7	19 52 26	2.5	Jämtland	Borgvattnet	III-IV	18	12	2.6	Fig. 2
5 a)	Aug. 25	67.9	19.5	19 39 14	3.1	Lappland	Årosjåkk	IV-V				
6	Jan. 8, 1985	64.8	20.1	01 50 33	3.0	Västerbotten	Bastuträsk	V	26	6	3.1	Fig. 3
7	Apr. 2	66.9	23.3	19 29 40	3.2	Norrbottn	Korpilombolo	V	74	18	3.7	Fig. 4
8	Jun. 15	56.6	12.3	00 40 21	4.6		Kattegat	VII ²⁾	168	13	4.5	Fig. 5
9	Jun. 22	64.6	20.9	14 37 23	3.3	Västerbotten	Burträsk	IV	34 ²⁾	16	3.0	Fig. 6
10	Aug. 8	63.5	16.7	22 45 59	2.7	Ångermanland	Ramsele	IV	24	11	2.9	Fig. 7
11	Oct. 31	62.8	18.0	02 55 52	2.6	Ångermanland	Ådalen	III	21	22	2.6	Fig. 8
12	Jan. 25, 1986	61.8	16.9	23 13 25	3.2	Hälsingland	Näsviken	IV	25	12	2.9	Fig. 9
13	Apr. 1	56.6	12.3	09 56 55	4.2		Kattegat	VI ²⁾	98	13	4.0	Fig. 10
14	Apr. 8	64.5	20.4	10 29 42	2.6	Västerbotten	Burträsk	III				
15 b)	Jul. 14	58.5	14.0	13 50 37	4.5	Västergötland	Skövde	V-VI	146	26	4.1	Fig. 11
16	Sep. 20	60.0	16.2	22 15 04	3.6	Västmanland	Salbohed	IV	57	26	3.3	Fig. 12
17	Oct. 27	64.3	21.0	05 46 05	2.6	Västerbotten	Ånäset	III-IV	25(IV)			

18	Nov. 2	58.7	13.5	07 48 00	3.6	Västergötland	Mariestad	V	79	19	3.7	Fig. 13
									16(IV)			
									5(V)			
19	Apr. 19, 1987	67.8	19.8	12 39 52	3.6	Lappland	Puoltsa	III-IV				
20	Apr. 25	64.7	21.0	06 52 43	2.4	Västerbotten	Skellefteå	IV	16	7	2.7	Fig. 14
21	Jul. 23	61.7	17.5	13 16 19	3.0	Hälsingland	Hudiksvall	III-IV				
22	Jul. 25	60.0	12.4	05 30 57	3.1	Värmland	Charlottenberg	V	44	11	3.4	Fig. 15
									12(V)			
23	Aug. 18	67.8	19.7	01 11 43	2.6	Lappland	Passekärsa					
24	Oct. 5	61.9	17.3	22 51 49	2.4	Hälsingland	Strömsbruk	III				
25	Oct. 16	56.6	13.3	20 06 25	2.2	Halland	Knäred					
26	May 16, 1988	67.5	22.0	23 50 22	3.3	Lappland	Masugnsbyn	IV	23	11	2.9	Fig. 16
27	Oct. 14	63.4	15.4	21 02 44	2.5	Jämtland	Nyby	IV				
28	Jul. 25, 1989	63.0	18.8	10 44 54	3.3	Ångermanland	Ulvöarna	III-IV				Fig. 17
29	Sep. 26	59.3	14.1	21 46 30	2.8	Värmland	Kristinehamn	IV				Fig. 18
30	Mar. 30, 1990	62.8	17.9	02 16 39	2.9	Ångermanland	Ådalen	IV				
31	May 24	56.6	12.1	09 51 57	3.3		Kattegat	IV				
32	Aug. 22	63.8	20.5	04 08 32	2.8	Västerbotten	Umeå	IV				Fig. 19
33	Dec. 12	59.8	16.8	15 27 28	3.7	Uppland	Heby	IV-V	30	10	3.1	Fig. 20
									8(IV)			

1) Radius of perceptibility; where possible radii corresponding to intensities IV and V.

2) Estimate due to offshore located epicentre.

a) Felt aftershock at 21 35 31, $M_L(\text{UPP}) = 2.6$.

b) Felt aftershock at 14 45 33, $M_L(\text{UPP}) = 3.4$.

Two earthquakes with epicentres in Finland and one in Norway, which were felt in parts of Sweden, are briefly reported below. In addition to the confirmed earthquakes listed in Table 1, several instrumentally recorded earthquakes during the period were not reported felt. Data on all recorded earthquakes are given in Seismological Bulletin, Uppsala.

FELT EARTHQUAKES

Below follow reports on where and how the earthquakes of Table 1 were felt. The geographical name given as the title for each event and reported in Table 1 has been selected from a place (mostly a town or village) near the epicentre and need not be one of the sites from which macroseismic data have been collected. The place name is in most cases followed by the name of the province. The descriptions are mostly qualitative; parameter values are given in Table 1. Where sufficient data exist, an isoseismal map is plotted.

FEBRUARY 2, 1984, LINGBO, HÄLSINGLAND

A weak shock was felt on the early morning of February 2, 1984, within a limited area at the Gästrikland-Hälsingland border. Searching through newspaper articles and using telephone interviews we could estimate the intensity of shaking at Klubbäcken (III), Lingbo (IV), Mörtebo (III) and Norrbo (III). The scarcity of data does not allow the isoseismals to be drawn for this shock.

MARCH 2, 1984, HOLMÖN, VÄSTERBOTTEN

On the early morning of March 2, 1984, a medium-size earthquake occurred off the coast of Västerbotten. About 50 questionnaires have been collected, revealing that the shock was felt in a rather limited area around the city of Umeå. The maximum intensity was reported from Holmön and Sävar. Positive reports were received from Fällforsån (III), Holmön (IV), Holmsund (III), Hörnefors (III), Norrmjöle (II), Obbola (II), Sävar (IV), Täfteå (III) and Umeå (II). The offshore location makes it hard to draw isoseismals.

MARCH 17, 1984, LAKE SKAGERN, NÄRKE

A weak shock was felt on the early morning of March 17, 1984, within the area around the lake Skagern. Only a few reports were received, indicating that the maximum felt

intensity was III in Ålesund, Rudskoga and Skagersvik. No isoseismal map can be drawn from the sparse data.

APRIL 27, 1984, BORGVATTNET, JÄMTLAND

A medium-size earthquake took place in eastern Jämtland on the evening of April 27, 1984. Positive answers to our questionnaires were received from six localities: Boberg, Borgvattnet, Fullsjön, Köttsjön, Skyttmon and Sörviken. As follows from Fig. 2, all reported intensities varied between III and IV. The figure also exhibits the area of perceptibility of 1000 km². The available macroseismic data yield a focal depth of 12 km.

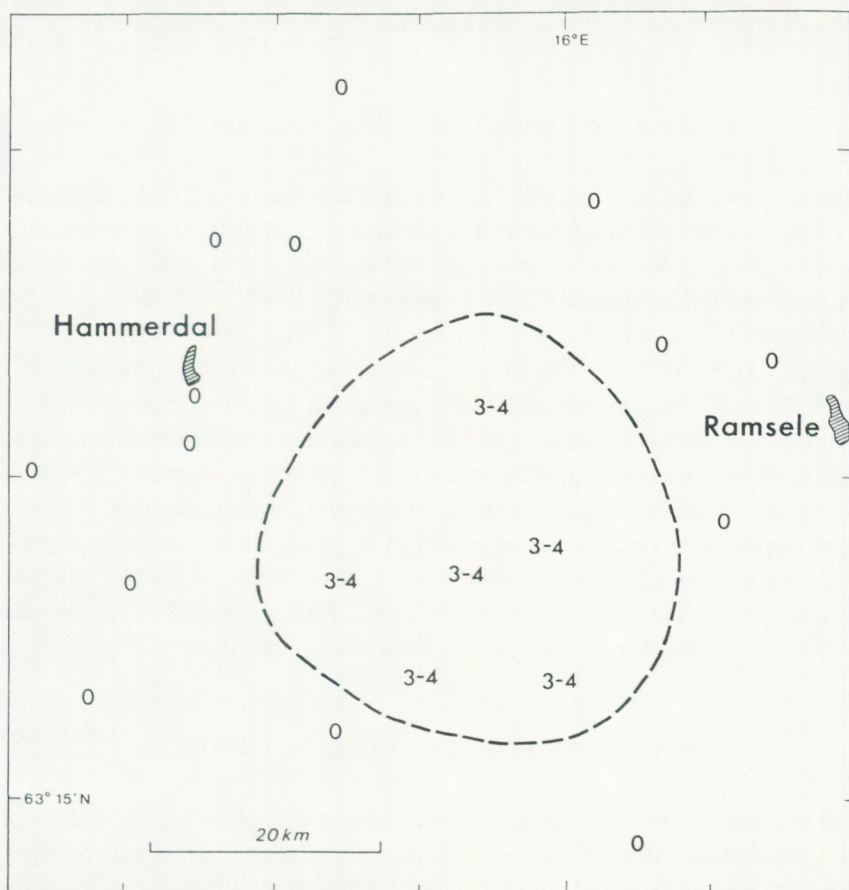


Fig. 2. Intensity distribution of the Borgvattnet earthquake of April 27, 1984. The dashed line limits the area of perceptibility, figures indicate intensity degree on the Modified Mercalli (MM) 1956 scale, zero means reported not felt.

AUGUST 25, 1984, ÅROSJÄKK, LAPPLAND

On the evening of August 25, 1984, a strong earthquake took place in northern Lappland, approximately 40 km west of Kiruna. The earthquake was followed, with approximately two hours delay, by a medium-size aftershock. Both shocks were reported felt. Due to the rather sparsely populated area, only six replies to our inquiries, published in local newspapers, were received. The main shock was felt in Årosjåkk (III), Kiruna (III), Laukuluspa (IV-V), south of the lake Paittasjärvi (IV-V), Pirttivuopio (IV-V), and Saivorova (IV). Buildings trembled and windows rattled. The main shock was felt by people indoors as well as outdoors. Earthquake sounds similar to a distant thunder were noticed at several localities. The directions of sound and vibration given in several reports are in good agreement with the instrumental epicentre. With respect to the geographically limited macroseismic information, no isoseismals could be drawn.

