Energy Sources of Microseisms in Sweden

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Introduction.

Microseisms in Scandinavia have been so fully investigated and discussed from various points of view by Båth in a number of papers (1949, 1951a, 1951b, 1951c, 1953 and 1962) that we can hardly add anything by the same method. There is another statistical investigation by Zátopek (1961) about the relation between the positions of energy sources over the northernmost Atlantic Ocean and the microseism activity of Europe, including Scandinavia.

The present author made other kinds of investigations of the relation between microseismic storms and the passage of cyclones, typhoons or cold fronts across or around Japan during I.G.Y., using data obtained at eleven stations along the Japanese Islands (Santò 1959a, 1959b and 1960). The writer found that microseisms with periods of 4 to 10 seconds are produced by standing ocean waves, due to interference between incident and reflected swells at some steep coasts.

He had favourable opportunity to investigate the microseisms at Kiruna und Uppsala, Sweden, by means of the same method. The main purpose of the present work is to investigate the validity of the conclusion found for Japan.

The materials used were the Z component amplitudes and periods of microseisms recorded at Kiruna by Galitzin seismographs and at Uppsala by Benioff long-period seismographs during I.G.Y. The weather maps published by the Swedish Meteorological and Hydrological Institute of Stockholm were used in order to find the energy sources of microseismic storms. As the weather maps used show the situation only once a day, the energy sources related to microseismic storms of shorter duration may sometimes be missing in the present investigation.

Comparative studies were made of the positions of energy sources and every remarkable microseismic storm both of amplitude and period in every month from July, 1957, to December, 1958. As there were no microseismic storms in July, 1957, and in August, 1958, the description of microseisms in these two months will be omitted. The microseisms studied belong to the period range of 3-10 seconds.

Comparative studies of microseismic storms and energy sources.

August, 1957.

Time variations of amplitudes and periods of microseisms at Kiruna (K) and Uppsala (U) in August 1957 are shown in Fig. 1 by solid and dotted curves respectively. The time scale in this figure has vertical marks corresponding to 00h 00m on every day in G.M.T., and amplitude (ground displacement in microns) and period (seconds) scales are given on left side for Kiruna and on right side for Uppsala respectively. In average, the microseismic activity in this month was quite poor and the periods were rather short, around four seconds both at Kiruna and Uppsala. The measurements of periods are often interrupted because of zero amplitudes, especially at Uppsala. Amplitude curves show two isolated storms, a small but sharp one around 12d 12h at Uppsala and a large one around 22d 12h at Kiruna. Figs 1-a to 1-c show the meteorological situations, which seem to be correlated with these microseismic storms. In these weather maps, positions and intensities of cyclonic centers at 06h every day are represented by different marks, as explained in the figure.

The microseismic storm in Fig. 1 at 12d 12h at Uppsala is quite remarkable, because microseismic storms are nearly always bigger at Kiruna than at Uppsala, as we shall see in the present paper. In the weather maps (Fig. 1-a), a cyclone at the eastern coast of England at 11d 06h moves northward, and separates into two at 12d 06h, of which one is located at the middle part and the other at the southern edge of the Norwegian coast. As seen in the next case (Fig. 1-b), the passage of a cyclone across the central Norwegian coast does not have great effect upon the Uppsala microseisms. Further, as we shall also recognize by many cases later, the passage of such an unimportant cyclone (995 mb) through the southern edge of the Norwegian coast cannot give a remarkable effect upon the Uppsala microseisms. Therefore, we can hardly say that the microseismic storm at Uppsala may be caused by any of these cyclones at 12d 06h. Moreover, as this storm started at Uppsala already from the beginning of the 11th, we cannot suggest

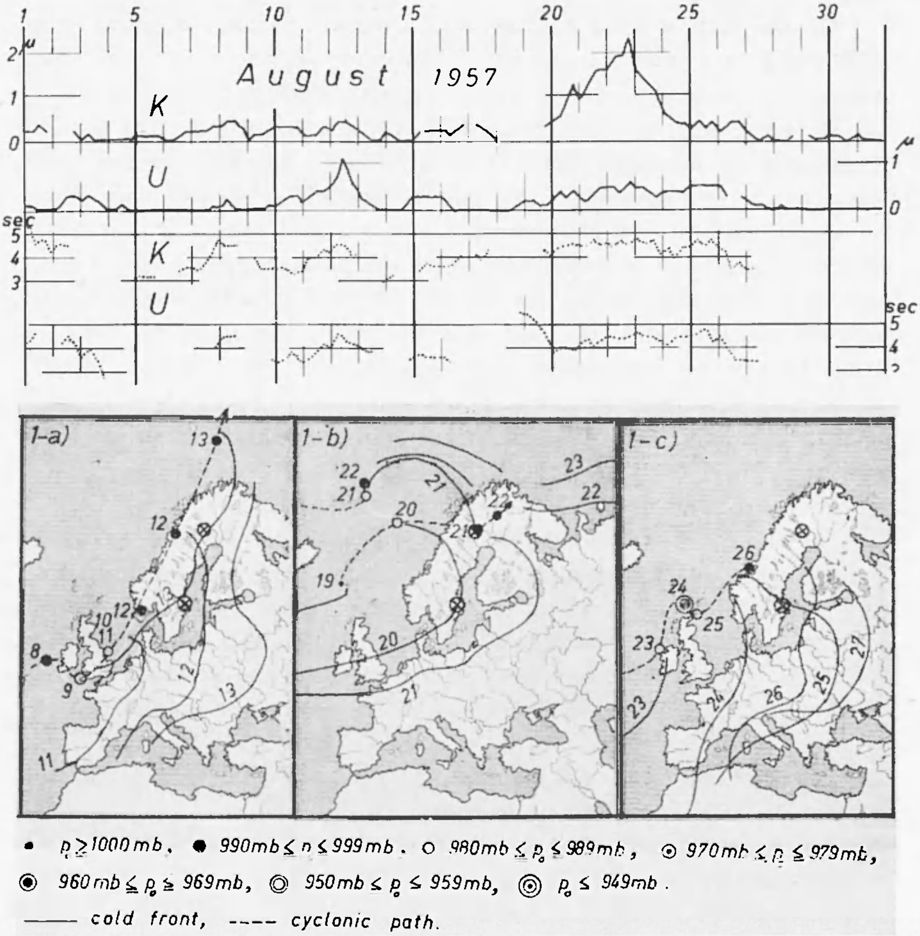

Fig. 1 – Amplitudes (solid curves) and periods (dotted curves) of microseisms at Kiruna (K) and Uppsala (U) in August, 1957. *a-c*: Weather maps with positions of cyclones and cold fronts every day at 06 h GMT. The numerals indicate the dates. Kiruna (northern station) and Uppsala (southern one) are marked in all maps.

that it occurred due to some other cause which appeared and disappeared suddenly near Uppsala and was missed on the weather maps of once a day. Furthermore, as will be shown later, the passage of a cold front across the Baltic Sea has a slight effect upon short-period microseisms but not upon those of more than 4 seconds at Uppsala. Considering this, we suggest that this peculiar storm is caused by the additive effect of the two cyclones.

On the 19th, a weak cyclone with a central pressure of more than 1000 mb passed over Kiruna and disappeared on the 23rd (Fig. 1-b). A large microseismic storm at Kiruna from the 20th to 23rd is no doubt due to the passage of this cyclone. It is strange, however, that such a remarkable microseismic storm is so isolated to Kiruna. Perhaps the origin of the microseisms in this case is located on such a place from where the transmission of microseismic waves to Uppsala is prevented due to some geological complexity along the path. In spite of the passage of a cold front across the middle and southern Norwegian coast between the 19th and 20th and over the Baltic Sea from the 20th to 21st, there is no remarkable microseismic storm at Uppsala. Short period Benioff seismograms at Uppsala, on the other hand, show a slight activity of microseisms of less than 1 second period, related to the passage of the cold front over the Baltic Sea. We shall have many other similar cases later.

On the 23rd, another cyclone approached the western coast of Ireland, with a path as shown in Fig. 1-c with a minimum central pressure of 965 mb on the 24th. The pressure increased gradually and the cyclone had almost disappeared on the 27th at the same position as on the 26th. Both the approach of a moderate cyclone to the southern coast of Norway and the sweeping of a cold front from the 24th to 26th over the same coast keep the microseismic amplitudes at Uppsala a little higher than at Kiruna.

In Fig. 1-c, a large microseismic storm may be expected around the 24th from the passage of an intensive cyclone near the British coast. Nevertheless, there is no increase of microseismic amplitudes, not even at Uppsala. This indicates that microseismic waves do not propagate through the ocean between England and Scandinavia.

September, 1957.

There are two microseismic storms (Fig. 2). The first one with a duration from the 6th to the 17th has two peaks around 10d 00h and 14d 12h at Kiruna. In the corresponding interval, a strong cyclone appeared west of England, which changed its direction to northward on the 6th, as shown in Fig. 2-a. Its central pressure became minimum on the 7th (965 mb) and then increased gradually. The first peak at

Kiruna around 09d 12h can be connected with the approach of this cyclone to the north-western coast of Norway. Periods of microseisms at Kiruna also show a little increase by the passage of this cyclone

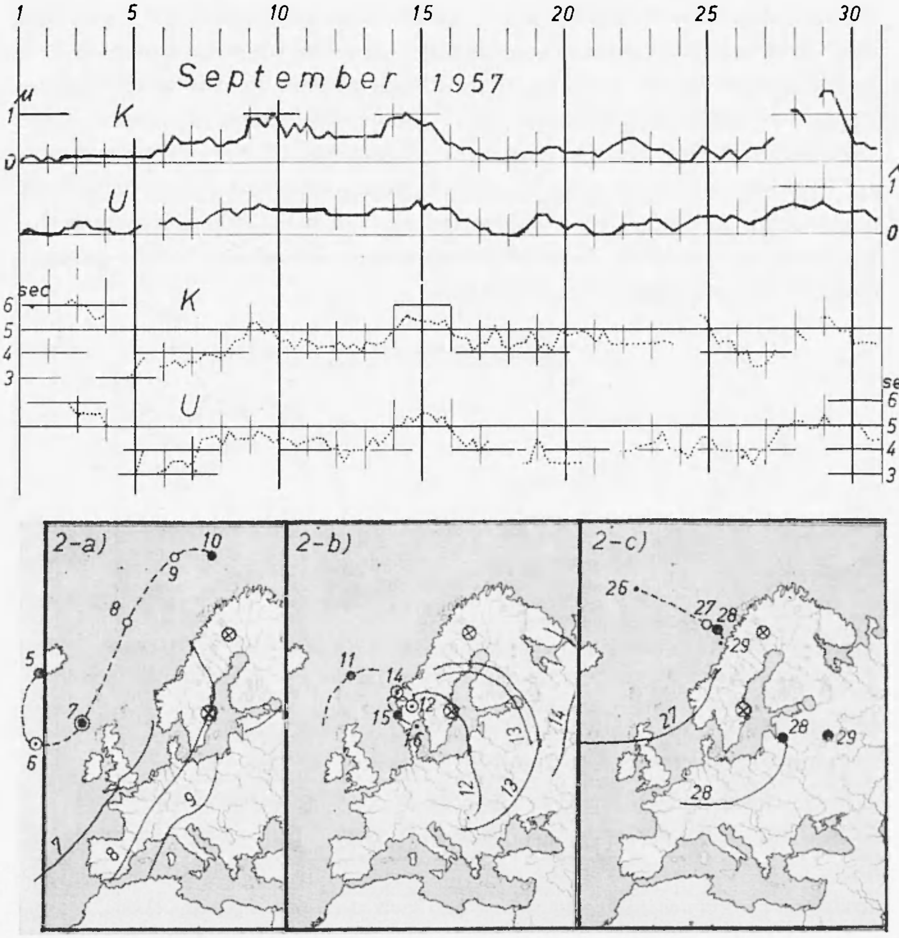

Fig. 2 – Amplitudes and periods of microseisms and weather situations in September, 1957.

along a path, at a distance from the coast. It must be noticed that in spite of the travel of such an effective disturbance (980 mb both on the 8th and the 9th) from south to north parallel to the Norwegian coast, the microseismic storm appeared at Kiruna only when the source came to the north. This fact suggests that the origin of the microseismic storm on the 9th is located on the northern coast of Norway and that the propagation of microseismic waves from this origin to Kiruna is much easier than to Uppsala.

A small cyclone arrived at south Norway on the 12th with increasing intensity (970 mb; Fig. 2-b). It went around in a small region till the 15th, loosing its energy gradually. A cold front passed over the Baltic Sea from the 12th to the 13th, as shown in the same figure. These two situations, however, gave almost no change of microseismic amplitudes at Uppsala. Seismograms of short-period Benioff instruments at Uppsala during the same period were examined. Amplitudes of microseisms around one second period showed a little increase from the beginning of the 12th. This little storm may be caused by the passage of the cold front across the Baltic Sea.

