

SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 776

AVHANDLINGAR OCH UPPSATSER

ÅRSBOK 74 NR 4

OTA KULHÁNEK AND RUTGER WAHLSTRÖM

MACROSEISMIC OBSERVATIONS
IN SWEDEN
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INTRODUCTION

During the period of January 1977 to December 1979, 22 earthquakes were recorded and located in Sweden and/or adjacent waters by means of the Swedish Seismograph Station Network (SSSN). When this paper is written, the record analysis for the year 1979 is not complete. Therefore, the given number of events is not final and may increase somewhat. Of the 22 earthquakes mentioned, eight were felt by residents in the respective areas and hence provide an opportunity for macroseismic investigations. Such investigations are extremely useful for estimating e.g. the depth of rupture and local ground accelerations, especially when teleseismic data and strong-motion records are not available.

The long-term time average gives approximately three earthquakes per year which are reported to be felt by people. In this respect, the seismic activity in Sweden during the years under review is well within the "normal".

The main objective of the present study is to summarize and interpret available macroseismic observations collected at the Seismological Dept. in Uppsala. Information has been extracted from mailed questionnaires and newspaper articles with exception of the event of December 23, 1979 for which direct interviews were carried out. The latter approach proved to be clearly superior. Relevant source parameters (instrumental determinations) for the eight earthquakes are summarized in Table 1. Epicentral locations together with the recording sites of the SSSN are shown in Fig. 1.

To determine the focal depth from macroseismic data a number of formulae are at hand. In the present work, we employ the so-called Blake-Shebalin formula (see e.g. Kárník 1969, pp 28–32)

$$I_0 - I_n = k \log_{10} (D_n/h) \quad (1)$$

the formula of Båth (1973, p 122)

$$I_0 - 2 = 3 \log_{10} \frac{r_p^2 - h^2}{h^2} \quad (2)$$

and the more recent formula of Båth (1980)

$$h = r_p [10^{0.63(I_0-3)} - 1]^{-\frac{1}{2}} \quad (3)$$

In formulae (1)–(3), I_0 = maximum intensity, I_n = intensity of degree n , k = coefficient of attenuation, $D_n^2 = h^2 + r_n^2$, r_n = radius of area limited by intensity I_n , h = focal depth and r_p = radius of equivalent circular area of perceptibility. For shallow earthquakes within the Baltic Shield, a value of $k = 3.5$ – 3.6 is recommended (Kárník 1969, Korhonen and Ahjos 1979). All intensities given in the present paper are those determined on the American Modified Mercalli Scale, MM, 1956 (Willmore 1979). For most practical purposes, intensity estimates made in terms of the MM-scale and of the more recent MSK-scale, 1964 (Willmore 1979), are essentially

