PULSATIONS IN THE TERRESTRIAL MAGNETIC RECORDS AT HIGH LATITUDE STATIONS

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1. Introduction. Besides the magnetic storms occurring on the records as great deflections, a number of finer details or smaller disturbances may occur, the explanation of which represents one of the minor problems in the science of terrestrial magnetism. It is previously known that if the variometers are made sufficiently sensitive, the records will reveal small perturbations or oscillations in the earth's magnetic field at all observatories. Eschenhagen[1]) who first investigated these small perturbations, showed that the perturbations most frequently occurred as waves or sinusoidal oscillations with an amplitude of 1γ to 2γ. The period was most frequently of the magnitude 30—40 seconds. These oscillations are in the literature known as Eschenhagen waves or «Elementerwellen» as they, in Eschenhagen's opinion, represented the limit in the analysis of perturbations.

A type of perturbations also occurring as sinusoidal oscillations, but of considerably greater amplitudes, was first described by Birkeland[2]) in 1911, this oscillation occurring on the magnetic records from the Haldde Observatory. The oscillations described by Birkeland consisted of about 50 sinusoidal waves with a period of oscillations of 120 seconds. The oscillations which were bautifully developed in the declination, also occurred in two earth-current cables laid out in the N—S and E—W directions. Later the study of this type of perturbations has been neglected until recent years.

The terrestrial magnetic registrations were started at the Observatory in Tromsø in March 1929. In a number of a cases oscillations of the same type described by Birkeland in 1911, have been recorded. On September 12, 1931 a beautifully developed series of oscillations occurring in all three components was recorded. The same series of oscillations was recorded in Abisko and Rolf[1]) has described this series and made a statistical survey of the same type of oscillations appearing on the records in Abisko in the period 1921—1930. Rolf called these oscillations «giant micropulsations» and the term «giant pulsations» (GP), is now commonly used for this type of magnetic perturbations. In the period 1921—1930 Rolf reports 27 GP from the Abisko records. The oscillations were most frequent between the hours 2^h and 4^h GMT, further an annual variation was indicated with a maximum in September—October.

Concerning the geographical distribution, Rolf showed that the especially well developed GP of September 12, 1931, occurred with the same magnitude of amplitudes and that the records from Tromsø and Abisko ranged from 15γ to 30γ in the three components. In Sodankylä the amplitude had dereased to 6γ to 9γ and at observatories on lower latitudes, the oscillations were not visible on the records. Later analysis has confirmed that the GP seem to occur most frequently and with greatest amplitude on records from the observatories near the auroral zone.

In the analysis of the terrestrial magnetic perturbations, the perturbing vector is usually derived and used in the further discussion. A study of the variation of the vector during *one* period should be of special interest. The GP occur as waves which oscillate about the quiet progress of the curve. We must therefore suppose that the per-

[1]) Sitz. Ber. Ak. Wiss., No. *39*, 965 (1896) Berlin and No. 678 (1897). See also H. Ebert, Sitz. Ber. Akad. Wiss., *36*, 527 (1906) München.

[2]) Birkeland, Expédition Norvégienne de 1899—1900, Kristiania, Vid.selsk. Skr. No. *1*, 7. See also The Norwegian Aurora Polaris Expedition 1902—1903, *1*, Second Section, 756, Kristiania (1913).

[1]) Rolf, Terr. Mag. *36*, 9 (1931).

turbing vector is reversed during each half period. By using a precise time marking system the phase-difference between the waves in the three earth-magnetic components may be measured and the variations of the perturbing vector during one period may be shown[1]).

The extensive terrestrial magnetic registrations undertaken during the last Polar Year, have presented valuable material for a closer study of these curious magnetic phenomena. A discussion of the GP occurring on the records from the three Norwegian stations at Bossekop, Tromsø and Bodø has been given in the report from the Polar Year[2]).

The fairly frequent appearance of the GP on the records from the Polar Year led to a proposal for closer study of this type of perturbation. According to a proposal at the Edinburgh Assembly of the International Association of Terrestrial Magnetism and Electricity, a committee for the study of this subject was formed, and a number of recording stations were set up on Iceland and were at work during the period August—December 1937. During this period no single GP was recorded on Iceland, and this was also the case in Tromsø. In fact the year 1937 (and 1939) showed the lowest frequency of occurrence of GP in the twelve years during which the registrations have been made in Tromsø.

A discussion of the GP at the Sodankylä observatory during the period 1914—1938 has been given Sücksdorff[3]). This discussion is of special interest as it provides material for a comparison between the occurrence and amplitudes of the GP at the two observatories.

It is well known that terrestrial magnetic perturbations are closely connected with changes within the ionosphere. In the last part of this paper an observation will be discussed which shows variation of the amplitudes of radio-echoes reflected from a scattering region in 600—800 km height during the occurrence of GP[4]).

Besides the regularly developed giant pulsations, having periods of oscillations lying between 70 and 150 seconds, oscillations with considerably smaller periods of oscillations have been observed on the rapid registrations, and especially during the Polar Year 1932—33 at the three stations at Bossekop, Tromsø and Bodø[1]). These vibrations are discussed in the last part of the paper.

1) Harang, Terr. Mag. *37*, 57 (1932).

2) Norwegian Publications from the International Polar Year 1932—33 No. 2. Work on Terrestrial Magnetism, Aurora and allied Phenomena. Publikasjoner fra Det Norske Institutt for kosmisk Fysikk nr. 6. Harang Terr. Mag., *41*, 329 (1936).

3) Sücksdorff, Terr. Mag., *44*, 157 (1939).

4) Harang, Terr. Mag. *44*, 17 (1939).

2. Appearance of GP at Tromsø during the Period 1929—1941. The terrestrial magnetic records discussed are from the period March 1929—March 1941, thus comprising somewhat more than a sunspot cycle. The variometers used at the observatory are a *D*- and *H*-variometer of the Askania type and a «Balance de Godhavn». The scale-values are $E_D = 1'.45$ per mm $\approx 4.9\gamma$/mm, $E_H = 5.1\gamma$/mm and $E_V = 6{,}8\gamma$/mm. From the autumn of 1932 a set «Variométre de Copenhague» with a la Cour rapid recorder has been used at intervals. Besides these rapid registrations, the earth-currents in a N—S and E—W cable have been recorded over some periods.

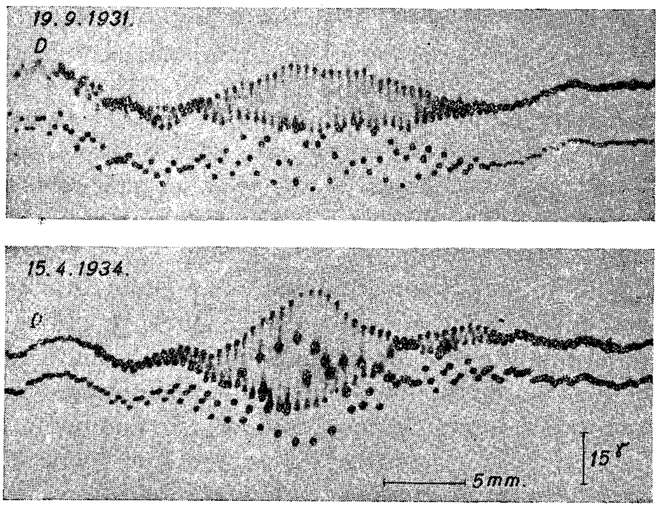

Fig. 1. «Giant Micropulsations», GP, in the declination recorded at Tromsø. No. 23 and 67.