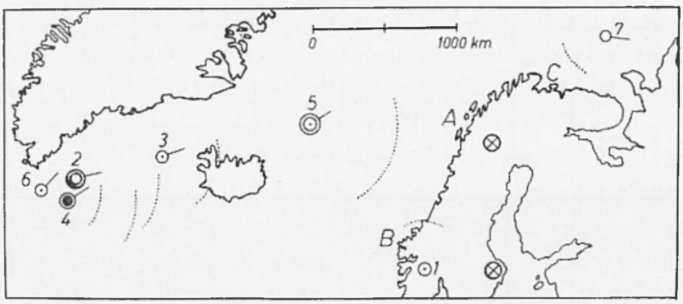

Fig. 3 – Positions of distant cyclones from October to November, 1957. Short bars at every cyclonic center mean the direction of cyclonic movement. Parts of the limits of the " eye of microseismic storm " are shown by dotted curves around each cyclonic center. Cyclone numbers correspond to those in Table I.

A microseismic storm occurred at Kiruna with a remarkable time delay after the arrival of the cyclone mentioned. There is a parallel increase of periods of microseisms at the two stations. From these observational facts, we suggest that the microseismic storm is produced by the long-period swell at some coast, distant from the energy source. This suggestion was checked by the following method.

The cyclone became intensive on the 12th. We introduce the conception of the " eye of microseismic storm " (see Appendix) around a cyclonic center, considering the situation on the 12th (see the cyclone No. 1 in Fig. 3). Taking into account the central pressure of 970 mb as well as its stationary state at that time, about 300 km may be taken as the radius of the " eye ". The travelling distance for the swell from the edge of this " eye " to the coast nearest to Kiruna is approximately 750 km. The group velocity of swell with a period T_w of 11 seconds (twice the observed period of microseisms at 14d 12h) was calculated as 24 km/hr from the formula $v = gT_w/4\pi$ (cm/sec), given by Unoki (1956), in which g is the gravitational constant. The travel time of swell becomes about 31 hours, i.e. the swell must have reached that coast at 14d 16h (Table I). This result nearly corresponds to the peak of the storm in question.

Table I – ESTIMATED ARRIVAL TIMES OF SWELLS – (September to November, 1957).

N.	Date GMT			p_o	$D - D_o$	v	t	T		C
		d	h	mb	km	km/hr	hr	d	h	
1	Sept.	13	06	970	750	22	34	14	16	A
2	Oct.	07	06	955	1700	28	61	09	19	A
					1400	26	54	09	12	B
3	»	08	06	975	1400	30	47	10	05	A
					1100	28	39	09	21	B
4	»	14	06	960	1500	26	58	16	16	B
5	»	27	06	945	450	26	17	27	23	B
6	»	30	06	970	1900	35	54	01	12	B
7	Nov.	15	06	980	250	22	11	15	17	C

p_o = central pressure of cyclone, $D - D_o$ = distance from the limit of the " eye of microseismic storm " to the coast, v = calculated group velocity of swell, t = travel time of swell, T = estimated arrival time of swell at the coast, C = part of Norwegian coast as seen in Fig. 3.

It may be questioned how stationary swell could occur by the swell travelling almost parallel to the coast. But, as is well-known, the wave fronts tend to become parallel to the coast when entering into shallower water. Moreover, even if the coast seems to be parallel to the paths of swell in general, there are many parts of the coast, which face the coming swell almost perpendicularly. In front of such steep coasts, stationary swell can easily arise due to interference between the incident and reflected swells.

In the following, we shall see many cases when periods of microseisms show a remarkable increase with a great time lag in relation to the appearance of a single distant cyclone over the ocean. In such cases, the same estimate concerning the arrival times of swell from a distant energy source to a certain part of the Norwegian coast will be made, and we shall see in every case a good time agreement between the calculated arrival of swell and the observed microseismic storm.

The last peak of microseismic amplitudes at Kiruna can be related to the approach of a cyclone to the central part of the Norwegian coast (Fig. 2-c).

October, 1957.

In this month, the disturbance sources ran over the ocean around Scandinavia successively, which made the microseisms quite active. The average amplitudes as well as periods became large compared to the preceding months. The amplitude scale in this month (Fig. 4) was reduced to half of the preceding months in order to show the peak of the microseismic storm at 28d 12h within a certain limit.

From the 3rd to the 4th, a cyclonic center passed over Uppsala and another approached the northern coast of Norway (Fig. 4-a). The storm at Kiruna around 04d 00h can be connected with the latter source. The one at Uppsala in the same interval might be caused by the additive effect of the other southern cyclone. As the southern cyclone was rather intense (980 mb at 04d 06h), a coast effect at the Baltic Sea near Uppsala would be sufficiently large to increase the microseismic amplitudes at Uppsala to the same level as at Kiruna. Short-period Benioff seismographs at Uppsala also recorded a microseismic storm around the 4th with the period of 1-3 sec.

There was a remarkable increase of periods at Kiruna as well as at Uppsala from the 9th. The energy source of this period storm was an intensive cyclone off eastern coast of southern Greenland on the 7th (cyclone No. 2 in Fig. 3). It approached Iceland on the 8th (No. 3 in Fig. 3) and then ran over the ocean with a course as shown in Fig. 4-b. Estimates of the arrival times of swell were made for two situations: 07d 06h and 08d 06h. Radii of 600 km and 400 km were assumed for the " eye of microseismic storms " towards the Norwegian coast around the centers, taking into account both the moving directions and the central pressures of 955 mb and 975 mb at these times, respectively. As periods began to increase at Uppsala a little earlier than at Kiruna,

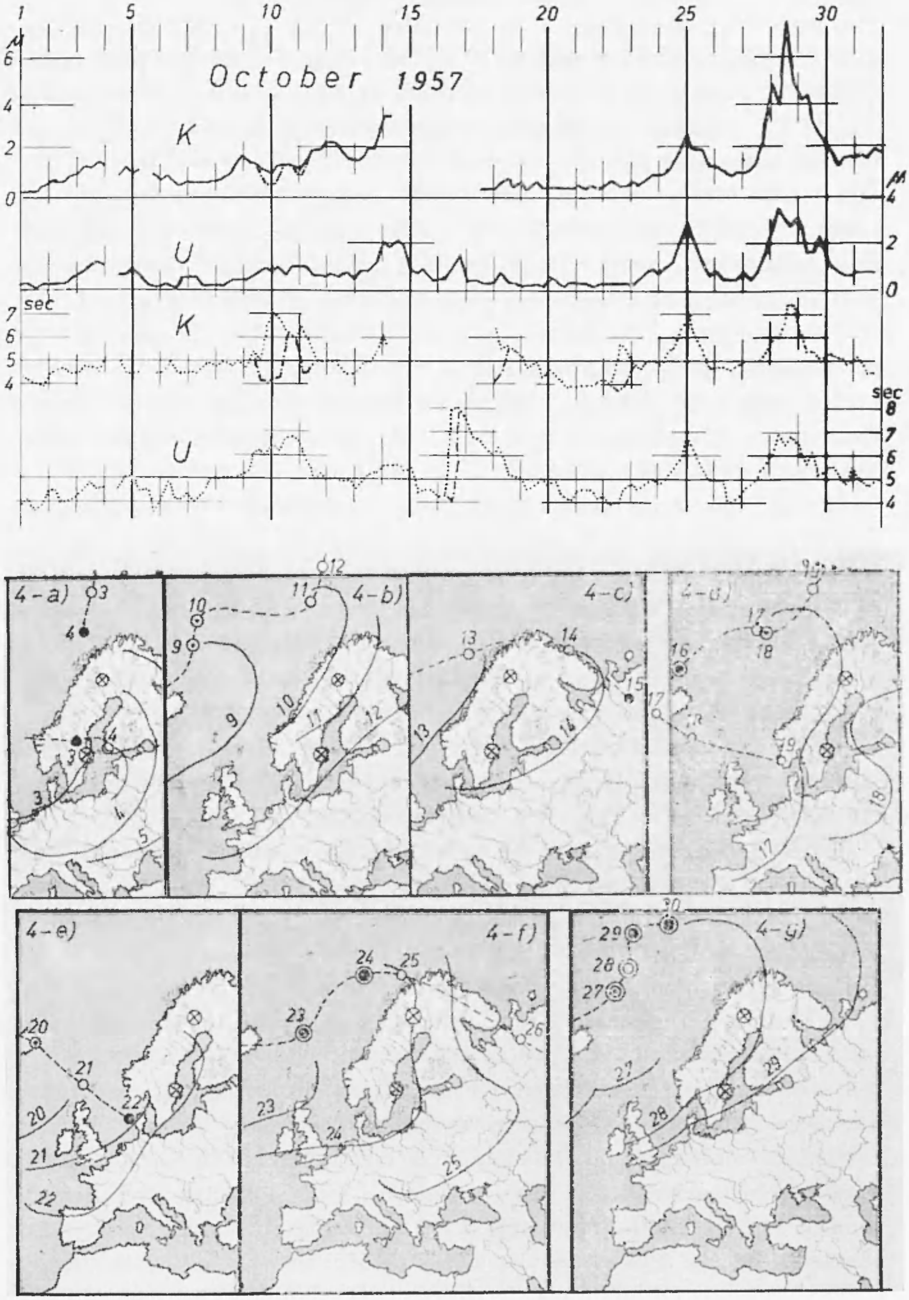

Fig. 4.– Amplitudes and periods of microseisms and weather situations in October, 1957. When two kinds of microseisms are measured simultaneously, the curves referring to shorter period microseisms are dash-dotted.

two arrival times of swell were estimated in this case, i.e. one for the northern coast (about A in Fig. 3) and the other for the southern coast (about B). In these calculations (Table I), for the case of the cyclone No. 2, for instance, the periods of swell were taken as 14 seconds for the northern coast A and 12 seconds for the southern coast B, respectively. The reason is that the observed periods of microseisms at the beginning of the storms at Kiruna and at Uppsala were 7 seconds and 6 seconds, respectively. The calculated arrival times of swell coincide well with the times of observed period increase at both stations.

Instead, if we assume the periods of swell to be the same as for the observed microseisms, the velocity of swell from the cyclone No. 2, to the coast A for instance, becomes 14 km/hr. Then, it is easily found that the swell must reach A at 12d 08h. But, this result differs markedly from the observations.

There is another fact to be noticed. By the cyclones No. 2 and 3, a large microseismic storm must occur on Greenland and Iceland respectively around the 7th and the 8th. These storms, however, did not appear at all at the two stations in Sweden. This means that microseismic waves do not propagate over the ocean to Scandinavia. The same results have been obtained by Båth (1953) and Monakhov (1959, 1960). We shall find the same result in many following cases.

Kiruna recorded another short-period microseismic storm at the same time. This can be explained by a cold front which swept the northern coast of Norway from the 10th to the 11th (Fig. 4-b).

A moderate cyclone and an accompanying cold front passed across the northern Scandinavia from the 13th to the 14th (Fig. 4-c). It is certain that the simultaneous amplitude increase from the 13th at both stations is connected with this meteorological situation. But, it is difficult to distinguish the microseismic effects of the cyclone and the cold front from the weather maps of once a day only. The amplitude ratio between Kiruna and Uppsala was about 1 : 0.5 on the 13th. Nearly the same value will be found for many cases when the microseismic origin is located at some coast in northern Scandinavia.

There was a strong cyclone (p_o = 960 mb) off the south-eastern coast of Greenland at 14d 06h (cyclone No. 4 in Fig. 3). The arrival time of swell from the limit of "eye" around the cyclonic center was estimated as 16d 16h (Table I), which nearly corresponds to the time of great increase of microseismic periods at Uppsala. The path of this cyclone from the 16th to the 19th is shown in Fig. 4-d. The extraordinary rapid increase of the periods at that time is considered to be due to the disappearance of another cyclone on the 16th (the position of this cyclone on the 15th is shown in Fig. 4-c), from which the swell disturbed the long-period swell from the distant source till that time.

It must be noticed that in spite of the appearance of another distant energy source at 17d 06h at the south-western coast of Iceland (Fig. 4-d), there is no increase of periods which could be expected about two days later, i.e. about the 19th. The reason is clear. There is another source from the 17th to the 19th much nearer to the coast, and therefore, the swell due to this cyclone disturbs the long-period swell from the distant cyclone. We shall find many such cases later. They demonstrate that period increase of microseisms occurs only when there is no other important disturbance of the swell from a distant source.

In the same map (Fig. 4-d), we see that the approach of a cyclone at the southernmost edge of Norway on the 19th (p_o = 980 mb) does not have any effect upon the microseismic amplitudes, not even at Uppsala. Quite the same result is found in Fig. 4-e. In this case, Uppsala is also quite calm. A remarkable peak of both amplitudes and periods on the 25th at both stations is certainly connected with the weather situation shown in Fig. 4-f.

