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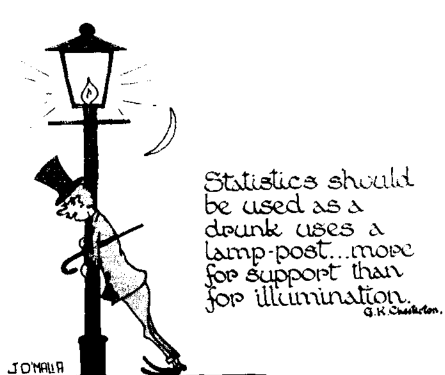
Some Features of Geomagnetic Micropulsations Observed During the Recent Quiet Solar Years, with Particular Reference to Data Obtained at the Near Conjugate Stations of Great Whale River and Byrd

J. A. Jacobs* and C. S. Wright

Summary

In dedicating this paper to Professor Sydney Chapman, the authors have taken the opportunity of describing some of the salient features of the early history of geomagnetic micropulsations since 1918, which were responsible for the Canadian interest in this field and the type of equipment still in use at many ground stations. In a sense, this is a review paper of the more recent work in this field, thus excluding that covered by other reviews such as that of Troitskaya (1964) and Kato, Saito and other workers in Japan. The importance of observations at polar stations is touched upon in relation to similar observations at mid-latitude stations during the recent years of quiet solar conditions when the 27-day solar rotation period is often prominent. This period is especially well-marked at the two near-conjugate stations, Byrd and Great Whale River, in the southern and northern auroral zones. The correlation between these two stations is only briefly mentioned, since it will be the subject of a separate report. The paper concludes with a brief discussion of the very important results of satellite observations. Better co-ordination of satellite data with that received on the ground is needed and internationally planned operations of land stations for the coming years of greater solar activity are necessary.



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1. Introduction

It is especially suitable that, in appreciation of Professor Sydney Chapman's many years of activity in the field of geomagnetism, this paper should appear in the *Geophysical Journal*, since an investigation of the micropulsation background originated in the United Kingdom and Holmberg's paper (1953) reporting the results obtained on the large horizontal land loop at Eskdalemuir appeared in the *Geophysical Supplement of the Royal Astronomical Society*. In 1919 January, Sir William Bragg, a senior member of the Admiralty's Board of Invention and Research measured micropulsations in a loop laid in Loch Lomond. The Eskdalemuir loop was laid at the request of the Admiralty and as a result of the interest of Sir George Simpson, then head of the Meteorological Office, doubtless arising from his work on the magnetic data taken at Cape Evans during Scott's last Expedition (1910–13) to the Antarctic.

Between the two world wars and during the last war, the fluctuating background magnetic activity now known as geomagnetic micropulsations was considered of some importance by the Admiralty's Department of Scientific Research and Development and it was during this period that Sydney Chapman was asked to advise on the best methods of minimizing the background effects. During the second war, the Royal Canadian Navy (RCN) with help from the National Research Council of Canada (NRC) and Canadian Westinghouse devised operational equipment for use in harbour defence. Thus the subsequent activities of the Pacific Naval Laboratory (PNL) in this field were in this way related to RCN harbour defence activities. The RCN supplied all the equipment subsequently used except for the first 10 mumetal detectors which were designed for other purposes and obtained from NRC. These 10 detectors were obtained through Dr J. E. Keyston of the Defence Research Board (DRB) of Canada who, while a member of the staff of the Admiralty Research Department, became familiar with the problems for which solutions were required. Like many other activities, such as the discovery of whistlers, and the first halting steps in electronics, the use of underwater loops owed their origin to experimental data gathered in the field where the background geomagnetic activity was the disturbing element in war-time operations. The interval between the two world wars and during the second world war yielded a wealth of new material, not all of which has yet been reported.

Thus the pattern of the early work at PNL on micropulsations was determined by origins and techniques based ultimately on war-time needs, and this was even true of the type of detectors used which determined the design of the chopper amplifiers built at PNL for this work. The major change which was made in 1965 and which was almost coincident with the take-over of the work by the University of British Columbia, was the introduction of PNL-designed slow-speed FM magnetic tape recorders. This followed an agreement in 1960 with Professor R. A. Helliwell of Standford University for co-operative action at Great Whale River on the eastern shore of Hudson Bay and at Byrd Station in the Antarctic. These two auroral zone stations, which are nearly conjugate, are still maintained. Great Whale River for which NRC has recently undertaken support is now responsible for gathering experimental data for a number of related Canadian and U.S. investigations in addition to geomagnetic micropulsations. A small unit at Ralston (Suffield Experimental Station, SES) was later added and is manned by Stanford University. This station provides a very useful mid-latitude supplement to the data obtained from the two conjugate auroral zone stations.

The present situation in the micropulsation field is far from clear and knowledge is now increasing so fast that modifications may be necessary even to 'facts' which seemed to be assured a very few months ago. An example is the diurnal variation of activity at Byrd Station in 1963, shown in Fig. 1 of a paper by Jacobs & Wright (1965). This figure contains an error which has come to light by re-examination of the data which show a very variable diurnal pattern of activity dependent on the 27-day rotation

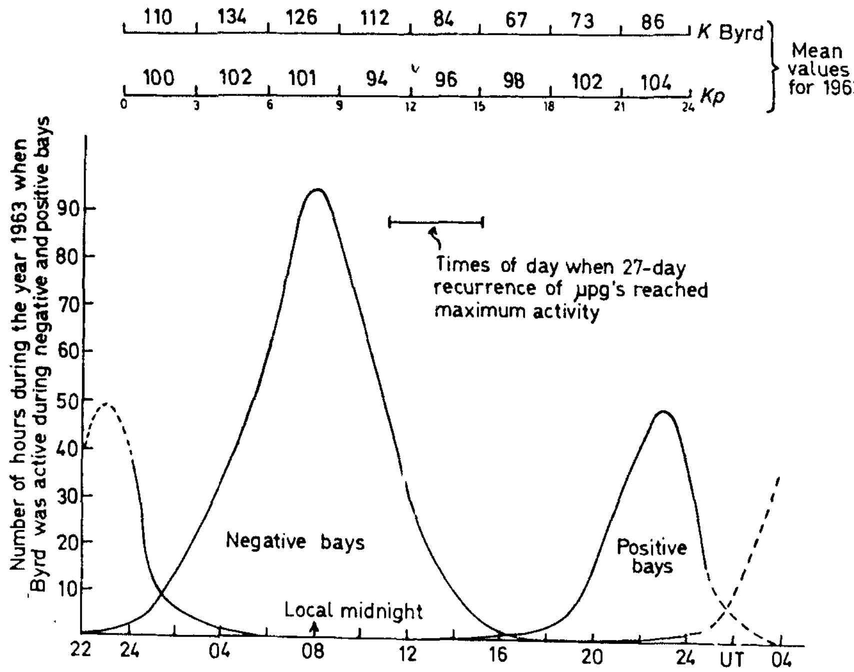

Fig. 1. Plot showing the diurnal variation of positive and negative bay systems at Byrd Station, 1963. Ordinates show the occurrence of these two bay systems recorded as displacements on the *H* magnetogram from the average for the day. Note the relative infrequency of the positive bay system which may, however, be due to lack of adequate sensitivity of the equipment, (see also Table 1). The time of day (1100–1500) when the large microgiant pulsations reach their maximum activity at 27-day intervals is also shown on the diagram.

period of the Sun which is most strongly expressed in auroral latitudes for the longer periods. The pulsations (Pc 5) are of maximum amplitude in the auroral zones. The resulting changes are incorporated in Fig. 1 of this paper which shows the occurrence frequency of negative and positive bays, measured below and above the general level on the Byrd *H* magnetograms, the negative bays appearing most commonly during the hour preceding 0800 UT and the positive bays during the hour preceding 2300 UT. Between the end of a negative bay and the start of a positive bay, we find, in 1963, very large, long period Pc type oscillations for a few days only during the 27-day period of the Sun's rotation—Selzer's (Eschenbrenner & Ferrieux 1961) micro-giant pulsations (µpg's)—the other days in the cycle (when conditions were favourable for display) showing much smaller oscillations, usually of decreasing amplitude and increasing period until the start of the next negative bay. Conditions between 1100 and 0100 UT are very variable and this variability is increased by the occasional presence of the impulsive positive bay system, which occurs less frequently than the impulsive negative bay system in the auroral zones. It should be emphasized that the data relate to the recent years of the quiet Sun and that the years of increased solar activity may show another pattern of geomagnetic disturbances.

