Titill
Geomagnetic micropulsations with periods 1/2 to 100 sec observed in southern California

Höfundur
Gunnar Böðvarsson (1916-1989)

Tímarit
Jökull
12. árgangur 1962
1. tölublað
Bls. 55-81

Geomagnetic Micropulsations with Periods $\frac{1}{2}$ to 100 sec Observed in Southern California and Iceland

BY

GUNNAR BODVARSSON

STATE ELECTRICITY AUTHORITY, REYKJAVIK, ICELAND

ABSTRACT

The present report covers an introductory study of geomagnetic oscillations with periods 0.5 to 100 sec recorded in Southern California in the period 1954 to 1957. Four main types of oscillations are described: (1) frequent day time oscillations with amplitudes to 20 microgauss and periods 10 to 40 sec strongly correlating with geomagnetic activity, (2) pulses and irregular transients occurring preferably during the night, (3) infrequent sinusoidal nighttime oscillations with amplitudes up to 0.3 microgauss and periods 0.5 to 2.5 sec occurring at days of low geomagnetic activity and (4) oscillations with periods 0.5 to 3.0 sec associated preferably with the pulses and the irregular trains. A brief description is given of similar oscillations observed in Reykjavik, Iceland.

ACKNOWLEDGEMENT

The present report is partially based on work carried out by the author during his stay in 1957 at the Seismological Laboratory of the California Institute of Technology, Pasadena. The research project was sponsored by the Office of Ordnance Research of the U. S. Army. The author is deeply indebted to Dr. H. Benioff, professor of seismology, for suggesting the present study and for the many helpful discussions, criticism and suggestions.

INTRODUCTION

A programme of recording oscillations of the earth's magnetic field in the period range $\frac{1}{2}$ to 100 sec was initiated by Benioff in 1954 (see *Benioff,* 1960). A number of recorders for this purpose have been installed in Southern California and this network was later greatly extended. The first recorder was installed in 1954 at Flintridge, California. In 1955 two additional recorders were installed at Palomar and Mount Wilson, California. In 1956 the recorder at Mount Wilson was moved to Tinemaha and later to Haiwee in Owens Valley, California. An additional recorder was installed in 1957 at Isabella, California.

During 1958 new recorders were installed in Reykjavik, Iceland, in Uppsala, Sweden, and at Resolute Bay, Canada.

A comprehensive review of the observational material recorded in this network has been given by *Benioff* (1960). The present paper is a delayed publication of a special report on an introductory study carried out by the present author and based partially on the same material. Parts of the work were carried out under the supervision of Dr. H. Benioff and the study is confined mainly to the material obtained from the California network in the period November 1954 to March 1957. A brief discussion is also given of more recent recordings from Reykjavik, Iceland.

INSTRUMENTATION

The recorders are flux rate variographs consisting of a circular coil, 192 cm in diameter, with 750 turns and connected directly to galvanometers recording photographically with standard seismograph recording drums. The coil is installed such that the north-south component of dH/dt is recorded. A further description of the equipment and the frequency response is given by *Benioff* (1960).