It is evident that at such a highly disturbed place as Tromsø the GP may often be masked, more or less, by irregular perturbances of often far greater amplitudes. Care must therefore be taken when selecting the GP. After the statistical survey given in Table 1 had been made, the list

1) Norwegian Publications from the International Polar Year 1932—33 No. 2. Work on Terrestrial Magnetism, Aurora and allied Phenomena. Publikasjoner fra Det Norske Insitutt for kosmisk Fysikk nr. 6. Harang, Terr. Mag. *41*, 329 (1936).

Table 1.

	No.	$2A_D$	$2A_H$	$2A_V$	T_1	T_2	Duration	Period (T)	Remarks
1929		γ	γ	γ	GMT	GMT	min.	sec.	
16.6	1	12	8	–	6h39m	9h42m	183	124	fine
17.6	2	8	2	–	4 40	5 30	50	122	medium
22.6	3	3	2	–	1 00	2 00	60	87	faint
8 8	4	2	3	–	8 20	9 30	70	138	faint
24.9	5	12	5	–	10 45	11 30	45	132	strong
25.9	6	13	6	–	8 02	8 45	43	125	fine
22.10	7	2	–	–	0 40	2 40	90	88	faint
23.10	8	5	3	–	6 00	7 30	90	90	medium
20.11	9	3	–	–	5 57	6 40	43	105	faint
1930									
10.1	10	2	–	–	1 30	2 20	50	120	faint
26.1	11	10	3	–	3 30	4 45	75	95	beautiful
9.2	12	4	1	–	6 40	7 30	50	104	faint
26.8	13	7	–	–	1 00	1 40	40	82	medium
10.9	14	7	3	–	22 00	24 00	120	77	medium
11.10	15	1	–	–	20 50	21 00	20	80	faint
12.10	16	12	5	8	8 10	9 30	80	118	strong
16.11	17	15	5	7	1 50	3 00	70	138	strong
1931									
24.2	18	10	5	4	3 20	4 45	85	95	medium
	19	7	5	–	23 30	0 45	75	89	medium
1.3	20	9	–	–	3 30	5 00	90	109	medium
24.8	21	8	8	–	3 45	4 30	45	86	medium
8.9	22	18	14	7	1 30	5 30	240	115	strong
19.9	23	18	13	9	0 30	1 30	60	87	beautiful
19.9	24	25	14	18	10 30	11 30	60	164	fine
20.9	25	3	–	–	0 35	2 30	115	72	faint
20.9	26	6	3	3	10 10	12 15	125	113	medium
30.9	27	7	5	3	1 00	3 30	150	88	medium
30.9	28	16	7	5	8 00	9 30	90	120	strong
14.10	29	3	–	–	23 20	0 00	40	78	faint
25.10	30	2	–	–	1 50	2 50	60	120	faint
24.11	31	7	–	–	2 40	3 50	70	113	medium
24.11	32	5	–	–	21 50	23 00	70	70	faint
26.11	23	12	–	8	2 50	4 00	70	102	medium
1932									
22.1	34	10	7	5	0 10	1 30	85	94	beautiful
22.1	35	22	22	17	2 25	3 30	65	97	beautiful
1.3	36	10	8	4	0 30	1 40	70	89	beautiful
13.3	37	12	4	3	8 00	9 30	90	109	fine
13.3	38	43	18	16	11 30	13 00	90	120	beautiful
14.3	39	12	3	–	2 00	2 45	45	70	fine
14.3	40	15	2	–	4 55	7 50	175	78	fine
18.3	41	11	12	–	0 20	1 25	65	82	irregular
18.3	42	11	2	9	7 10	8 30	80	95	medium
13.4	43	6	6	–	4 30	8 30	240	125	medium
13.4	44	6	6	–	10 30	11 30	60	125	medium
8.8	45	5	10	–	8 30	9 10	40	145	medium
4.9	46	6	6	–	6 50	7 40	50	150	medium
9.10	47	6	–	3	5 00	6 00	60	78	medium
	48	6	–	3	23 55	2 50	175	92	fine
21.10	49	9	4	3	22 00	23 45	105	90	beautiful
22.10	50	14	8	4	7 30	8 50	140	131	disturbed
18.11	51	13	8	3	6 10	8 00	110	120	disturbed

	No.	$2A_D$	$2A_H$	$2A_V$	T_1	T_2	Duration	Period (T)	Remarks
1933		γ	γ	γ	GMT	GMT	min.	sec.	
15.1	52	2	–	–	1h40m	2h40m	60	84	faint
3.3	53	2	–	–	1 35	2 50	75	72	faint
23.3	54	–	–	–	2 55	3 30	35	73	very faint
12.4	55	8	6	5	0 30	1 40	70	94	disturbed
25.4	56	6	–	4	1 30	2 10	40	79	medium
1.5	57	–	–	–	1 55	2 10	15	90	very faint
9.5	58	5	4	3	3 20	5 30	70	138	faint
17.6	59	8	6	5	0 30	2 15	105	110	medium
30.7	60	5	4	2	1 16	3 50	154	110	medium
13.9	61	–	–	–	0 50	2 00	70	80	very faint
21.10	62	8	6	2	1 30	2 15	45	86	medium
1934									
7.1	62	3	1	1	1 00	2 30	90	90	faint
7.1	64	3	2	1	3 30	5 20	110	95	faint
20.1	65	16	2	4	0 20	3 30	190	85	medium
14.4	66	12	8	4	0 45	2 20	95	76	fine
15.4	67	32	14	10	3 30	4 40	70	96	beautiful
16.4	68	14	3	3	4 00	6 30	150	80	disturbed
4.6	69	2	–	–	1 00	1 50	50	59	very faint
14.6	70	5	5	–	4 00	6 30	150	82	faint
22.10	71	3	2	–	23 00	24 00	60	76	fine
15.12	72	2	–	–	0 30	1 40	70	70	very faint
27.12	73	6	4	3	1 00	2 10	70	144	medium
1935									
9.1	74	29	20	14	0 30	2 35	125	98	beautiful
11.1	75	4	–	–	0 10	0 40	30	78	disturbed
5.3	76	13	5	6	0 30	2 30	120	123	fine
23.4	77	2	–	–	2 05	3 30	85	88	very faint
21.5	78	7	5	–	3 00	4 00	60	113	medium
22.9	79	7	3	3	1 00	2 30	90	93	fine
22.9	80	5	–	–	23 00	23 50	50	98	fine
10.11	81	5	5	–	0 55	1 35	40	109	medium
1936									
30.3	82	8	3	3	5 00	6 00	60	109	medium
25.6	83	16	8	–	5 20	6 15	55	124	medium
1937									
24.5	84	10	3	–	7 30	10 40	190	144	irregular
13.9	85	12	4	6	0 30	2 15	105	134	irregular
1938									
9.3	86	7	2	3	4 30	9 20	110	134	medium
29.3	87	3	1	2	4 40	7 20	160	123	medinm
1.5	88	3	3	–	6 20	7 05	45	173	faint
2.5	89	4	–	–	0 40	2 00	80	109	medium
18.8	90	10	5	4	1 20	2 50	70	130	medium
3.9	91	8	–	–	2 00	2 45	45	150	faint
26.12	92	4	3	–	7 35	8 40	65	138	medium
28.12	93	3	–	–	1 40	3 05	85	115	medium
1939									
10.4	94	5	6	–	5 40	8 30	190	150	medium
1940									
18.7	95	10	11	–	4 05	7 35	210	195	medium
19.7	96	5	3	–	1 40	3 20	100	132	medium
19.7	97	5	7	–	5 00	7 30	150	132	medium

1941 — until March 1 none observed.

was compared with the list published from Sodankylä. It then appeared that almost all GP recorded in Sodankylä appeared in the list, and besides these a number of others appeared. In Table 1 the double amplitudes in D, H and V, $2A_D$, $2A_H$ and $2A_V$, time of appearance (T_1) and disappearance (T_2), duration and time of oscillation (T), are given.