It is well known that the 27-day geomagnetic activity pattern shows up most clearly during the less active solar years. This is clearly shown by the records from the conjugate auroral zone stations of Byrd and Great Whale River. A characteristic feature of recent years is the occurrence of long intervals of relative inactivity separated by much shorter bursts of moderate activity. These same inactive intervals appear also at our mid-latitude station at Ralston if the signal–noise ratio is sufficiently large and this occurs most often when the *Kp* index of magnetic activity is not of such magnitude as to swamp the high-latitude pattern. Thus the high latitude pattern is clearly expressed when the published figures of local *K* at Byrd and *Kp* are both low; this seems to be a rule which enables us to choose hours when this pattern is almost certain to have appeared on the records.

While the present set-up was determined by the near conjugacy of the two auroral zone stations, the mid-latitude station is of particular value in comparing the quiet intervals and low activity with those at the auroral conjugates and in observing how these are related to the mid-latitude measure of magnetic activity *Kp*. The simultaneous occurrence of abrupt events at auroral zone and mid-latitude stations when first observed in 1961 was hardly expected, and the widespread occurrence of quiet intervals in mid-latitudes is of some interest and possibly of some importance. Fig. 2 shows the positions of the stations at Great Whale River, Byrd, Ralston (SES) and Victoria. Westham Id is on the mainland close to the University of British Columbia.

2. Regular micropulsations in mid-latitudes

(a) *Pc activity*

There is a day-time regime of near-sinusoidal fluctuations from a very few s period (Pc 1) to regular oscillations of several min. period (Pc 5). The night-time activity is of irregular form and includes both long and much shorter periods (Pi 2 and Pi 1) which led us to name them impulsive in contrast to the regular day-time activity in our mid-latitudes. Both forms can appear nearly simultaneously at the same time and place and may be interrupted, even during magnetic and micropulsation storms by intervals of relatively quiet conditions (see Figs 3 and 4). *Kp* is found to be an appropriate measure for indicating relative magnetic disturbance in mid-latitudes for micropulsations as well as for the activity shown on standard slow speed magnetograms. During moderate and especially during great magnetic storms, all types of activity can extend to high latitudes as well. Similarity of Pc micropulsation records is sometimes seen at two stations in mid-latitudes more than 1500 km apart; simultaneous quiet intervals can be even more pronounced since quiet intervals occur when the solar wind velocity is very low and thus might be expected sometimes to encompass the whole Earth. (Snyder *et al.* 1963, Saito 1964, 1965a, 1965b.)

In recent years much effort has been devoted to the investigation of pearls (micropulsations in the frequency range 0·3–3 cps) which can occasionally be seen simultaneoulsy with the same period all the way from one auroral zone to the other (Tepley *et al.* 1965). As the name suggests, these relatively high frequency pulsations look like the beating of two oscillations of regular type with nearly equal periods. They appear to be related to the 27-day rotation period of the Sun (Ness and Wilcox 1965) and are thus associated with the UM regions on the Sun which have a more pronounced geomagnetic effect during a series of 3, 4 or 5 days. The 27-day period seems to be more evident when the middle day of this period is chosen rather than the day of maximum amplitude. Some broad band records show the simultaneous occurrence of riders of relatively high frequency when the amplitude of the lowest frequency component is also high (see Fig. 5). Also psc's (*p*olar *s*udden *c*ommencement or *c*hange), if sufficiently abrupt, contain frequencies up to more than 3 c/s.* Some of the psc's observed at Byrd on the micropulsation equipment are also sometimes seen simultaneously on the VLF whistler records. Many examples can be seen in the report by Morozumi & Helliwell (1966) which shows 8-channel records from Byrd of VLF noise (1–25 kc broad band), the intensity of the green auroral line (5577 Å), micropulsations (0·02–5 c/s), ELF (2–40 c/s) and ionospheric absorption. The authors

* Fig. 6 shows clearly what seems to be longer period pearl type oscillations, later called by Troitskaya IPDP. We believe that this was the first time the 'sonagram' technique was used in the work on micropulsations for demonstration at the DRB annual meeting about the end of 1957.

Fig. 2. Geographical distribution of the ground stations recording data used in this paper.

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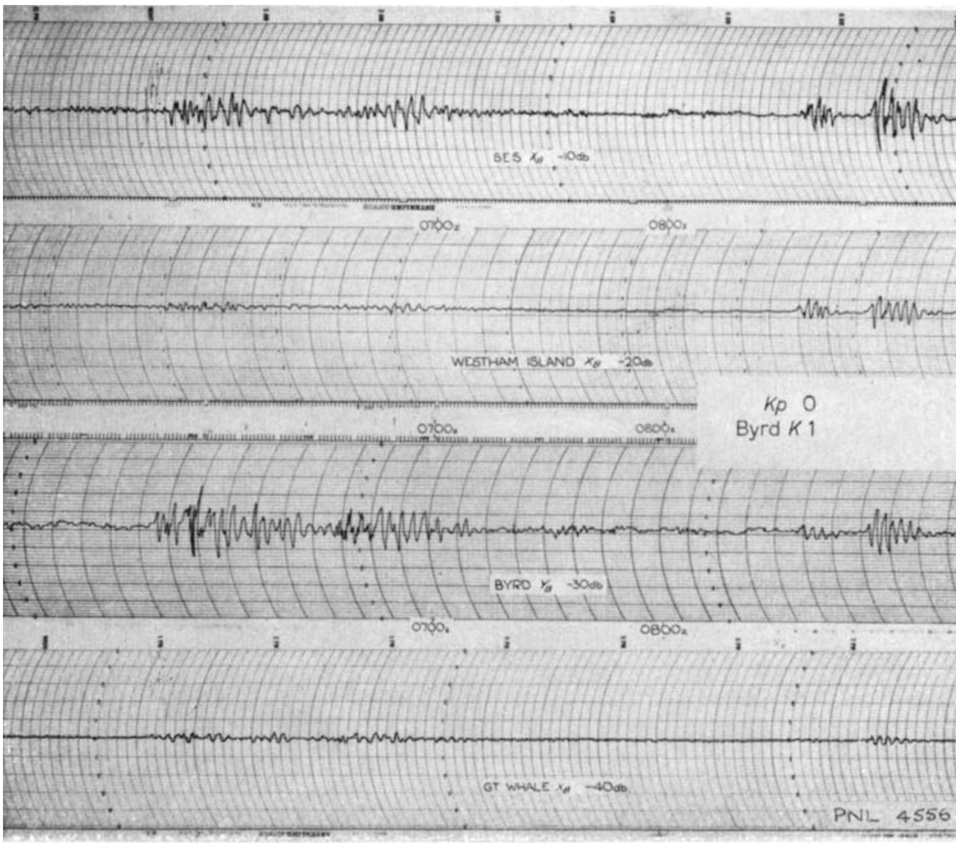

Fig. 3. Diagram showing quiet micropulsation intervals on 1965 January 31—a quiet day as measured by *Kp* and local *K* at Byrd. The short interval ending about 0900 appeared at all four stations. Westham Island and Ralston (SES) are by no means conjugate to one another or to the stations in the auroral zones.