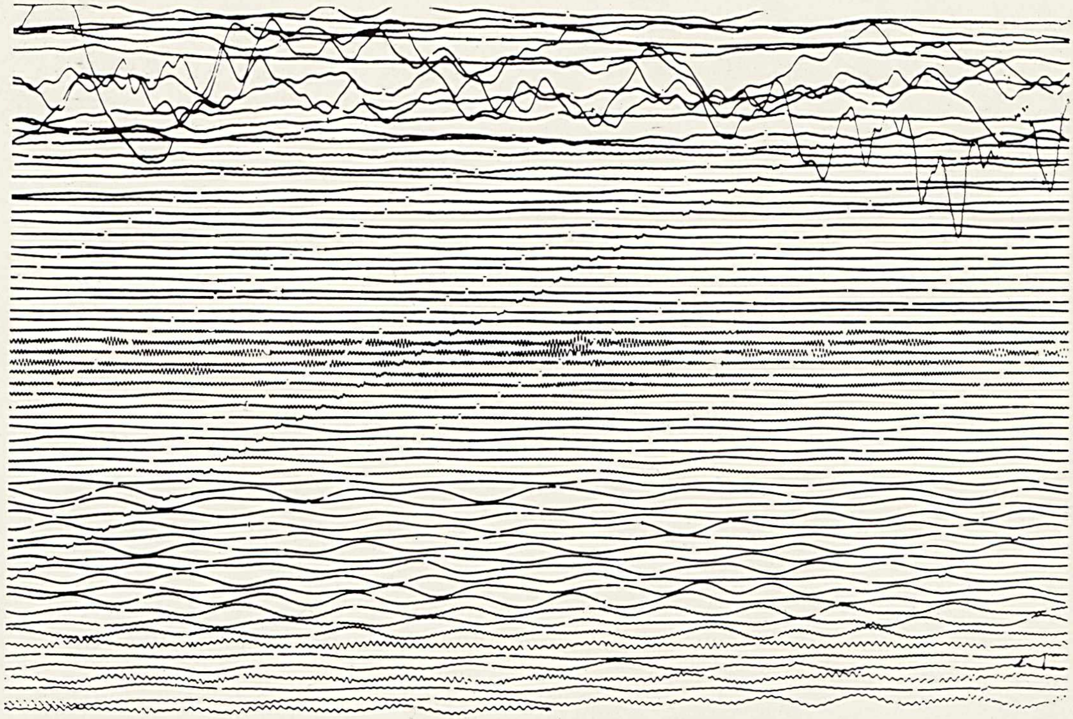

Fig. 1. Type C, A and R oscillations observed in Reykjavik on Feb. 1–2 1963. The record begins at 2100 h and ends at 1200 h. Typical A oscillations occur around midnight whereas typical C oscillations commence in the early morning. Very faint R oscillations are observed at the end of the irregular oscillations around midnight. The short period oscillations at the bottom of the record are either A or R oscillations.

GENERAL PATTERN OF THE OBSERVED OSCILLATIONS

A train of similar magnetic oscillations, continuous or interrupted, will in the following be regarded as a single magnetic event. The main criteria for similarity are the form and the period of the oscillations. On this basis an event may last for a considerable part of the day.

As shown by *Benioff* (1960) the magnetic events can be divided into rather distinct groups. In the case of the present observational material from California a grouping into 4 groups, A, C, DP and DI, and R, appears suitable.

(A) *Short-period oscillations.* Infrequent long beating trains of sinusoidal or quasi-sinusoidal oscillations with periods 0.5 to 2.5 sec observed in California preferably during the night or in the early morning. A typical example is shown in Fig. 1.

(C) *Medium-period oscillations.* Frequent trains of sinusoidal or quasi-sinusoidal oscillations with periods 10 to 40 sec observed preferably during the day. An example is shown in Fig. 1.

(DP) and (DI) *Pulses and irregular trains.* Transients in the form of regular pulses with relatively long periods and long irregular trains, both observed in California preferably during the night. An example of a DP event is shown in Fig. 2.

(R) *Short-period rider oscillations.* Infrequent trains of sinusoidal or quasi-sinusoidal oscillations with periods 0.5 to 3.0 sec accompanying some of the C, DP and DI oscillations. Some of the small short-period oscillations shown in Fig. 1 may represent R events.

