GEOMAGNETIC MICROPULSATIONS RECORDED AT HALLEY BAY, 1963–64

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ABSTRACT. Digital techniques were used to analyse quick-run records of the S.R.D.E. Fluxgate magnetometer now operational at Halley Bay. The site and its effects are discussed. Further analysis appears to be necessary to determine whether seasonal and solar-cycle effects exist.

GEOMAGNETIC field pulsations of varying amplitude and periodicity have been detected since continuous recording began. As instruments became capable of greater discrimination, i.e. more sensitive and with faster recording speeds, so the spectrum of such pulsations recorded increased. It now seems that there is no lower limit to amplitude (hundredths of a gamma are possible) and there is only a little evidence for a lower period limit of about 0·2 sec. (Heirtzler, 1964).

INSTRUMENTATION

The S.R.D.E. pattern recording fluxgate magnetometer at Halley Bay has a Band II sensitivity of 0·125 γ/mm.; however, the trace-width then limits the minimum detectable deflection to about 0·1 γ. The Band II output is filtered so that the signal is 3 db. down from its peak at 1 c./sec. and at 0·01 c./sec., i.e. the response is flat between 2 and 70 sec. period. The fall-off is rapid above 100 sec. period (16 db./octave) and at the other end of the pass-band the cut-off is a direct function of the chart speed; this is 30 cm./hr. and thus effectively limits the perceived periods to those above 15 sec. The frequency response curve is given in Fig. 1.

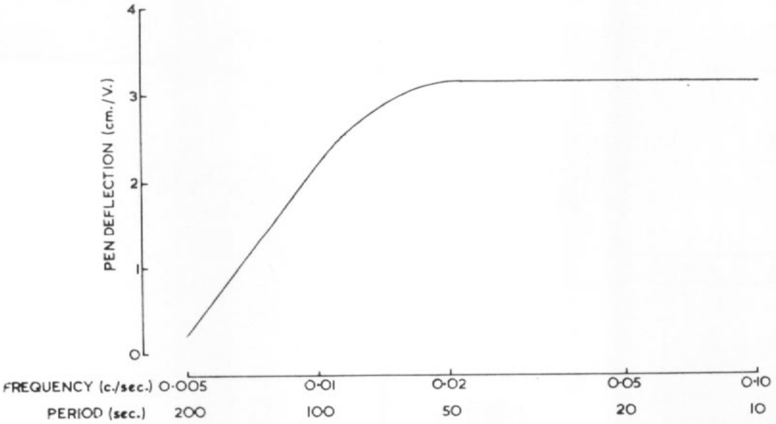

Fig. 1. Frequency response of fluxgate Band II recorder; the phase shift is zero over the frequency range shown.

PULSATION TYPES

The 1963 Committee of the International Association of Geophysics and Aeronomy classified pulsations of a regular nature (Fig. 2) by their periods. Of these groups, *Pc* 3 formerly *Pc* I; 10–45 sec. period) and *Pc* 4 (*Pc* II; 45–50 sec. period) are well received on Band II of the fluxgate magnetometer. Another pulsation form (Fig. 3), *Pt* (or *Pi* 2; 45–150 sec. period), could also be studied. Most of the records, however, do not show such clearly defined forms and there is often a variable amount of irregular activity either superimposed or just by itself. During magnetic storms, the maximum amplitude range of 5 γ is often exceeded and the records are then off scale.

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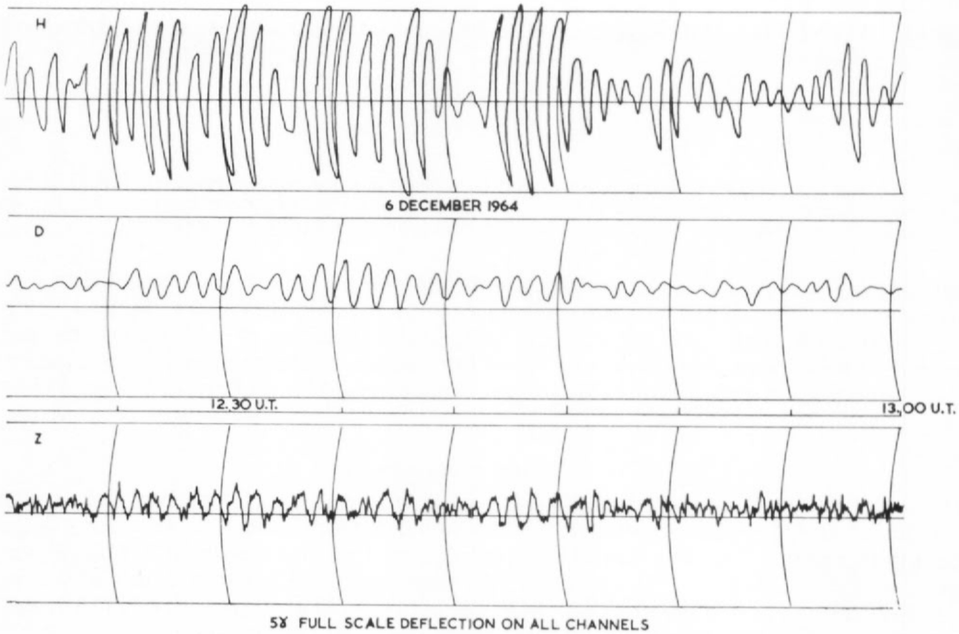