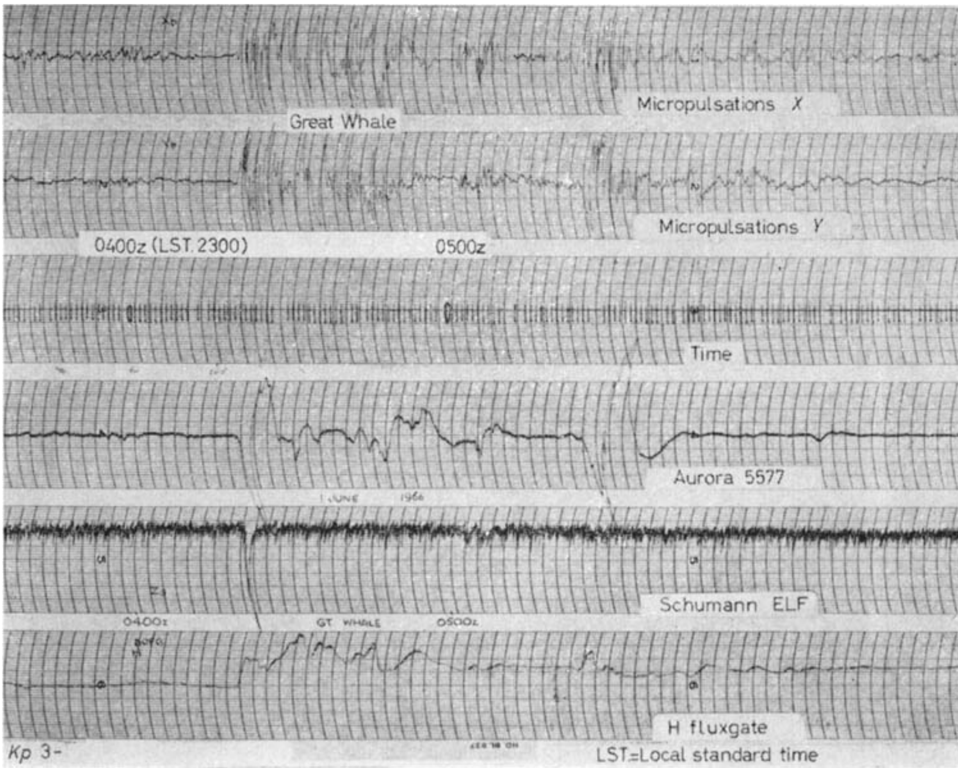

Fig. 4. This record (1966 June 1) was the first to be made at Great Whale River on the old 6-channel Brush and displays the quiet interval which precedes the active psc's at about 0421 appearing on the records of micropulsations, aurora (5577Å), *H* fluxgate and ELF (0·5 to 40 cps) which occur when the pcs's are sufficiently abrupt. The less abrupt change in auroral activity at about 0528 is matched by a less pronounced change in fluxgate *H*.

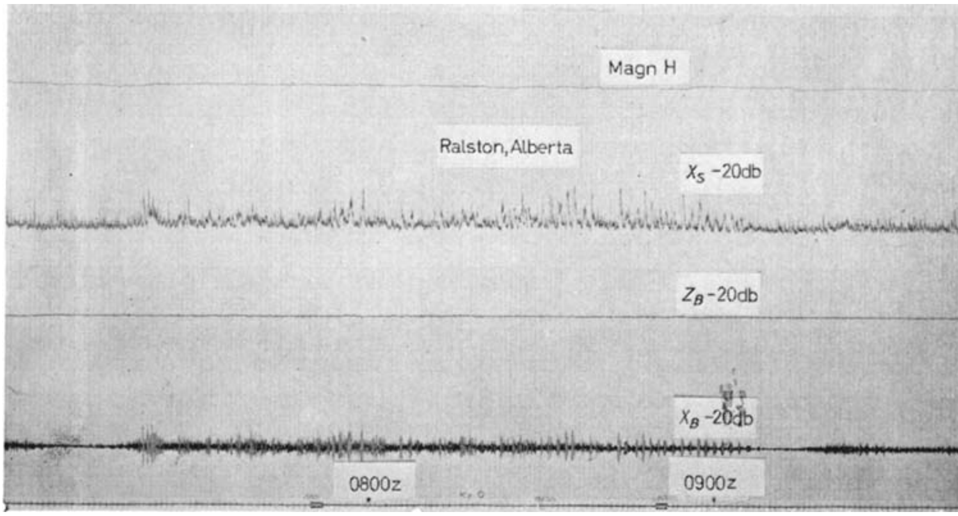

Fig. 5. This record (1966 March 24) is one of a number made at Ralston (SES). The ELF record (0·5 to 40 cps) X_s shows how the peak activity is overloaded at times when the higher frequency component is of greater amplitude (at intervals of about $1\frac{1}{2}$ min). The subsequent short quiet interval after 0906 is clearly shown on the broad band X record while the X_s record still shows some higher frequencies marked by a small upward displacement of the base of the trace.

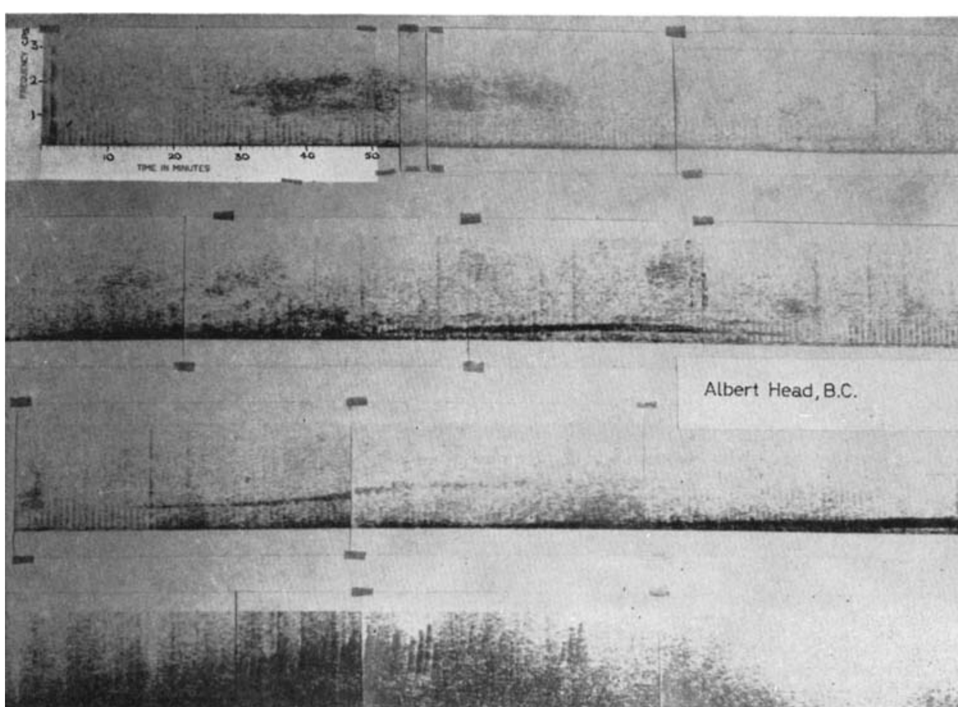

Fig. 6. This is believed to be the first sonagram record made, and shows the micropulsation of 1957 September 13. The lowest section of the record shows a structure whose existence at the time was thought to be due to faulty equipment. It can probably now be identified as Troitskaya's IPDP. Judging from the preceding few minutes of the record, the higher frequency components would have risen well above 3 cps.