The groups are here designated according to

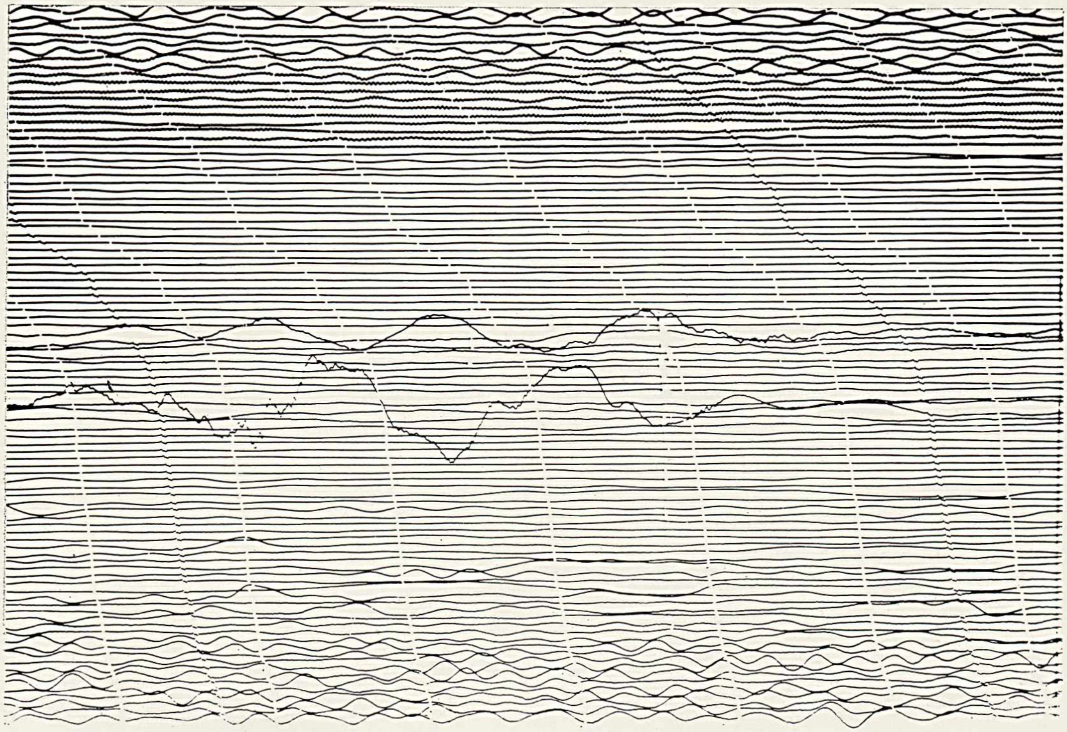

Fig. 2. Type DP, C and R oscillations observed in Reykjavik on Dec. 9—10 1962. The record begins at 1200 h and ends at 1200. A large DP event occurs at midnight whereas typical C oscillations occur also in the record.

Benioff (1960) who gives a more detailed description. However, Benioff's group B is not significant in the present material and his group D has here been split up into DP and DI events. Moreover, the rider oscillations, also described by Benioff, have here been treated as a separate group.

A great number of authors, especially European investigators, have grouped the micropulsations into two main groups, that is, continuous pulsations, P_c, and transient pulsations, P_t. This is less specific than Benioff's grouping. It is clear that the type C and D events fall into the P_c respectively the P_t groups.

There is a considerable literature on magnetic micropulsations and the effort devoted to the study of this phenomenon has been increasing at a fast rate mainly during the past decade. The work of the Japanese group (see *Kato* and *Watanabe,* 1957), Jakobs (see *Westphal and Jakobs,* 1962), Campbell (see *Campbell and Matsushita,* 1962) and *Troitskaya* (1961) should be mentioned.

METHOD OF CLASSIFICATION

The observational material will in the following be treated in accordance with the above grouping of the magnetic events. For each event the following data have been extracted from the records:

(1) The time of commencement and end of each event.

(2) The main period, or periods, where a period can be defined.

(3) The maximum amplitude.

Generally, there are no difficulties in obtaining approximate data on the commencement, the end and the periods of the events, except in the cases of the DI oscillations where a period can not be defined.

On the other hand, the maximum amplitude is a figure of a more doubtful significance. Generally, C and A oscillations exhibit a pronounced beating and the maximum amplitude is in many cases a very transitory characteristic. Therefore, it appears more appropriate to apply the maximum amplitude only for a classification of the magnitude of the events on the basis of a relatively coarse scale. A 4-step scale will be introduced in the following.

This scale can be based on the observed maximum amplitude of the north-south component of dH/dt, or on the computed maximum amplitude of the north-south component H. The former procedure will be applied in the case of C, DP and DI oscillations whereas the latter will be applied in the case of A oscillations.

The main observational data in the case of the various types of events are given in Fig. 3 to 12. The numerical data on the magnitude scales are given below.