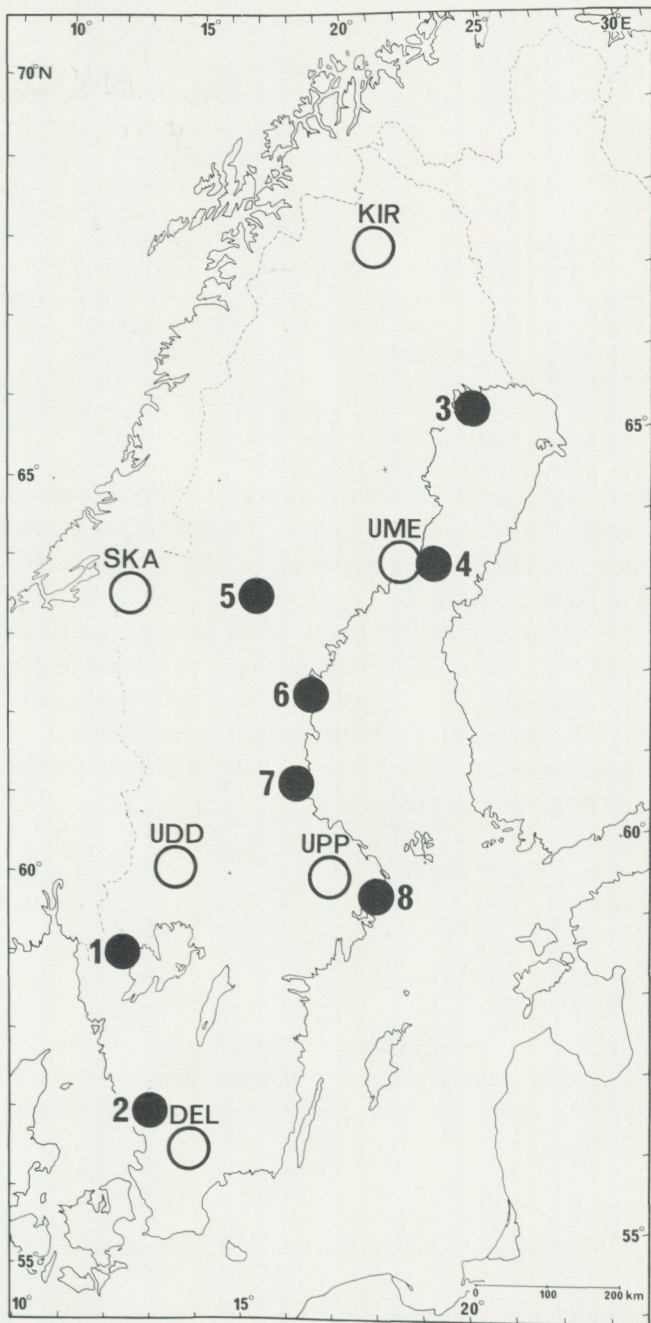


Fig. 1. Swedish Seismograph Station Network, SSSN (open circles) and instrumental epicentres of earthquakes felt in Sweden, 1977-1979 (solid circles). Earthquake numbers are those used in Table 1. Epicentre of event 6. is given from macrosismic data.

TABLE 1. Instrumentally determined parameters of earthquakes felt in Sweden, 1977-1979

Event number	Date	Epicentral coordinates		Origin time GMT	Magnitude M_L^1	Province
		°N	°E			
1	Aug. 27, 1977	59.0	12.3	16 14 54	2.3	Dalsland
2	Sep. 5, 1977	57.0	13.0	23 40 21	3.4	Halland-Småland-Västergötland
3	Nov. 10, 1977	65.6	22.9	15 40 33	3.2	Off coast of Norrbotten
4	Dec. 14, 1978	63.7	21.1	14 24 48	2.9	Off coast of Västerbotten
5	Jan. 1, 1979	63.5	16.0	07 17 29	2.4	Jämtland-Ångermanland
6	Apr. 2, 1979	-	-	12 40 34	2.5	Medelpad
7	Nov. 11, 1979	61.1	16.9	23 58 14	2.3	Hälsingland
8	Dec. 23, 1979	59.6	18.7	14 09 13	3.2	Uppland

¹ From scale in Wahlström (1979).

the same. Whenever possible, focal depths were determined as average values due to relations (1)-(3). As far as our data are concerned, the three depth estimates are consistent with each other and differ at most by 6 km. Numerical results are summarized in Table 2.

For the MM intensity scale, ranges of likely peak ground accelerations are presented e.g. in Willmore (1979). Formulae for approximate peak accelerations, within a limited interval of MM-intensities, have also been suggested by Trifunac and Brady (1975) among others. Note that values of Willmore relate to total parameter values, whereas values due to Trifunac and Brady are given separately for vertical and horizontal components as

$$\log_{10} a_v = -0.18 + 0.30 I_0$$

and for $IV \leq I_0 \leq X$ (4)

$$\log_{10} a_h = 0.014 + 0.30 I_0$$

respectively, where a = peak ground acceleration in cm s^{-2} . Measured peak accelerations plotted against intensity usually display a wide scatter and consequently, our estimates (see Table 2) should be considered as first approximations only.

MACROSEISMIC DATA AND ANALYSIS

Below, we briefly describe the available macroseismic data for the eight earthquakes listed in Table 1. For each event, we provide localities where the earthquake was felt and an estimate of the maximum intensity, macroseismic epicentre, focal depth, area of perceptibility and range of peak ground accelerations.

TABLE 2. Derived macroseismic parameters of earthquakes felt in Sweden, 1977-1979

Event number	Macroseismic epicentre ¹	Maximum felt intensity MM (1956)	Focal depth km	Area of perceptibility km ²	Range of maximum ground acceleration ⁴ % g
1	Billingsfors	IV	10 ²	1500	≤ 1.6
2	Kinnared	V	14 ²	7100	1.2-3.1
3		IV-V			≤ 3.1
4		IV			≤ 1.6
5	Borgvattnet	III	11 ³	470	
6	Njurunda				
7	Sandarne	V	7 ²	1900	1.2-3.1
8	Löparö	V+	2 ²	150	2.5-5

¹ For earthquakes with epicentres at sea the macroseismic epicentre as well as the focal depth and area of perceptibility are not specified.