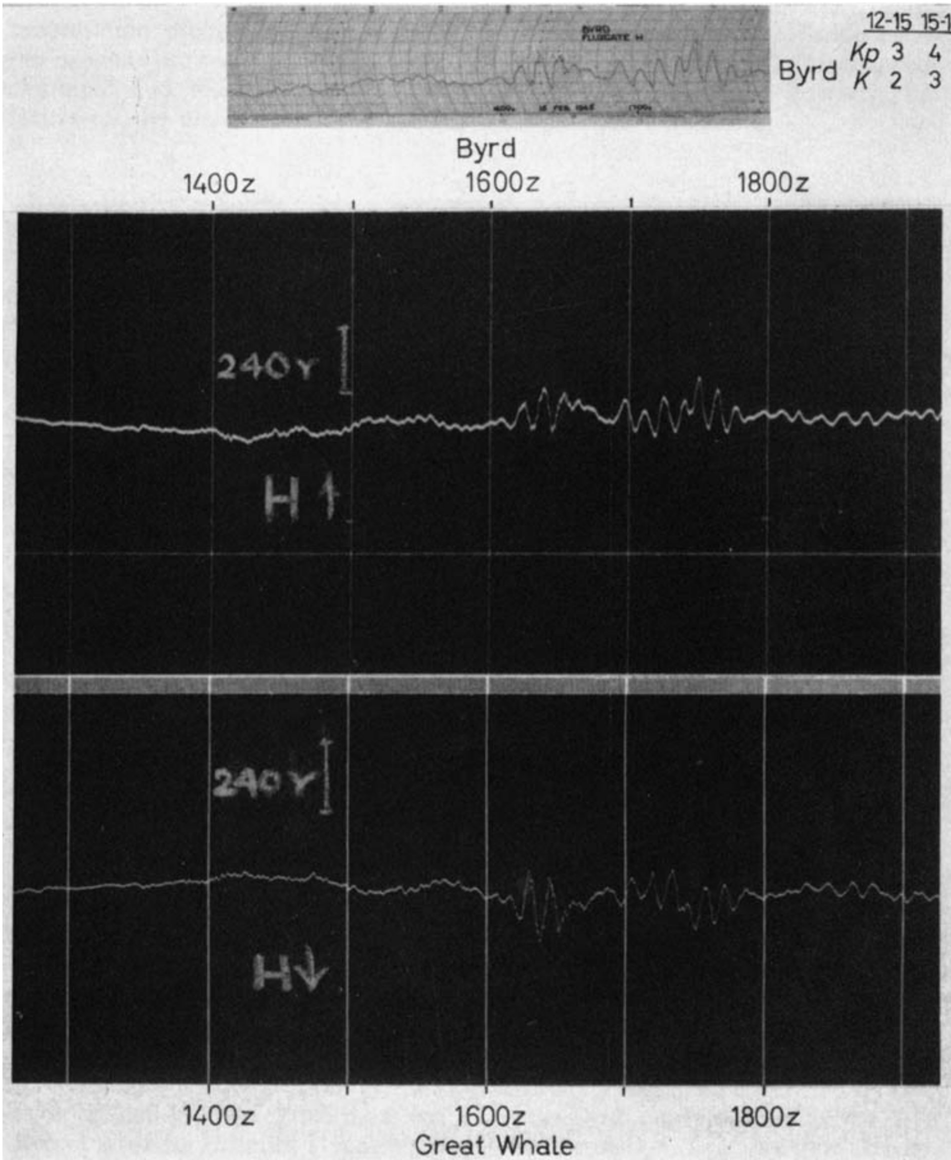

Fig. 7. Simultaneous H magnetogram records at Byrd Station and Great Whale River with Great Whale fluxgate H on 1965 February 15. This record illustrates the type which occurs near maximum activity corresponding to the 27-day rotation period of the Sun. The period of oscillation is not far from 10 min. and does not always appear clearly at mid-latitude stations.

divide the night-time activity into three types N_1, N_2 and N_3 of which N_2 includes the whistler frequencies. When this activity starts sufficiently abruptly it occurs as a psc simultaneously introducing a polar sub-storm. The N_1 type begins before N_2 and is associated with the occurrence of hiss while type N_3 follows N_2 and is associated with chorus. It is not easy to account for the nearly simultaneous start of N_2 and micropulsation psc's. The occurrence of whistlers is related to the incidence of lightning while psc's and polar substorms are considered to be part of the geomagnetic background and related to solar activity. Helliwell (1963) found however that whistlers can be responsible for triggering VLF periodic emissions.

(b) *Micro-giant pulsations (μpg's) and padm's*

Obviously the formation of pearl-like structures depends on the existence of a sufficiently regular type or types of activity maintained for a sufficient time. These conditions alone will not necessarily lead to their occurrence at any station unless suitable local ionospheric conditions occur. Their absence may be due to the fact that the periods of regular type pulsations may not be independent of latitude at the time. Indeed Jacobs & Sinno showed in 1960 that long period Pc's were more common in the auroral zones than elsewhere. We have no exact data on the amplitude of these micropulsations inside the auroral oval, but larger amplitudes can be seen visually and are more likely to occur there than in lower latitudes. We find that their periods range from about ½–8 min. or more, and their amplitudes may vary by a factor of 100 or more over the 27-day solar period. Since they are especially large at the longer periods, they can be seen best on standard magnetograms (see Fig. 7). When conditions are suitable, they may appear at the same time on both sets of records—micropulsation and normal magnetograms. They are the same phenomenon as Selzer's micro-giant pulsations (μpg) and seem also to be related to the *p*etite *a*gitation *d*u *m*atin (padm), which can be seen on either sets of records when background conditions are favourable. At Byrd, micro-giant pulsations usually appear in the recovery stage of the negative bay system around 1100 UT. On disturbed days the greatest activity usually lasts for about 4 or 5 h and sometimes lengthens in period and usually decreases in amplitude until it fades into the quiet period of the day which precedes the negative bay system. The diurnal variation of activity at Byrd in 1963 was shown in Fig. 1, the maximum frequency of occurrence of negative bays being during the hour preceding 0800 UT. This time is not to be confused with the earlier time of maximum occurrence of the abrupt psc's at about 0400 UT at all stations which record them (see Fig. 5 Wright & Lokken 1965). Positive bay systems often appear at Byrd between 1900–0200 but occur less frequently and are of smaller amplitude than the negative bay systems. The psc's which may introduce the positive polar sub-storms are also usually less abrupt and are less likely to be seen simultaneoulsy in mid-latitudes. When the signal–noise ratio is suitable, even the small padm's can sometimes be seen at the same times on the mid-latitude (Victoria) as well as on the Byrd magnetograms.