JANUARY 8, 1985, BASTUTRÄSK, VÄSTERBOTTEN

On the early morning of January 8, 1985, a strong earthquake occurred near Bastuträsk. The quake was felt within a large area of northern Västerbotten. Information collected from questionnaires was usually cross-checked by means of telephone interviews. The earthquake was felt in Älgräsk (III-IV), Arnberg (IV), Boliden (IV), Brännfors (IV-V), Fjällboheden (V), Forsbacka (III), Forsberget (V), Frautjälen (IV), Kåge (III-IV), Långträsk (II), Medle (IV), Mörttjärn (IV), Orrträsk (III-IV), Renström (IV), Risberg (III), Risliden (IV) and Skellefteå (III-IV). It was felt by many people indoors; many sleeping people awoke. Windows and doors rattled, floors creaked and furniture began to shake. At one locality a flower-pot and a table-lamp were overturned. There were three reports (Frautjälen, Kåge, Skellefteå) of animals (dogs, cat) reacting. According to several reports, the event was accompanied by a sound, similar to nearby explosions, lasting approximately 5 s. One report of minor damage (cracks in plaster) was received from a resident living in Fjällboheden. Collected macroseismic observations are displayed in Fig. 3, together with the area of perceptibility of 2100 km².

APRIL 2, 1985, KORPILOMBOLO, NORRBOTTEN

On the evening of April 2, 1985, a strong earthquake took place near Korpilombolo in eastern Norrbotten. Affluent macroseismic data were collected from both Sweden and Finland (A. Kataja, personal communication; Ahjos et al. 1986). Intensity estimates are available from some 160 localities (see Fig. 4). On the Swedish territory the quake was felt in Aapua (IV), Allsjärv (III), Hirvijärvi (III), Hunki (III-IV), Jarhois (III), Jockfall (III), Kangos (IV), Kassa (III-IV), Kimujärvi (IV), Kompelusvaara (III), Korpi-

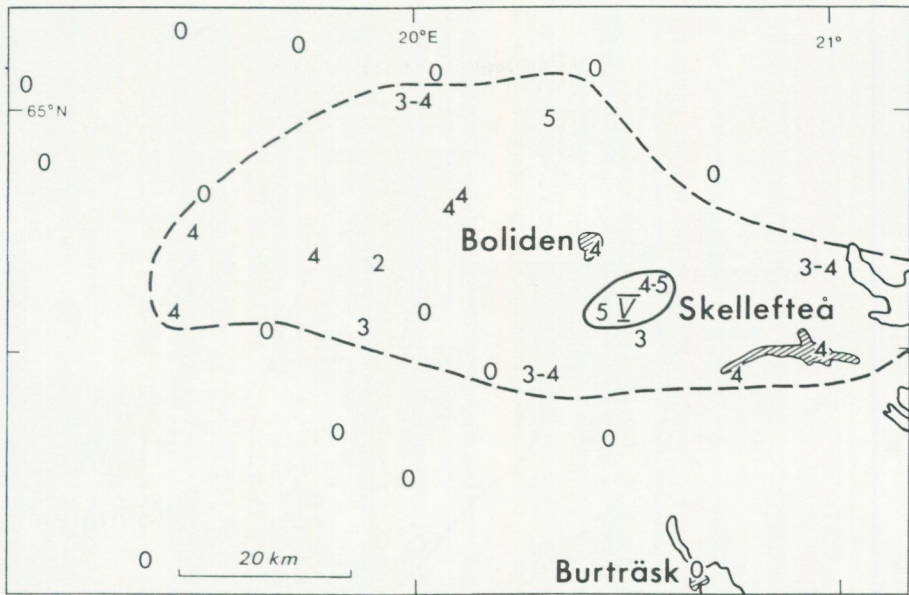


Fig. 3. Intensity distribution of the Bastuträsk earthquake of January 8, 1985. Conventions as for Fig. 2.

kylä (III), Korpilombolo (IV-V), Kuurajärvi (III), Lahenpää (IV), Lansån (III), Lovikka (III), Narken (III), Neistenkangas (IV), Övertorneå (III), Pajala (IV), Pello (III), Pempe-lijärvi (III-IV), Rantajärvi (III-IV), Skröven (II), Suaningi (V), Svanstein (III) and Tändö (IV). From a number of places a sound similar to a distant thunder or heavy traffic was reported. Felt vibrations lasted between 10 s and 20 s. At several localities, dogs became uneasy before and during the earthquake. The area of perceptibility was 17,000 km² which, together with the maximum felt intensity V (in Suaningi), provides a focal depth of 18 km. Fig. 4 shows the intensity distribution, the area of perceptibility and the area of intensity IV.

JUNE 15, 1985, KATTEGAT

A strong earthquake on the early morning of June 15, 1985, with epicentre at the off-shore border between Sweden and Denmark north of Zealand, was felt over a large portion of southern and southwestern Sweden with intensities up to VI. In eastern Denmark, the event was felt with intensities up to V. Minor damage occurred in Torekov (Sweden) and the neighbouring area. Several reports indicate cracked external walls and broken windows. In spite of the fact that the earthquake occurred beneath the seafloor,

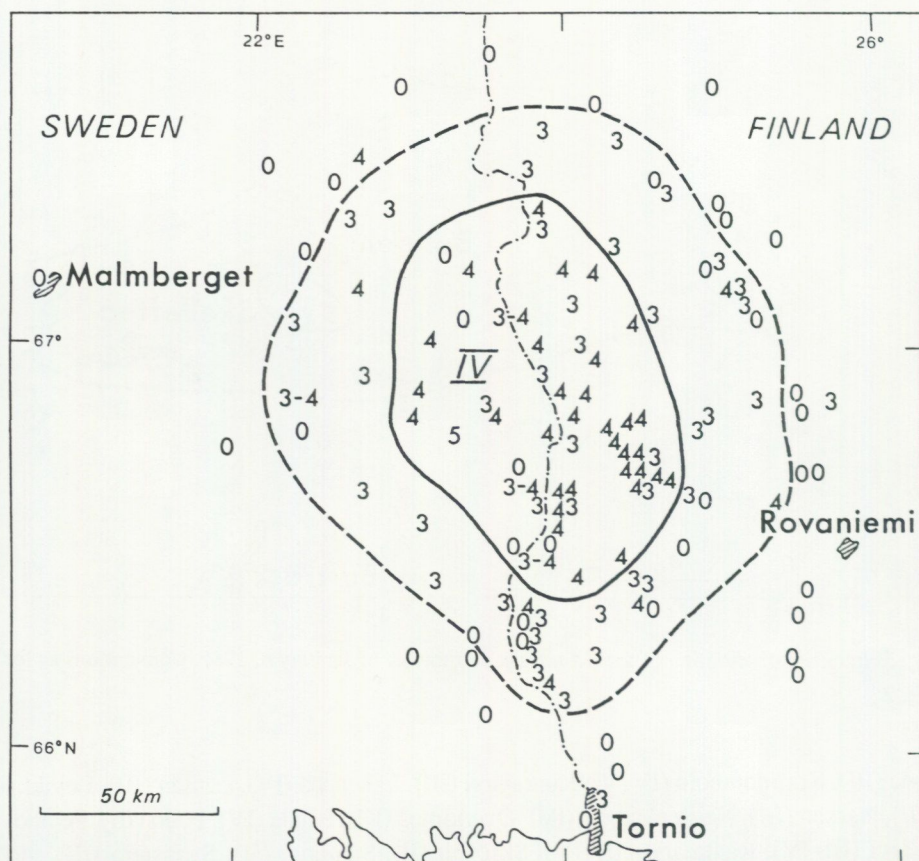


Fig. 4. Intensity distribution of the Korpilombolo earthquake of April 2, 1985. Conventions as for Fig. 2.

the outer limit (intensity II–III) of the area over which the earthquake was generally perceptible is well defined by the macroseismic surveys conducted by the Seismological Department, Uppsala University and the National Survey and Cadastre, Copenhagen. Approximately 500 written reports of intensity effects were received in response to questionnaires sent to postmasters in the area and to requests in local newspapers. In addition, a thorough survey of newspaper reports was carried out and local residents were interviewed. MM intensities were assigned to many localities and the resulting isoseismal map is shown in Fig. 5. For more details, the reader is referred to the two research units above. The experience from this and other similar studies is that the intensity at any given location may be very different from those at neighbouring locations. Obviously, the felt intensity is much dependent on local geology which in this case varies from bedrock to Quaternary deposits.

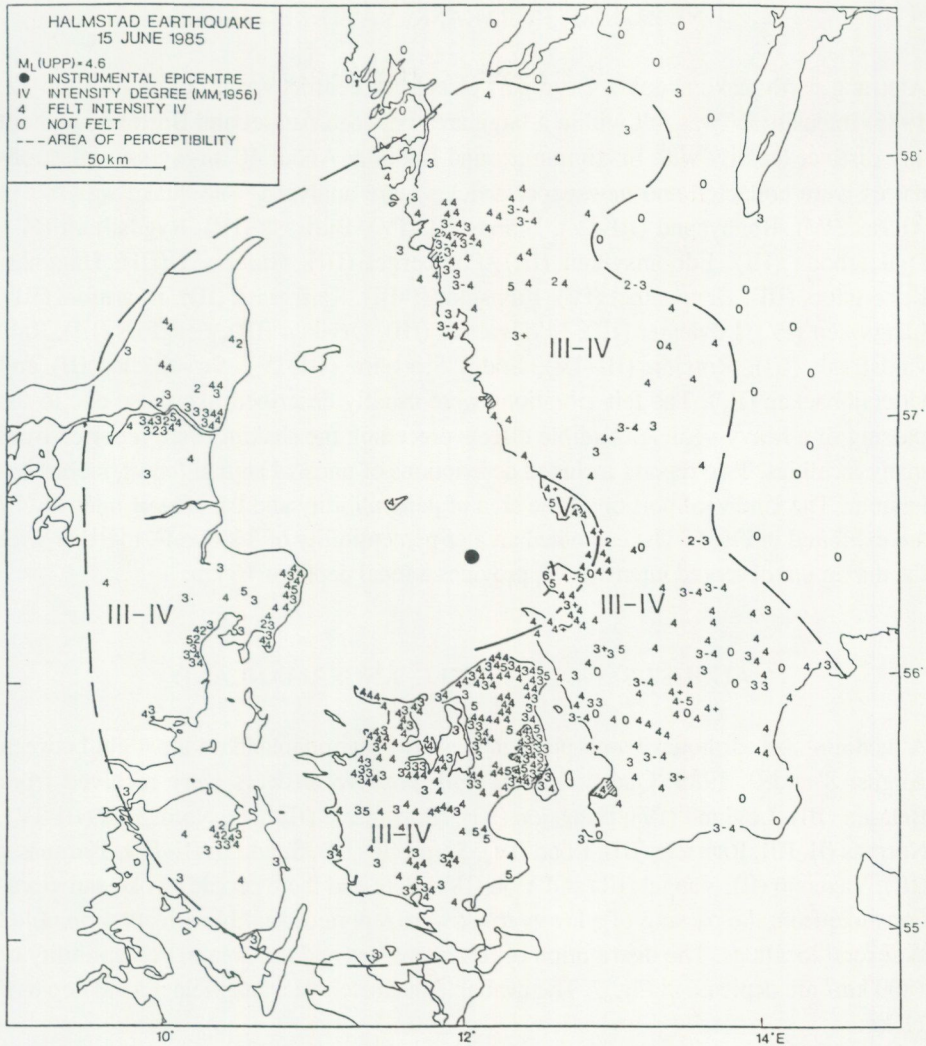


Fig. 5. Intensity distribution of the Kattegat earthquake of June 15, 1985 (from Arvidsson et al. 1991a).