A cyclone arriving from west has become very intense with a central pressure of 945 mb on the 27th (Fig. 4-g). In this case, a microseismic " eye " with a radius of 700 km was supposed around the center towards the Norwegian coast (cyclone No. 5 in Fig. 3). The arrival time of swell from this fringe to the southern coast was calculated as 27d 23h (Table I), which also corresponds well to the beginning of the period storms of microseisms actually observed.

November, 1957.

A rapid increase of microseismic period on the 2nd can be well explained by long-period swell from the limit of " eye " around the cyclonic center (970 mb) which appeared on October 30th at the southern edge of Greenland (cyclone No. 6 in Fig. 3). In this case, the arrival time of swell at the nearest Norwegian coast was estimated as 01d 12h (Table I), which also agrees well with the time of the beginning of the microseismic period storm. In this case, there are also other near cyclones at the same time (Fig. 5-a). A great difference between the swell periods due to these cyclones can be supposed (they might be around 17 seconds and 9 seconds respectively as judged by the observed microseismic periods). Therefore, microseismic periods and amplitudes produced by these different energy sources are measured separately as shown in Fig. 5.

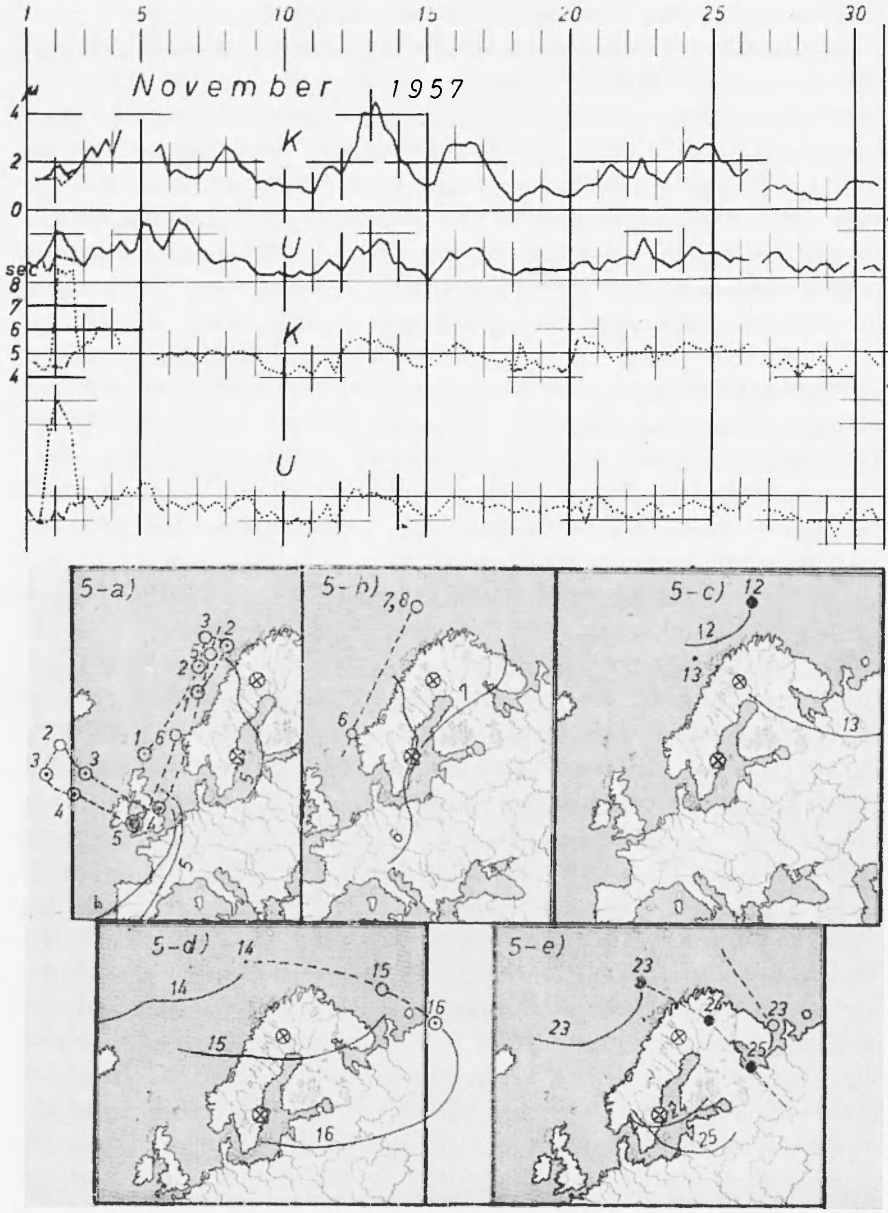

Fig. 5 — Amplitudes and periods of microseisms and weather situations in November, 1957.

A microseismic storm with rather high amplitudes lasting from the beginning of this month to the 9th at both stations, would be produced by two successive cyclones with similar paths (Fig. 5-a and -b). The amplitude peaks around 05d 00h and 06d 12h at Uppsala might be caused by the successive moderate cyclones at the south Norwegian coast not far from Uppsala. The second peak in the Kiruna amplitude curve around 08d 00h is considered to be caused by the cyclone which stayed in the same position (Fig. 5-b). The third large peak around 13d 00h at Kiruna, probably caused by a cold front or a cyclone on the 12th (Fig. 5-c), is extremely high compared with the weakness of the cyclone. This fact also tells how Kiruna microseisms are sensitive to energy sources off the northern coast of Scandinavia. The simultaneous microseismic storm at Uppsala must have the same northern origin as at Kiruna. This is also suggested by the similarity of amplitude variation at the two stations. The amplitude ratio between Kiruna and Uppsala is about 1 : 0.4.

The same can be said for the following storm around 16d 06h (Fig. 5-d). A remarkable delay of maximum amplitudes in this case is due to later increase of energy. This suggestion is verified by the estimate of arrival time of swell from the cyclone of 15d 06h to the coast C (cyclone No. 7 in Fig. 3 and Table I). The estimated arrival time of swell (15d 17h) agrees very well with the observed beginning of the microseismic storm. Microseismic waves at Uppsala would come from the same northern origin as for Kiruna. The amplitude ratio Kiruna : Uppsala is about 1 : 0.5.

From the 20th, small cyclones or weak cold fronts passed over Scandinavia successively till the 25th. Irregular noisy situation of microseismic amplitudes at the two stations seems to result from these sources. A remarkable increase of amplitudes from the 23rd at Kiruna is surely caused by a cyclone, passing across the Norwegian coast near the station (Fig. 5-e).

December, 1957.

There were many microseismic storms in this month. The average microseismic amplitudes reached 2 μ at Kiruna and nearly 2 μ at Uppsala. The periods also often increased beyond 6 seconds. This is due to the fact that in this month, cyclones with rather high intensity successively passed across or around Scandinavia. At first, a small but developing cyclone passed over the northern coast of Scandinavia

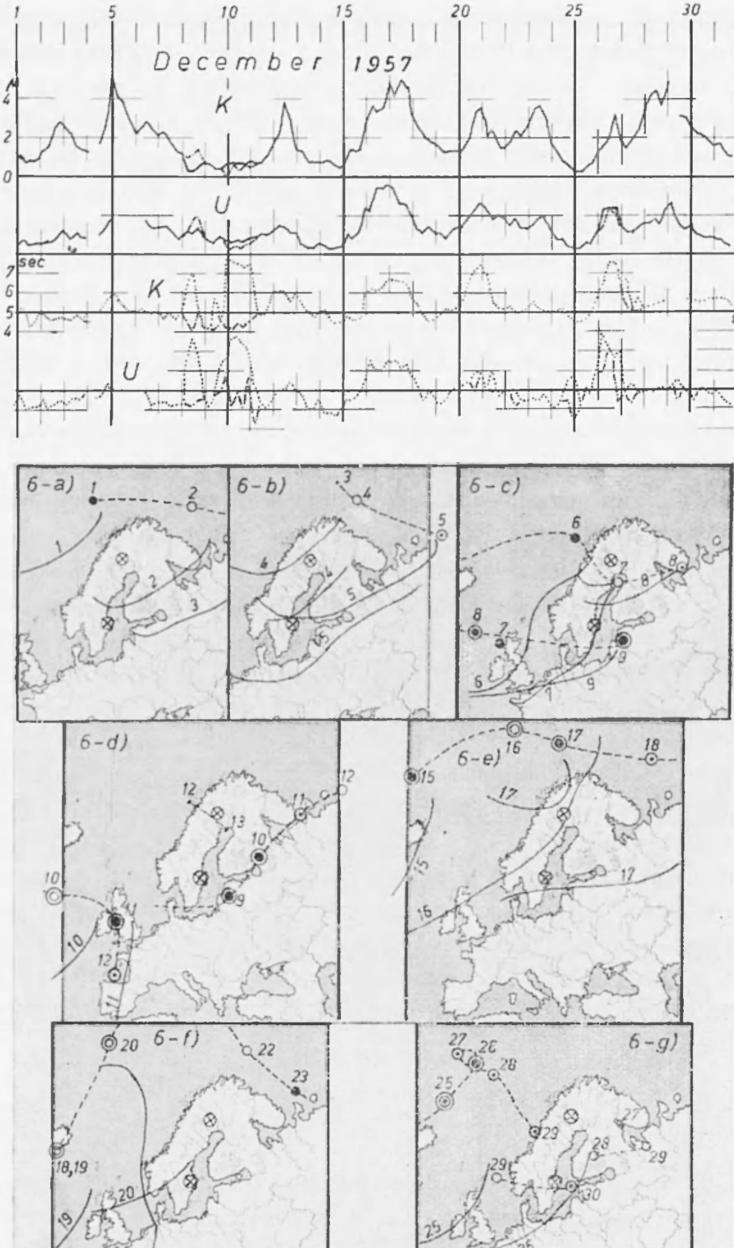

Fig. 6 – Amplitudes and periods of microseisms and weather situations in December, 1957.

(Fig. 6-a). The next passage of a developing cyclone (Fig. 6-b) made a remarkable storm at Kiruna. As for the time lags of peaks against the passages of these two cyclones, the same conclusion can be made as for 16d 12h, November 1957 (Fig. 5-d).

Table II – ESTIMATED ARRIVAL TIMES OF SWELLS – (December, 1957).

N.	Date GMT			p_o	D - D_o	v	t	T		C
		d	h	mb	km	km/hr	hr	d	h	
8	Dec.	06	06	990	1700	30	57	08	15	A
					1300	30	43	08	01	B
9	»	08	06	965	1500	32	47	10	01	A
					700	32	22	09	04	B
10	»	11	06	970	350	26	13	11	19	C
11	»	12	06	980	700	26	27	13	09	C
12	»	15	06	960	700	26	27	16	09	A
					700	26	27	16	09	B
13	»	16	06	950	250	26	10	16	16	A
14	»	19	06	995	500	24	21	20	03	B
15	»	20	06	955	700	30	23	21	05	A
16	»	25	06	950	600	26	23	26	05	A
					400	26	15	25	21	B
17	»	26	06	960	700	30	23	27	05	A

Due to a following moderate cyclone, passing through the middle part of Scandinavia (Fig. 6-c), the amplitudes of microseisms at both stations remained rather high till the 7th.

A rapid increase of microseismic periods at both stations at 08d 12h can be explained by the appearance of a cyclone off western coast of Greenland (cyclone No. 8 in Fig. 7). The estimated arrival time of swell from the fringe of the " eye " at 06d 06h (Table II) agrees quite well with the time of observed microseismic period increase. Because of a near energy source at the easternmost coast of White Sea around the same time (Fig. 6-c), short-period microseisms due to the swell from this cyclone are also measured.

A cyclone at 08d 06h (Fig. 6-c and No. 9 in Fig. 7) caused the next rapid increase of periods from the end of the 9th. The arrival time of swell due to this cyclone was estimated as 09d 04h for the southern and 10d 01h for the northern coasts of Norway (Table II), which also agree with the observed times. This cyclone approached with high velocity from the west (Fig. 6-d) and entered the Arctic Ocean on the 11th. It must be noticed that even by the passage of such a strong cyclone through Finland, no microseismic storm at either station was observed until it entered the Arctic Ocean. The estimates of arrival times of swell from the cyclones of 11d 06h and 12d 06h to the coast C (cyclone Nos. 10 and 11 in Fig. 7) also clear up the cause of this

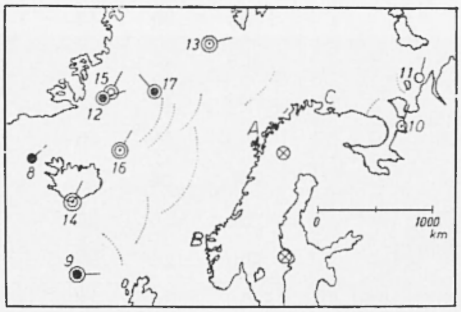

Fig. 7 – Positions of distant cyclones in December, 1957.

phenomenon. The calculated arrival times of swell become 11d 19h and 13d 09h respectively, which correspond to the beginning and end of the period storm in question. Taking into account the rather small amplitudes at Uppsala, another small cyclone which ran near Kiruna from the 12th to the 13th (Fig. 6-d), would contribute to the sharp and isolated amplitude peak at Kiruna just at 12d 12h.