Recent work by Heacock (1966) has emphasized a high latitude day-time activity during the summer with periods from 3–8 s (mean value about 4 s). Since the ½–8 min. regular activity and that centred at about 1 c/s both show the development of nodes and loops and exhibit a 27-day period of activity, we may speculate whether this 27-day period may not also show in Heacock's range of periods. Certainly, our early experiments at Byrd in 1960–61 often exhibited amplitude variations in that period range with two regular periods of nearly the same value beating against one another. Since the longest series and most regular oscillations occur when the observing station is facing the direction of the solar wind, it is not unreasonable to expect that there should be a single series of micropulsations with periods from 8 min. to 3 c/s or less and of regular type which follows the 27-day period of the solar UM regions, and with

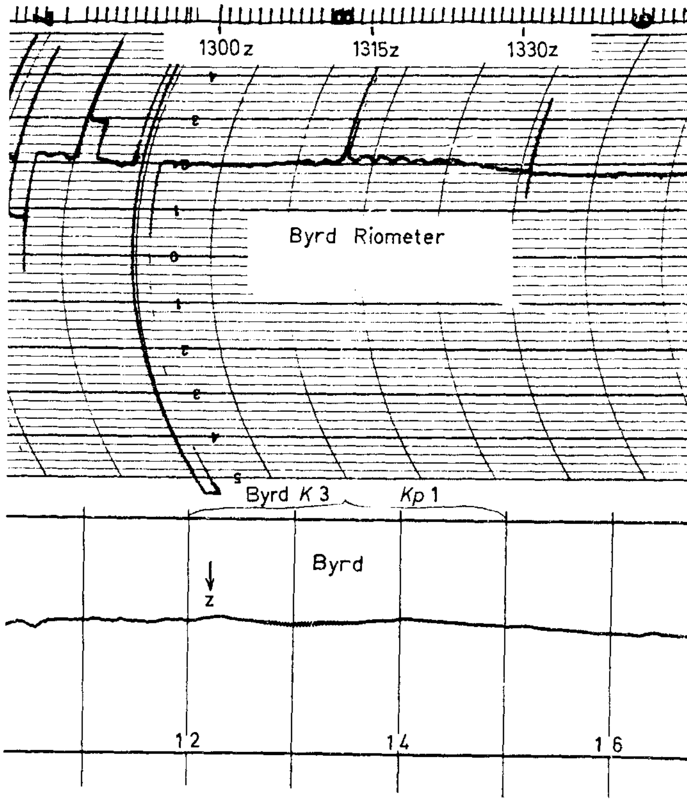

Fig. 8. Record of Byrd riometer and Z (vertical component) magnetogram, 1963 October 19—a quiet day. So far as we can judge the oscillation periods are identical and of regular type, characteristic of day-time activity.

signals enhanced at auroral zone stations for the longer periods.* We expect the impulsive types of activity to occur more often during bay activity when stations are facing away from the Sun; we do not know whether such activity is so closely related to the 27-day period of solar rotation as are the Pc types. A gradual change has taken place during the declining phase of solar activity, but by 1965 it became clear that the dominant control of activity was still the negative and positive bays, made up of polar sub-storms sometimes introduced by abrupt changes with relatively high frequency components which appeared simultaneously in mid-latitudes, especially when the commencements of the polar sub-storms were sufficiently abrupt.

3. Impulsive activity

Troitskaya first drew attention to the contrast at stations in the U.S.S.R. between Pc regular day-time and Pt (Pi) irregular pulsations. The latter have been called by us impulsive because of the form of the records which often include both low frequency (Pi 2) and much higher frequency (Pi 1) components at the same time. When these can clearly be recognized, they occur within a minute or two at stations at

* Exception might be taken to the use of the word ' regular ' when applied to μpg's and padm's but such pulsations can hardly be called ' impulsive ' in character. The Byrd magnetogram of 1963 October 19 (Fig. 8) shows regular μpg's from 1200–1400.

latitudes in and between the two auroral zones over large areas of the Earth.* The psc's observed in lower latitudes lose to some extent their abruptness and we have found that the negative psc's of the auroral zones are more and more liable to appear as positive psc's in lower latitudes, at least as far south as 18° geographic latitude. We think that these results are due to the return current system of the auroral electrojet in the local ionosphere.

It is this system of psc events, the following impulsive Pi activity and the preceding quiet interval which govern the general pattern of night-time activity at the conjugate auroral zone stations, Great Whale River and Byrd. There is a very persistent statistical occurrence of psc's between 0300 and 0400 UT at these two stations, which has not varied much recently from year to year (see Fig. 5, Wright & Lokken 1965). A quiet interval which often precedes the first psc of the Greenwich day makes possible greater accuracy in the timing of the event (see Fig. 2, Wright & Lokken 1965). Negative psc's without exception move initially in the direction corresponding to a decrease in *H*, in contrast to the relatively few day-time positive psc's in 1963 which all moved in the direction of increasing *H*.

We have made a comparison of the times of individual abrupt negative psc's at Byrd and Great Whale River (1965). Examination of a series of 140 days from 1963 September 28 to 1964 February 21, yielded 72 cases judged suitable for comparison of times. Measurements were made to the nearest ½ min. from paper records moving

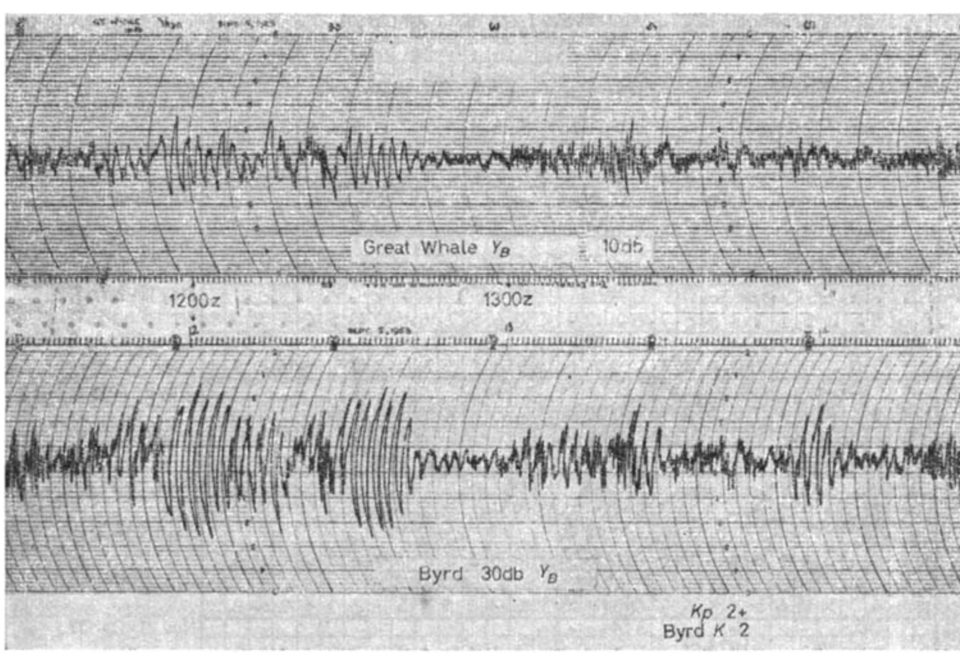

Fig. 9. These broad band records of 1963 September 5 at Byrd and Great Whale River are interesting, but not unique. They show what seem to be micropulsations of regular, quiet, day-time type, of period about 1½ min., fighting for position with a frequency component some three times higher. September 5 was a quiet day.