Fig. 5 shows that the area of perceptibility was somewhat elongated in the north-south direction, suggesting a stronger attenuation towards the west and east of the epicentre. The observed asymmetry of the macroseismic field may also be due to the source radiation pattern. The area of perceptibility was 87,000 km². The epicentre being offshore, we assume I_0 to be one degree higher than the maximum observed intensity, i.e., we put $I_0 = VII$. With a mean radius of perceptibility of 168 km, introducing these entries into eq. (1) gives a focal depth of 13 km which is near the value (11 km) obtained from the arrival-time location (Arvidsson et al. 1991a).

JUNE 22, 1985, BURTRÄSK, VÄSTERBOTTEN

A strong earthquake shook a large part of eastern central Västerbotten on June 22, 1985. Intensity IV was felt within a large area between Ånäset and Burträsk, without any distinct locality with maximum ground shaking. About 40 answers to questionnaires were collected and newspaper articles were analysed. The quake was felt in Ånäset (IV), Bodbysund (III–IV), Brände (III–IV), Burträsk (IV), Bygdsiljum (IV), Djäkneboda (III), Edbomsviken (III), Forsberget (III), Gumboda (III), Hägnäs-Robertsfors (III), Hemvattnet (IV), Kamsjön (II–III), Kattisträsk (III), Kvarnfors (III), Långviken (IV), Lövånger (III), Mjödvattnet (III), Örviken (III), Pengfors (III), Ragvaldsträsk (III), Rotsjön (III–IV), Södra Stortjärn (III–IV), Strycksele (III) and Uttersjöbäcken (IV). The felt vibrations were usually described like those due to the passing of a heavy vehicle. Audible effects preceding the shaking were reported from many localities. Two reports included descriptions of unusual animal (cows, rabbit) behaviour. The landward portion of the area of perceptibility and the area of intensity IV are exhibited in Fig. 6. The estimated area of perceptibility of 3600 km², together with the maximum observed intensity IV, provides a focal depth of 16 km.

AUGUST 8, 1985, RAMSELE, ÅNGERMANLAND

A medium-size earthquake took place in western Ångermanland on the night between August 8 and 9, 1985. Questionnaires with positive answers were received from Betåsen (III), Lövlund (IV), Lungsjön (III), Mo-Junsele (III–IV), Nordantjäl (III–IV), Normäs (II–III), Ramsele (III), Röån (IV), Sörmoflo (III), Sundmo (III–IV), Tjännäset (III), Vägersjö (II), Vängel (III) and Ysjö (IV). Here and there people awoke and vibrations like from the passing of a heavy truck were reported. Audible effects were noted at several localities. The distribution of felt intensities and the area of perceptibility of 1800 km² are depicted in Fig. 7. The available macroseismic data yield a focal depth of 11 km.

OCTOBER 31, 1985, ÅDALEN, ÅNGERMANLAND

On the early morning of October 31, 1985, a medium-size earthquake was felt in the coastal area of Ådalen in Ångermanland. Intensity estimates at 15 localities were obtained through questionnaires obtained from Åsäng (III), Bönhamn (III), Brunne (II), Finsvik (III), Folkja (II), Hohl (III), Käckelbäcksmön (III), Kramfors (IV), Lillsela (II), Lugnvik (III), Mjällom (II), Norrkrånge (III), Sprängsviken (III), Svarvarböle (II) and Väja (III). Many observers described the vibrations as light trembling of buildings. A number of reports referred to audible effects of duration of several seconds. In Lill-

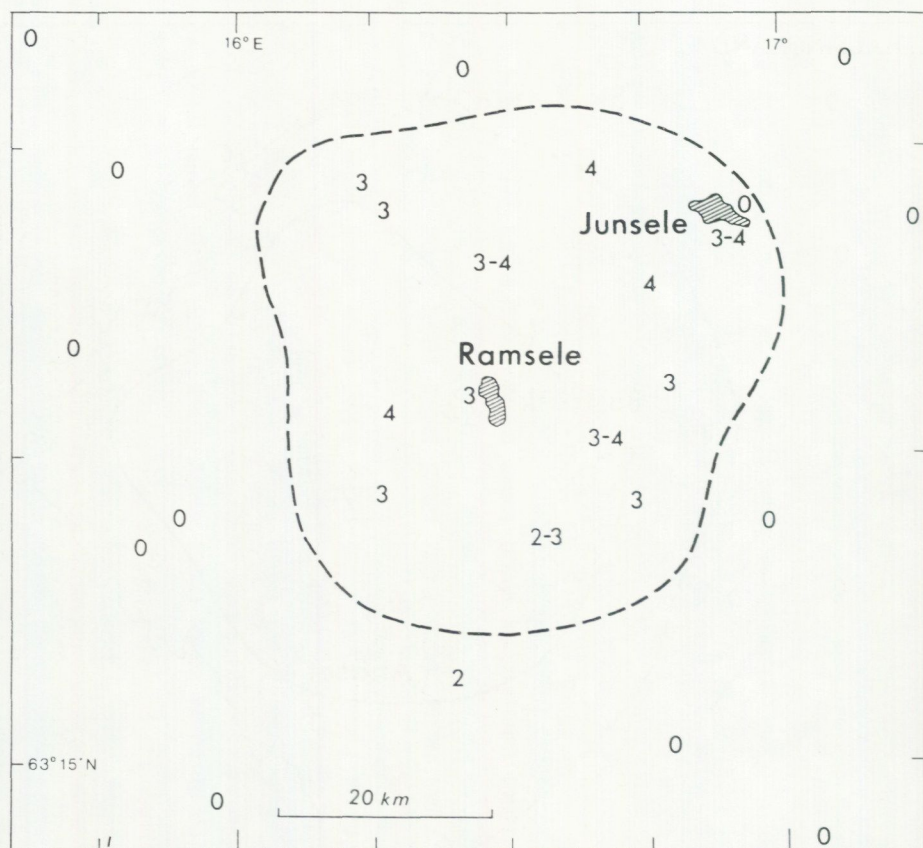


Fig. 7. Intensity distribution of the Ramsese earthquake of August 8, 1985. Conventions as for Fig. 2.

JANUARY 25, 1986, NÄSVIKEN, HÄLSINGLAND

On the night between January 25 and 26, 1986, the area between Bergsjö, Delsbo and Hudiksvall, in eastern Hälsingland, was shaken by a strong earthquake. The observed macroseismic field of a total area of 1900 km² does not show any distinct maximum of shaking (Fig. 9). Intensities III and IV were felt in a rather large region. With IV as maximum intensity we obtain a focal depth of 12 km. Questionnaires with positive reports were received from Ängebo (III), Arbrå (II), Bergsjö (IV), Bjästa-Bergsjö (IV), Bjuråker (IV), Delsbo (IV), Ede (IV), Forsa (II), Hålsjö (IV), Harmånger (II-III), Hassela (II-III), Hogland (II), Hudiksvall (III), Ilsbo (II-III), Källeräng (II-III), Malungen (III), Norrberg (III), Norrbo (III), Norrbobyn (III), Norrböle (II), Överälve (II-III), Ramsjö (III), Storsand (II), Strömsbruk (III), Svedja (III) and Vålsta (IV). Residents

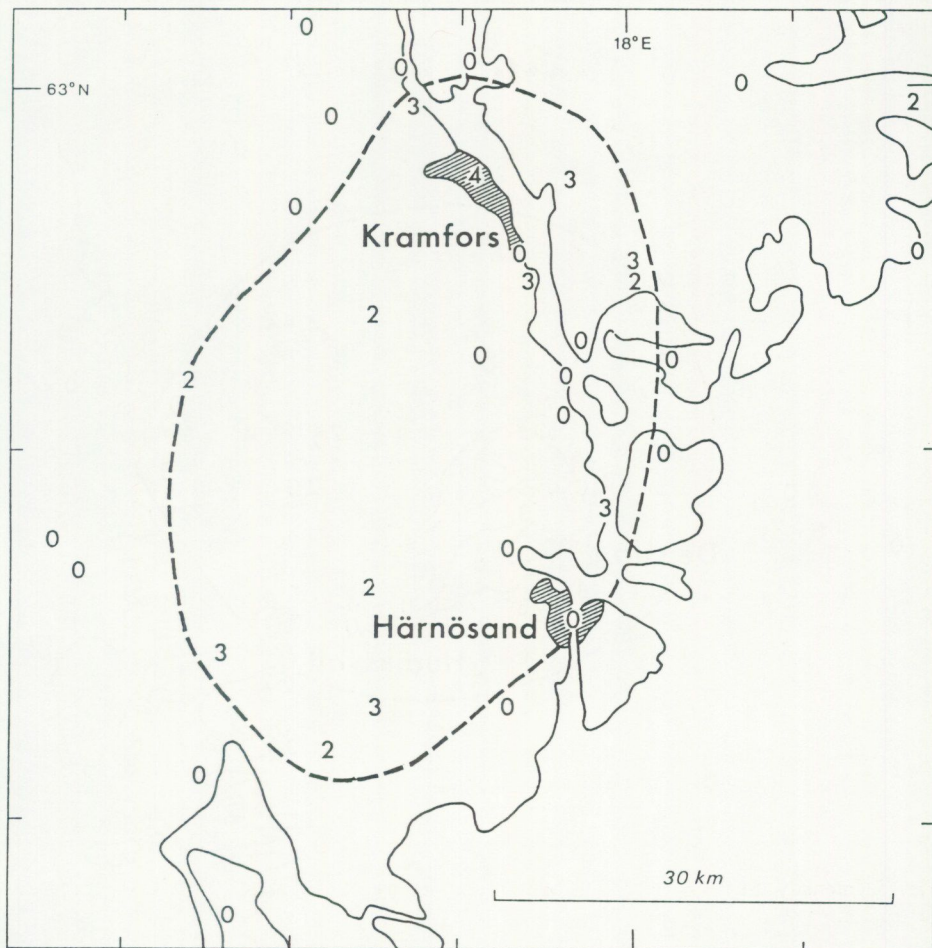


Fig. 8. Intensity distribution of the Ådalen earthquake of October 31, 1985. Conventions as for Fig. 2.

within the macroseismic area reported on shaking of buildings, windows and furniture rattling, and displacement of small objects. In most localities, the shaking was accompanied by a sound similar to that of a distant thunder.