² Average value according to formulae (1)-(3).

³ According to formula (2).

⁴ According to eqs. (4) and Willmore (1979).

Corresponding numerical values are summarized in Table 2. For events located on land and with a reasonable amount of observations we drew isoseismal charts. These are presented in Fig. 2 and Fig. 3.

AUGUST 27, 1977, BILLINGSFORS, PROVINCE OF DALSLAND

A weak earthquake was felt in the afternoon of August 27, 1977 in northern Dalsland. Questionnaires with positive answers were received from (in alphabetic order) Bengtsfors, Billingsfors, Dals Långed and Gustavsfors. The maximum felt intensity was IV at Billingsfors. Isoseismals together with the area of perceptibility of 1 500 km² are depicted in Fig. 2. Close to the macroseismic epicentre, vibrations of total duration of several seconds were felt by all. Residents of Billingsfors thought that their furnaces had exploded. At several places windows, doors and dishes rattled and audible booms were noticed.

The available distribution of intensities given in Fig. 2 provides a focal depth of about 10 km. The maximum ground acceleration is expected not to exceed 0.016 g.

SEPTEMBER 5, 1977, KINNARED, PROVINCE OF HALLAND

In the early hours of September 6, 1977 (local time) a relatively strong earthquake was felt within neighbouring areas of Provinces of Halland, Småland and Västergötland. Reports with positive answers were received from 18 localities, namely from Broaryd, Fritsla, Harplinge, Horred, Hyltebruk, Kinnared, Lidhult,