Fig. 2. *Pc* type pulsation, 12.20–13.00 U.T., 6 December 1964.

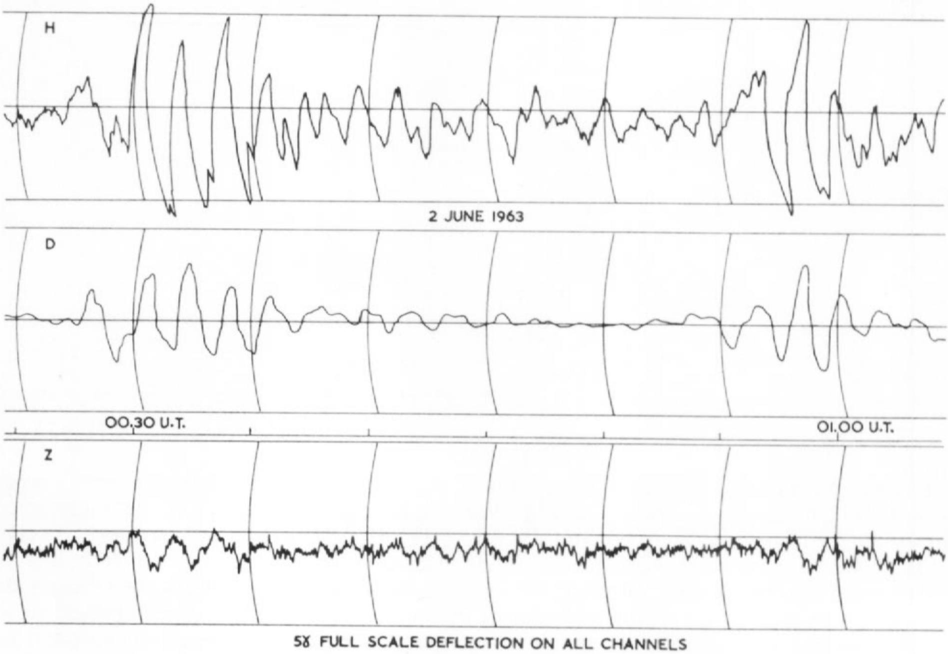


Fig. 3. *Pt* type pulsation, 00.25–01.05 U.T., 2 June 1963.

LOCAL EFFECTS

The amplitude of the horizontal field component (*H*) pulsations was usually greater than that of the declination (*D*) pulsations. Only very occasionally was the amplitude of *D* significantly greater than that of *H*. For quiet periods ($Q = 0, 1, 2$) *H* was almost twice *D*, on average. Fig. 4a shows the activity dependence of amplitude for all months analysed.

Further, the amplitude of the vertical field component (*Z*) pulsation was very much less than that of *H* or *D*, only the longer periods coming through at all clearly. This could, apparently, have been predicted from previous results from stations adjacent to the sea. Weaver (1963, p. 484; in British Columbia) and Parkinson (1962, p. 441; in Australia) found an enhancement of *Z* amplitude compared to *H* which increased with the proximity of the recording station to the sea. Fig. 5 shows the computed effect due to an idealized coastal boundary (Weaver, 1963); the land–ocean boundary is assumed infinite in both length and depth and the inducing field was assumed perpendicular to this boundary. It will be seen that the ratio of *Z* to *H* is