METHOD OF ANALYSIS

In analysing the observed data the following items appear to be of main interest:

(1) Diurnal pattern.
(2) Annual pattern.
(3) Period-magnitude relation.
(4) Correlation with events recorded on slow-run magnetograms.
(5) Correlation of records from distant stations.
(6) Correlation with solar activity.
(7) Correlation with ionospheric conditions.
(8) Correlation with cosmic-radiation intensity, auroras, whistlers and other natural electromechanical phenomena.

Items (1) to (3) can be obtained directly from the recorded data and do at this juncture not require further discussion.

A measure of the average daily activity of the earth's magnetic field is given by the average planetary amplitude A_p which is computed for each day by the magnetic observatory in De Bilt, Holland.

In the following the magnitude and the period of the various observed events will be correlated with the A_p figure of the day on which they occur. The correlation pattern is obtained by comparing the average A_p figures of days associated with the various magnitudes and period ranges.

Moreover, an attempt will be made to correlate the individual events with events observed on slow-run magnetograms. For this purpose the magnetograms from the observatory in Tucson, Arizona, were applied.

The largest distance between any two of the 4 stations in Southern California is between Haiwee and Palomar, or about 250 km. This distance is relatively small. The degree of identity of the records from these stations has been studied.

The solar activity during the period from November 1954 to February 1957 is characterized by a sharp rise in the sunspot activity from a minimum to a fairly high level. The general pattern of the variations in the frequency of the various magnetic events during this change can be obtained directly from the records.

The main observational data on the condition of the various layers of the ionosphere are the critical frequency f_0 and the apparent height h of the layers. These data are now furnished by a great number of stations. A fairly complete study of the relation between the magnetic events and the conditions in the ionosphere requires a considerable work and has not been carried out. The only step carried out is an attempt at correlating a few individual magnetic events with ionospheric data given by the Stanford Station in Palo Alto, California. This station is located some 500 km north of the recording stations in Southern California.

A study of the relations of the magnetic events to the phenomena listed in item (8) could not be made. Special facilities would be required for this purpose.

OBSERVATIONAL DATA ON TYPE C OSCILLATIONS

The magnitude scale for C oscillations is based directly on the maximum amplitude of the records, that is on the maximum amplitude of the north-south component of dH/dt. The 4-step scale has been selected as follows:

TABLE 1

Magnitude scale for C oscillations.

Maximum recorded amplitude	Magnitude	Approximate field amplitude at Palomar by a period of 25 sec
≤ 0.25 mm	I	≤ 0.7 microgauss
0.26 – 0.75	II	0.7 – 2.2
0.76 – 2.25	III	2.2 – 6.6
> 2.25	IV	> 6.6

The same scale has been used for all recorders although the sensitivity is somewhat different.

The data on the timing, magnitude and the periods of individual C oscillations are given in Fig. 3 to 6. The occurence of R oscillations accompanying the C oscillations is indicated in the figures.

The data given in Fig. 3 to 6 exhibit a clear diurnal pattern and the frequency of occurrence of the oscillations increases rapidly with increasing solar activity. The data on the sunspot activity are given in Fig. 13 to 16.

Moreover, there is a less conspicuous annual pattern. The activity (magnitude by duration) of the C oscillations appears to be at maximum at the equinoxes. The period is shorter in the summer than in the winter and the oscillations commence at a later hour of the day in the summer.

The A_p figures for the period November 1954 to February 1957 are given in Fig. 13 to 16. The relation of the magnitude of the C oscillations to the A_p figure of the days on which they occur is illustrated briefly in the following *Table 2.*

These figures exhibit a very clear positive correlation between the magnitude of the C oscillations and the average A_p figure.

In studying the period pattern of C oscillations some difficulties arise from the fact that a number of the individual events have a wide period band. A more elaborate spectral analysis would be necessary in these cases.

However, in the present introductory study it is considered permissible to base the analysis on those events only that have a relatively narrow period band. A maximum band width of 40% has been selected. This leads to the rejection of about 100 C events out of a total of 450.

The period range 10 to 40 sec will be divided into the 4 subranges given in *Table 3*. The number of days with C oscillations in each range has been counted and the average A_p figures for the days of each range computed. These data are given in *Table 3.*

Due to the clear annual variation of the period the data in *Table 3* are given for the intervals between the equinoxes and also for the whole recording period.