A long-period microseismic storm to be expected from an intensive cyclone on the 10th off eastern coast of England (Fig. 6-d), is rather obscured by a near cyclone around the calculated time of swell arrival.

A large microseismic storm around the 17th at both stations is surely due to an intensive cyclone, passing off northern Scandinavia (Fig. 6-e). By several distant and intensive cyclones the periods of microseisms at both stations varied in phase with each other. The swell from the cyclone at 15d 06h for instance (No. 12 in Fig. 7), reached the Norwegian coast around 16d 09h, which agrees well with the observations.

The next cyclonic centers on the 19th and the 20th (Fig. 6-f and Nos. 14 and 15 in Fig. 7) are situated about 1100 km and 1300 km respectively from the nearest coast of Norway. From Table II, the arrival time of swell at the coast becomes 20d 03h and 21d 05h respectively, which correspond to the beginning and peak of the amplitude and period storm on the 20th.

A trial was made to see how the arrival time of swell is affected, if we assume that the most effective swell was delivered from the cyclonic center and not from the fringe of the cyclone (No. 15). In this case, the travelling path of swell to the coast (A) becomes 1300 km. Then, the arrival time is calculated as 22d 01h. At this time, however, the observed period storm of microseisms had already ceased.

The next amplitude storm on the 23rd, which was remarkable at Kiruna, is due to the arrival of a cyclone from the 22nd to the 23rd (Fig. 6-f). The simultaneous storm at Uppsala probably has the same origin as at Kiruna. The amplitude ratio Kiruna: Uppsala is about 1 : 0.5. The next peak on 26d 12h in both amplitude and period is surely produced by the swell which reached the Norwegian coast at that time from strong cyclonic centers on the 25th and the 26th respectively (Fig. 6-g and Nos. 16 and 17 in Fig. 7). The estimated arrival times of swell from the limits of the " eye " around these cyclonic centers at the Norwegian coast nearly correspond to the beginning and end of the observed period storm (Table II).

A cyclone approached the central Norwegian coast on the 29th and disappeared there. Maximum microseismic amplitudes at both stations a little later than the 29th are considered to be caused by this cyclone together with two others, one near the coast of southern Norway and the other at the southern coast of White Sea. Being disturbed by the increase of microseismic amplitudes with shorter periods due to these cyclones, the period storm disappeared around the 29th.

January, 1958.

In order to picture the extremely large microseismic storm on the 18th (as large as 12 μ at Kiruna) within a certain limit, the scale of amplitudes in this month is further decreased to half of that of the preceding month. Till the 7th, there were no disturbance sources around Scandinavia.

On the 7th, a cyclone (as strong as 955 mb on the 7th) ran through northern Europe (Fig. 8-a). But, as is always the case, such a situation has no remarkable effect upon the microseisms, not even at Uppsala. On the 10th, there were two cyclones off the northwestern coast of

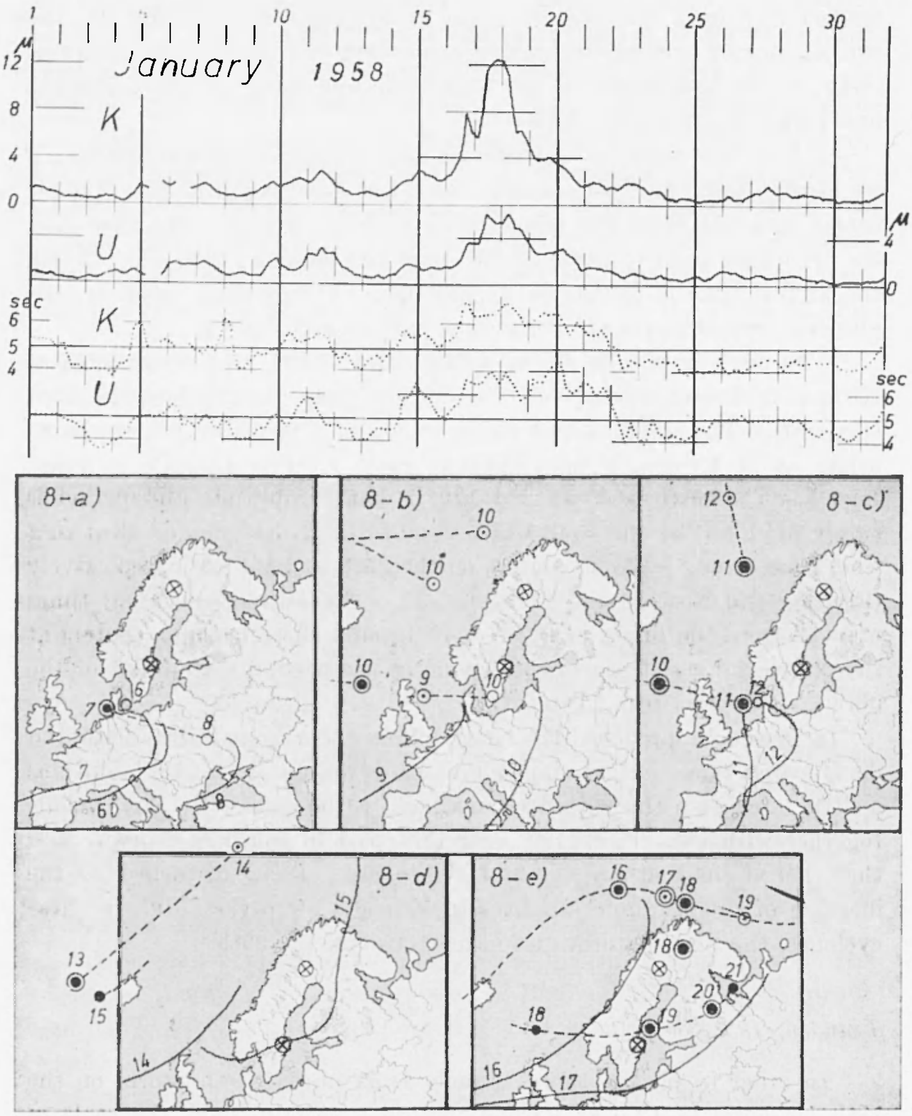

Fig. 8 – Amplitudes and periods of microseisms and weather situations in January, 1958.

Norway (Fig. 8-b). They were combined on the 11th (Fig. 8-c) and then ran to the north. There were other intensive ones around Denmark during the same period (Fig. 8-b and -c). The microseismic storm at Uppsala with almost the same maximum amplitudes as at Kiruna around 11d 12h, would result by the additive effects of these strong cyclones.

An intensive cyclone ran far off Scandinavia, as shown in Fig. 8-d. The maximum periods of microseisms at both stations on the 15th are caused by the swell from the fringe of the " eye " around the cyclonic center of the 13th (No. 18 in Fig. 9). The estimated swell arrival time becomes 14d 18h (Table III), which agrees quite well with the observed results.

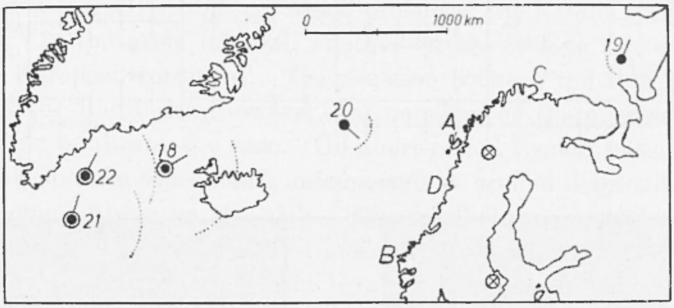

Fig. 9 – Positions of distant cyclones from January to April, 1958.

Another strong cyclone followed, as shown in Fig. 8-e. It had its minimum central pressure on the 17th and was divided into two, which caused the largest microseismic storm at Kiruna. Another intensive cyclone inside northern Sweden on the 18th would have an additive effect to make such an extremely large storm at Kiruna. A little later, on the 19th, another strong cyclone ran eastward just over Uppsala. At the passage of this intensive cyclone over Uppsala a little before 19d 06h, the microseismic storm at Uppsala was already decreasing. It means that the storm at Uppsala in question was much more effected by the northern energy source than by the southern one.

The period storm of long duration, lasting until 22d 00h, is explained by swell due to the cyclone moving eastward over the Atlantic Ocean. But, as the locations of the cyclonic centers after the 19th were unknown, no verification of this suggestion was possible.

February, 1958.

As we have seen hitherto, the weather situation like the one of 03d 06h in Fig. 10-a with a cyclone around north Norway or still more in north Russia, is very effective for microseismic storms. The same

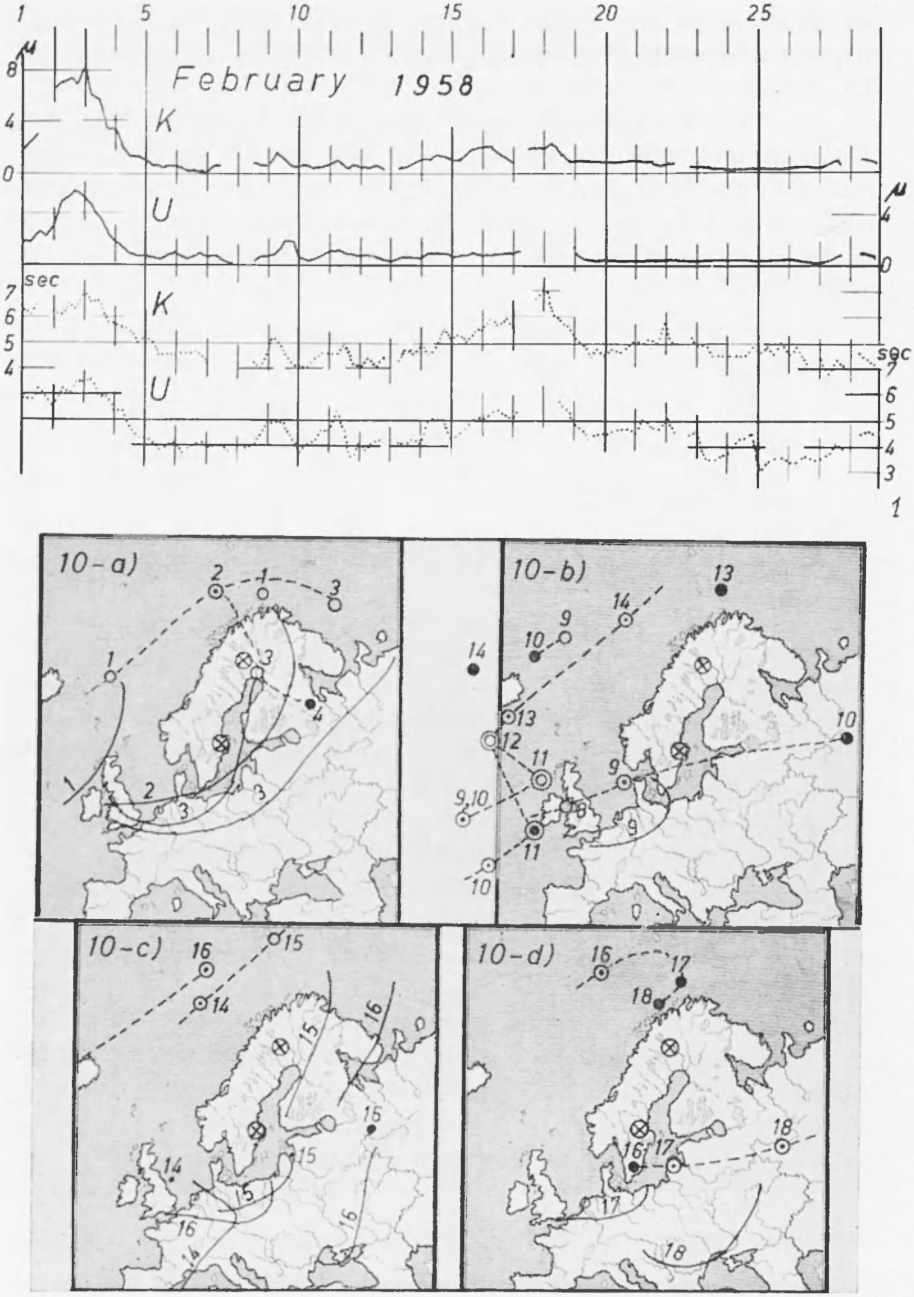

Fig. 10 – Amplitudes and periods of microseisms and weather situations in February, 1958.

results were found by Båth (1952a). This situation resulted in a remarkable microseismic storm at both stations around the 3rd. Another developing cyclone approached the southern coast of Norway on the 9th (Fig. 10-b) and produced a little storm at Uppsala. Two much stronger cyclones approached on the 11th far out on the ocean west of England (Fig. 10-b). As they were mostly double, the corresponding swells disturbed each other at the coast. Therefore, there is no remarkable microseismic period storm.