* Burdo reported in 1955 that the situation is different inside the auroral zone where the geomagnetic times of all maxima seen in the diurnal variations at a number of high latitude observatories are determined by the distance of the observing station from the 'corrected' geomagnetic latitude of the auroral zone. (The 'corrected' geomagnetic latitude is measured from the auroral oval, not from the geomagnetic pole.) These times fall into three groups and in each group the geomagnetic time of occurrence of the maximum is 'quite linearly dependent' on the distance from the 'corrected' auroral zone. The author relates the three straight lines of the 24-hour day to three spirals issuing from the geomagnetic pole.

at a speed of 6 in per hour. This analysis showed 17 cases of zero difference, 29 cases of positive difference and 26 cases of negative difference (Byrd minus Great Whale). Excluding the 17 cases of zero difference the average differences were +1·1 min. and −1·1 min. The differences do not conform to a smooth error curve and personal errors in judging the times are not wholly responsible; instead we believe that the stations are not truly conjugate at the times of all negative psc's.

We believe that this correspondence of the time of impulsive events often holds true also for day-time regular oscillations of longer periods, but changes are not sufficiently abrupt to achieve accurate timing with Pc oscillations since they wax and wane gradually. Certainly, the long period Pc nodes and loops seen at Byrd and Great Whale River often increase and decrease together, while the appearance of long period pearls can often be seen at the same time on sonagraph records.

The fact that Pc and Pi type micropulsations seem to be generally exclusive in mid-latitudes as regards time of occurrence during the 24-hour day is doubtless associated with the position of the station facing the solar wind or facing the tail of the magnetosphere formed in the lee of the Earth. It will be interesting to learn from observations in satellites the effects of low and high solar wind velocity on the shape

Ap values arranged in 27day intervals from 1963 January 1

														15																	Jan.1-27
5	1	2	8	3	0	7	2	0	3	6	5	29	31	26	24	19	15	19	6	3	5	9	10	7	2	1	2	5	29	43	
															12																Jan.28-Feb.23
2	5	29	43	13	2	3	3	3	4	3	1	8	45	21	21	27	19	8	4	4	3	2	9	6	6	6	2	4	5	2	
														10																	Feb.24-Mar.22
2	4	5	2	7	15	6	8	4	3	5	9	31	18	48	20	12	8	2	2	2	4	6	7	4	3	2	11	4	3	2	
													5	**6**																	Mar.23-Apr.18
11	4	3	2	1	4	5	3	4	12	4	4	19	32	19	15	7	7	2	3	9	10	17	15	6	7	15	10	7	4	11	
													2																		Apr.19-May 15
10	7	4	11	9	2	4	5	10	3	4	23	35	24	14	19	10	9	6	10	14	14	18	9	22	12	6	8	6	3	5	
													28																		May 16-June 11
8	6	3	5	8	5	3	3	2	8	6	7	16	21	12	9	11	10	6	5	2	16	43	12	10	5	6	5	5	5	9	
														26																	June 12-July 8
5	5	5	9	2	9	21	10	13	8	4	4	6	23	26	16	13	9	11	5	3	3	14	18	20	11	13	15	10	6	4	
															24																July 9-Aug.4
15	10	6	4	5	4	4	7	16	9	5	7	26	13	22	30	13	14	16	6	4	28	18	17	15	9	13	12	11	10	6	
														19	**20**																Aug.5-31
12	11	10	6	9	7	4	4	3	3	7	6	9	26	24	58	27	8	18	9	8	10	16	26	15	10	17	15	8	9	5	
														15																	Sept.1-27
15	8	9	5	9	9	5	15	14	9	20	13	8	82	38	33	43	15	26	13	44	126	78	18	68	27	34	48	19	12	4	
														12	**13**																Sept.28-Oct 24
48	19	12	4	3	4	6	8	5	11	16	6	9	22	39	24	31	16	16	5	5	5	13	9	3	3	63	16	8	4	7	
														8																	Oct.25-Nov.20
16	8	4	7	74	35	6	8	16	16	6	2	12	39	48	33	29	16	14	5	5	4	3	16	3	2	4	2	6	8	20	
												3	**4**																		Nov.21-Dec.17
2	6	8	20	16	2	4	5	8	18	5	12	36	25	28	23	15	14	7	0	2	4	8	11	7	7	4	2	4	20	11	

Fig. 10. Byrd 1963 *Ap* values (from U.S. Dept. Commerce, Boulder, Colo. CRPL-F235 Part B) arranged in 27-day intervals. December is not included as full data were not available. The figures in heavier type represent our judgment of the middle day of the sequence of larger amplitudes, not necessarily the day of maximum activity. The pattern is, we think, normal for a year of low solar activity, and deviations from the 27-day periodicity could probably be accounted for by differences in the time of passage of events carried by the solar wind from the Sun to the Earth and by possible movements of the UM regions on the Sun. The May 30 maximum was not very clearly indicated and we find that this was a time when micropulsation activity was least associated with *Ap*.

of the tail for comparison with simultaneous ground-based micropulsation records, especially at high latitude stations situated inside an auroral zone.

4. Micropulsations and magnetic activity in the auroral zones and in mid-latitudes in relation to solar conditions

Excluding magnetic storm conditions there is an obvious difference in the type of records obtained during years of high and years of low solar activity. This may be most simply described in years of low solar activity as an increase in the number and/or duration of those quiet intervals of about an hour which separate the shorter active bursts. At *Kp* values of about 4 it is possible to see the regular and impulsive types competing with one another for a place on the mid-latitude records (see Fig. 9), while for low *Kp* values combined with low Byrd (local) *K* values the quiet intervals stand out strongly to form a recognizable pattern in the quiet years both in the auroral zones and in mid-latitudes. We have the impression that auroral zone activity controls that in mid-latitudes during quiet solar conditions. However, when $K \geqslant 4$, mid-latitude activity will probably be so large as to swamp high latitude activity at some or all of the stations and this may give a false impression of the relative importance of the two types.

The 27-day period of magnetic activity is shown intermittently in 1963 by examination of the *Ap* values taken from Part B, Solar-Geophysical Data (see Fig. 10). If January 15 is taken as the day of maximum activity (not because this day shows the maximum *Ap* value for January, but because it is the middle day of seven days showing enhanced activity), and if the middle days of subsequent groups are taken in every case, we obtain the following 27-day sequential intervals, 27, 27, $26\frac{1}{2}$, $27\frac{1}{2}$, 27, 27, 27, $27\frac{1}{2}$, $26\frac{1}{2}$, $27\frac{1}{2}$, $25\frac{1}{2}$ and $25\frac{1}{2}$ with an average value of 26·8 days. However activity at the end of May and the beginning of June does not seem to fit very well into the pattern. On the whole, an independent examination of the days of micro-giant pulsations at Byrd in 1963 shows that they occur within one or two days of these *Ap* maxima. The larger values of *K* (local) at Byrd also fit into this 27-day pattern, as well as the occurrence of pearls at about 1 c/s.

In the auroral zones these micro-giant pulsations were generally largest between 1100–1500 UT and were of regular type. They were usually small after that time and before the occasional invasion by the positive bay system of impulsive type. In general the regular micro-giant pulsations and padm's also decrease in amplitude and lengthen in period after about 1600 UT. They show up well at Great Whale River and at Byrd station. In spite of the occasional positive bays which usurp their normal time of appearance, the padm's are seemingly also of regular type. They sometimes also appear at the same time at our mid-latitude stations.

They supplement the two dominant bay systems* (see Fig. 1) of which the negative is more persistent, occurring between 0100–1500, more prominent, and more striking than the less frequent positive bay system which occurs between 1900–0200. The quietest period of the day at Great Whale River and Byrd is between 2000–0100, and thus covers about the same interval as the positive bay when it appears.