The duration of the pulsations varies from 20 minutes to 240 minutes with a mean value of 88 minutes. The period of oscillation was determined by measuring the duration of 10 swings. The period seemed to be constant during one oscillation. The period of oscillation varies from 59 sec. to 174 sec. with a mean value of 106 sec.

The total number of the series of oscillations during the twelve years of observation is 97. Table 1 shows the great variation in number from year the year. The frequency was highest in 1932 with a total number of 18 and lowest in 1939 with only one. The occurrence of the GP during the 12 years is demonstrated in Fig. 2.

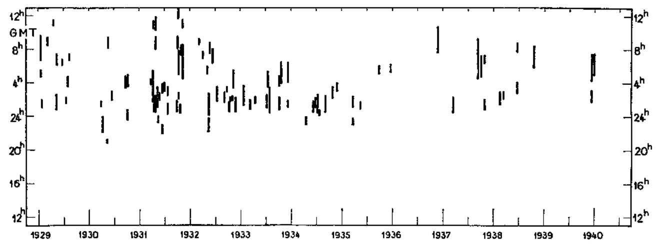

Fig. 2. Appearance of GP on the Tromsø records in the period March 1929—March 1941.

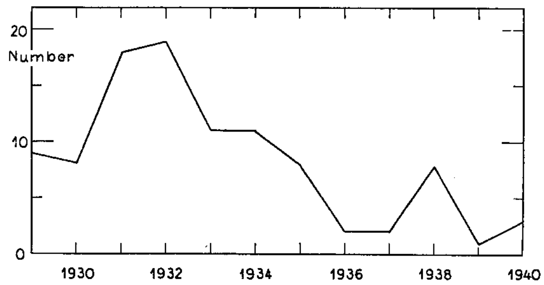

Fig. 3. The annual numbers of GP.

The occurrence from year to year, the annual and the diurnal variations are more clearly shown in Figs. 3, 4 and 5.

The *secular* curve shows that frequency was highest during the years 1931—1933 which coincide with minimum solar activity. At such a highly disturbed place a Tromsø this could, at least partly, be explained by the fact that during minimum years the GP will not be masked so easily by irregular perturbations. That this circumstance, however, does not play a decisive role, is indicated by the *annual* variation, demonstrated in Fig. 4.

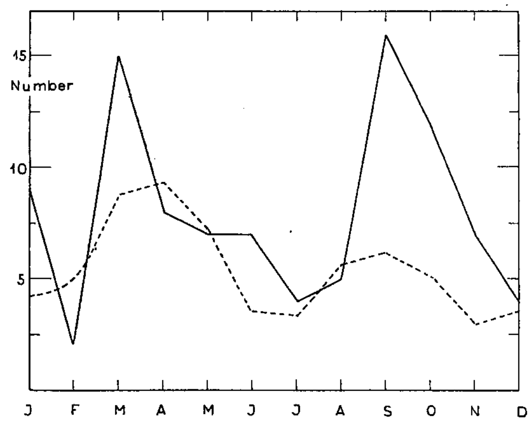

Fig. 4. The annual variation of GP. The broken curve indicates the annual variation of the storminess at Tromsø (for the year 1932).

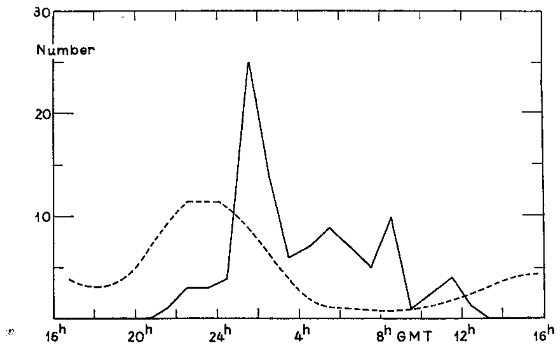

Fig. 5. The diurnal variation of the GP. The broken curve indicates the diurnal variation of the stormness at Tromsø (for the year 1932).

The annual variation shows maxima at the equinoxes, in March and September, and minima during midsummer and midwinter. Now this coincides approximately with the annual curve of terrestrial magnetic storminess, so it is not probable that the effect of masking the GP by irregular perturbations plays any decisive role in the frequency curves given here.

The diurnal variation of frequency demonstrated in Fig. 4, shows a distinct maximum between 1 and 2 GMT. It is especially remarkable that no GP have occurred during the interval 13^h—21^h GMT. Compared with the diurnal curve for terrestrial magnetic storminess, which has its maximum at 22^h—24^h GMT, the curve for the GP has its maximum about $2\frac{1}{2}$ hours later.

From Table 1 it is further evident that the GP show a tendency to appear in groups on two successive days. Of the 97 GP listed, no less than 20 have appeared on two successive days. This is much more than could be expected by chance.

The period of oscillation of the GP may range from 57 sec. to 190 sec. A closer study shows that the period is dependant on the time of appearance of the GP. Pulsations with short periods show a tendency to occur early in the morning, whereas the pulsations with longer periods occur later. Fig. 6 illustrates the variations of the period during night. On the other hand there seems to be no connection between the number of swings of the GP and the time of appearance or period of oscillation.

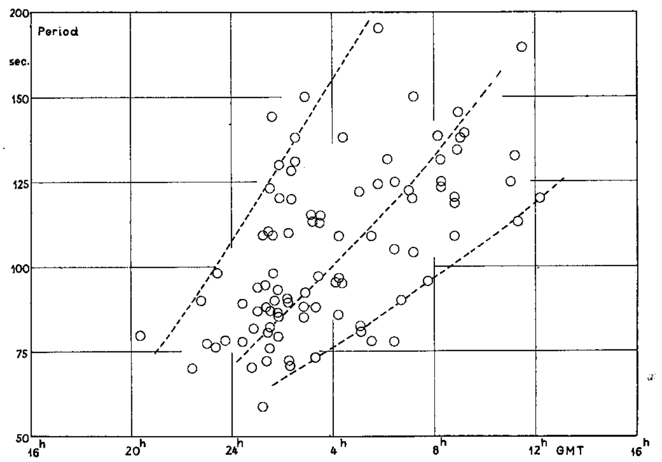

Fig. 6. Period of oscillation of the GP as a function of the time of appearance.

3. Variation of GP with Latitude. In his first discussion of the GP, Rolf[1]) pointed out that the amplitudes decreased rapidly with increasing distance from the auroral zone. Almost all the GP given in the list from Sodankylä[2]) have been recorded in Tromsø during the same period. Further an additional number have been recorded in Tromsø. In the period 1929—1938 Sodankylä reports 69 GP and for the same period 93 are observed in Tromsø.