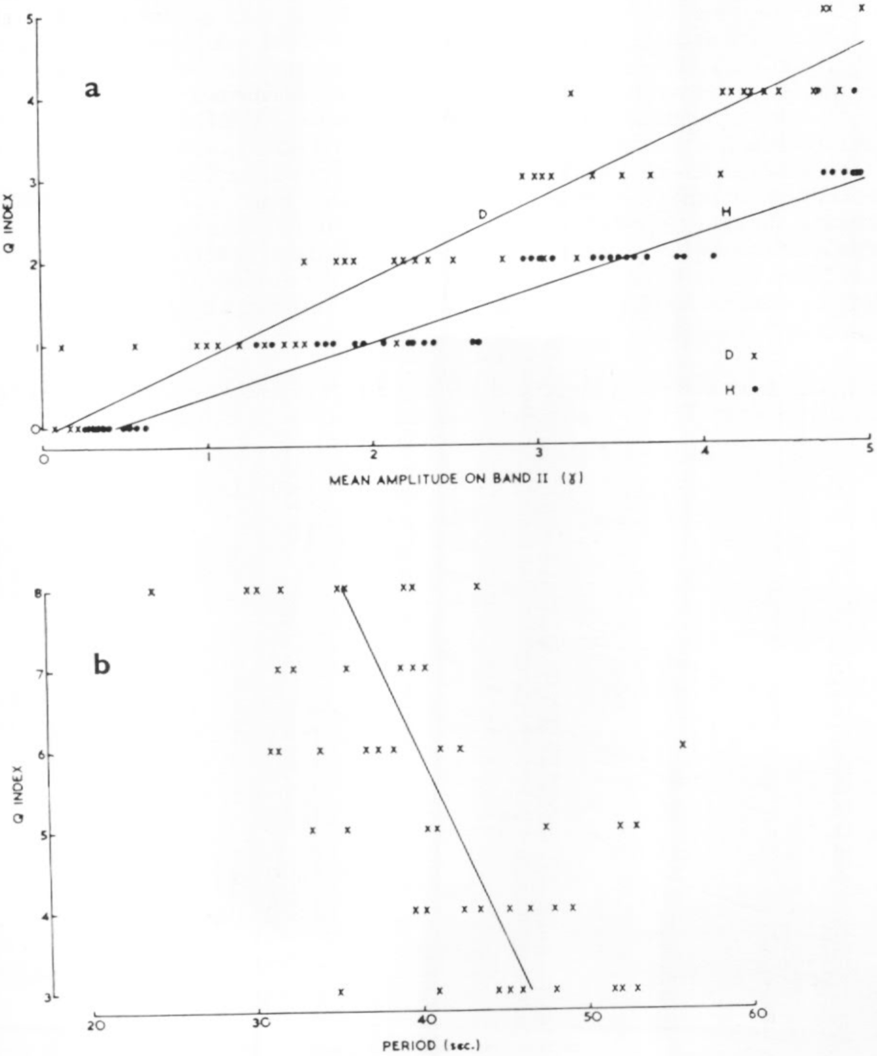


Fig. 4. Variations of pulsation period and amplitude with *Q* index of magnetic activity.

reversed over the sea. Observations on a floating ice island (Zhigalov, 1960) and at Halley Bay show this "damping" of high-frequency geomagnetic field oscillations in the vertical component.

There was always a short-period, small-amplitude (about 0·1 γ) element superimposed on the vertical field component oscillations (Figs. 2 and 3). The chart speed of the recorder is too slow to allow resolution of this "background", but visual observations of the pen showed the period to be around 2–4 sec. Occasionally such "background" was seen on the horizontal field component channel. When this occurred, the "background" on Z was enhanced; such effects could be reduced by changing electronic components in the "backing-off" supply, but it was never possible to eliminate the superimposed Z fluctuations entirely.

Possible explanations are:

i. Real pulsations of the vertical field; this is difficult to justify as a similar period of enhanced amplitude would be expected on H.

ii. Oscillations of the ice shelf in the stationary field; this is just possible. Seismometers run at Halley Bay in 1957–58–59 showed such periodic microseisms (MacDowall, 1959, p. 364); under average conditions the required vertical field gradient (1 γ/cm.) is too large; the vertical field gradient as estimated from the horizontal field gradients (assuming a potential field) is only 1 γ/m. at most. Nevertheless, at peak microseismic activity this explanation is just tenable. However, MacDowall found a seasonal variation (the microseisms are due to wind-induced ocean swell, and they are inhibited by the seasonal sea-ice cover) which is not apparent on the fluxgate records.

iii. Backing-off or other electrical noise. This certainly exists at times (see above) but in general it should exist on H at half the amplitude of that on Z (mean H field is 20,400 γ; mean Z field is 43,100 γ). This is not apparent. The diesel generators might produce such noise; they are, however, fairly remote (200 yd. (183 m.) from the recorder and 300 yd. (274 m.) from the heads) and it is again difficult to explain why Z alone is affected.

MODE OF ANALYSIS

A preliminary examination of the records (H and D) for Pc and Pt showed apparent day- and night-time dependence. Thus a winter and a summer month were chosen (June and December).