Two cyclones successively passed off the north-western coast of Scandinavia (Fig. 10-c and -d), which prolonged the Kiruna storm until the 18th. In the same interval, another strong cyclone ran eastward over the European continent. The situation between the 16th and the 17th over the Baltic Sea, however, has no effect on the microseisms at Uppsala, as is always the case. On short-period Benioff seismographs at Uppsala, on the other hand, microseisms of around 3 second period showed some activity on the 17th. This small storm would be caused by the passage of a cyclone over the southern Baltic Sea. The distant energy source which increased the microseismic periods very gradually until 18d 00h could not be discovered on the weather map.

March, 1958.

In this month the microseisms at the two stations were so small, that the average amplitudes were reduced to about $0.5\,\mu$.

A cyclone approached the northern coast of Norway from west with high velocity (Fig. 11-a). This cyclone is related to the first storm of this month, around the 6th. At the same time, two cyclones appeared west and east of southern Scandinavia. The former increased in intensity on the 6th at nearly the same position and then disappeared on the 7th. These two cyclones on the 6th on both sides of Uppsala may contribute to prolonging the storm at Uppsala more than at Kiruna.

Though not shown in the map there was a cyclone on the 11th and the 12th (990 mb and 995 mb respectively) over the south Baltic Sea. On the 13th and 14th a cyclone (995 mb and 990 mb respectively) appeared in eastern Europe. As always, these situations do not influence the microseisms very much, not even at Uppsala. On the other hand, the weak cold front (Fig. 11-b) from the 21st to 23rd increased the amplitudes at Kiruna. It shows again the strong effect along northern Scandinavian coast for the microseisms at Kiruna.

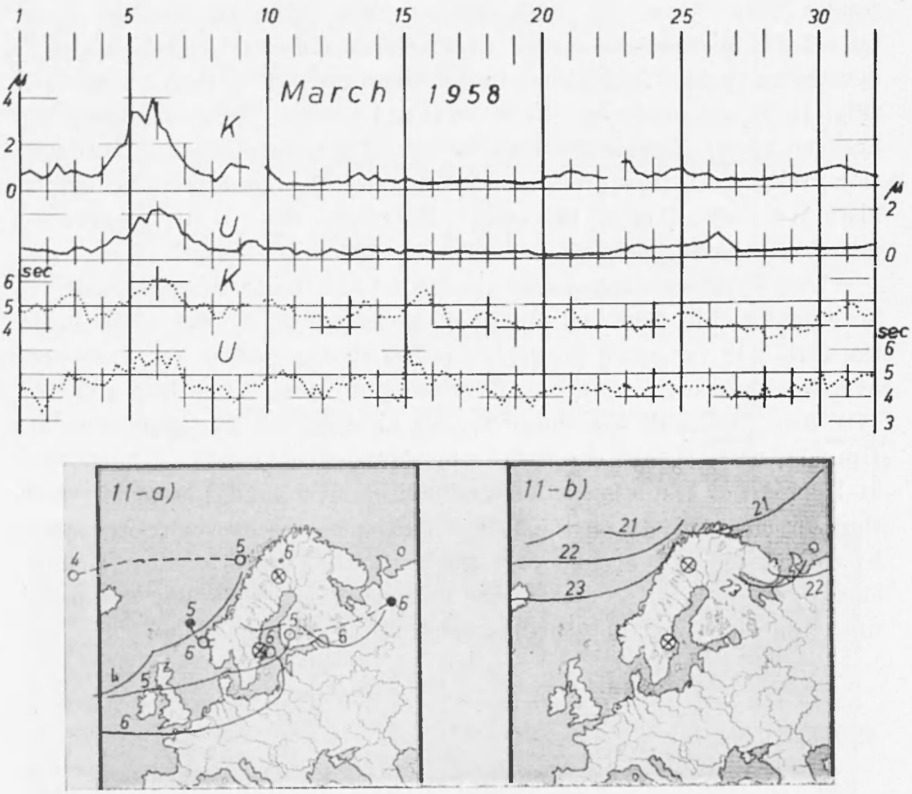

Fig. 11 – Amplitudes and periods of microseisms and weather situations in March, 1958.

April, 1958.

Till the 10th, weak cyclones (about 1000 mb) or cold fronts passed successively over the sea around Scandinavia. Due to them, many irregular variations appeared both in amplitude and period curves. For instance, due to the developing cyclone which entered the Arctic Ocean slightly after 07d 06h (Fig. 12-a), microseismic amplitudes at both stations began to increase from 06d 12h. A sharp period storm around 09d 12h might be caused by a cyclone at 08d 06h in the Arctic Ocean (Fig. 12-a and No. 19 in Fig. 9). This conclusion is ascertained by the estimate of arrival time of swell from the cyclone to the coast C (Table III). The calculated result of 09d 07h corresponds to the observed beginning of the period storm. The next increase of amplitudes at Kiruna on the

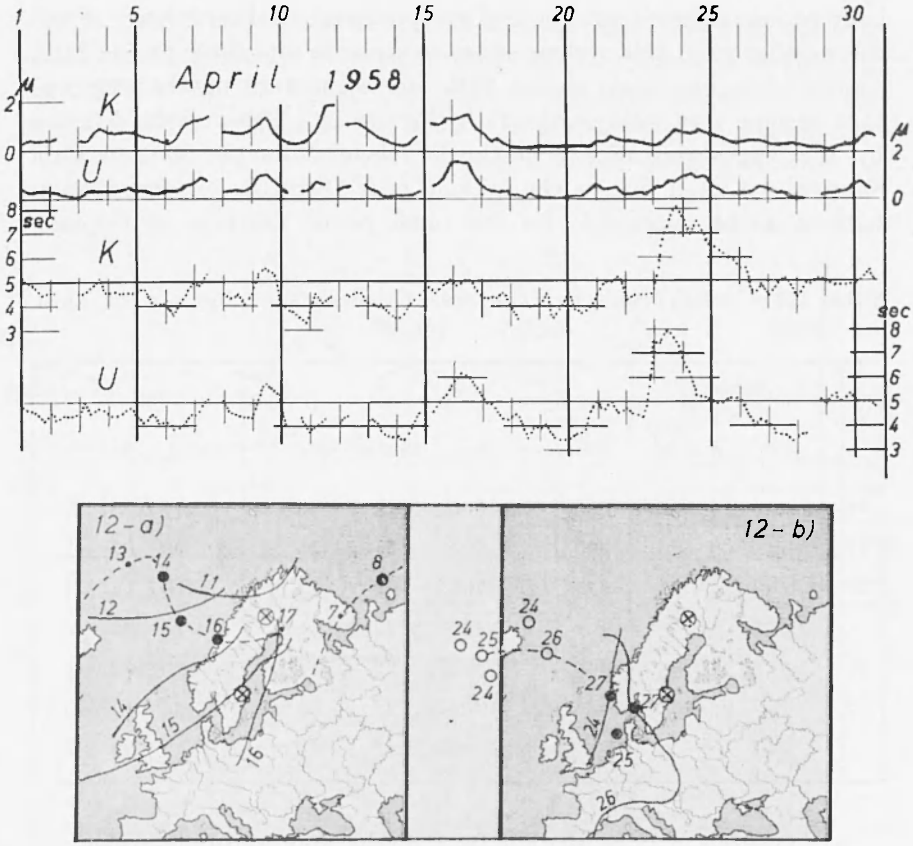

Fig. 12 – Amplitudes and periods of microseisms and weather situations in April, 1958.

12th was caused by a cold front, scratching the northern coast of Norway (Fig. 12-a). The following storm around the 16th both in amplitudes and periods can be explained by the approach of a moderate cyclone to the central Norwegian coast (Fig. 12-a). The arrival times of swell from the cyclone in its position at 14d 06h to the central (D) and to the southern coast (B) (No. 20 in Fig. 9) were estimated as 15d 14h and 15d 23h respectively (Table III). Both agree quite satisfactorily with the observational results.

An intensive cyclone appeared near the south-eastern coast of Greenland on the 21st. It moved a little northward on the next day (Nos. 21 and 22 in Fig. 9). It is also clear by the estimate of arrival times of swell from these two positions (Table III), that the extremely large period increase from the 23rd was produced by this cyclone. From the weather map, this cyclone seems to separate into three on the 24th, combine into one again on the 25th, move eastward on the 26th and then become very weak on the 27th (Fig. 12-b). The periods decrease by the appearance of two or three cyclones from the 23rd to 25th. Short-period swell due to the cyclone near Denmark on the 25th is without doubt responsible for the rapid period decrease at Uppsala.

Table III – ESTIMATED ARRIVAL TIMES OF SWELLS – (January to April, 1958)

N.	Date GMT			p_0	D_0	v	t	T		C
		d	h	mb	km	km/hr	hr	d	h	
18	Jan.	13	06	965	1000	28	36	14	18	B
19	Apr.	08	06	990	600	24	25	09	07	C
20	»	14	06	995	700	22	32	15	14	D
					900	22	41	15	23	A
21	»	21	06	965	1400	32	44	23	02	B
22	»	22	06	965	1700	32	53	24	11	A
					1400	32	44	24	02	B

It must be noticed that in spite of the approach of a cyclone to the southern coast of Norway on the 27th, there is practically no microseismic storm at Uppsala.

May, 1958.

As the amplitudes of microseisms became rather small in this month, the amplitude scale is enlarged to twice that of the preceding months. As shown in Fig. 13-a, a cyclone reached the western coast of Scandinavia on the 9th. The cyclone stayed nearly in the same position with decreasing intensity. A cold front moved across south Scandinavia from the 9th to 10th. Judging from the time of beginning of the microseismic storm from 10d 00h, the cold front is likely to produce the storm. But, it is difficult to explain why amplitudes had begun to decrease from 11d 12h despite the fact that the cyclone was keeping its intensity until 12d 06h at least.

A peak which appeared only at Uppsala about 20d 12h might be produced at the south Norwegian coast by the cyclone in its situation of 20d 06h (No. 23 in Fig. 14). The arrival time of swell from this position of the cyclone to the nearest southern coast of Norway was estimated as 20d 15h (Table IV), which agrees quite well with the observations.

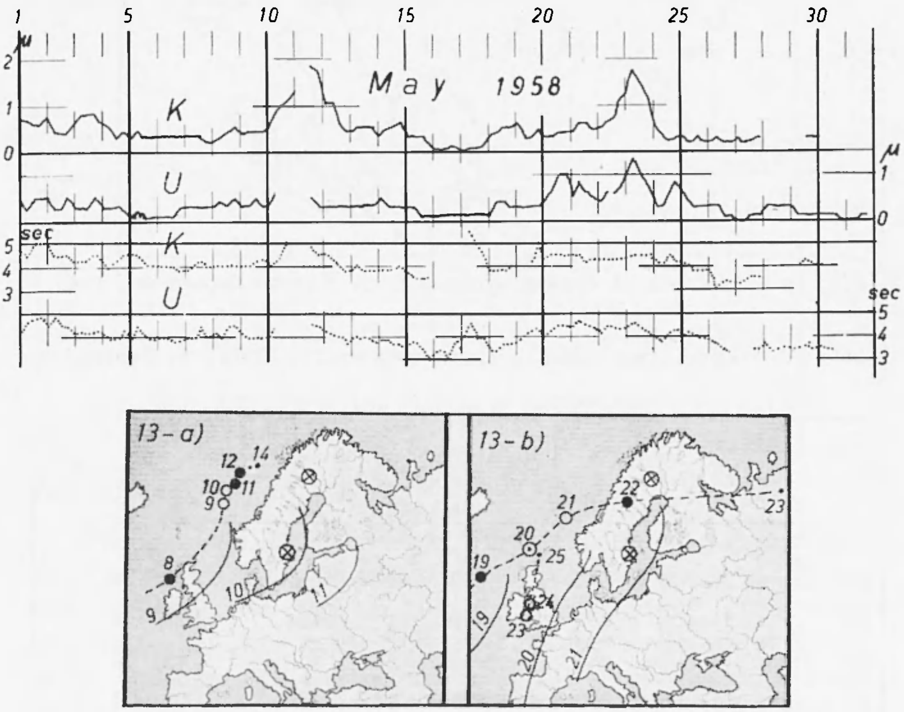

Fig. 13 – Amplitudes and periods of microseisms and weather situations in May, 1958.