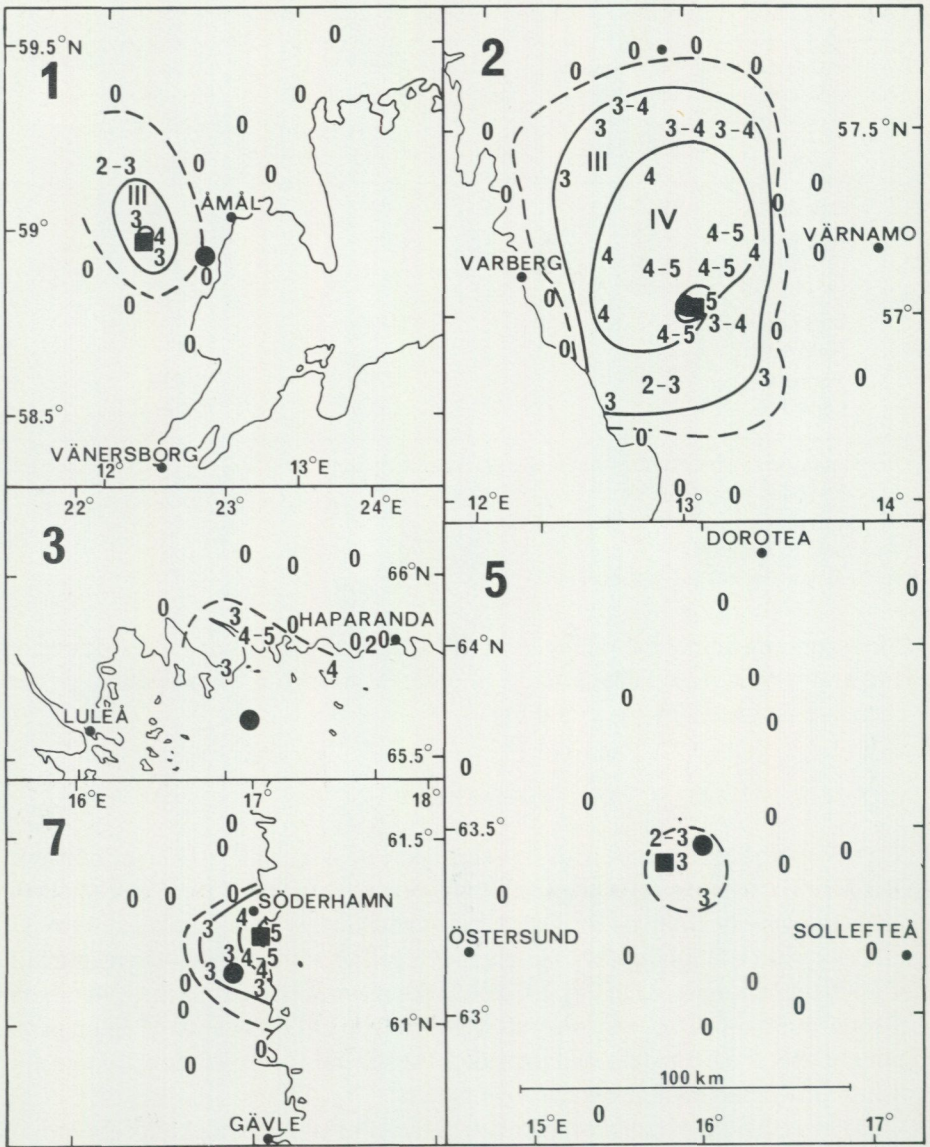


Fig. 2. Intensity (MM) distribution of earthquakes felt in Sweden: 1—August 27, 1977, Dalsland; 2—September 5, 1977, Halland—Småland—Västergötland; 3—November 10, 1977, Off coast of Norrbotten; 5—January 1, 1979, Jämtland—Ångermanland; 7—November 11, 1979, Hälsingland. Instrumental and macroseismic epicentres are shown by solid circles and squares, respectively. Dashed lines limit areas of perceptibility, solid lines limit areas of certain intensity. Zeros mean not felt.

Oskarström, Skene, Smålands Burseryd, Smålandsstenar, Svenljunga, Torup, Tranemo, Ullared, Vessigebro, Ätran and Överlida. Average intensities estimated from questionnaires are shown in Fig. 2. The maximum intensity was V at

Kinnared. The felt area extended over about 7 100 km². At and close to the macroseismic epicentre, windows and doors rattled, floors and walls creaked, hanging lamps swung, at one place a hall-clock rung. The earthquake was felt indoors by all, many sleeping people awoke and many were frightened. Vibrations of buildings like those due to the passing of a heavy truck or a train were felt. Between one and six shocks of total duration of about 5 to 60 s were reported. There were many descriptions of sounds like thunder which accompanied the shocks.

The intensity distribution, depicted in Fig. 2, provides a focal depth estimate of 14 km. The peak ground acceleration, derived from the maximum felt intensity, lies within the range of 0.012–0.031 g.

NOVEMBER 10, 1977, OFF COAST OF NORRBOTTEN

On November 10, 1977, in the afternoon, a moderate earthquake was felt in Kalix, Nyborg, Risögrund, Salmis, Seskarö and Storöhamn in the Province of Norrbotten. The maximum intensity was IV–V in Risögrund where about 20 strong shocks were noticed. Windows, doors and dishes rattled, hanging lamps swung and many people indoors were frightened. As follows from Fig. 1 and from data in Table 1, the epicentre was located at sea. Due to the missing information from the seaward portion of the epicentral area, it is not possible to draw the isoseismals. A rough approximation of the landward portion of the area of perceptibility is shown in Fig. 2.

DECEMBER 14, 1978, OFF COAST OF VÄSTERBOTTEN

In the afternoon of December 14, 1978, a weak earthquake took place off coast of the Province of Västerbotten. The event was felt, with intensity IV, on the Holmön island, about 15 km westerly of the instrumentally determined epicentre. Obviously, the available data do not permit to draw the isoseismals.

JANUARY 1, 1979, BORGVATTNET, PROVINCE OF JÄMTLAND

A weak earthquake was felt in Borgvattnet, Fullsjön and Köttsjön in the morning of January 1, 1979. One shock of total duration of 2–3 s was noticed together with a faint boom. Some of the residents of Borgvattnet, where the intensity was about III, thought that their furnaces cracked. The area of perceptibility was approximately 470 km² providing a focal depth estimate of 11 km. The area of perceptibility is depicted in Fig. 2.

APRIL 2, 1979, NJURUNDA, PROVINCE OF MEDELPAD

In the afternoon of April 2, 1979, a weak earthquake took place in the Province of Medelpad. Since the shock was detected by only one seismograph station (UME) of the SSSN, a more accurate location of the event is not possible. According to a newspaper notice, the earthquake was felt in Njurunda.