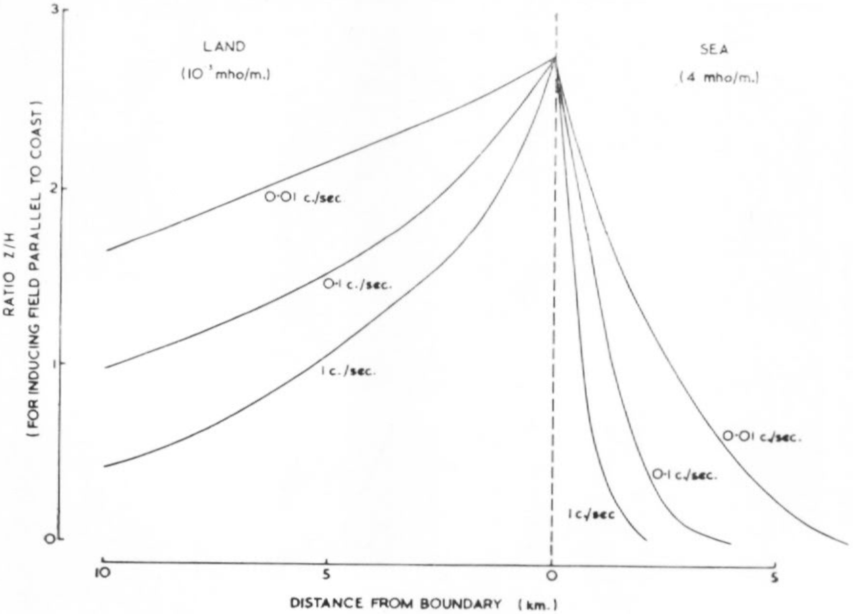


Fig. 5. Idealized coastal field effect (after Weaver, 1963).

Records for 1963 and 1964 were available; they were used in an attempt to assess the variation with solar activity. An equinoctial month was not chosen because, under storm conditions likely to be prevalent, the records go off scale and are very disturbed and confused generally.

A scale was hand-engraved to enable times to be read to 6 sec. (0·5 mm.) and pen deflections to 0·1 γ (0·8 mm.). All the *H* and *D* records for the months concerned were hand-scaled. In a particular hour it was considered whether *Pc* and *Pt* existed or not (one burst of *Pt* was deemed significant but *Pc* required continuity over at least 15 min.). When pulsations were present on both channels, their respective clarity of signal and frequency were noted. About 40 per cent of the pulsations were considered significant on one channel only. Of the total length of the records examined, about 60 per cent showed pulsations, and of these about 10 per cent were digitally analysed.

The samples selected for digital analysis were of from 45 to 60 min. duration. Equally spaced ordinates, at 6 sec. interval, were read to the nearest 0·1 mm. and punched on to paper tape, using a "d-mac pencil follower". The computational procedure outlined by Tukey (1949, p. 47) was used to obtain smoothed estimates, $U(l)$, of the power spectral density (Fig. 6). The calculations were programmed in Atlas Autocode and were carried out on a KDF 9 computer.

The procedure consists of:

i. Obtaining the auto-correlation, $W(l)$, for a sequence of lags, l, from 0 to m.
ii. Taking the Fourier transform, $t(l)$, of the $W(l)$.
iii. Smoothing the $t(l)$ to obtain $U(l)$.

Thus,

$$W(l) = \frac{1}{(N-l)\sigma^2} \sum_{i=1}^{N-l} y(i).y(i+l) \qquad \text{for } l = 0, 1, \ldots, m,$$

where N is the number of ordinates in the sample, $y(i)$ for $i = 1, \ldots, N$ are the ordinates reduced to deviations from the mean ordinate, and σ is the standard deviation of the $y(i)$.

$$t(l) = \frac{1}{m}\left[W(o) + 2 \sum_{k=1}^{m-1} W(k).\cos\frac{kl\pi}{m} + W(m).\cos l\pi\right] \qquad \text{for } l = 0, 1, \ldots, m.$$

The "hamming" window was used for smoothing:

$$U(l) = 0{\cdot}23t(l-1) + t(l+1) = 0{\cdot}54t(l) \qquad \text{for } l = 0, 1, \ldots, m,$$

taking $t(-1) = t(1)$ and $t(m+1) = t(m-1)$. $U(l)$ estimates the power contributed by a sinusoidal oscillation of period T sec., where

$$T = \frac{2m \times \text{sampling interval in sec.}}{l}.$$

The effective resolution is therefore dependent on the truncation lag m; however, m cannot be too substantial a fraction of N (e.g. Blackman and Tukey, 1959, p. 124), and $m = 120$ provided a reasonable compromise in this case (N between 450 and 600).

Below 100 sec. period, the method was probably accurate to 3 sec. or better. Above this period. however, the fall-off was rapid (as was the frequency response of recorder) and at 200 sec. period the accuracy was probably about 20 sec.