To get an impression of the variation of amplitudes with latitude, we shall give the maximum amplitudes for three especially well developed GP. The value have been taken from the literature quoted[3])[2]). (Bossekop: $\varphi = 69°.9$ N, $\lambda = 23°.2$ E.G., Tromsø: $\varphi = 69°.7$, $\lambda = 18°.9$ E.G., Bodø: $\varphi = 67°.3$, $\lambda = 14°.4$ E.G., Sodankylä: $\varphi = 67°.4$, $\lambda = 26°.6$ E.G.).

Table 2.

	GP recorded 21. 10. 1932			GP recorded 21. 4. 1933			GP recorded 17. 6. 1933		
	$2A_D$	$2A_H$	$2A_V$	$2A_D$	$2A_H$	$2A_V$	$2A_D$	$2A_H$	$2A_V$
Bossekop	11	4	4	12	5	5	11	3	5
Tromsø	6	4	4	8	6	5	8	6	5
Bodø	6	6	11	2	2	(1)	3	5	3
Sodankylä	11	12	12	4	5	3	none		

The main feature is that the amplitudes decrease with increasing distance from the auroral zone. Further the decrease is different in the three terrestrial magnetic components. The decrease is by far strongest in the declination and smaller in the vertical intensity. In some cases there may even be an increase in the vertical intensity over the distances here treated.

This fact reminds us of a general feature in the Birkeland's[1]) analysis of the field of perturbation of a polar storm. According to Birkeland a polar storm may, at least formally, be explained as the effect of a current system following the direction of the auroral zone. South of the auroral zone the effect in the vertical intensity will increase with the distance from the auroral zone until a certain critical distance. For greater distances the perturbation will again decrease.

Although the occurence of the GP mainly seems to be restricted to regions near the auroral zone, they may also occur in lower latitudes without being traced on the records of higher latitude stations. La Cour[2]) has published a beautifull GP from Rude Skov (Copenhagen) on April 22, 1938. This has not been traced on the records either in Sodankylä[3]) or in Tromsø.

4. Occurrence of GP in Earth Currents. The first observation of GP by Birkeland[4]) showed that

[1]) Rolf, Terr. Mag., *36*, 9 (1931).

[2]) Sücksdorff, Terr. Mag., *44*, 157 (1939).

[3]) Norwegian Publications from the International Polar Year 1932—33 No. 2. Work on Terrestrial Magnetism, Aurora and allied Phenomena. Publikasjoner fra Det Norske Institutt for kosmisk Fysikk nr. 7. Harang Terr. Mag., *41*, 329 (1936).

[1]) Birkeland, The Norwegian Aurora Polaris Expedition, *1*, First Section, 86, Kristiania (1913).

[2]) D. la Cour, Terr. Mag. *43*, 199 (1938).

[3]) Sücksdorff. Terr. Mag. *44*, 17 (1939).

[4]) Birkeland, Expédition Norvégienne de 1899—1900, Kristiania, Vid.selsk. Skr. No. *1*, 7. See also The Norwegian Aurora Polaris Expedition 1902—1903, *1*, Second Section, 756, Kristiania (1913).

waves syncronous with the waves in terrestrial magnetic records also occurred in the earth-currents. In the registration at Bossekop during the Polar Year and in later rapid registrations in Tromsø, the GP were always accompanied by simultaneous waves in the earth-currents. A comparison of the amplitudes on the magnetic records and on the earth-current record is given in the following.

5. Perturbing Vector of the GP. In the further analysis of the GP it will be of special interest to construct the perturbing vector. In case of pure sinusoidal oscillations the perturbing vector will be determined by the following equations:

$$\triangle D = A_D \sin \frac{2\pi t}{T}, \quad \triangle H = A_H \sin \left(\frac{2\pi t}{T} + \alpha\right),$$

$$\triangle V = A_V \sin \left(\frac{2\pi t}{T} + \beta\right)$$

Here are: $\triangle D$, $\triangle H$ and $\triangle V$ the perturbing forces in the three components. A_D, A_H and A_V are the maximal amplitudes in γ, and T is the period in seconds. The perturbing vector is as usual in D reckoned positive towards W in H towards N and in V positive downwards. α is the phase-difference between the waves in D and H and β between the waves in D and V. Similarly we may express the GP in the earth-currents in the N—S and E—W cables by the following equations:

$$E_N = I_N \sin \frac{2\pi t}{T}, \quad E_W = I_W \sin \left(\frac{2\pi t}{T} + \varphi\right)$$

where E_N and E_W are the perturbing currents expressed in millivolt/km. The perturbing current, or voltage, is reckoned positive towards N in the E—S cable and positive towards W in the E—W cable. In the tables given in the following, λ denotes the phase-difference between the waves in D and the waves in the N—S cable.

In order to get a precise time marking system with no lags in the marks for the curves of the three cmponents, the time marks were produced in the following way. The current to the register lamp went through a small resistance of 3—5 ohm. This was shortcircuited by a relay every 5 minutes (as usual by the la Cour rapid recording system). The time marks thus appear as small dots on the continuous curves. When measuring out the pulsations, copies of the curves were taken on contrast plates and the copies were measured out in a microscope. The phase-differences were determined by measuring out the distances from on time mark to the nearst crest of the pulsations in the three terrestrial magnetic components. Usually, these distances were different in D, H and V due to the relative phase-differences.

Table 3.

	Bossekop.									*Tromsø.*					*Bodø.*				
Time	$2A_D$	$2A_H$	$2A_V$	α	β	$2J_N$	$2J_W$	φ	λ	$2A_D$	$2A_H$	$2A_V$	α	β	$2A_D$	$2A_H$	$2A_V$	α	β
GMT	γ	γ	γ	°	°	mv/km	mv/km	°	°	γ	γ	γ	°	°	γ	γ	γ	°	°
22^h 5^m	—	—	—							(2.2)	—	—	—	—	(3.5)	—	—	—	—
10	(9.8)	(2.6)	(3.1)	255	191	43	80	35	156	(2.9)	—	—	—	—	(4.7)	—	—	—	—
15	12.9	4.0	4.8	268	186	58	123	24	131	6.4	4.4	3.0	270	184	5.4	4.6	6.6	201	260
20	11.2	4.0	3.7	290	193	38	85	32	139	6.8	3.7	4.0	271	188	8.0	5.6	9.8	181	297
25	10.5	3.4	4.0	270	197	40	85	22	136	5.7	4.4	4.0	275	195	5.9	6.8	15.2	178	261
30	8.7	2.8	2.3	283	188	35	58	36	162	5.7	2.8	3.5	288	183	5.5	6.2	13.0	164	250
Mean:	10.8	3.5	3.7	273	191	43	86	30	145	6.2	3.8	3.6	276	187	6.2	5.8	11.1	186	254
45	7.0	1.7	2.1	276	194	30	50	25	157	2.6	2.1	1.7	169	181	3.2	2.2	5.3	—	260
50	9.8	2.8	2.8	289	200	38	73	23	148	6.4	4.0	3.0	280	181	6.1	5.6	9.8	141	264
55	10.8	3.4	3.4	289	198	38	80	33	151	7.2	4.4	3.0	276	190	8.2	5.6	9.6	140	259
23 0	8.4	2.8	2.1	290	198	32	44	22	141	5.9	4.2	3.0	270	196	6.1	5.6	9.4	126	255
5	3.5	1.1	1.2	260	194	21	29	—	147	4.2	2.1	1.7	276	180	5.1	3.1	5.7	122	260
Mean:	7.9	2.4	2.3	281	197	32	55	26	159	5.3	3.4	2.5	274	186	5.7	4.4	8.0	(132)	260
20	4.8	2.0	—	274	—	—	—	—	—	2.6	1.8	—	261	—	—	—	—	140	257
25	3.5	1.7	—	273	—	—	—	—	—	2.8	2.5	—	242	—	(2.4)	—	(3.3)	130	252
30	3.8	1.7	—	236	—	—	—	—	—	3.7	8.1	—	248	—	(43)	(3.1)	(5 7)	129	249
Mean:	4.0	1.9	—	261	—	—	—	—	—	2.0	2.5	—	250	—	(3.3)	—	(4.5)	133	253

In the following, two examples of determining the perturbing vector during one oscillation of the GP will be given. The rapid registration records used are from the Norwegian stations during the Polar Year 1932—1933.