A sharp amplitude storm at both stations at 23d 06h is certainly caused by swell arriving at the northern coast from the cyclone on the 21st (No. 24 in Fig. 14). The arrival time of swell at the coast (A) is estimated as 23d 05h (Table IV), which agrees with observations. The velocity of the cyclone from the 19th to 20th and from the 20th to 21st is calculated as 33 km/hr and 32 km/hr respectively, i.e. much higher than the estimated swell velocity (see also Table IV). For this reason, the short-period swell from the cyclonic positions nearer to the coast reaches the coast earlier than the long-period swell from the distant positions. Therefore, there are no long-period microseisms in this case.

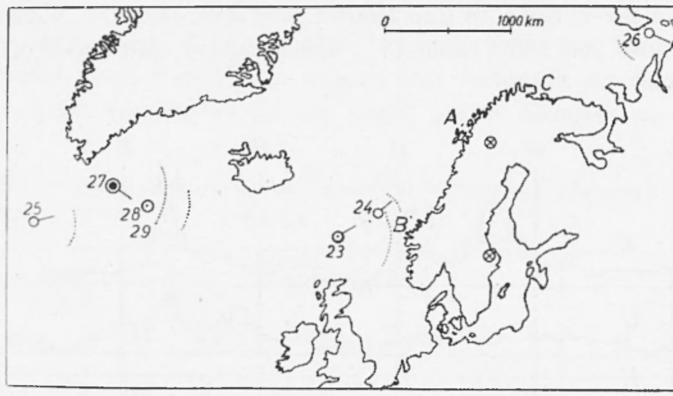

Fig. 14 – Positions of distant cyclones from May to September, 1958.

Table IV – ESTIMATED ARRIVAL TIMES OF SWELLS – (May to September, 1958).

N.	Date GMT			p_0	$D - D_0$	v	t	T		C
		d	h	mb	km	km/hr	hr	d	h	
23	May	20	06	975	150	17	09	20	15	B
24	»	21	06	985	800	17	47	23	05	A
25	June	11	06	985	2400	26	92	15	02	B
26	Sept.	08	06	980	700	22	32	09	14	C
27	»	17	06	960	1600	24	67	20	01	B
28	»	18	06	970	1300	24	54	20	12	B
29	»	19	06	965	1300	24	54	21	12	B

June, 1958.

In this month, microseismic activity was poor and there are some interruptions at Kiruna. The weather situation related to a remarkable period increase between the 14th and 18th, is the only one of interest.

This period storm resulted from the appearance of a cyclone about 600 km off the southern coast of Greenland on the 11th (No. 25 in

Fig. 14). The arrival time of swell from this cyclone at the nearest Norwegian coast (B) is given in Table IV. The result, 15d 02h, corresponds to the time of the largest period observed. Furthermore, the cyclone gradually approached with decreasing energy the southern coast of Iceland (985 mb, 995 mb, 990 mb and 995 mb on the 12th, 13th, 14th and 15th respectively). This approach and energy decrease caused a gradual decrease of microseismic periods.

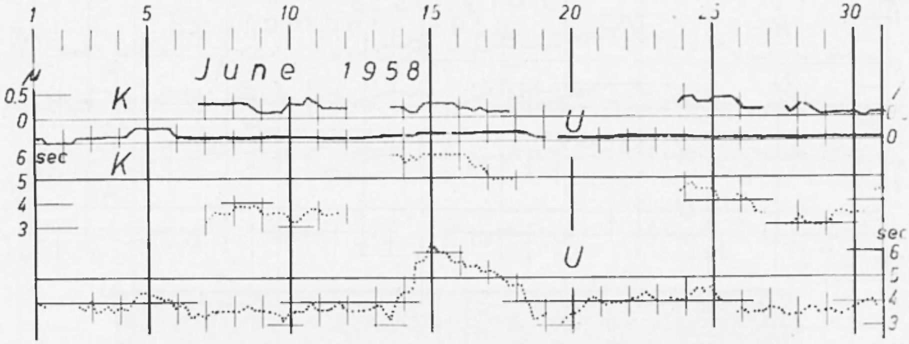

Fig. 15 – Amplitudes and periods of microseisms in June, 1958.

July, 1958.

The first microseismic storm of which a small peak appeared about 10d 12h can be connected with a cyclone passing through the northern part of Scandinavia from the 10th to 11th (Fig. 16-a). This cyclone was divided into two on the 12th near the northern coast of Norway, which prolonged the microseismic storm. The passage of a smaller cyclone from the 8th to 9th also seems to have some effect upon the microseismic amplitudes at Kiruna. Another cyclone ran through Scandinavia (Fig. 16-b). It must be noticed that the peak of the amplitude curve at Uppsala due to this source occurred when the cyclone reached near north-eastern part of Scandinavia.

Very small cyclones (central pressure higher than 1000 mb) successively passed over and around Scandinavia in this month. But, they did not have much effect on the microseisms at the two stations.

As to the remarkable storm which occurred only at Kiruna about 26d 12h, the general explanation from the intensity or the movement of a cyclone only is impossible. The only indication the writer could find from the meteorological data was a small cyclone (1005 mb) very near Kiruna at 26d 06h and that the greatest wind velocity was measured at the northernmost coast of Norway just at that time. Therefore, this microseismic storm was caused by such local meteorological conditions, which were missing in weather maps of once a day.

As there is nothing to say about microseisms in the next month, it is omitted.

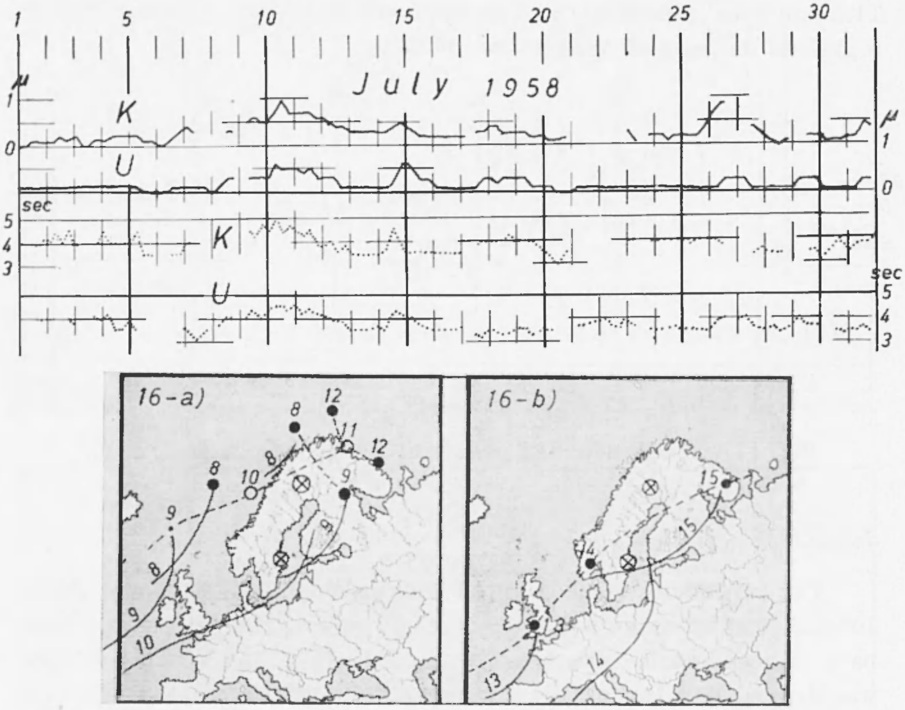

Fig. 16 – Amplitudes and periods of microseisms and weather situations in July, 1958.

September, 1958.

The first storm occurring from the 7th, is surely due to the passage of a developing cyclone far off the northern coast of Scandinavia (Fig. 17-a). There is also a parallel period increase at both stations. The microseisms of about 5.5 second period around 09d 00h are caused by the swell from the cyclone at some stage from 07d 06h to 08d 06h. For instance, the arrival time of swell from the cyclone at its later stage at 08d 06h (No. 26 in Fig. 14) at the northern coast of Scandinavia (C) was estimated to be 09d 14h (Table IV), which nearly corresponds to the end of the period storm.

From the 11th to the 12th, a cyclone of decreasing intensity and a cold front passed across northern Scandinavia (Fig. 17-a). Perhaps, because of the decreasing energy, the effect upon microseisms is very poor. However, a larger cyclone follows with high velocity off the north-eastern coast of Scandinavia (Fig. 17-b). The time lag of the peak of

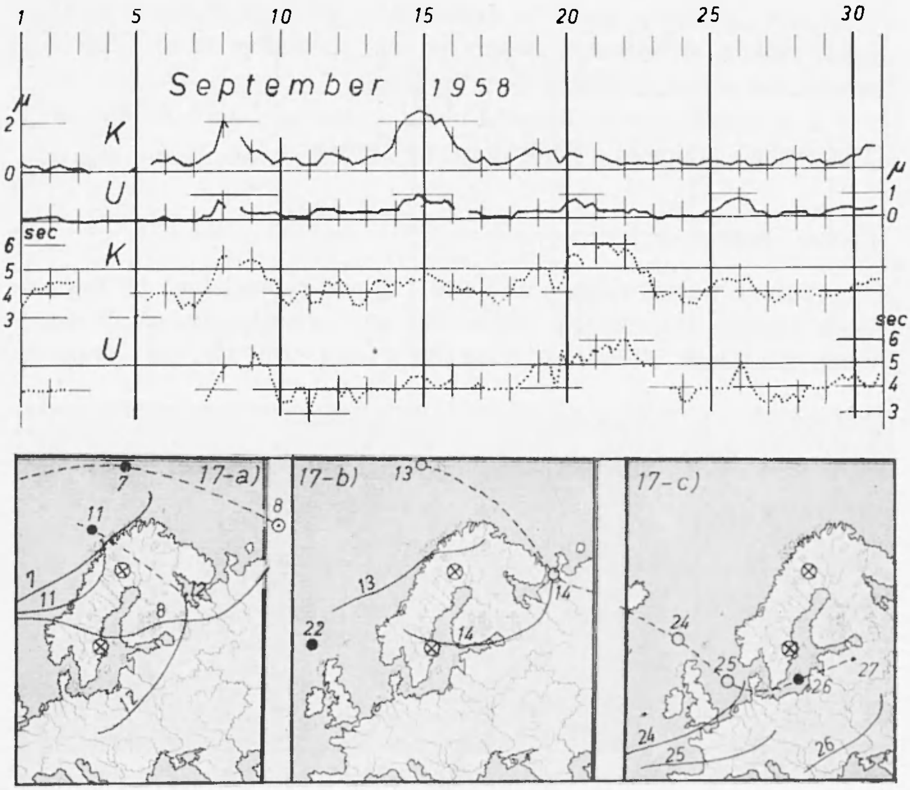

Fig. 17 – Amplitudes and periods of microseisms and weather situations in September, 1958.

amplitudes around 15d 00h is too large to be explained by the travelling velocity of this cyclone. The only meteorological data which can explain this, is the wind velocity at the northernmost coast which reached its maximum at 15d 06h. Therefore, the storm might be caused by a local phenomenon at that coast. An intensive cyclone appeared between Greenland and Iceland on the 17th, which moved till the 22nd around the same position with nearly the same intensity (Nos. 27, 28 and 29 in Fig. 14). Arrival times of swell from the fringes of "eye" around the cyclonic centers at each position are given in Tabe IV. The results cover the earlier part of the period storm observed. The cyclone moved slowly towards England and reached about 500 km off the southern coast of Iceland with decreasing energy (975 mb and 980 mb on the 20th and 21st respectively). The long-period swell from the cyclones on these days, however, would be disturbed by the appearance of another small cyclone off northern Britain on the 22nd (Fig. 17-b). For this reason, the period decreased from the 22nd.

A moderate cyclone followed along a path as shown in Fig. 17-c. This cyclone produced a small storm at Uppsala.

October, 1958.

A small period maximum at 07d 12h can be explained by the cyclone around 04d 06h (No. 30 in Fig. 19), of which the swell could reach the south Norwegian coast (B) arbund 07d 03h, as given in

Table V – Estimated arrival times of swells – (October, 1958).

N.	Date GMT			p_o	$D - D_0$	v	t	T		C
		d	h	mb	km	km/hr	hr	d	h	
30	Oct.	04	06	980	1800	26	69	07	03	B
31	»	08	06	975	1500	28	54	10	12	B
					1000	26	38	09	20	B
32	»	09	06	975	1000	30	33	10	15	A
					700	30	23	10	05	B
33	»	14	06	980	1600	30	53	16	11	B
34	»	15	06	985	1200	30	40	16	22	B
35	»	17	06	975	2100	26	81	20	15	B
36	»	18	06	990	1600	26	62	20	20	B

Table V. This result agrees quite well with the observations. As another cyclone (p_o = 990 mb) appeared on 05d 06h about 600 km off the western coast of south Norway, the period of microseisms decreased quickly, because the swell was disturbed by the near source.