RESULTS AND DISCUSSION

Storm-type disturbances on the slow-run records (Band I) showed a marked micro-structure on Band II; however, these pulsations (regular and irregular) had amplitudes greater than 5 γ. Thus the records were very confused, but an attempt at period analysis was made by using the crossings of the central line. It appeared (Fig. 4b) that the period decreased as the level of activity (as measured by *Q* indices on Band I) increased. However, of the 4 months considered, only June 1963 had much such activity.

The more frequent "bay"-type activity on Band I (bays are departures from the quiet level, mostly almost entirely of one sign or the other, of any one field component; usually lasting for more than 1 hr.) usually showed a pulsation micro-structure. Periods were of 70 sec. upwards and amplitudes very variable. When such pulsations were clear, they were frequently

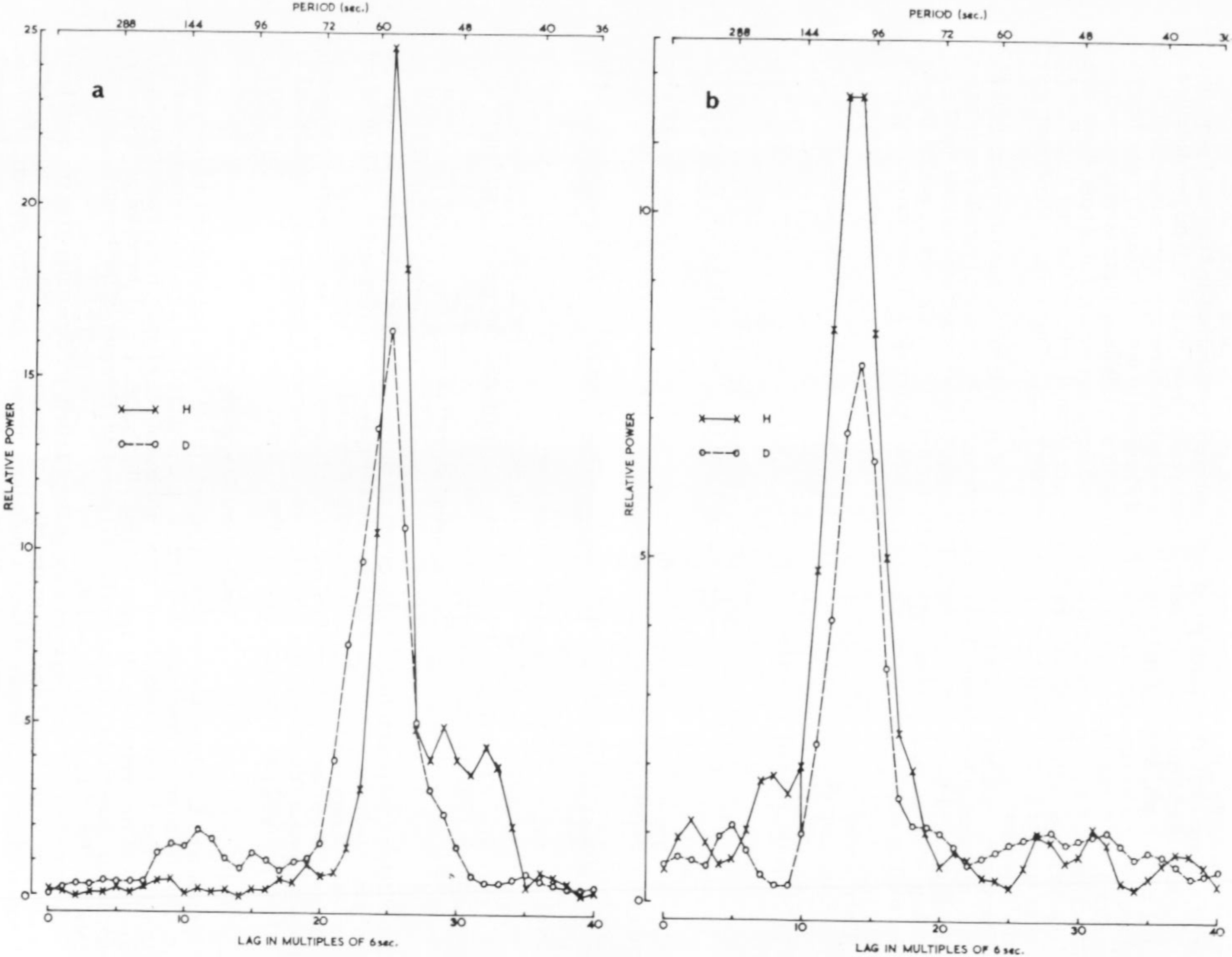


Fig. 6. Smoothed estimates of power spectral density.
a. For *Pc* sample of Fig. 2; relative power < [illegible] for lags 41 to 120.
b. For *Pt* sample of Fig. 3; relative power < 0·5 for lags 41 to 120.