We will treat in detail GP No. 49, occurring on 21. 10. 1932, as this group was the most persistant and regularly developed group of pulsations which appeared during the Polar Year during which records from the three Norwegian stations are available. The pulsations occurred after a small magnetic storm during which aurorae of medium strength were observed. During the pulsations no or only faint aurorae were observed.

In Table 3 the results of measurements on the rapid registration records from the three stations at intervals of five minutes are given.

The mean values of the determinations in Table 3 are given in Table 4.

Table 4.

	$2A_D$	$2A_H$	$2A_V$	α	β	φ	λ
	22h10m—22h—15m						
	γ	γ	γ	°	°	°	°
Bossekop ..	10.8	3.5	3.7	273	191	30	145
Tromsø	6.2	3.8	3.6	276	187	26	159
Bodø	6.2	5.8	11.1	—	—	—	—
	22h—45m—23h—15m						
Bossekop ..	7.9	2.4	2.3	281	197	—	—
Tromsø	5.3	3.4	2.5	274	186	—	—
Bodø	5.7	4.4	8.0	—	—	—	—

Another beautifully developed group of GP occurred on 17. 6. 1933 (No. 59). The mean values of amplitudes and phase angles at the three stations are given in Table 5.

Table 5.

	$2A_D$	$2A_H$	$2A_V$	α	β	φ	λ
	γ	γ	γ	°	°	°	°
Bossekop ..	10.8	3.4	4.7	116	191	14	161
Tromsø	8.0	5.5	4.6	126	222	—	—
Bodø	3.4	4.7	2.6	122	236	—	—

In Table 6 a summary of phase-determinations is given.

From the Tables 4, 5 and 6 it is evident that the phase-differences at the three stations show values which are of the same order of magnitude at the three stations. (The determinations from

Table 6.

Date	No.	Tromsø Bossekop		Tromsø Bossekop		Bossekop	
1932		α_0	α_0	β_0	β_0	φ_0	λ_0
9.10	47	—	—	—	215	10	138
20.10	48	—	—	210	209		153
21.10	49	275	277	186	194	28	152
12.4	55	133	—	210	—	—	—
25.4	56	106	—	232	—	—	—
9.5	58	146	86	220	180	—	—
17.6	59	126	116	222	191	14	161
30.7	60	166	—	185	—	—	—
Mean:		—	—	209	198	13	151

9. 5. 1933 in Table 6 are somewhat uncertain). Most constant are the phase-differences between the pulsasions in the N—S and E—W cables (φ) at Bossekop. Further the phase-difference between the waves in D and the N—S cable (λ) shows a constant value during the year. This is what we must expect, if we explain the earth-currents as induced currents.

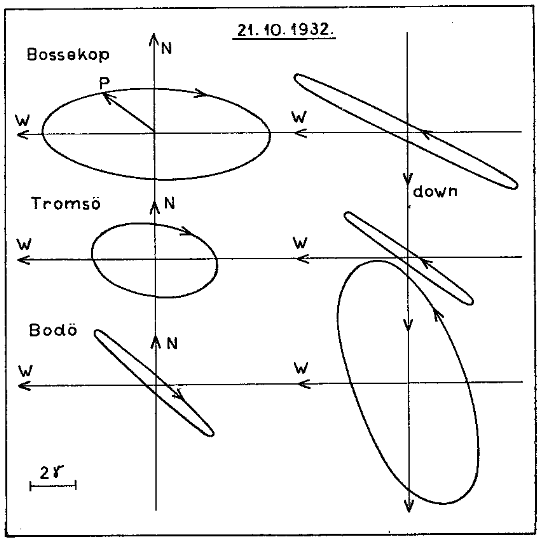

Fig. 7. Variation of the perturbing vector P during one period of oscillation.

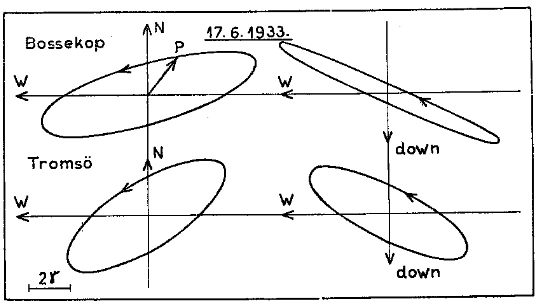

Fig. 7 a.

The phase-differences between the waves in D and V (β) are also fairly constant whereas the phase-differences between the waves in D and H (α) show a greater variation from one GP to the other. Further there is a qualitative agreement between the values at Tromsø and Bossekop. Regarding the values of α we see that all values, except for GP No. 49, lie between 86° and 166°. In Fig. 7 the rotation of the perturbing vector P during one period is illustrated for the two GP selected.

6. Connection between GP and Variation of Amplitudes of Radio Echoes Reflected from a Scattering Region in 600—800 km Height. It is well known that there is an intimate connection between terrestrial magnetic perturbations and the conditions in the ionosphere. According to experience from the radio echo observations in Tromsø, however, small perturbations with amplitudes of 10γ to 20γ whic is the magnitude of amplitudes of the GP, do not seem to have so great an influence on the ionosphere that the effects may be observed by the usual radio echo methods.

During the last days of December 1938 the radio echoes on a fixed frequency of 11 Mgc/sec were recorded continuously, using a pulse transmitter of great output, — more than 50 KW. Previous experiments had shown that when using sufficient energy from a transmitter on frequencies higher than the critical penetrating frequency of the F_2 layer, echoes could regularly be obtained from scattering and reflecting regions at virtual distances corresponding to values lying between 500 and 2500 km[1]). The reflecting power of these scattering regions is very low. Only when using considerably energy from the transmitter and a specially designed receiver adjusted up to the highest possible gain, are the echoes visible above the noise level on the cathode ray oscillograph.

During the appearance of GP on 28. 12. 1938 (No. 93) the echo record shows pulsations in the amplitudes of the scattered echoes from a virtual height of 600—800 km with exactly the same period as those of the GP. On the echo record the pulsations are clearly visible from 3^h30^m to 4^h MET, although they may also be traced on the original racord from about 2^h40^m, which coincides with the instant when the pulsations start on the magnetogram. Fig. 8 shows the appearance of the pulsations on the echo record and Fig. 9 shows the virtual distances to the scattering regions recorded during the same day.

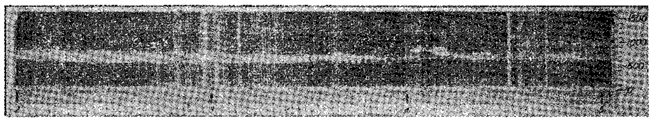

Fig. 8 a. Scattered reflections on 11 Mg/sec during the appearance of GP in the terrestrial magnetic records. The amplitudes of the echoes show pulsations of the same period as those of the GP.