Both amplitudes and periods at the two stations increased from about the 9th with their peaks nearly at 10d 12h. There were two cyclones on the 7th, which combined into one on the 8th (Fig. 18-a).

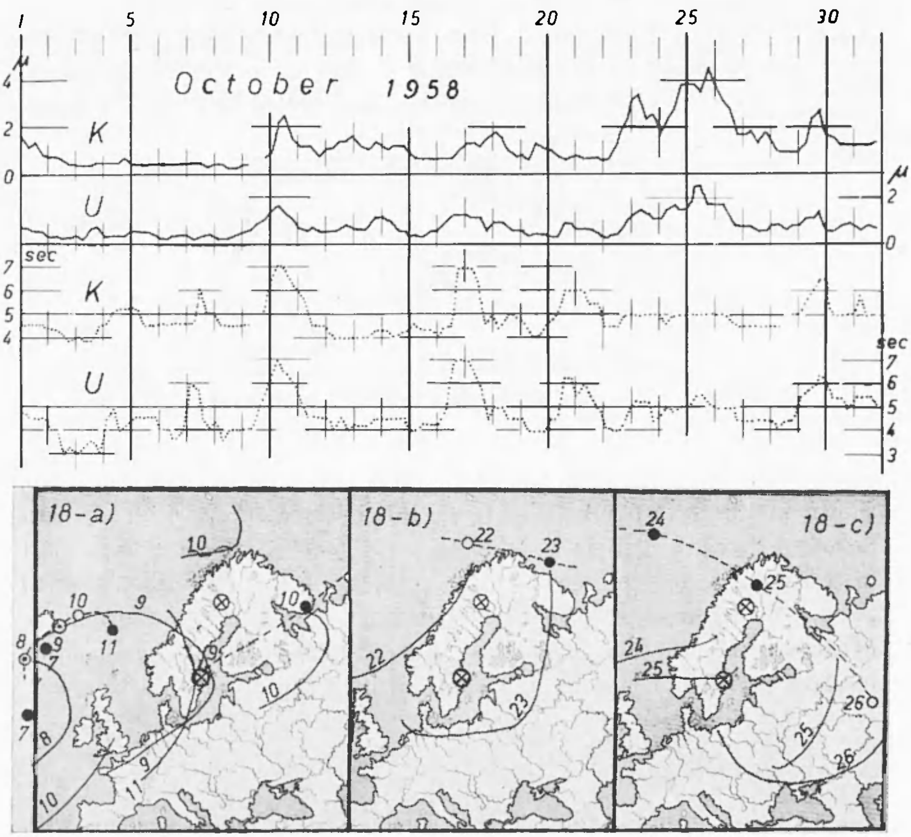

Fig. 18 – Amplitudes and periods of microseisms and weather situations in October, 1958.

The microseismic storm is probably caused by the single cyclone near Iceland in its situations of 08d 06h and 09d 06h (Fig. 18-a and Nos. 31 and 32 in Fig. 19). Arrival times of swell at southern (B) and northern (A) coasts of Norway were estimated separately (Table V). These times correspond to the beginning and peak of the period storm.

There was another cyclone near the coast of Iceland during the 14th to 15th and from the 17th to 18th. As shown in Table V, the swells from these cyclones (Nos. 33, 34, 35 and 36 in Fig. 19) are found to reach the Norwegian coast just around the 17th and 21st respectively, both in agreement with observations.

An increase of amplitudes from the 23rd, especially remarkable at Kiruna, is undoubtedly due to a cyclone which passed along the northern coast of Norway (Fig. 18-b). There was a distant cyclone near the coast of Greenland on the 21st (nearly in the same position as No. 30 in Fig. 19). The swell from this cyclone is expected to cause a remark-

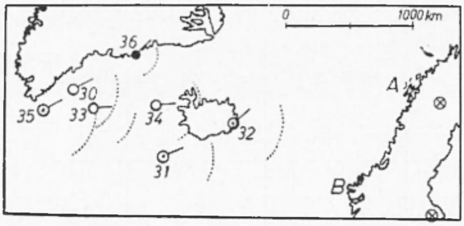

Fig. 19 – Positions of distant cyclones in October, 1958.

able period storm around the 24th. But this was not the case. As shown in the next figure (Fig. 18-c), this cyclone approached northern Scandinavia with a high velocity and had reached the northern coast of Norway already before the 25th, i.e. before the arrival of long-period swell. Therefore, the long-period but small-amplitude swell from the cyclone in its situation on the 21st was effectively masked by the swell of short period but large amplitude from its situation on the 25th.

November, 1958.

In this month, Scandinavia was surrounded by many cyclones with central pressures lower than 1000 mb. Such a circumstance made the microseismic amplitudes at both stations always high. Therefore, the amplitude scale (Fig. 20) was again reduced to half of those in the preceding month. The periods also rose to around five seconds in average.

A cyclone with decreasing intensity approached the middle Norwegian coast on the 3rd (Fig. 20-a). However, it produced no obvious microseismic effect.

There was a sudden increase of periods somewhat after the 13th. A single distant cyclone appeared between Greenland and Iceland on the 11th (No. 37 in Fig. 21). The estimated arrival time of swell from this cyclone coincides with the time of this rapid period increase

(Table VI). The next increase of microseismic periods, at 16d 00h, corresponds to the arrival time of swell at the south Norwegian coast (B) from a single cyclone at 13d 06h (No. 38 in Fig. 21 and Table VI).

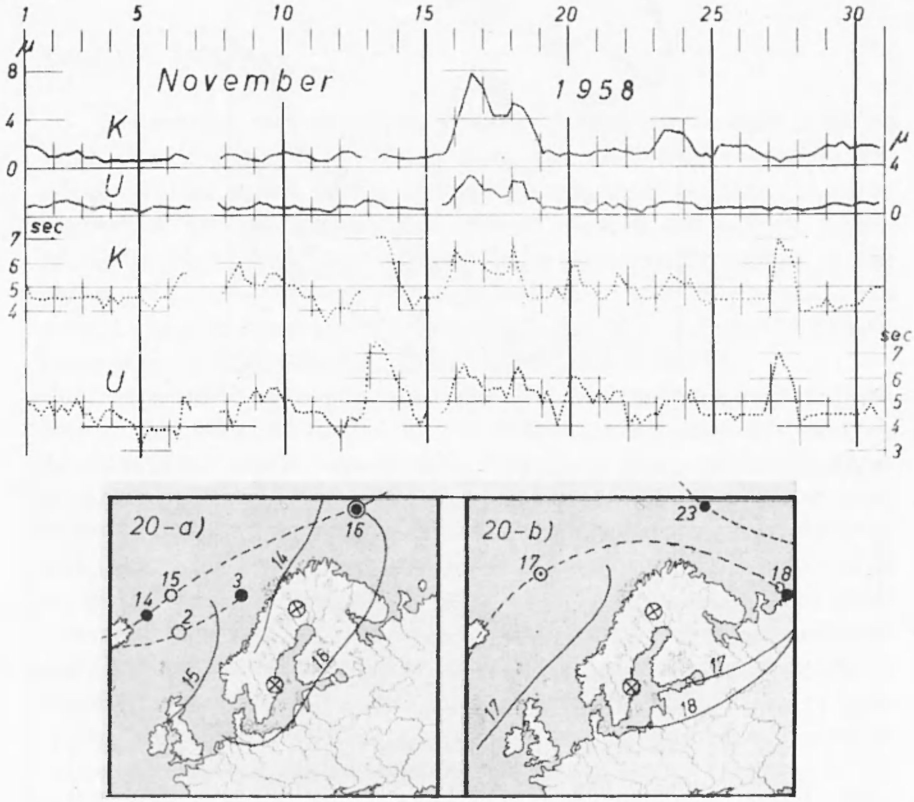

Fig. 20 – Amplitudes and periods of microseisms and weather situations in November, 1958.

It crossed Iceland and moved outside the northern coast of Norway (Fig. 20-a), causing a large amplitude storm at 16d 12h. By the approach of this cyclone to the northern coast, the periods of microseisms decreased a little.

Another cyclone followed with decreasing intensity along a path as shown in Fig. 20-b. This produced the next peak on the 18th. Judging from the similar amplitude variation from the 16th to 19th at both stations, the microseisms at both stations seem to have the same origin somewhere along the northernmost coast. The amplitude ratio Kiruna: Uppsala is approximately 1 : 0.5.

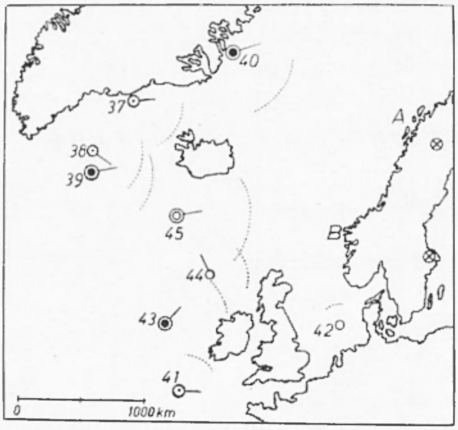

Fig. 21 – Positions of distant cyclones from November to December, 1958.

Table VI – ESTIMATED ARRIVAL TIMES OF SWELLS – (November to December, 1958).

N.	Date GMT			p_0	$D - D_0$	v	t	T		C
		d	h	mb	km	km/hr	hr	d	h	
37	Nov.	11	06	975	1400	30	47	13	05	B
38	»	13	06	970	1600	24	67	16	01	B
39	»	25	06	965	1400	30	47	27	05	B
40	Dec.	03	06	965	900	30	30	04	12	A
41	»	16	06	970	2300	30	77	19	11	A
					1300	30	43	18	01	B
42	»	17	06	985	1600	20	80	20	14	A
					500	20	25	18	07	B
43	»	21	06	965	1900	37	51	23	09	A
					1100	30	37	22	19	B
44	»	22	06	980	1400	37	38	23	20	A
					700	30	23	23	05	B
45	»	28	06	950	1200	37	32	29	14	A
					700	37	19	29	01	B

As seen in Table VI, the last rapid increase of microseismic periods on the 27th is caused by the single distant cyclone at 25d 06h off the eastern coast of Greenland (No. 39 in Fig. 21).

December, 1958.

The general meteorological conditions in this month were quite the same as in November, i.e. Scandinavia had continuously small microseismic storms caused by the successive passages of cyclones. A great increase of periods from the 3rd at both stations and a great microseismic storm with its peak on the 5th are undoubtedly related to the passage of an intensive cyclone, as shown in Fig. 22-a. The period storm around 04d 12h coincides with the arrival time of swell from the cyclone in its stage of 03d 06h (No. 40 in Fig. 21 and Table VI).

There were successive strong and distant cyclones over the ocean between Iceland and Britain from the 10th to the 23rd (Fig. 22-b and -c). As there were simultaneously other distant or near cyclones in these days, except for the 16th, 21st and 22nd, microseismic period storms, to be expected from distant and intensive cyclones, appeared only in such favourable days when swell from the single distant cyclone could reach the coast without being disturbed by other swell due to other cyclones. The locations of cyclones with such favourable conditions are shown in Fig. 21 by Nos. 41, 43 and 44, and the estimated arrival times of swells at the Norwegian coast are given in Table VI. From these results, we understand that the two sharp increases of microseismic periods around 19d 00h and 23d 06h are caused by the swell due to the energy sources at 16d 06h and 21d 06h or 22d 06h, respectively. The estimated arrival time of swell (18d 01h) from the energy source 41 to the south Norwegian coast (B), taking a slightly curved path into account, is earlier than observed. This is explained by the existence of another cyclone between England and Denmark at 17d 06h (see Fig. 22-b and No. 42 in Fig. 21). The estimated arrival time of swell from this cyclone to the southern coast (B) becomes 18d 07h, which is nearly the same as for cyclone 43. Therefore, long-period swell from No. 43 would be disturbed by short-period swell from No. 42 at the southern coast. This condition does not appear at the northern coast (A). As shown in Table VI, the arrival times of swell from the two sources are 19d 11h and 20d 14h respectively, which are sufficiently different from each other.