APRIL 1, 1986, KATTEGAT

The strong earthquake of June 15, 1985, was followed on April 1, 1986, by another strong shock with magnitude $M_L(\text{UPP}) = 4.2$. The 1986 event was felt in a limited re-

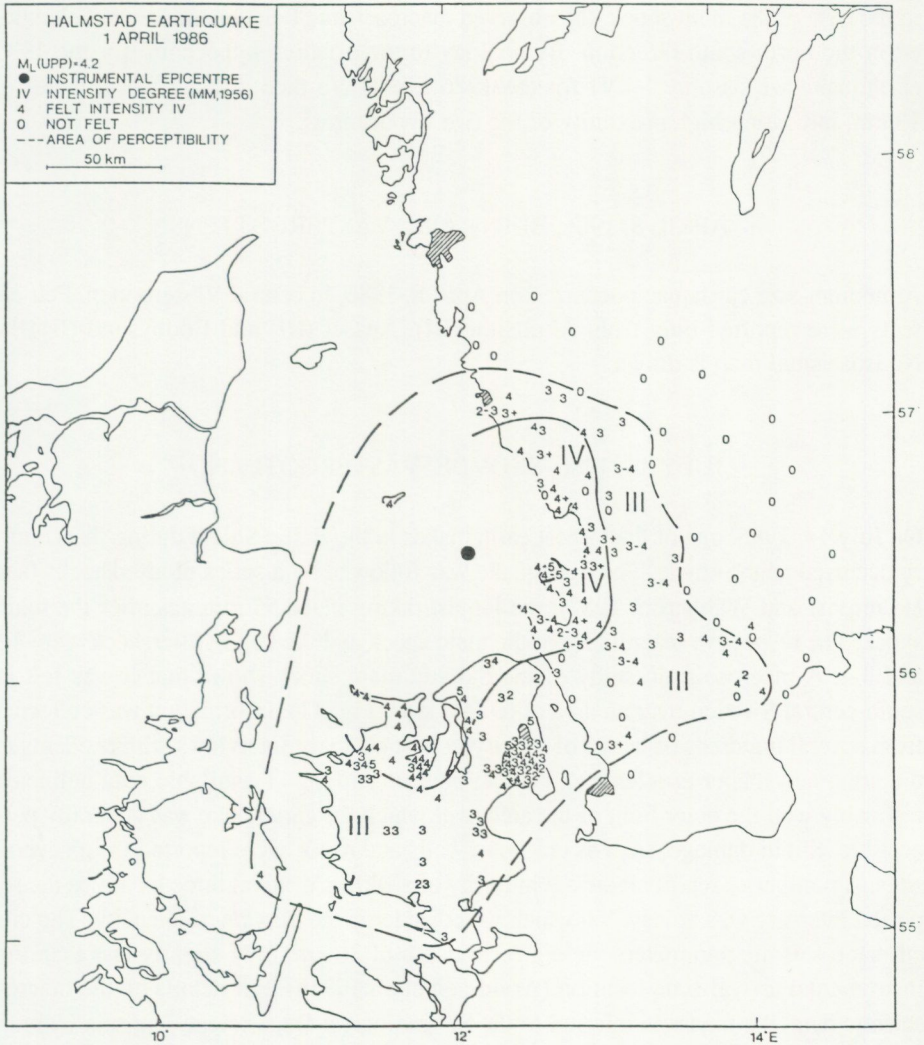


Fig. 10. Intensity distribution of the Kattegat earthquake of April 1, 1986 (from Arvidsson et al. 1991a).

gion of southwestern Sweden with maximum intensity IV+, and in eastern Denmark with maximum intensity V at several rather scattered localities. The isoseismal map (Fig. 10) was compiled from approximately 300 replies to questionnaires, direct interviews and newspaper reports (for details, contact research agencies mentioned in the text for the 1985 earthquake). Many reports indicate swinging lamps and trembling buildings. Fig. 10 shows that the macroseismic field is well constrained except for the directions towards west and northwest. The area of perceptibility was 30,000 km². As

in the case of the main shock, the observed macroseismic field was somewhat elongated in the north-south direction. By analogy to the offshore hypocentre for the 1985 earthquake we assume $I_0=VI$ for the 1986 event. We then obtain a focal depth of 13 km, indicating high proximity of the two hypocentres.

APRIL 8, 1986, BURTRÄSK, VÄSTERBOTTEN

A medium-size earthquake occurred on April 8, 1986, in central Västerbotten. Felt effects were reported only from Åkullsjön (III), Ånäset (III) and Bodbysund (II-III). No isoseismal map is drawn.

JULY 14, 1986, SKÖVDE, VÄSTERGÖTLAND

On July 14, 1986, one of the largest earthquakes in the Baltic Shield during this century occurred near Skövde. The earthquake was followed by a series of aftershocks (see Holmqvist and Wahlström 1987), the largest taking place 55 minutes after the main shock. The respective magnitudes of the main shock and the largest aftershock were 4.5 and 3.4. A macroseismic study of the Skövde main shock shows that it was felt in south-central Sweden over an area of 67,000 km² (Fig. 11). Information was collected from several hundreds of letters of inquiry to post officials, interviews with residents in the area, newspaper articles, etc. As can be seen in Fig. 11 available data delineate reasonably well the outer limit of the area over which the earthquake was generally perceptible. Slight damage, such as cracks in walls and roofs, were reported from several sites. A number of reports indicate intensity of shaking V and at three localities the reported intensity was at least V+ which we consider is the maximum intensity. The cited macroseismic parameters yield a focal depth of 26 km, only slightly less than the instrumental arrival-time location (Arvidsson et al. 1991b). For details on the macroseismic data, the reader is referred to the Seismological Department, Uppsala University. The proximity in time of the large aftershock, less than one hour after the main shock, makes an independent macroseismic evaluation unreliable.

SEPTEMBER 20, 1986, SALBOHED, VÄSTMANLAND

On the night between September 20 and 21, 1986, a strong earthquake was felt around Sala in eastern Västmanland. Reports of felt intensities were received from Alunda (II), Årsunda (III), Avesta (IV), Bäckby (III-IV), Folkärna (III), Hallstavik (III), Heby (IV-V), Horndal (IV-V), Jugansbo (IV-V), Karlbo (III), Kolsva (IV), Kungsör (III), Morgongåva (IV), Norberg (IV), Örsingsbo (IV), Österfärnebo (III), Östervåla (III-IV),

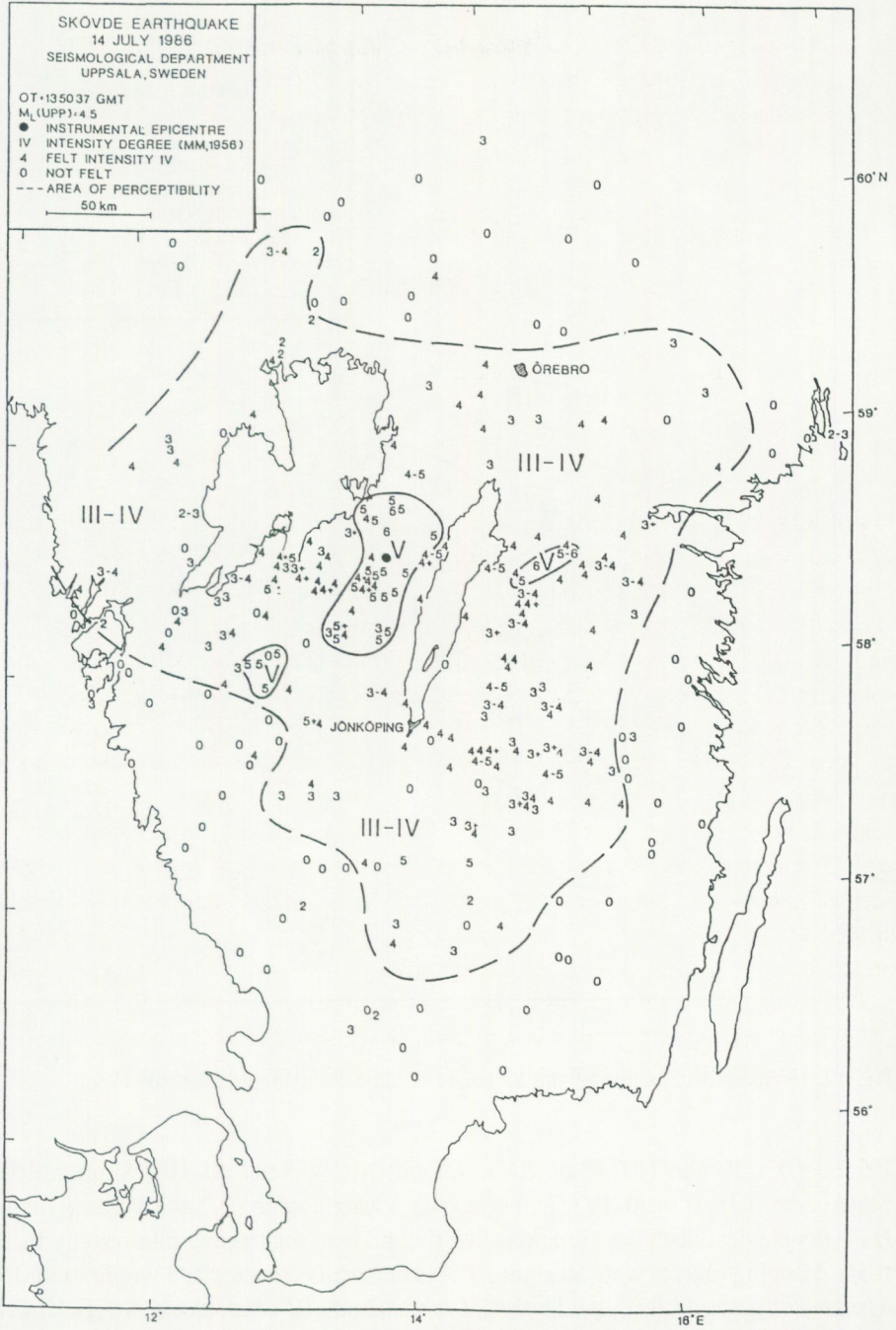


Fig. 11. Intensity distribution of the Skövde earthquake of July 14, 1986 (from Arvidsson et al. 1991b).