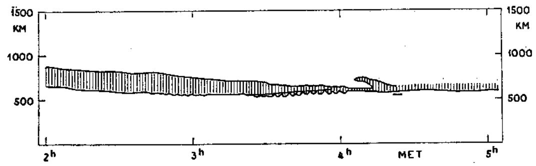

Fig. 8 b.

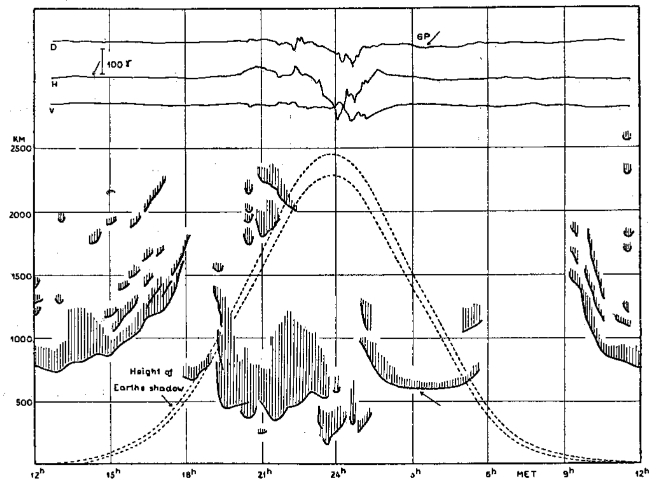

Fig. 9. Diurnal variation of virtual distances of the scattered echoes on the same day.

The interpretation of the diurnal variation of the scattered echoes in Fig. 9 will be given in a following paper. But for the present it may be mentioned here that the echoes recorded during the period 1^h—6^h from a virtual distance of 600—800 km, most probably must be explained by scattering from ionspheric clouds or irregularities lying in or near the zenith.

The simultaneous occurrence of the GP and the rhythmical variation of the echo amplitudes supports the view that the GP, like the general

[1]) L. Harang and W. Stoffregen, Nature, *142*, 832 (1938). The results of registrations with great transmitting energies will be given in a following paper in this series of publications.

terrestrial magnetic perturbations, must be produced by processes within the ionosphere.

Concerning the rythmical variation of the echo amplitudes during the pulsations, the following alternatives may be discussed.

1. Periodic expansions and contractions of the atmosphere in a vertical direction at 600—800 km height. This will alter the refractive index of the ionosphere within short distances and scattering areas will be formed.

2. Periodic intrusion of a ionizing agency in the ionosphere.

3. Periodic occurrence of an absorbing layer at lower heights.

Of these alternatives the two first ought to be the most probable. In connection with the second alternative we will call to mind the classes of orbits of an electrically charged particle coming into the earth's magnetic field calculated by Størmer. One class of orbits may in this connection be of special interest, namely the orbits according to which the electrically charged particle oscillates between the N- and S-pole inside a «hornlike» envelope[1]).

If the GP were explained as the magnetic action by a cloud of charged particles travelling along the orbits mentioned, this would mean that the GP appearing near the northern auroral zone should be accompanied by similar GP near the southern auroral zone. As the southern auroral zone goes over regions where magnetic observations scarcely can be carried out, this problem will be difficult to solve.

It would of course be of the greatest interest to state whether the GP are accompanied by variations in the amplitude of the redio echoes reflected from the ordinary E- and F-layers. This can be done by recording the echoes on a suitable fixed frequecy, for instance on 4.5 Mgc/sec. Preparations for starting such registrations are now being made.

7. Observations of Vibrations in the Earth Terrestrial Magnetic Records. As previoutly Mentioned, a set of «Varométre de Copenhague» was used for the rapid registrations during the Polar Year. The suspended magnets in the D- and H-variometers of this set have a considerably smaller free-period than in the Askania set used for normal registrations. Further, the heavy copper damping of the suspended magnets is much reduced in the set of variometers first mentioned. These qualities have made it possible to record pulsations of considerably smaller periods of oscillations than with variometers of the older type.

On the rapid registration records from the Polar Year and the following years, oscillations occurring as continuous broadening of the curves have been recorded on a number of occasions. Plate 1, Nos. 12—14, illustrate this type of oscillation. Judging from the broadening of the time-marks (which last about 1.5 sec.) the period must be of one second or even less. This type of oscillations which we shall *vibrations*, appears simultaneously in the D- and H-curves. During the Polar Year we have a number of cases in which the vibrations occurred simultaneously at the three stations of Bossekop, Tromsø and Bodø. The vibrations appearing for instance on March 27, 1933 at about 6^h GMT, showed the same general character of vibration in the amplitudes in Bossekop and Tromsø. The maximum deflections in D- and H in Tromsø were 31γ and 22γ, in Bossekop 12γ and 24γ respectively. In Bodø the same vibrations occur on the records but with much reduced amplitudes. The simultaneous appearance of these vibrations in Bossekop, Tromsø and Bodø shovs that the vibrations cannot be produced by artificial disturbances. Further the vibrations show a decrease of amplitudes with increasing distance from the auroral zone.

In the period September 1932 to June 1936, during which rapid registration records for Tromsø are available. these vibrations have occurred on 42 days. The annual and diurnal occurrences are shown in Fig. 9 and 10.

The frequency shows a pronounced maximum

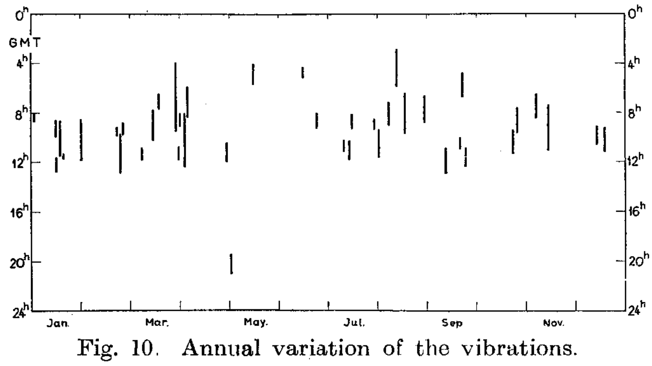

Fig. 10. Annual variation of the vibrations.

[1]) Sur les trajéctoires des corpuscules électrisés dans l'éspace sous l'action du magnetisme terréstre. Arch. des. Sc. phys. et nat., Genève 1907. *24,* 1. See p. 131—135.

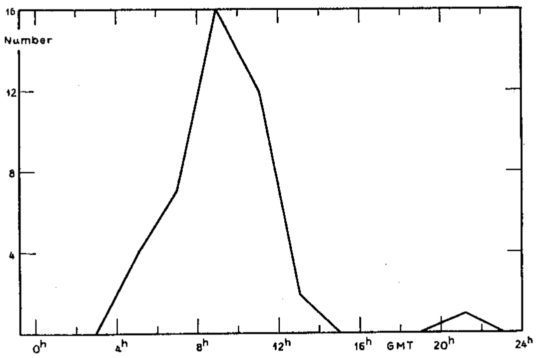

Fig. 11. Diurnal variation of the vibrations.

at 8^h—10^h GMT. The annual variation seems to indicate two maxima at the equinoxes.