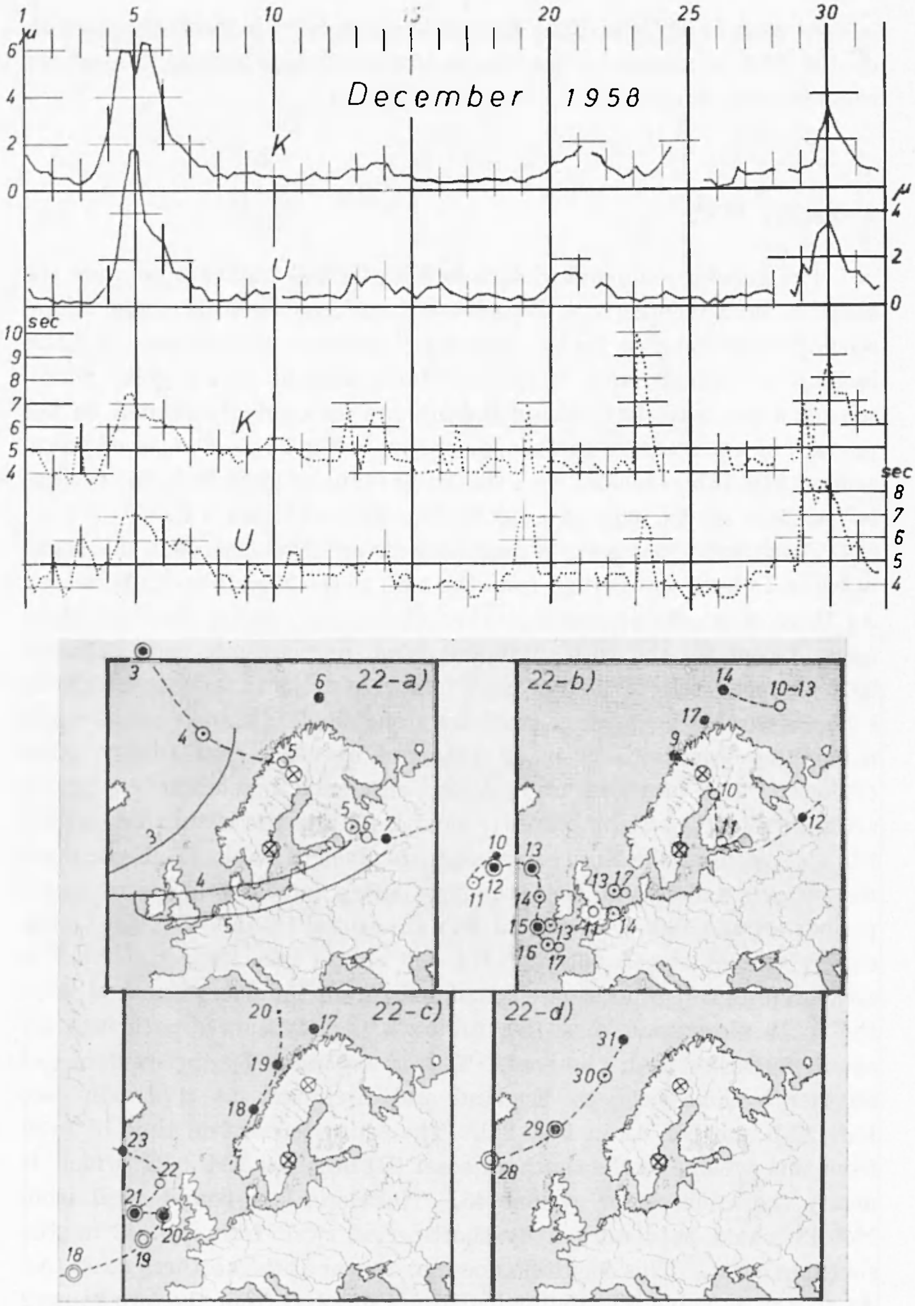

Fig. 22 – Amplitudes and periods of microseisms and weather situations in December, 1958.

DISCUSSION AND CONCLUSIONS.

Through the comparative studies of the time variations of microseismic amplitudes and periods at Kiruna and Uppsala, Sweden, and the weather situations around Scandinavia in every month during I.G.Y., the following conclusions can be drawn.

a) As cyclones and the accompanying cold fronts often pass the coasts of Scandinavia nearly at the same time, it is often difficult to decide whether a certain microseismic storm is due to the passage of a cyclone or a cold front, without using more continuous observations. But, in a few favourable cases, it was found that cold fronts are the origin of microseisms.

b) The northern coast of Norway gives comparatively stronger microseismic storms at Kiruna than the southern coast does at Uppsala. Microseismic storms originating at the northern coast of Scandinavia show parallel variations of amplitudes at Kiruna and Uppsala, but the amplitude ratio of Kiruna: Uppsala is usually close to 2 : 1.

This amplitude ratio is just what should be expected for distribution of microseismic waves over a homogeneous structure (Båth 1951 b). However, this distribution is disturbed by inhomogeneities in the crustal structure, mainly by the mountainous region along the Scandinavian peninsula. This has been pointed out especially by Russian seismologists, e.g. Prosvirnin, Proskuriakova, Rykhunov and Savarensky (1959) and Rykhunov and Mishin (1962).

An example showing the poor transmission of microseismic waves, especially of short period, is the following. On March 31st, 1962, a cyclone (p_o — 980 mb) arrived just at the southernmost edge of Sweden. This produced a remarkable short-period (around 2.5 seconds) microseismic storm at Karlskrona, quite near the cyclonic center. But there was almost nothing at Uppsala which is only about 350 km apart.

The same results are clearly observed in Japan. When a cyclone runs over the Pacific Ocean from south to north, the microseismic storm shifts gradually from southwestern stations to northeastern, as if it runs after the cyclone. In other words, microseismic storms in Japan occur quite independently at many places located near each other.

Passages of energy sources across the Baltic Sea hardly increase microseismic amplitudes even at Uppsala, as far as those with periods of more than 4 or 5 seconds are concerned. However, a small amplitude increase is observed at Uppsala for microseisms of shorter periods. The reason may be that the area of the Baltic Sea is not large enough to produce long-period swell.

c) When there is a single cyclone far off Scandinavia over the ocean, only the period of microseisms increases remarkably with a great time lag. In all cases these time lags agree quite well with the estimated travel times of swell of twice the microseismic period from an area at a certain distance from the cyclonic center to the nearest Norwegian coast. This result confirms the writer's previous conclusion (Santô 1960) that microseisms are produced by stationary swell, due to interference between incident and reflected swell at steep coasts. As the swell from a distant source reaches the coast with long period but small amplitude due to the dispersion, our conclusions are quite reasonable.

When there are several cyclones over the ocean with swell arriving at the same coast at the same time, the microseismic period storm does not always show up, even if one of them is located far off the coast. In this case long-period swell from the distant source will be disturbed by swell from other sources.

There are a few cases when a distant source approaches the coast faster than the swell, which had been delivered from the cyclone in an earlier position. In these cases, the increase of microseismic periods, expected from the swell arrival, is not observed.

d) From the theoretical study by Longuet-Higgins (1950) and the experimental investigation by Cooper and Longuet-Higgins (1951), it is well known that the water pressure variation due to standing sea waves propagates downward to the bottom of the sea without attenuation. There is certainly a possibility that standing sea waves will also be generated by interference of two wave systems from two cyclonic centers. Geddes (1958) has actually found that microseismic amplitudes increase when coupled cyclones appear over the ocean.

There are many such situations in the present investigation, and the writer carefully searched for microseisms due to such cases. But, this was unsuccessful. The reason that we cannot find any effect of coupled cyclones over the ocean on microseisms may be due to the poor transmission of microseismic waves under the ocean (Båth 1953 and Monakhov 1959, 1960).

e) There are many cases when large cyclones pass quite near the coasts of Greenland, Iceland or the British Isles. These cyclones must cause large microseismic storms on these islands. The microseismic amplitudes in Sweden, however, do not show any increase in any such case. From these facts, we have to suggest that the transmission of microseismic waves is quite poor from these lands to Scandinavia. The reason is again the poor transmission across the ocean floor.

Appendix.

When a cyclone passes over the ocean off the coast, the microseismic amplitudes at a station on land become largest later than the time of nearest passage of the cyclone. Through the investigations of microseisms recorded at eleven stations in Japan, it was found (Santô 1960) that this time lag depends upon several quantities (Fig. 23): the distance from the coast to the path of the cyclone (D), the intensity of cyclone (p_o), the travelling velocity of the cyclone (V) and even upon the side of the coast facing the path of cyclones.

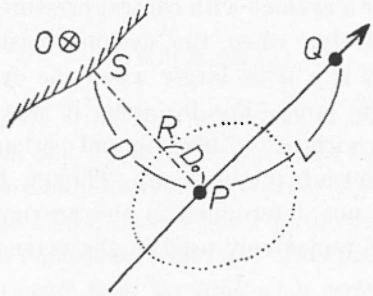

Fig. 23 – Schematic figure for explanation of the concept "eye of microseismic storm".

The conception of the "eye of microseismic storm" was introduced by the present writer in order to explain the time lag phenomenon.

In Fig. 23, Q means the position of a cyclone at the time of maximum microseismic amplitudes at the station O, and P is the nearest position of the cyclone. The writer investigated the relation between L (= PQ) and D (= PS) from observations at many stations in Japan for 14 cyclones and 7 typhoons and the following empirical relation was found to be valid:

$$D(p_o) = v(p_o)\, L/V + D_o(p_o) \qquad [1]$$

in which v = group velocity of swell, V = travelling velocity of cyclone, and D_o = an additive term which depends upon the central pressure of the cyclone (p_o).

The physical meaning of the term D_o (p_o) can easily be understood if we change equation [1] into the following:

$$(D - D_o)/v = L/V \qquad [2]$$

This equation has the travel time dimension. Therefore, the numerator of the left-hand side of this equation corresponds to the path length of the swell. Then, the physical meaning of this empirical result is as follows:

The microseismic amplitudes at the station O become largest when the swell from the limit of the hypothetic region around the cyclonic center reaches some coast near the station. This hypothetic region around the cyclonic center was named " eye of microseismic storm ". The term D_o (p_o), therefore, means the radius of this " eye " against the land. According to previous results, D_o was estimated as about 50 km and 300 km for a cyclone with central pressures of about 1000 mb and 970 mb respectively, when the cyclone passes on the left-hand side of the land. D_o is a little larger when the cyclone passes on the right-hand side of the land. For instance, it was found to be about 100 km for a cyclone with p_o = 1000 mb and perhaps about 600 km for a cyclone of p_o = 950 mb in this case. Though D_o for cyclones with other intensities was not determined in the previous investigation, the following values were tentatively used in the present paper:

Central pressure	Cyclone on left-hand side	Cyclone on right-hand side
1000 mb $\leqslant p_o$	50 km	100 km
990 mb $\leqslant p_o \leqslant$ 999 mb	100 km	200 km
980 mb $\leqslant p_o \leqslant$ 989 mb	200 km	300 km
970 mb $\leqslant p_o \leqslant$ 979 mb	300 km	400 km
960 mb $\leqslant p_o \leqslant$ 969 mb	400 km	500 km
950 mb $\leqslant p_o \leqslant$ 959 mb	500 km	600 km
$p_o \leqslant$ 949 mb	600 km	700 km

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Seismological Institute, Uppsala, Sweden
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SUMMARY

Comparative studies of the time variations of microseismic amplitudes and periods at Kiruna and Uppsala, Sweden, and the corresponding meteorological situations around Scandinavia during I.G.Y. were made.

A distant cyclone over the ocean has a great effect only on the periods of microseisms with a remarkable time lag. This time lag is well explained by the travel time of swell from the limit of a certain region around the cyclonic center to the nearest Norwegian coast.

The effect of double or triple cyclones upon the microseisms is more obscure, as different effects mask each other.

The transmission of microseismic waves from the southern Norwegian coast to Uppsala is less efficient than from the northern coast to Kiruna. The vertical amplitude ratio of microseisms Kiruna: Uppsala from a source at the northern coast is in average about 1 : 0.5.

Transmission of microseismic waves beneath the ocean is found to be quite poor.

RIASSUNTO

Sono stati eseguiti a Kiruna e Uppsala (Svezia) studi comparativi fra le variazioni nel tempo delle ampiezze e dei periodi dei microsismi, e la

corrispondente situazione meteorologica intorno alla Scandinavia durante l'I.G.Y.

Un ciclone oceanico lontano ha grande effetto, con notevole ritardo, solo sui periodi dei microsismi. Questo ritardo è giustificato dalla più lenta propagazione del moto ondoso dal limite di una certa area intorno al centro ciclonico alla più vicina costa Norvegese.

L'effetto di cicloni multipli sui microsismi è più complesso, interferendo i diversi effetti gli uni sugli altri.

La propagazione delle onde microsismiche dalla costa meridionale della Norvegia a Uppsala, è meno evidente di quella che avviene dalla costa settentrionale a Kiruna. Il rapporto fra le ampiezze verticali delle onde microsismiche Kiruna: Uppsala, è in media di circa 1 : 0.5.

La propagazione delle onde microsismiche sul fondo dell'oceano è risultata pressochè nulla.

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