A few C events have a period range which is divided equally between two of the subranges (a) to (d). Such events are counted as ½ event on each side. Hence the ½ values of the number of days.

The data given in *Table 3* show a clear and significant statistical correlation between the

TABLE 2

Average A_p figures for different magnitudes of C oscillations observed in California.

	Magnitude 0	I	II	III	IV
Nov. 1. 54 to Dec. 31. 55					
Number of days	323	60	36	6	1
Average A_p (2γ)	8.5	11.8	17.8	32.3	62.5
Jan. 1. 56 to Feb. 28. 57					
Number of days	77	133	127	72	15
Average A_p	12.3	11.8	17.0	23.0	62.5
Nov. 1. 54 to Feb. 28. 57					
Number of days	400	193	163	78	16
Average A_p	9.3	11.8	17.3	23.7	62.5

TABLE 3

Average A_p figures for different subranges of the period of C oscillations observed in California.

	Period subrange			
	(a)	(b)	(c)	(d)
Range in sec	10–14	14–20	20–28	28–40
Nov. 1. 54 to March 21. 55				
Average period 15 sec				
Number of days	1	2		
Average A_p (2γ)	43	17		
March 22. 55 to Sept. 21. 55				
Average period 18 sec				
Number of days	7½	20½	3	3
Average A_p	25	16.1	26	13
Sept. 22. 55 to March 21. 56				
Average period 24 sec				
Number of days	10	21	35½	23½
Average A_p	20.5	17.8	12.2	6.9
March 22. 56 to Sept. 21. 56				
Average period 20 sec				
Number of days	4	81½	40½	7
Average A_p	34	17.5	16.3	9.5
Sept. 22. 56 to Feb. 28. 57				
Average period 23 sec				
Number of days	2	22½	59½	6
Average A_p	18.5	19.9	16.3	7.1
Nov. 1. 54 to Feb. 28. 57				
Average period 22 sec				
Number of days	24½	147½	138½	39½
Average A_p	24.8	17.8	15.4	7.9

TABLE 4

Number of days for a given magnitude and period subrange of C oscillations observed in California during the period Nov. 1. 54 to Feb. 28. 57

	Period subrange				
	(a)	(b)	(c)	(d)	Sum
Range in sec	10–14	14–20	20–28	28–40	
Magnitude I	4	61½	64	35½	165
II	11½	61	46½	4	123
III	9	25	26	–	60
IV	–	–	2	–	2
Sum	24½	147½	138½	39½	

period and the A_p number. The longer periods are associated with lower A_p figures.

The number of days having C events of a given magnitude and period subrange is given in *Table 4*. The same numbers are given in a more condensed form in *Table 5*. These data indicate no correlation between the magnitude and the period of C oscillations.

TABLE 5

Table 4 condensed

	Subranges (a) + (b)	(c) + (d)
Magnitudes I + II	138	150
III + IV	34	28

A comparison of records from Haiwee and Palomar reveals that the oscillations are almost identical at both stations. However, there are occasional small deviations.

No numerical data will be given on the correlation of C oscillations with ionospheric data from the station at Palo Alto, California. The C events appear to coincide more or less with the high values of f_0F2 (critical frequency of the F-layer) during the day.

SUMMARY OF MAIN DATA ON TYPE C OSCILLATIONS OBSERVED IN CALIFORNIA

(1) *Field amplitude:* Up to 20 microgauss. Magnitude scale based on the maximum record amplitude, that is, on the maximum amplitude of the north-south component of dH/dt.

(2) *Period:* 10 to 40 sec. Individual C events may include a wide period band where, in cases, two periods with a ratio of 1 : 2 are prominent.

(3) *Character:* Sinusoidal or quasi-sinusoidal oscillations with a less regular beating of a period of few minutes.

(4) *Period-magnitude relation:* No correlation.

(5) *Diurnal pattern:* Occur during the day. Duration 5 to 15 hours.