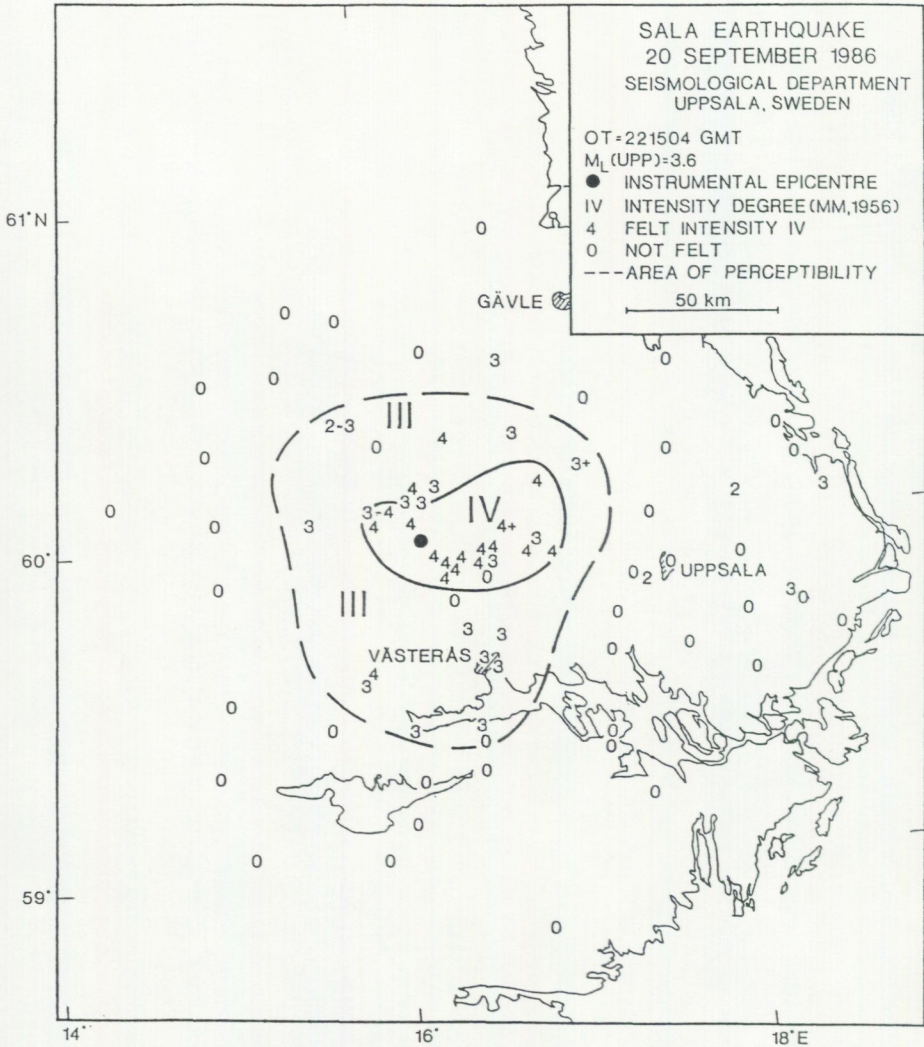


Fig. 12. Intensity distribution of the Salbohed earthquake of September 20, 1986.

Persbo (IV), Rimbo (III), Sala (IV), Salbohed (IV), Säter (II-III), Skultuna (III), Söderbärke (III), Tämsjö (IV), Tillberga (III), Västerfärnebo (IV) and Västervrenninge (IV). People described the vibrations like those due to the passing of a heavily loaded truck. Hanging objects were swinging, floors and walls cracking and windows rattling. The area of perceptibility and the area of felt intensity IV are depicted in Fig. 12. From the maximum intensity IV and area of perceptibility 10,000 km² we estimate the focal depth at 26 km.

OCTOBER 27, 1986, ÅNÄSET, VÄSTERBOTTEN

A medium-size earthquake was felt on the morning of October 27, 1986, in central Västerbotten. We received letters describing felt effects in Burträsk (III), Hökmark (III-IV), Innansjön (II) and Lövånger (III). The macroseismic data are too sparse to draw an isoseismal map.

NOVEMBER 2, 1986, MARIESTAD, VÄSTERGÖTLAND

On the morning of November 2, 1986, a strong earthquake took place with the epicentre in Lake Vänern close to Mariestad. The earthquake was felt over an area of 20,000 km² (Fig. 13). The available macroseismic information consists of about one hundred reports. For details, the reader is referred to the Seismological Department, Uppsala University. The maximum intensity, V, was observed some 20 km east-northeast from the instrumental epicentre (Fig. 13). The focal depth deduced from macroseismic data is 19 km, in good agreement with the corresponding instrumental arrival-time determination (21 km; Arvidsson et al. 1991b).

APRIL 19, 1987, PUOLTSA, LAPPLAND

A strong earthquake occurred in northern Lappland, approximately 20 km west of Kiruna, on April 19, 1987. Due to the scarce population in the region, reports on felt effects, corresponding to intensity III-IV, were received only from two localities, namely Årosjåkk and Laukuluspa. In Laukuluspa, dogs also showed unusual behaviour during and after the ground shaking. No isoseismal map can be drawn.

APRIL 25, 1987, SKELLEFTEÅ, VÄSTERBOTTEN

A medium-size quake took place on the morning of April 25, 1987, in the coastal region of northern Västerbotten. Letters with reports of felt effects were received mainly from the area near Skellefteå. The maximum intensity was IV. Altogether reports from the following 13 localities were collected: Boliden (II), Drängsmark (III), Ersmark (III), Frostkåge (III-IV), Gärdsmark (II), Gummark (II), Holmselet (II), Kåge (IV), Klintforsliden (II), Kusmark (III), Östanbäck (III), Skellefteå (III) and Tarsmyran (II). The area of perceptibility is 800 km² (Fig. 14) and the estimated focal depth is 7 km.

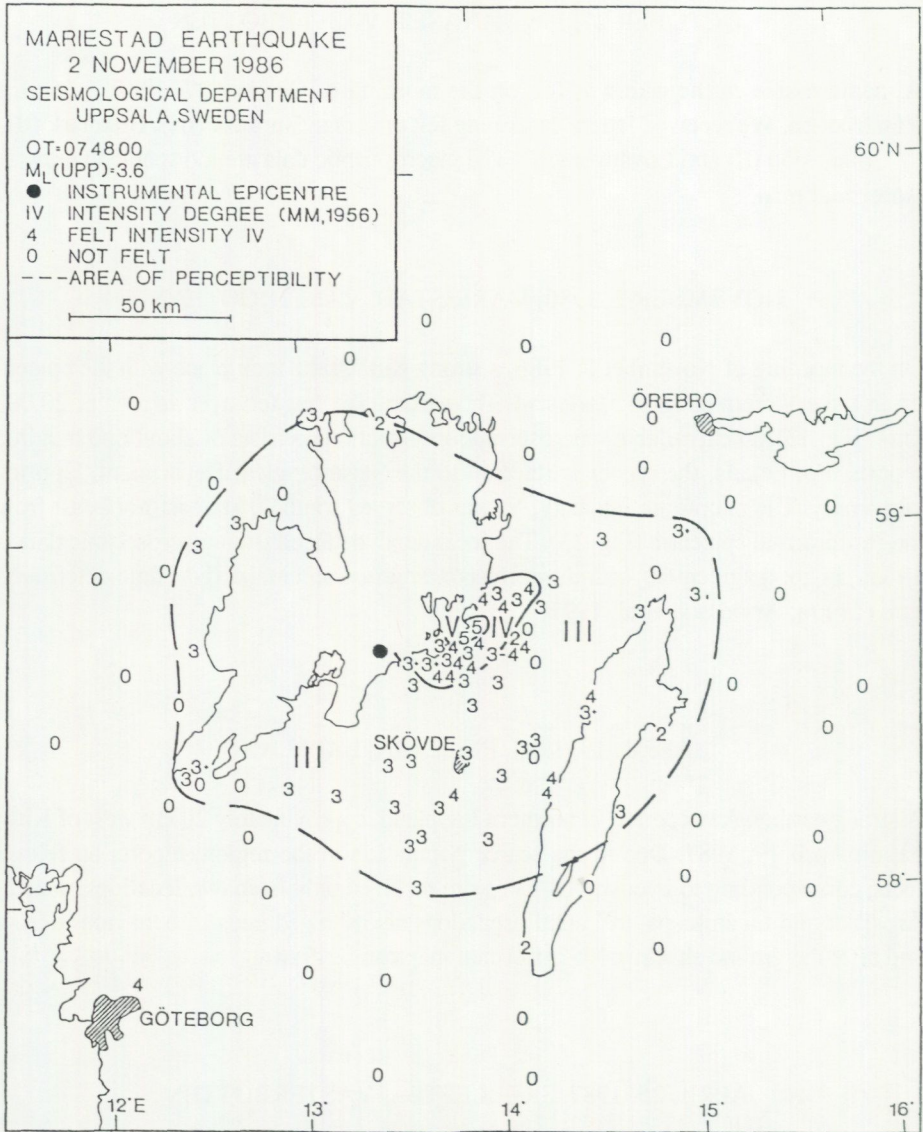


Fig. 13. Intensity distribution of the Mariestad earthquake of November 2, 1986 (from Arvidsson et al. 1991b).