of the *Pt* type; also, being of longer period, such pulsations were often seen on Z as well as on H and D. *Pt* pulsations also occurred during quiet intervals when no disturbance at all was seen on the Band I records. Nevertheless, the correlation with "bay" occurrence was high, and it was slightly higher in winter than in summer. This seems merely to reflect the rather more frequent occurrence of bays in winter than in summer; the incidence of the *Pt*'s themselves did not show a seasonal variation. There was a peak of occurrence at about 02.00 U.T. (local apparent midnight; local geomagnetic midnight is nearer 03.00 U.T.) and no *Pt*'s were seen between 09.00 and 18.00 U.T. (Fig. 7a). The spectrum was broad but it probably had a maximum at about 100 sec. (Fig. 7b). There was no difference of pattern between 1963 and 1964, although it was noted that the clearer examples were on H in 1964 but on D in 1963. Others (Yanagihara, 1963, p. 3383) have found an increase of *Pt* occurrence with decrease in solar activity. The results from Halley Bay tend to show that they are more easily seen in lower activity periods (Fig. 4 shows the difference between H and D; H in 1964 was comparable with D in 1963 because of change in solar activity). Unfortunately, their irregular spectrum (even within one "chain" of "bursts") hinders power spectrum analysis. *Pt*'s occur sometimes in these "chains" (Fig. 3 is part of a "chain" of five) and the spectral analysis suggests that the interval between "burst" occurrences is from 11 to 12 min., fairly consistently. However, the sample was small (70 per cent of the *Pt*'s seen were isolated examples) and the analysis is certainly doubtful for such long periods.

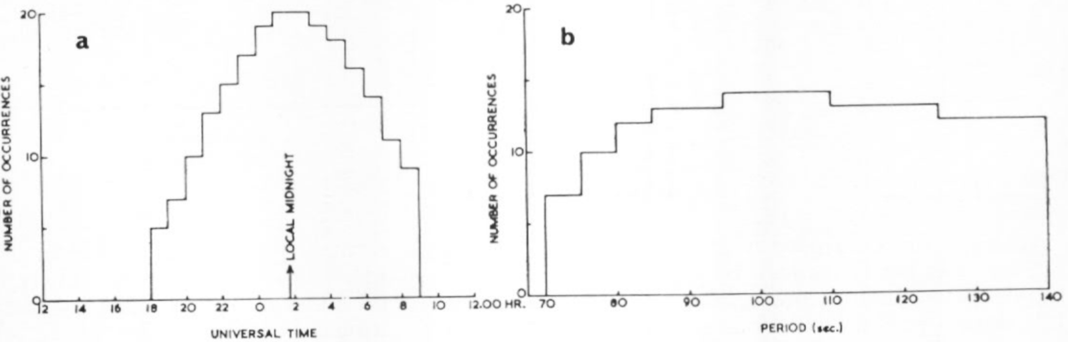


Fig. 7. a. Diurnal variation of *Pt* occurrence.
b. Spectrum of *Pt* periods.

Pt's are thought to be poloidal oscillations of the field, i.e. across the lines of force and distorted within the cavity formed by the solar wind (Mead, 1964, p. 1181). They are also thought to be connected (Heirtzler, 1964) with the auroral electrojets which cause "bays". Their association with the night side of the Earth would therefore be attributed in some way to the "dumping" there of high-energy electrons (Satellite Injun 3 (O'Brien, 1964, p. 13)) because of the above distortion of the geomagnetic field cavity. If the "train" period has any reality, it may be because of conjugacy, i.e. reflection from the mirror point in the Northern Hemisphere. Some results from the conjugate stations Reykjavik (Iceland) and Syowa (Antarctica) have suggested (Sugiura and Wilson, 1964, p. 1211) that there exists a common period of about 8 min. in a not dissimilar situation.

The regular pulsations (*Pc*'s) have a definite daytime occurrence. They also have more marked period peaks (Fig. 8), specific examples (Figs. 2 and 6) having very sharp peaks. Thus it would seem that, if they were hidden to hand analysis by the general increase in night activity, the digital analysis would probably find any regular pulsations. This was not so and hence Fig. 8 shows the diurnal variation of occurrence. Although the general peak was centred about 13.00 U.T., when the pulsations were divided into two groups ($<$ 45 sec. period and $\geqslant$ 45 sec.) it was found that the shorter period pulsations peaked before noon and the longer ones well after noon. This splitting into two groups was done after it was seen that the occurrence spectrum (Fig. 8) showed two peaks. The shorter period (30 sec.) is sharper and its