NOVEMBER 11, 1979, SANDARNE, PROVINCE OF HÄLSINGLAND

In the early hours of November 12, 1979 (local time) an earthquake occurred in the southern coastal part of Hälsingland. The earthquake was felt at the following eight localities: Bergvik, Gullgruva, Ljusne, Sandarne, Stråtjära, Sunnäsbruk, Söderhamn and Vallvik. The macroseismic epicentre was located to Sandarne. The maximum felt intensity was V. In the epicentral region, several shocks of total duration of about 15 s were noticed. Buildings trembled, sleepers wakened, many were frightened. Windows, doors and dishes rattled, walls and floors creaked, flower-pots were shifted, pictures swung out of place and furniture was shaking.

Due to the epicentral location close to the coast, only the landward portion of the macroseismic field can be mapped (see Fig. 2). It is reasonable to assume from the isoseismal chart in the figure that the available areas of perceptibility and of the n -th intensity on land are about one half of the total areas. If this is the case, then the area of perceptibility was about 1 900 km², yielding an estimate of the focal depth of 7 km.

DECEMBER 23, 1979, LÖPARÖ, PROVINCE OF UPPLAND

In the afternoon of December 23, 1979, an earthquake sequence occurred near Bergshamra in Roslagen (hereafter Bergshamra), about 50 km northeast of Stockholm. The sequence took place in a zone of very low seismicity in eastern central Sweden and had an unusually shallow depth for Swedish earthquakes. The main shock, which was assigned a magnitude $M_L = 3.2$, was followed, after 3 minutes, by a shock of magnitude $M_L = 2.6$ and, after another 21 minutes, by a shock of magnitude $M_L = 2.0$. Whereas the main shock was recorded by almost all Finnish, Norwegian and Swedish permanent stations, the whole sequence has been observed only at UPP ($\Delta = 68$ km). An exhaustive description of the sequence is given in Kulhánek et al. (1980).

The Bergshamra sequence occurred in a fairly populated area of Roslagen. Intensity estimates were obtained from 94 direct interviews, covering the landward portion of the epicentral area reasonably well. For the seaward portion (Norrtälje archipelago) the observations are obviously less complete. The main shock was felt at Bergshamra, Grovsta, Hemmarö, Helgö, Hysingsvik, Lagboda, Lögla, Löparö,