JULY 23, 1987, HUDIKSVALL, HÄLSINGLAND

A strong earthquake occurred near the coast of Hälsingland on July 23, 1987. The quake was felt weakly only in the coastal rim between Hudiksvall and Sundsvall. Felt

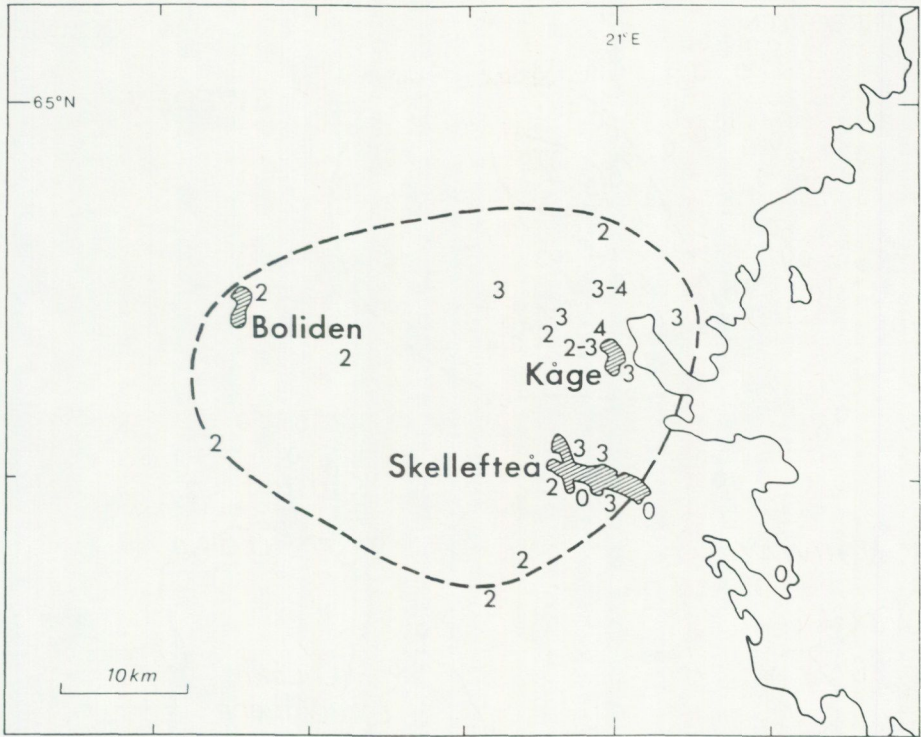


Fig. 14. Intensity distribution of the Skellefteå earthquake of April 25, 1987. Conventions as for Fig. 2

effects were reported from Gnarp (III), Hudiksvall (III), Kvissleby (II), Njurunda (III), Norrfjärden (III), Stocka (III), Strömsbruk (III) and Sundsvall (III-IV). No isoseismal map was drawn.

JULY 25, 1987, CHARLOTTENBERG, VÄRMLAND

On the morning of July 25, 1987, a strong earthquake took place in western Värmland, close to the Norwegian border. Buildings trembled, windows rattled and furniture began to shake. Reports on felt effects were obtained from 13 localities in Värmland through our questionnaires and newspaper articles: Adolfsfors (II), Åmotfors (IV), Arvika (II), Charlottenberg (III-IV), Fjällby (III-IV), Gunnarskog (III-IV), Håvilsrud (III), Helgeboda (II), Simonstorp (III), Torsby (III), Tøssebergsklätten (III), Uddheden (III) and Vitsand (II). The quake was also reported felt from many localities on the Norwegian side

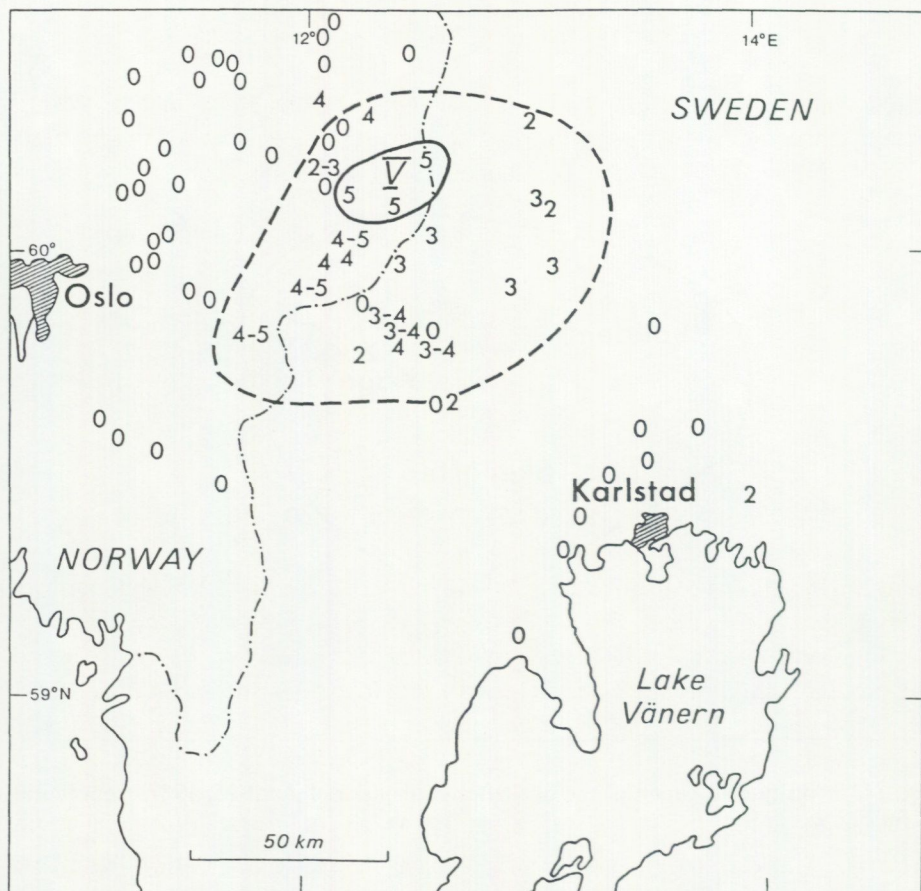


Fig. 15. Intensity distribution of the Charlottenberg earthquake of July 25, 1987. Conventions as for Fig. 2.

of the border (Seismological Bulletin, Bergen), where also the maximum intensity of V was observed (Fig. 15). The area of perceptibility was estimated at about 6000 km² and the focal depth at 11 km.

AUGUST 18, 1987, PASSEKÅRSA, LAPPLAND

A medium-size earthquake occurred on the early morning of August 18, 1987, some 40 km west of Kiruna. The earthquake was reported felt in Ratekjäkk. No macroseismic quantification can be made.

OCTOBER 5, 1987, STRÖMSBRUK, HÄLSINGLAND

A weak earthquake was felt shortly before midnight (local time) on October 5, 1987, in a rather limited area of northern Hälsingland. Reports with positive answers were received from Bergsjö (III), Gnarp (II), Harmånger (III) and Strömsbruk (II). No isoseismal map was drawn.

OCTOBER 16, 1987, KNÄRED, HALLAND

A weak earthquake was felt locally in southeastern Halland on the evening of October 16, 1987. No detailed information on macroseismic effects exists.

MAY 16, 1988, MASUGNSBYN, LAPPLAND

On the night between May 16 and 17, 1988, a strong earthquake occurred in northern Lappland near the border to Norrbotten. The quake was felt within a rather large area with maximum intensity of IV. Buildings vibrated, many sleeping people awoke and windows rattled. At two localities, household pets (cat, dog) showed unusual behaviour. The vibration was accompanied with a sound of about 30 s duration, similar to that of a distant thunder. From many places another shock some 30 minutes later was reported. This event has not been clearly recorded. Letters and positive answers to our questionnaires were received from Kiruna (III), Malmberget (II), Masugnsbyn (III), Nilivaara (II), Parakka (III), Puoltikasvaara (IV), Skaulo (IV), Tärendö (II) and Vettasjärvi (IV). Intensities and the area of perceptibility of 1700 km² are exhibited in Fig. 16. With a maximum intensity of IV the focal depth is estimated at 11 km.

OCTOBER 14, 1988, NYBY, JÄMTLAND

On the late evening of October 14, 1988, a medium-size earthquake occurred in eastern Jämtland. The shock was felt, with intensity IV, only in Nyby, about 30 km northeast of Östersund.

JULY 25, 1989, ULVÖARNA, ÅNGERMANLAND

A strong earthquake occurred on July 25, 1989, off the coast of central Ångermanland. The quake was felt in localities in the central coastal part of the province. Many people related the vibrations to those of a passing heavily loaded truck, windows rattled, furni-