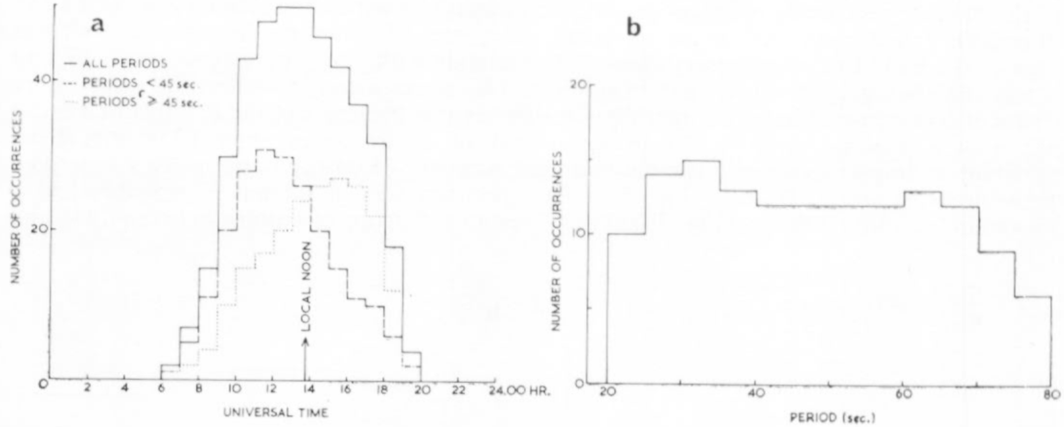
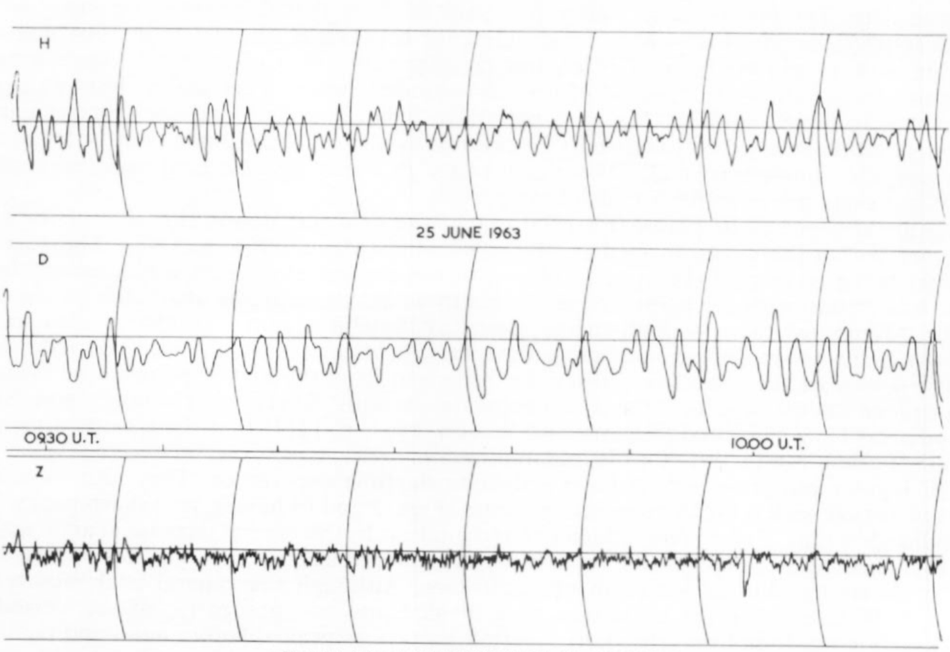


Fig. 8. a. Diurnal variation of *Pc* occurrence.
b. Spectrum of *Pc* periods.

likelihood of occurrence is greater; the longer (60 sec). is much broader. The division at 45 sec. was partly justified by suggestions (Heirtzler, 1964) that this is the division between modes of oscillation, also because it is the division between *Pc* 3 and *Pc* 4. It is suggested that the shorter period oscillations are poloidal and the longer toroidal, i.e. along the lines of force and therefore latitude dependent. The period of the "envelope" of the *Pc*'s (Fig. 2) varied between 160 and 270 sec.; there was apparently no connection with the *Pc* period.

No dependence of period or occurrence upon general activity (*Q* index)) was found. There was apparently no seasonal or annual change either, but (as with the *Pt*'s) it was found that the best examples were on *H* in 1964 and *D* in 1963. It has been suggested (Benioff, 1960, p. 1413)



5γ FULL SCALE DEFLECTION ON ALL CHANNELS

Fig. 9. Sample of pulsation record, 09.28–10.08 U.T., 25 June 1963.

that there is an increase in occurrence of *Pc*'s with the increased activity of the solar cycle. There was, perhaps, a tendency for the longer period *Pc*'s to have a slightly longer period in 1964 than 1963; this peak in the spectrum is very broad, however, and more information would be necessary for significance. *H* and *D* records almost always had the same primary spectral peak, when digitally analysed, but secondaries were usually different on each channel. Fig. 10 shows the plot of an example (Fig. 9) of a confused period of pulsations. Only two spectral peaks (of lags 21 and 42) coincide. This is the only example so far found where harmonics apparently exist, although an obvious interpretation of the total spectrum (Fig. 8) is in terms of such harmonics, if we assume the same mode of oscillation throughout the band of 15–100 sec. period.