It might be supposed that at least some of the vibrations may be of seismic origin, the broadening of the curves thus representing mechanical vibrations. The existence of a pronounced diurnal maximum excludes this possibility as a general source.

Compared with the GP the vibrations show a distinct difference with respect to diurnal variation.

In a recent paper Sücksdorff[1]) has described a type of rapid micropulsations occurring in the records from Sodankylä. These vibrations seem to appear with far greater frequency in Sodankylä than in Tromsø. Further there does not seem to be such a pronounced diurnal variation as in Tromsø. The maximum in the diurnal variation at Sodankylä seems at lie between 10^h and 16^h local time.

The records reproduced from Sodankylä seem to indicate that the vibrations recorded in Sodankylä are of a somewhat different type. The vibrations in Sodankylä are described as a number of short shuttles, whereas the Tromsø vibrations appear as continuous widening of the curves which may last for many minutes. The series of shuttles appearing in Sodankylä does not seem to appear with any frequency in Tromsø.

It may therefore be doubted whether the two types of vibrations occurring in Tromsø and Sodankylä are terrestrial magnetic perturbations of the same type.

[1]) Sücksdorff, Terr. Mag., *41*, 337 (1936).

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turbing vector is reversed during each half period. By using a precise time marking system the phase-difference between the waves in the three earth-magnetic components may be measured and the variations of the perturbing vector during one period may be shown[1]).

The extensive terrestrial magnetic registrations undertaken during the last Polar Year, have presented valuable material for a closer study of these curious magnetic phenomena. A discussion of the GP occurring on the records from the three Norwegian stations at Bossekop, Tromsø and Bodø has been given in the report from the Polar Year[2]).

The fairly frequent appearance of the GP on the records from the Polar Year led to a proposal for closer study of this type of perturbation. According to a proposal at the Edinburgh Assembly of the International Association of Terrestrial Magnetism and Electricity, a committee for the study of this subject was formed, and a number of recording stations were set up on Iceland and were at work during the period August—December 1937. During this period no single GP was recorded on Iceland, and this was also the case in Tromsø. In fact the year 1937 (and 1939) showed the lowest frequency of occurrence of GP in the twelve years during which the registrations have been made in Tromsø.

A discussion of the GP at the Sodankylä observatory during the period 1914—1938 has been given Sücksdorff[3]). This discussion is of special interest as it provides material for a comparison between the occurrence and amplitudes of the GP at the two observatories.

It is well known that terrestrial magnetic perturbations are closely connected with changes within the ionosphere. In the last part of this paper an observation will be discussed which shows variation of the amplitudes of radio-echoes reflected from a scattering region in 600—800 km height during the occurrence of GP[4]).

Besides the regularly developed giant pulsations, having periods of oscillations lying between 70 and 150 seconds, oscillations with considerably smaller periods of oscillations have been observed on the rapid registrations, and especially during the Polar Year 1932—33 at the three stations at Bossekop, Tromsø and Bodø[1]). These vibrations are discussed in the last part of the paper.

[1]) Harang, Terr. Mag. *37*, 57 (1932).

[2]) Norwegian Publications from the International Polar Year 1932—33 No. 2. Work on Terrestrial Magnetism, Aurora and allied Phenomena. Publikasjoner fra Det Norske Institutt for kosmisk Fysikk nr. 6. Harang Terr. Mag., *41*, 329 (1936).

[3]) Sücksdorff, Terr. Mag., *44*, 157 (1939).

[4]) Harang, Terr. Mag. *44*, 17 (1939).

2. Appearance of GP at Tromsø during the Period 1929—1941. The terrestrial magnetic records discussed are from the period March 1929—March 1941, thus comprising somewhat more than a sunspot cycle. The variometers used at the observatory are a *D*- and *H*-variometer of the Askania type and a «Balance de Godhavn». The scale-values are $E_D = 1'.45$ per mm $\approx 4.9\gamma$/mm, $E_H = 5.1\gamma$/mm and $E_V = 6{,}8\gamma$/mm. From the autumn of 1932 a set «Variométre de Copenhague» with a la Cour rapid recorder has been used at intervals. Besides these rapid registrations, the earth-currents in a N—S and E—W cable have been recorded over some periods.

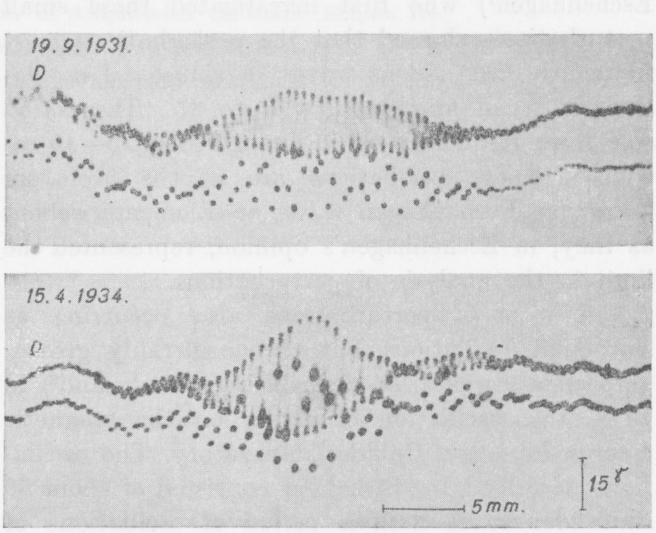

Fig. 1. «Giant Micropulsations». GP, in the declination recorded at Tromsø. No. 23 and 67.

It is evident that at such a highly disturbed place as Tromsø the GP may often be masked, more or less, by irregular perturbances of often far greater amplitudes. Care must therefore be taken when selecting the GP. After the statistical survey given in Table 1 had been made, the list

[1]) Norwegian Publications from the International Polar Year 1932—33 No. 2. Work on Terrestrial Magnetism, Aurora and allied Phenomena. Publikasjoner fra Det Norske Insitutt for kosmisk Fysikk nr. 6. Harang, Terr. Mag. *41*, 329 (1936).

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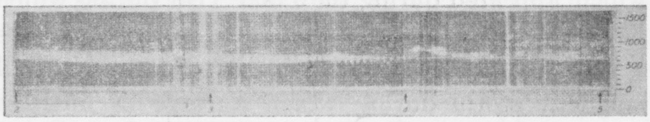

Fig. 8 a. Scattered reflections on 11 Mg/sec during the appearance of GP in the terrestrial magnetic records. The amplitudes of the echoes show pulsations of the same period as those of the GP.

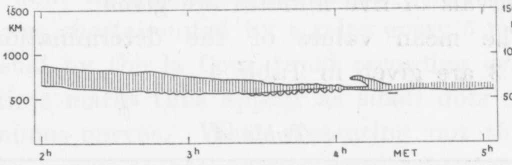

Fig. 8 b.

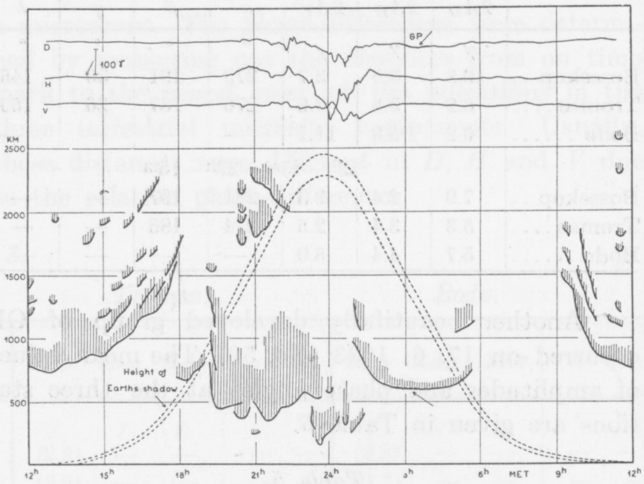

Fig. 9. Diurnal variation of virtual distances of the scattered echoes on the same day.