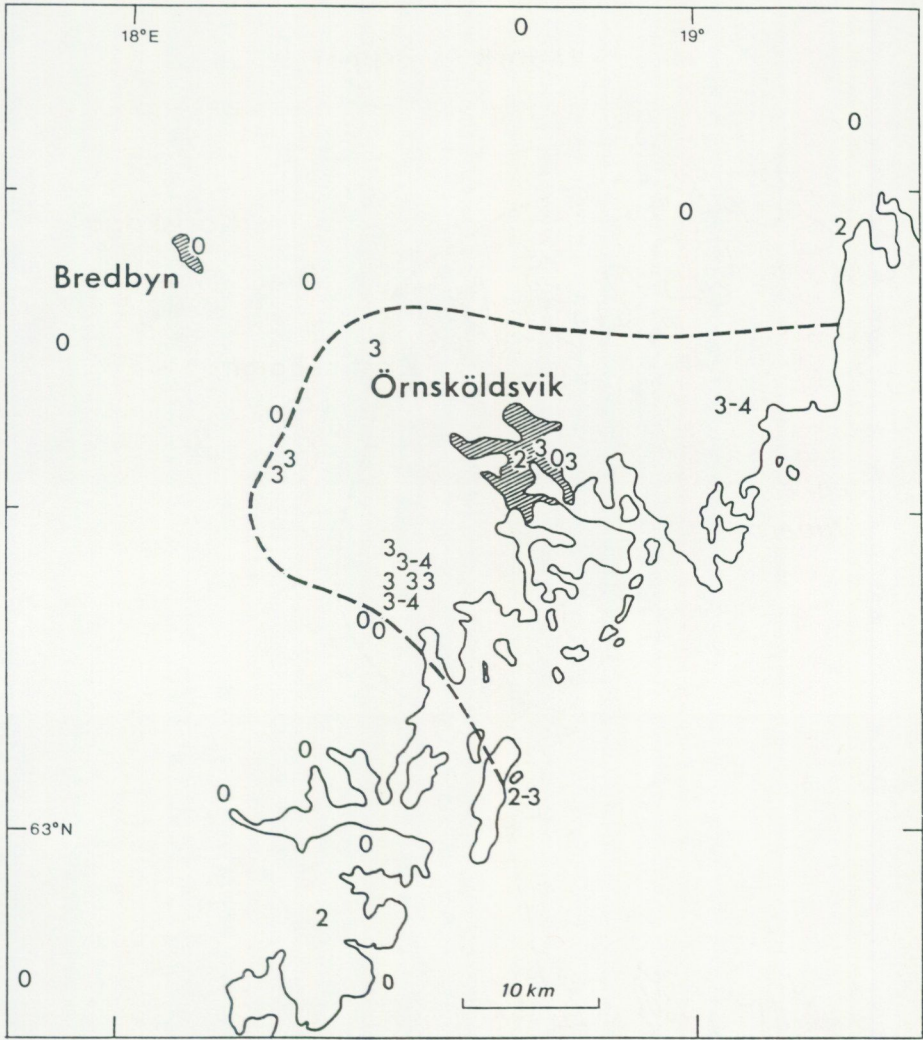


Fig. 17. Intensity distribution of the Ulvöarna earthquake of July 25, 1989. Conventions as for Fig. 2.

focal depth are hard to estimate due to the epicentral location near Lake Vänern. Felt intensities and the landward portion of the area of perceptibility are presented in Fig. 18.

MARCH 30, 1990, ÅDALEN, ÅNGERMANLAND

On the early morning of March 30, 1990, a medium-size earthquake took place in southern Ångermanland. The quake was felt in Bollstabruk (IV), Lugnvik (III) and Rø (III-IV). The data are too sparse for an isoseismal map to be drawn.

MAY 24, 1990, KATTEGAT

On May 24, 1990, a strong earthquake occurred in Kattegat off the coast of southwestern Sweden. The quake took place in the same area as the shocks of June 15, 1985 and April 1, 1986 (see Table 1). The 1990 event was felt in a limited coastal area of Sweden, north of the Bay of Laholm. The usual postal survey resulted in about 90 reports of macroseismic effects (for details the reader is referred to the Seismological Department, Uppsala University). The maximum intensity IV was felt at several rather scattered localities. The limited macroseismic information indicates a shift of the macroseismic field towards the north when compared with those of the 1985 and 1986 earthquakes. This difference is not consistent with the proximity of instrumental epicentral locations of all three earthquakes (Fig. 1). The offshore epicentral location, scarcity of macroseismic data and lack of information about felt effects in Denmark make it impossible to estimate the area of perceptibility or the focal depth.

AUGUST 22, 1990, UMEÅ, VÄSTERBOTTEN

On the morning of August 22, 1990, a medium-size earthquake shook part of the coastal area of Västerbotten. Reports of felt intensities were received from Brattfors (III), Gunnismark (IV), Innertavle (III), Krokfors (IV), Kroksjö (II), Norrmjöle (III), Robertsfors (III), Sävar (IV), Sofiehem (III), Sörfors (II), Täfteå (IV), Tålsmark (IV) and Umeå (III). The intensity distribution and the landward portion of the area of perceptibility are shown in Fig. 19. Again, the location of the epicentre at the coast makes any estimates of the area of perceptibility and the focal depth unreliable.

DECEMBER 12, 1990, HEBY, UPPLAND

A strong earthquake was felt over a large part of Uppland on December 12, 1990. Received letters and questionnaires reported that doors and windows rattled, floors creaked and some unstable objects fell off shelves. The vibration was often compared to that of the passing of a heavily loaded truck. A sound often accompanied the shaking. The quake was felt in Björklinge (IV), Harbo (II-III), Heby (IV), Hedesunda (III), Järlåsa

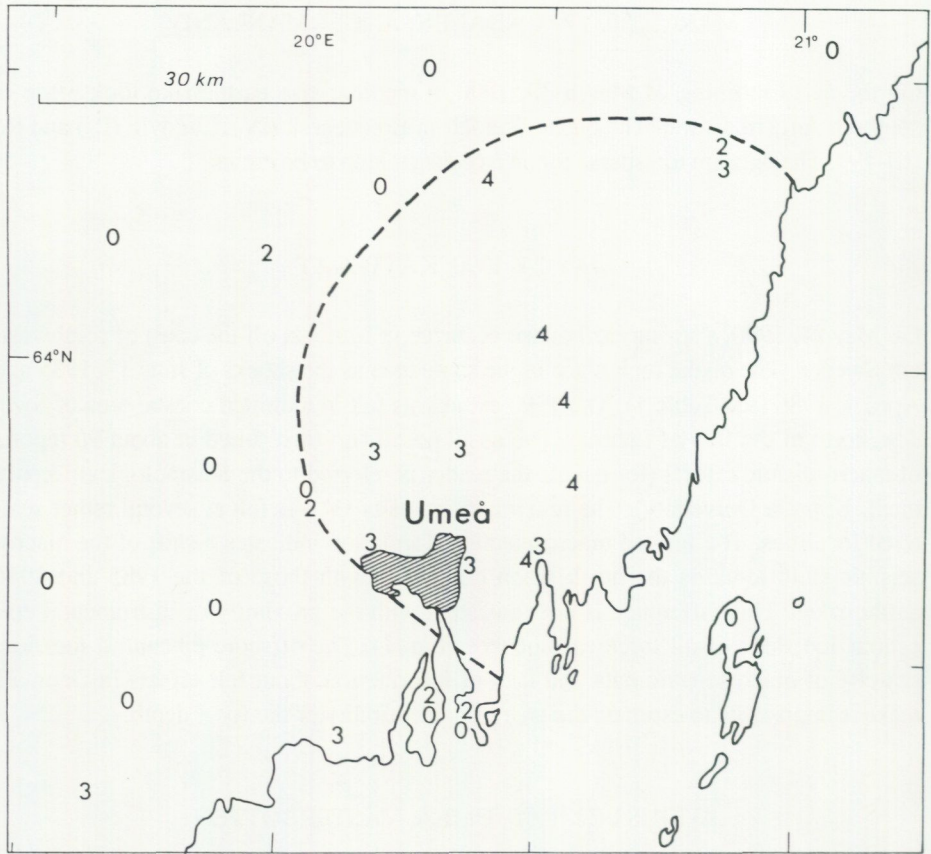


Fig. 19. Intensity distribution of the Umeå earthquake of August 22, 1990. Conventions as for Fig. 2.

(III), Kerstinbo (III–IV), Månkarbo (III), Morgongåva (IV), Ramsta (IV), Sala (III), Storvreta (II), Tärnsjö (III), Västerfärnebo (IV) and Vittinge (IV–V). Felt intensities together with the area of perceptibility of 2800 km² are displayed in Fig. 20. With a maximum intensity IV–V the focal depth is estimated at 10 km.

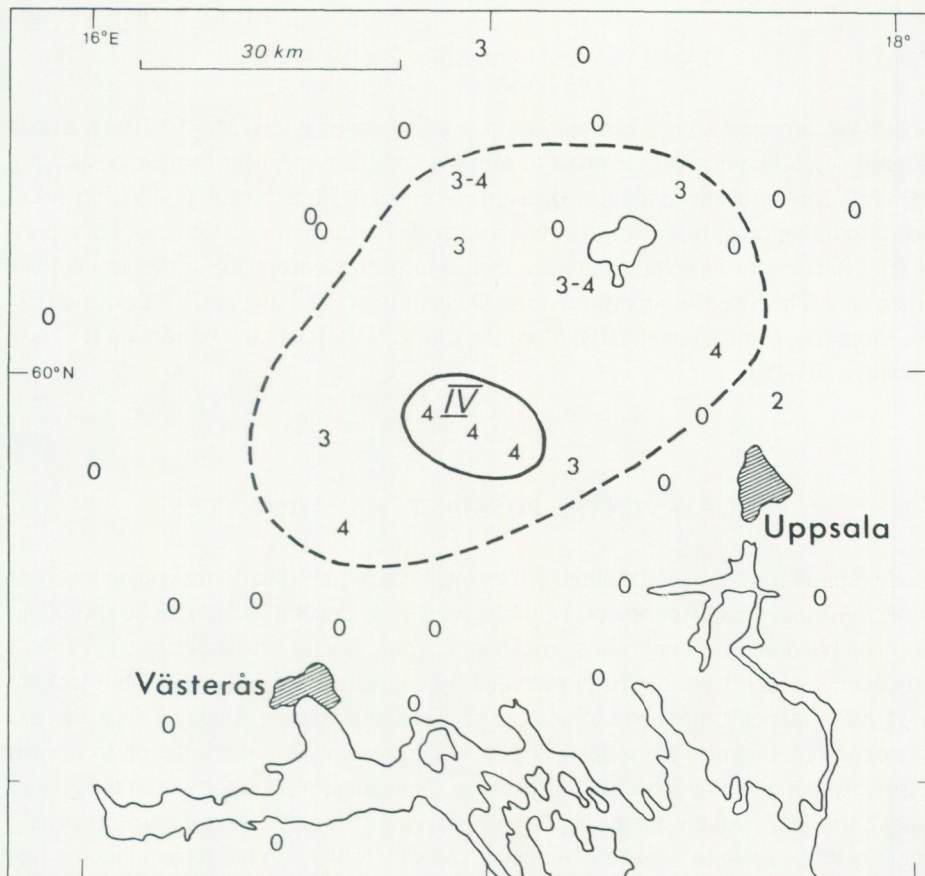


Fig. 20. Intensity distribution of the Heby earthquake of December 12, 1990. Conventions as for Fig. 2.