There seems to be a pronounced seasonal variation of the ratio of the number of occurrences of negative to positive bays seen on the Byrd magnetograms† in 1963. The ratio of the number of occurrences in each month is given in Table 1.

* The times of these bay systems were noted by inspection of the Byrd magnetograms as the hours during which the impulsive part of the day's *H* record was below or above normal. It is not to be confused with the record of psc's which occur naturally at an earlier time. Of course a measure of selection of data is involved even when one compares (for example) the times of similar occurrences at two stations and chooses those events which only occur within a certain time interval and/or display a similar pattern.

† Some of the positive excursions from normal conditions may however be too small to detect.

Table 1

Ratio by months of the number of occurrences of negative to positive bays at Byrd Station during 1963

January 1 : 1	May 6 : 4	September 5 : 8
February 2 : 1	June 4 : 8	October 2 : 5
March 2 : 1	July 6 : 7	November 3 : 7
April 3 : 0	August 8 : 8	December 1 : 1

These figures suggest that the ratio of negative to positive bay activity is much greater at Byrd during the southern winter months, but confirmation is required by examination of records for other years and from Great Whale River. Table 2 shows that the active events are almost absent between 0800–1800 UT which is the time when the negative bay system for H is generally in the recovery stage. Since the maximum occurrence of the active events and of psc's in 1965 was at about 0400 (Table 2) it seems reasonable to assume that the active events are probably all of the same type even when the abrupt commencement is absent. Indeed, we think the abruptness of the events is more evident in the early stages of the development of the bay systems. Active and quiet solar years exhibit the same general features, the differences being expressed by the relative importance of quiet and active features from year to year.

Table 2

Diurnal variation of short active events at Byrd, 1965

Interval hours (UT)	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8
No. of active hours	33	61	83	117	115	77	51	25
Interval hours (UT)	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16
No. of active hours	9	3	3	0	1	2	3	3
Interval hours (UT)	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
No. of active hours	2	2	0	1	1	1	1	1

The quiet intervals are of special interest and the five recurrences of such intervals on 1965 April 13, suggest that there may be a favoured separation of about 1 h, which must be incorporated into any model which is formulated. By examination of the 1965 records from Byrd the average separation was found to be between 50 and 55 min. (probably about 53 min., see Table 3), but the fact that the data from 1965 August to December, though scanty in amount, showed a maximum number of shorter intervals, suggests the need for confirmation by analysis of data for other years. The agreement of separation times at Byrd and Great Whale River as well as at Ralston shown in Fig. 11 does not conform with any suggestion that the interval is related to the length of the L line terminating at the place of observation.

Table 3

Duration of quiet intervals at Byrd Station, 1965

Separation (min.)	No. of cases
10–20	19
20–30	36
30–40	45
40–50	42
50–60	60
60–70	37
70–80	28
80–90	20

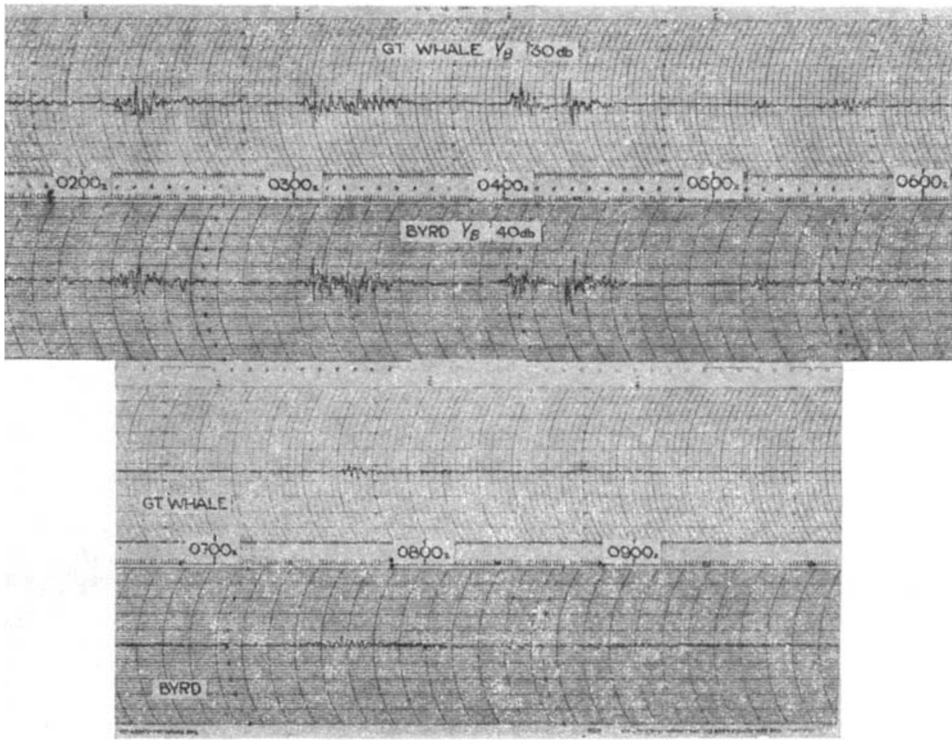

Fig. 11. This figure shows parts of records (1964 April 13) from Great Whale River and Byrd on Y (broad band) which are unusual in the persistence of an interval of about 56 min. between onsets of activity. The occurrence of this interval at the mid-latitude station, Ralston (SES) (not shown in the figure) was unexpected. The cause of this interval is very much open to question.

90–100	10
100–110	18
110–120	18
120–130	11
130–140	3

The evidence confirms that Kp is a mid-latitude measure of magnetic activity and indicates that local K (Byrd) is a measure of activity in the auroral zones. Each can at times be seen in the other's area and we think that this represents the effect of the appropriate return current system of the auroral electrojet in the local ionosphere. An obvious, but important, point is that they are both measures of activity, and that the quiet intervals appear simultaneously and last for separation times from 15 up to 120 min. and must be associated with a very low velocity of solar wind (Saito 1962). When Kp and local K are both small (ΣKp for the day < 12 and K (Byrd) < 3), it seems to be an invariable rule that one can use a combination of these indices for choosing particular days for closer examination of the prominence of quiet intervals. One of the many examples which shows Pc and Pi type micropulsations competing for appearance in a 'disputed' time zone was shown in Fig. 9. Another, but apparently unusual, occurrence (Fig. 12) shows the termination of the mid-latitude active type practically coinciding with the commencement of the auroral type and raises still another question as to whether the two types of activity are nearly time-coincident only on rare occasions—a question which can hardly be answered without much more data.