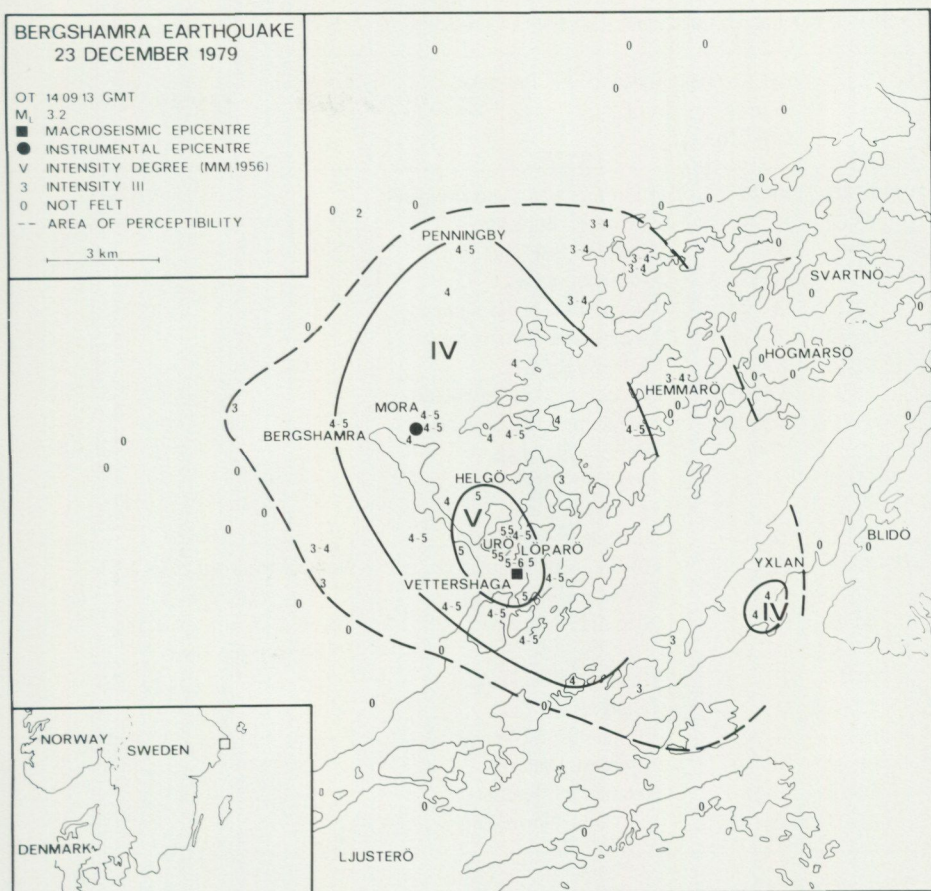


Fig. 3. Intensity (MM) distribution of the Bergshamra earthquake, coast of Uppland, December 23, 1979 (after Kulhánek et al., 1980).

Mora, Mörtsunda, Norrtälje, Penningby, Ribacken, Rävsvund, Skällöpet, Skälvholmen, Solö, Spraggarboda, St. Aspön, Tranvik, Urö, Uttersättra, Vaxtuna, Veda, Vettershaga, Vik, Väringsö and Yxlan. The macroseismic epicentre was located to western Lörparö, about 6 km southeast of the instrumental location. The maximum intensity $I_0=V+$. The distribution of intensities IV and V together with the area of perceptibility are depicted in Fig. 3. Exceptional pockets of higher intensity occurred on the Yxlan island and in Norrtälje (not shown in Fig. 3).

Except for a deep crack in the basement and small cracks in walls of one house in Lörparö and one in Helgö, respectively, no damage was reported. Within the macroseismal region a large majority of the houses are properly built (of brick or wood). The foundation materials consist mainly of solid rock and, to a lesser extent, of clay. People within the epicentral area reported on several shocks. Heavy shaking

TABLE 3. Felt not recorded events possibly earthquakes, 1977-1979

Date	Approximate time GMT (h)	Locality and Province	Comment
1977-02-02	10-13	Kramfors area, Ångermanland	
03-02	10	Sotenäset, Bohuslän	
03-05	10	Northern Dalsland	
03-11	11+13+13	Gothenburg area	
03-25	14	Gnesta area, Södermanland	
04-12	10	Gnesta area, Södermanland	
06-16	02	Gothenburg area	
11-02	13+16	Noraström, Ångermanland	
1978-09-03	morning	Söderhamn, Hälsingland	
10-17	20	Western Blekinge	
11-27	12	Northern Värmland	
12-13	12	Gothenburg area	
12-30	02	Arvidsjaur, Lappland	
1979-01-01	14	Hoting, Ångermanland	Possibly recorded at SKA 13 24
02-11	12	Uppsala, Uppland	
04-02	13	Njurunda, Medelpad	2 events, 16 min apart, the 2 nd one not recorded
04-15	03	Huskvarna, Småland	
05-08	11	Östergötland	
05-17	11	Värmlandsnäs, Värmland	Possibly recorded at UDD 10 23
08-29	16	Älvdalen, Dalarna	
10-16	09+16	Tammerdal, Jämtland	
11-03	22	Piteå area, Norrbotten	

was felt indoors and outdoors, and sounds similar to those of distant thunder were heard. Windows and doors rattled, walls and floors creaked, pictures swung out of place, and furniture was shaking. At many places people thought that their furnaces had exploded. Close to the epicentre, there were several cases of frightened people taking to the outdoors. There is one report of a biological precursor observed in Mora. At many places, animals became uneasy during the earthquake. It is also interesting to mention that at several places severe ground shakings have been experienced during the preceding years.

The area of perceptibility extended over about 150 km². An unusually shallow focal depth of about 2 km was clearly demonstrated by the small area of perceptibility, and was further confirmed by clear Rg-waves recorded at UPP. Formulae (1)-(3) provide an average focal depth of 2 km.

FELT EVENTS, POSSIBLY EARTHQUAKES

Reports to the Seismological Dept. in Uppsala about suspected earthquakes felt by people are routinely checked on corresponding seismic records. Events which were felt but not recorded by any of the SSSN stations are given in Table 3. Some reported events have been identified as sonic booms or chemical explosions and are not included in the table. Neither are suspected rockbursts, irrespective of whether recorded or not, included. Some of the events have possibly been recorded by the nearest SSSN station, but since reported times of occurrence are not very precise, the correlation cannot be made with reasonable confidence. These events are commented in Table 3.

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