APRIL 7, 1984, AND MARCH 12, 1985, NW FINLAND

Earthquakes on April 7, 1984, $M_L(\text{UPP}) = 2.5$, north of Tornio, Finland, and on March 12, 1985, $M_L(\text{UPP}) = 3.0$, near Enontekiö, Finland, were felt also in neighbouring parts of Sweden. Macro seismic data and maps are given in Ahjos et al. (1985, 1986).

JANUARY 25, 1989, BERGEN, NORWAY

One of the strongest known earthquakes in or near Fennoscandia, $M_L=5.1$ (Bergen coda magnitude), took place off the coast of southwestern Norway, near Bergen, on January 23, 1989. Macroseismic and other data are presented in Hansen et al. (1989). No systematic compilation of macroseismic data was made for the Swedish territory, but reports of felt effects were received from a number of localities, several as far east as the Lake Siljan area. The Swedish reports are from Gunnarskog (IV), Långlet (IV), Leksand (IV-V), Lima (II), Limedsforsen (III), Mora (IV), Orsa (IV), Rättvik (II), Sörsjön (IV) and Vikarbyn (III-IV).

FELT EVENTS, POSSIBLY EARTHQUAKES

Many reports from the public about felt events believed to be earthquakes are received at the Seismological Department, Uppsala, each year. Several events can be sorted out as other phenomena (explosions, rockbursts, sonic booms, frost chirps,..). Table 2 lists events which have not been recorded by any seismological station, but lacking 'negative evidence' cannot be excluded as possible earthquakes. Amongst these there is a strong predominance from densely populated areas, with no correlation to known seismicity (recorded or historical). Especially, there are several reports from the greater Stockholm area, which has been virtually aseismic since at least the 16th century. There is thus reason to assume that many events in Table 2 do not have a seismic origin. Not listed in Table 2 is a report from Blidö, Uppland, on a crack in a chimney wall believed, by the observer, to have been caused by an earthquake during the winter of 1984/85.

TABLE 2. Times and locations of felt, not instrumentally recorded, events, possibly earthquakes, 1984-1990

Date	Approximate time h (GMT)	Locality(-ies) / Province(s)
Jan. 22, 1984	00	Nacka / Södermanland
Feb. 20, 1984	08 & 10	Kvissleby, Lucksta, Ragvaldsnäs / Hälsingland, Medelpad
Feb. 21, 1984	00-01	Ramsle / Ångermanland
Mar. 12, 1984	03 & 04	Svartsjölandet / Uppland
Mar. 20, 1984 (or 21)	evening	Piteå, Svensbyn / Norrbotten
Mar. 30, 1984	08	Glommen, Ullarp (Falkenberg) / Halland
Apr. 5, 1984	02	Fläckebo / Västmanland
Apr. 17, 1984 (or 16)	13	Löparö / Uppland
Apr. 26, 1984	07	Hagafjärden (Hudiksvall) / Hälsingland
May 3, 1984	18	Västergidsjö / Ångermanland
Jun. 24, 1984	00	Kvikkjokk / Lappland
Jul. 20, 1984	22	Finskatörp gård (Skövde) / Västergötland
Sep. 5, 1984	daytime	Lake Ramsjön / Västerbotten
Sep. 14, 1984	04	Bomhus / Gästrikland
Oct. 1, 1984	00	Söderhamn / Hälsingland
Oct. 1, 1984	12	Landvetter, Långedrag, Vinga / Västergötland
Oct. 2, 1984	11	Luleå / Norrbotten
Oct. 3, 1984	00	Karlskrona / Blekinge
Dec. 10, 1984	10-11	Svängsta / Blekinge
Dec. 16, 1984	05	Ingarö / Uppland
Aug. 19, 1985		Ava / Ångermanland
Aug. 22, 1985	08	Skåpviken / Ångermanland
Aug. 30, 1985	21	Kramfors / Ångermanland
Nov. 20, 1985	08	Alnön / Medelpad
Dec. 16, 1985	15	Ludvika / Dalarna
Jan. 27, 1986	08-09	Särö / Halland
Jan. 29, 1986	10	Gånghester / Västergötland
Feb. 2, 1986	20	Svärdsjö / Dalarna
Feb. 13, 1986	12	Ånäset, Lövånger / Västerbotten
Feb. 13, 1986	15	Burträsk / Västerbotten
Apr. 2, 1986	21	Gränna / Småland
May 12, 1986	17	Göteborg / Västergötland
May 13, 1986	14	Haverdal / Halland
May 15, 1986	22	Södermalm (Stockholm) / Södermanland
Jun. 1, 1986	01	Nyland (Kramfors) / Ångermanland
Jun. 2, 1986	23	Älvdalen / Dalarna

TABLE 2. (cont.)

Date	Approximate time h (GMT)	Locality(-ies) / Province(s)
Jun. 5, 1986	09	Jokkmokk, Luleå, Suddesjaur, Sudok / Lappland, Norrbotten
Jun. 9, 1986	08	Orust (western part), Tjörn / Bohuslän
Aug. 19, 1986	01	Strand (Vännäs) / Västerbotten
Aug. 21, 1986	21 & 22	Strand (Vännäs) / Västerbotten
Sep. 1, 1986	07-08	Kristinedal / Västergötland
Sep. 2, 1986	07 & 09	Kristinedal / Västergötland
Sep. 4, 1986	19-20	Krapperup / Skåne
Sep. 18, 1986	12	Hedemora / Dalarna
Sep. 27, 1986	21	Björklinge / Uppland
Oct. 7, 1986	09	Davidshyttan / Dalarna
Nov. 17, 1986	20	Järfälla / Uppland
Dec. 3, 1986	12	Kalix / Norrbotten
Dec. 21, 1986	night to 21st & 21	Storlien / Jämtland
Feb. 13, 1987	04	Lund / Skåne
Mar. 17, 1987	02	Norberg / Västmanland
Apr. 12, 1987	07	Mariefred / Södermanland
Apr. 16, 1987	06	Hova / Västergötland
Apr. 18, 1987	21	Eskilstuna / Södermanland
Apr. 23, 1987	01	Vintrosa / Närke
Apr. 25, 1987	05 ¹⁾	Kåge / Västerbotten
May 11, 1987	02	Västerhaninge / Södermanland
Jun. 28, 1987	22	Båstad / Skåne
Jul. 1, 1987	12	Northern Halland / Halland
Jul. 16, 1987	00	Mantorp / Östergötland
Aug. 18, 1987	16-20	Dalsjöfors / Västergötland
Aug. 21, 1987	11	Bromölla / Skåne
Aug. 26, 1987	10 & 17	Kårböle / Hälsingland
Nov. 5, 1987	14	Främmestad / Västergötland
Nov. 15, 1987	14	Älvängen / Västergötland
Nov. 18, 1987	07	Trosa / Södermanland
Nov. 24, 1987	15	Norberg / Västmanland
Dec. 10, 1987	10	Täby / Uppland
Dec. 29, 1987	00	Nordmaling / Ångermanland
Jan. 8, 1988	08	Upplands Väsby / Uppland
Feb. 21, 1988	00	Älvängen / Västergötland
Mar. 3, 1988	10 & 12	Kristianstad / Skåne
Mar. 20, 1988	13	Storuman / Lappland
Mar. 21, 1988	10	Lake Sillen, Torö / Södermanland

TABLE 2. (cont.)

Date	Approximate time. h (GMT)	Locality(-ies) / Province(s)
Mar. 31, 1988	07	Näs (Hallstahammar) / Västmanland
Apr. 28, 1988	06	Gunneryd (Jönköping) / Småland
May 19, 1988	07	Onsala / Halland
May 21, 1988	18	Lund / Skåne
May 22, 1988	18	Lund / Skåne
May 31, 1988	02	Huddinge / Södermanland
Jun. 2, 1988	12-13	Göteborg / Västergötland
Jun. 3, 1988	10	Göteborg / Västergötland
Jun. 8, 1988	20	Älandsbro / Ångermanland
Jul. 8, 1988	23	Southern Värmland / Värmland
Sep. 1, 1988	22	Alingsås / Västergötland
Oct. 17, 1988	forenoon	Harmånger / Hälsingland
Oct. 27, 1988	11-13	Helsingborg, Höganäs / Skåne
Nov. 10, 1988	08	Hanaberg (Härnösand) / Ångermanland
Dec. 21, 1988	12	Viksberg / Dalarna
Dec. 23, 1988	17	Hägersten (Stockholm) / Södermanland
Jan. 8, 1989	09 & 12	Kramfors / Ångermanland
Jan. 19, 1989 (or 20)	after 15	Sundsvall / Medelpad
Feb. 1, 1989	06	Västra Frölunda (Göteborg) / Västergötland
Feb. 16, 1989	14	Almunge / Uppland
May 18, 1989	17	Handen / Södermanland
May 30, 1989	24	Koskullskulle / Lappland
Jun. 13, 1989	17	Southern Gotland / Gotland
Jun. 15, 1989	08	Västra Husby / Östergötland
Jun. 23, 1989	00	Alanen Aptašjärvi / Lappland
Aug. 19, 1989	22	Stensjö (Hunnebostrand) / Bohuslän
Oct. 6, 1989	05	Södertälje / Södermanland
Oct. 15, 1989	21	Roslagsbro / Uppland
Oct. 26, 1989	19	Piteå skärgård / Norrbotten
Nov. 30, 1989	10 & 11	Kalmar / Småland
Dec. 5, 1989	05	Löttorp / Öland
Dec. 5, 1989	12	Bygdeå / Västerbotten
Jan. 4, 1990	08	Ljunghusen / Skåne
Mar. 17, 1990	24	Öregrund / Uppland
Mar. 20, 1990	22	Lödöse / Västergötland
Apr. 10, 1990	17 & 20	Tyresö / Södermanland
May 15, 1990	23	Höllviken / Skåne
Jul. 17, 1990	02	Bollnäs / Hälsingland

TABLE 2. (cont.)

Date	Approximate time h (GMT)	Locality(-ies) / Province(s)
Jul. 21, 1990	20	Smögen / Bohuslän
Jul. 22, 1990	00	Göteborg / Västergötland
Sep. 2, 1990	00	Uppsala / Uppland
Oct. 29, 1990	24	Gäddvik / Hälsingland
Dec. 16, 1990	21	Kramfors / Ångermanland

1) Probably foreshock to event 20 of Table 1.

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