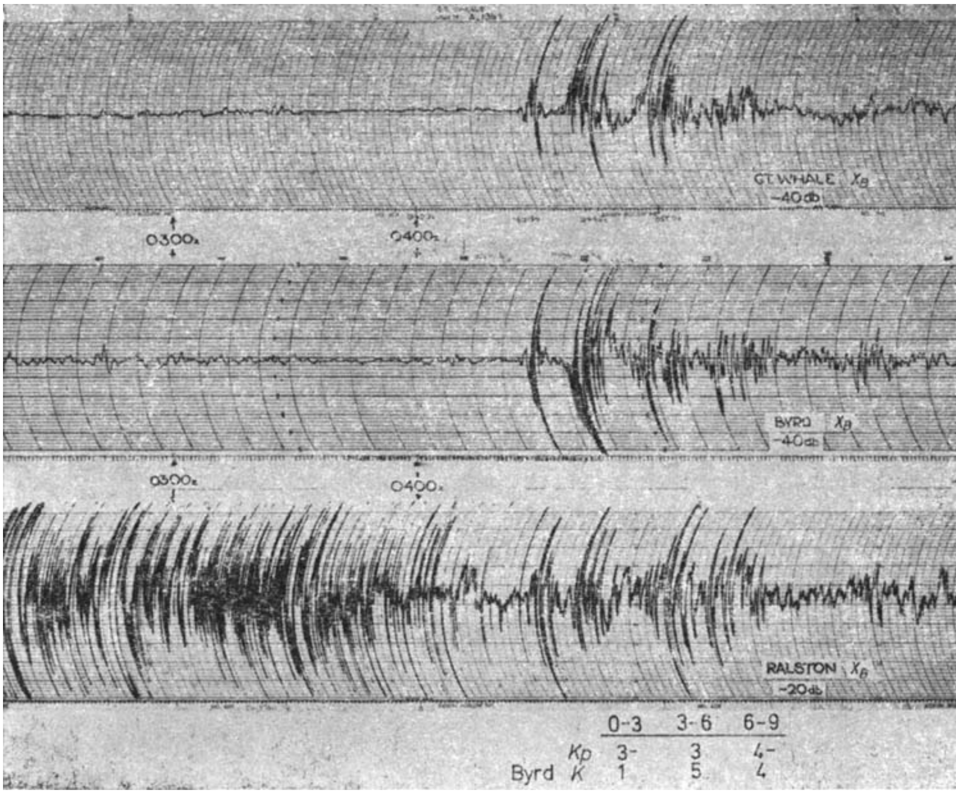

Fig. 12. This is another unusual example (1964 July 3) when the Byrd and Great Whale records seem much alike. The record of the mid-latitude station, Ralston (SES) seems to show this activity also, but is preceded by stormy conditions which seem to die away just as the auroral zone activity begins. The unanswered question is whether this is an isolated instance or if there is a common cause for such a nearly simultaneous occurrence of the auroral zone and mid-latitude patterns.

The recent introduction of slow speed FM magnetic tape recorders is bringing in a wealth of data for correlation studies. Observations of the records at Byrd and Great Whale River appear to the eye to be very similar while the Tukey comparison by computer shows a low correlation. No doubt the known changes in relative amplitude (Chivers & Hargreaves 1966), in the differences in the times of the events and, probably more important, in the phase differences are all causes of the low correlation shown instrumentally but not readily apparent to the eye. Judged by eye, the records at Ralston also sometimes show great similarity and this raises the question whether the results may not owe something to the fact that local mean time and local geomagnetic time differ less in the western hemisphere than elsewhere, because the geomagnetic and geographical poles are roughly in the same geographical longitude as our northern stations.

5. Discussion

In the absence of more precise data from satellites and from the point of view of the causes of the differences between the two types of micropulsations, we think that the bow shockwave may not exist during very quiet intervals and that perhaps the magneto-pause may then be so attenuated as to permit easier access of the solar plasma to the outermost field lines.

It is known that the quiet period which precedes the first psc of the day is normally associated with a steady value of H which varies little from day to day when K at the high latitude station of Byrd is small, i.e. during aurorally quiet days. Kleimenova *et al.* (1966) report from observations at the conjugate pair, Kerguelen Island and Sogra, that when the outer boundary of the magnetosphere lies at a distance of 10–11 Earth radii and is fairly stable in position, the Earth's magnetic field is also fairly stable if ΣKp did not exceed 12 or 15 for several days in succession. (On these occasions Earth current periods were > 50 s). Even when not so restricted to a long sequence of days of low ΣKp, we have observed that the value of H at Byrd tends to a stable value in advance of the first psc of the day, following a quiet interval of only two hours or even less. This freedom from fluctuations in H is not true at all times and the common occurrence of a steady value of H during the early stages of a negative bay is probably related to an absence of auroral intensity changes and changes of auroral position. The coincident fluctuations of the quiet auroral arc and of the associated regular micropulsations reported by Helms & Turtle (1964) should be Pc activity.

Even this short review of the morphology of micropulsation activity is sufficient to indicate the complicated patterns and their variation from day to day, although the statistical pattern may be quite stable from year to year and vary little from month to month. Considerable changes may occur in the pattern as we approach the more active solar years. The report on the similarity of the records taken at the conjugate stations of Byrd and Great Whale River and at our mid-latitude stations will be delayed in publication by the computation of some of the more continuous data taken on slow speed FM magnetic tapes. The visual similarity of micropulsation records at the conjugate stations is however sometimes startling—it is not known if this agreement is characteristic of the quiet years only. The occasional similarity with records from our mid-latitude stations will, we hope, throw some light on the mechanisms involved and of what we might expect in the next two or three years.

From this very incomplete review of the recent work on micropulsations during the years of the quiet Sun especially in the auroral zones, it is clear that these developments owe much to the clues provided by observations in balloons, rockets and satellites, but equally clear that the picture is far from complete, both in relation to observations at ground stations, in the magnetosphere and also beyond. Comparison with ground-based records should be very rewarding but more international co-operation both on the ground and above is needed to solve many of the problems. At ground stations what is especially required is continuous magnetic tape recording from a number of stations suitably placed in latitude and longitude, including stations in the equatorial regions and particularly within the auroral zones.

Yet one must not be too greatly impressed by the plethora of data already available and the number of problems which still await solution. In part this is due to the considerable number of phenomena related to micropulsations and to one another, which must be incorporated in the general statistical picture or model at appropriate times of the day, month, year and solar cycle. We think the importance of the 27-day solar rotation period during the quiet solar years has not been sufficiently appreciated. The range of amplitudes at the 27-day maximum is greatest at our high latitude stations but can often be seen even in mid-latitudes on magnetograms at Victoria.* As is well known, however, this 27-day period cannot really be relied upon for accurate prediction purposes. In quiet solar years, the period can sometimes be traced through several solar rotations, but not to the extent that specific days of greater disturbance can be prophesied with great accuracy. It seems reasonable, however, that days of low micropulsation disturbance can be nominated in advance with a greater chance of success, if only because the relative number of disturbed days is less in those years. The variations in intensity and in position of the active solar regions is probably adequate to account for the vagaries of the 27-day period.

* According to Sakurai (1966) the maximum occurrence of disturbance occurs near the sector boundary and seems to emanate from the weak magnetic solar regions. The abrupt events are the result of higher energy plasma overtaking that of lower energy in the solar wind.

Short period pearls (Pcl) wax and wane with the 27-day period and may be a class apart from the longer period pearls of period varying from ½ to about 8 min. However, all types—regular and inpulsive—seem to follow the 27-day activity cycle, although it is not known if the 3–8 s period band observed by Heacock (1966) in earth current records from College, Alaska also follows this rule. It seems very probalble that it should do so.

If adequate international arrangements could be made for cooperation and ground stations set up in the most suitable positions, much light would be thrown on the following questions:

(a) How the background magnetic disturbance, agreeing in general details at the two conjugate auroral stations, may also appear at a mid-latitude station.

(b) The relationship between some of Anderson's microbursts measured in balloons (1966), and micropulsations recorded at ground stations.

(c) The possible differences in micropulsation records at stations in the western and European continents due to the circumstance that magnetic and solar times are not very far apart in the former case.

(d) The reason for the preference in recent years for the recurrence of activity at intervals of slightly less than one hour. This means also that quiet intervals tend to be of about this duration, since the active periods last on the average only some 10 to 20 min.

(e) The relationship between phenomena occurring on the Sun and associated results measured in the solar wind, in the magnetosphere and on the Earth. Particular interest may attach to the sub-section divisions within the main 27-day sectors.

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