Calculations by various authors (Heirtzler, 1964) have suggested that the toroidal oscillations (latitude dependent) should have a period of about 120 sec. for a station in the position

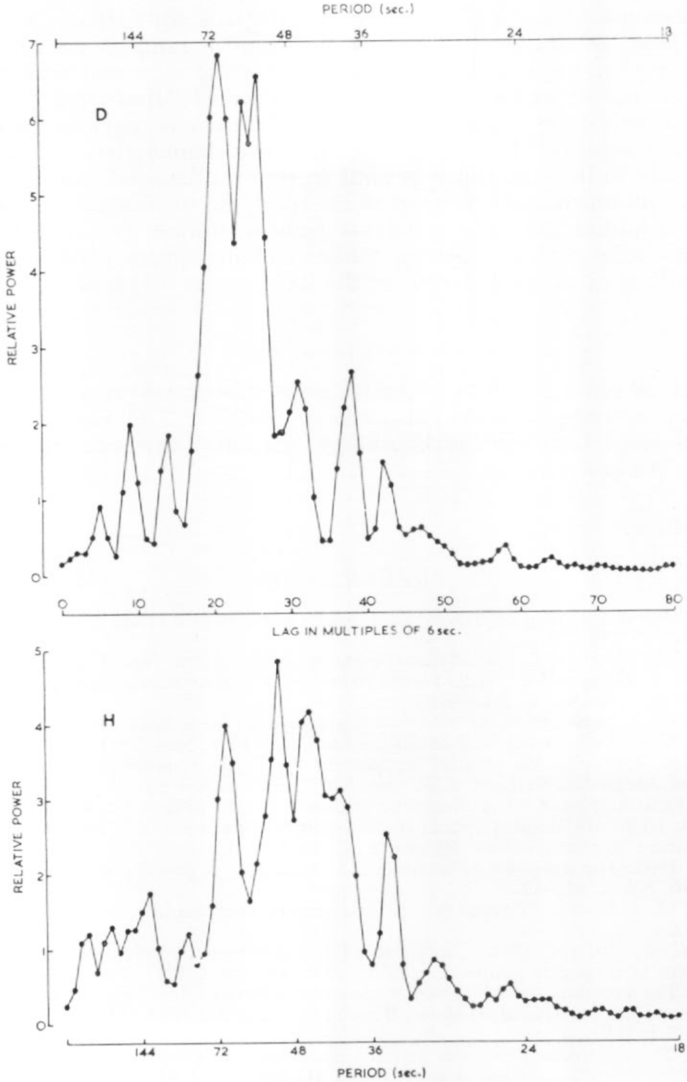


Fig. 10. Smoothed estimates of power spectral density for sample of Fig. 9; relative power < 0·1 for lags 81 to 120 on both *H* and *D*.

of Halley Bay. This period is not seen at best on the Band II fluxgate records but 1963 and 1964 yielded no examples.

Mathematical models of the high-latitude ionosphere (Greifinger and Greifinger, 1965) suggest a resonance at about 0·015 c./sec. (65 sec. period) which would explain the observations; satellite observations (i.e. above the ionosphere but within the magnetospheric cavity) have, so far, only recorded pulsations of longer period (180-240 sec.).

Comparison with records from other stations is difficult because very few use component recorders (total field recorders are usually used) and none use ones with similar recording characteristics. However, a similar S.R.D.E. magnetometer is now operating at Lerwick, Shetland Isles, at a similar geomagnetic latitude.

Conclusions

The period response of the instrument seems adequate for further observations of *Pc*'s, i.e. the spectral peaks of 30 and 60 sec. are well within the range of 15–100 sec., but the amplitude range (5 γ peak-to-peak) will be too small for the increased activity nearer sunspot maximum. *Pt*'s are not so well seen and it is very difficult to discover if the "train" period is real. Recording of pulsations during more of the solar cycle is required for inspection of any effects, as 1963 and 1964 were both relatively quiet. The characteristics of *Pt*'s, as observed at Halley Bay, seem to fit into the vague general pattern (as deduced from other observations). *Pc* characteristics are much more complex to interpret and to compare, as shown by observations at spaced (in latitude, same longitude) stations in Britain (Stuart and Usher, in press); site characteristics (local geology, adjacency to sea and ionospheric conductivity) are suggested by the above authors as an explanation of the differences; if this is so, Halley Bay has no parallel.

Acknowledgements

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