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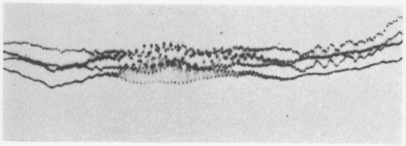

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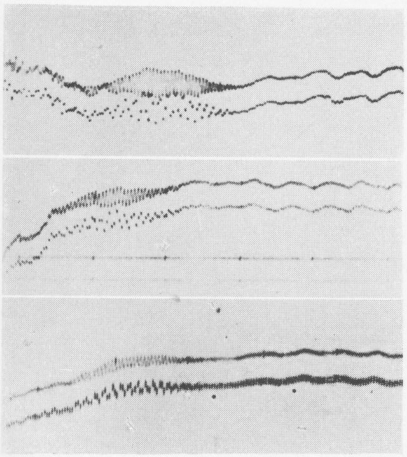

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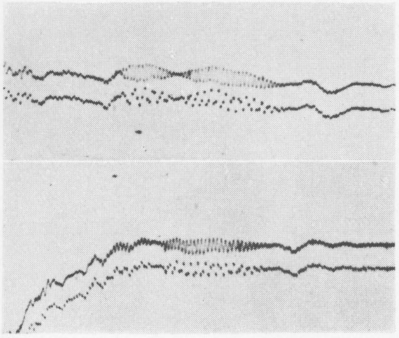

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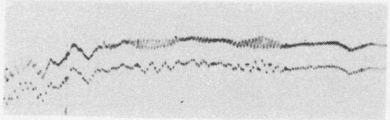

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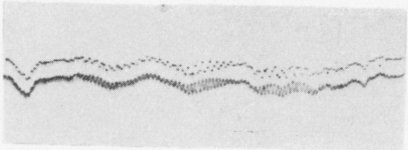

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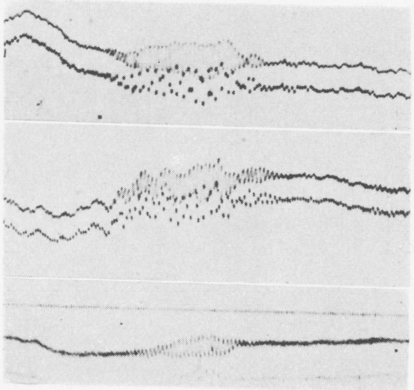

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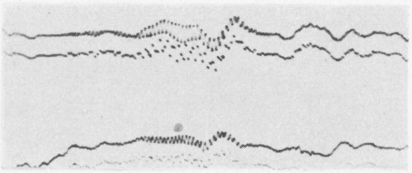

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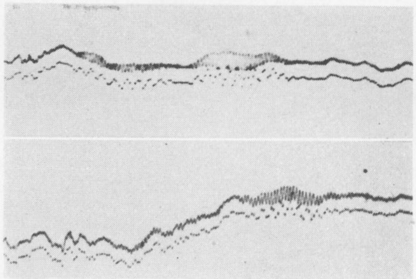

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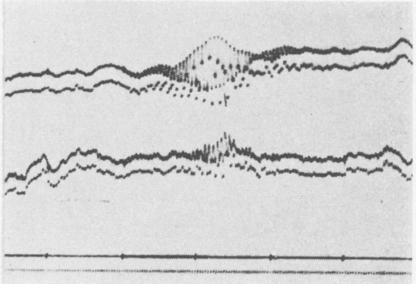

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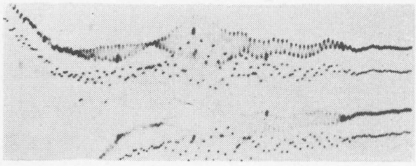

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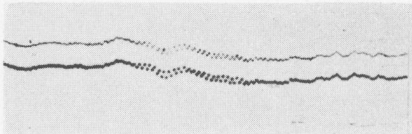

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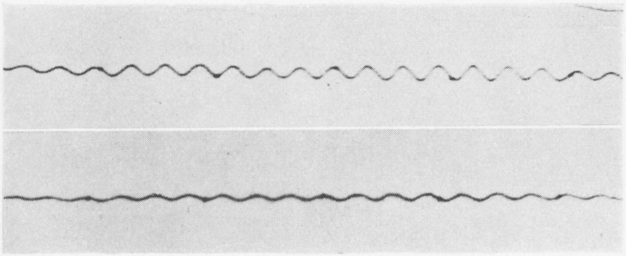

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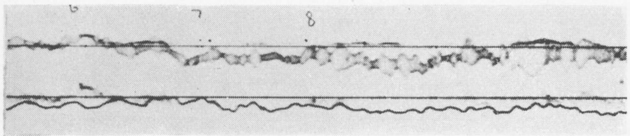

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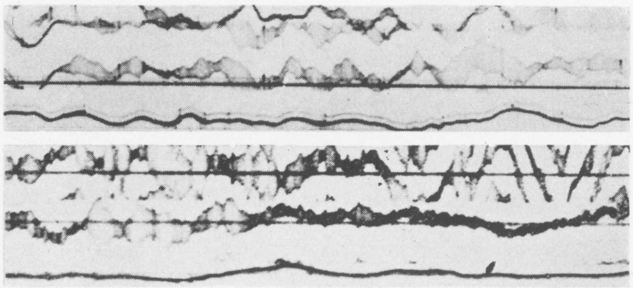

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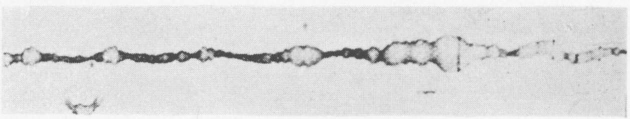

15.

Explanation to Plate I.

Picture No. 1. G.P. No. 11, 26. 1. 1930, *D*.
» » 2. » » 23, 19. 9, 1931, *D*, *H* and *V*.
» » 3. » » 20, 1. 3. 1931, *D* and *H*.
» » 4. » » 34, 22. 1. 1932, *H*.
» » 5. » » 49, 21. 10. 1932, *D*.
» » 6. » » 35, 23. 1. 1932, *D*, *H* and *V*.
» » 7. » » 55, 12. 4. 1933, *D* and *H*.
» » 8. » » 66, 14. 4. 1934. *D* and *H*.
» » 9. » » 67, 15. 4. 1934, *D* and *H*.
» » 10. » » 74, 9. 1 1935, *D* and *H*.
» » 11. » » 93, 28. 12. 1938, *D*.

Picture No. 12. G.P. No. 49, rapid registration record of earth-currents, Bossekop, N—S and E—W cable, 21. 10. 1932.
» » 13. Rapid registration record of *vibrations* in *D*, Bossekop 19. 10. 1932.
» » 14. Rapid registration record of vibrations simultanously appearing at Bossekop and Tromsø in *D*, 26. 3. 1933.
» » 15. The same vibrations appearing in *H* Tromsø.