(6) *Annual pattern:* C activity highest at the equinoxes. Higher in the summer than in the winter. Commence at a later hour of the day in the summer. Period shorter in the summer.

(7) *Relation of distant recording stations:* In few cases slight transitory differences between the Palomar and the Haiwee records.

(8) *Relation to events on slow-run magnetograms:* Strong positive correlation between the A_p figure and the magnitude of C oscillations. Longer periods associated with lower A_p figures.

(9) *Relation to solar cycle:* C activity increases with increasing solar activity.

(10) *Relation to ionosphere conditions:* No definite results but positive correlation of the C activity with f_0F2 probable.

(11) *Relation to DP, DI and R. oscillations:* C events on days of high magnetic activity include large DP oscillations. Association with R oscillations very rare.

OBSERVATIONAL DATA ON TYPE DP AND DI OSCILLATIONS

The magnitude of DP and DI oscillations is given in the same scale as used for C oscillations. The data on the magnitude, period and timing are given in Fig. 7 to 10. A moderately regular DP event is shown in Fig. 2.

Generally, the DP oscillations consist of ½ to a few full waves of a fairly sinusoidal character. In the majority of cases the amplitude decreases with time and the wave train resembles the typical response of a damped linear oscillator to a transient excitation. The integration of the recorded dH/dt reveals that the oscillation is associated with sudden change of the strength of the magnetic field.

The correlation of the magnitude of the DP oscillations with the A_p number is given in *Table 6*.

Table 6 does not reveal a clear trend. During the period Nov. 1, 1954 to December 31, 1955 the DP events appear to occur on days having slightly higher than average A_p figures. The trend is different in the period January 1, 1956 to February 28, 1957, and the average A_p for all days of DP events during the entire recording period is much the same as the figure for days of no DP events.

The correlation of the period of the DP oscillations to the A_p figure is given in *Table 7*.

No clear trend is revealed by the figures in *Table 7*.

TABLE 6

Average A_p figures for different magnitudes of DP oscillations observed in California.

	Magnitude 0	I	II	III	IV	(I to IV)
Nov. 1. 54 to Dec. 31. 55						
Number of days	385	12	20	9	–	41
Average A_p (2γ)	10.4	12.1	11.8	15.0		12.7
Jan. 1. 56 to Feb. 28. 57						
Number of days	403	2	12	6	1	21
Average A_p	17.9	7.5	15.8	25.1	27	18.1
Nov. 1. 54 to Feb. 28. 57						
Number of days	788	14	32	15	1	62
Average A_p	14.3	11.5	13.3	19.3	27	14.6

TABLE 7

Average A_p figures for different subranges of the period of DP oscillations observed in California.

Period subrange Range in sec	< 30	30 – 50	50 – 80	> 80
Nov. 1. 54 to Feb. 28. 57				
Number of days	5	19½	30½	5
Average A_p (2γ)	13.4	15.7	13.8	33.8

TABLE 8

Average A_p figures for different magnitudes of DI oscillations observed in California.

	Magnitude 0	I	II	III	IV
Nov. 1. 54 to Dec. 31. 55					
Number of days	403	16	5	1	1
Average A_p (2γ)	10.0	7.5	13.5	32.5	62.5
Jan. 1. 56 to Feb. 28. 57					
Number of days	272	45	79	21	7
Average A_p	12.8	17.0	25.5	33.7	46.7
Nov. 1. 54 to Feb. 28. 57					
Number of days	675	61	84	22	8
Average A_p	11.2	14.5	24.7	33.7	48.7

The majority of the DP oscillations appears to coincide with sudden commencements and magnetic bays recorded on the slow-run magnetograms from Tucson, Arizona.

The DI oscillations are characterized by an irregular character and a longer duration than the DP oscillations. No period can be defined. The relation between the magnitude of DI events and the A_p figure is given in *Table 8*.

Table 8 reveals a clear positive correlation between the magnitude of DI events and the A_p figure.

A great number of the DI events may coincide with sudden changes of the field recorded on slow-run magnetograms. However, the relation is obscured by the circumstances that the DI events occur preferably on disturbed days where the slow-run magnetograms are quite irregular.

No results were obtained as to a correlation of the DP and DI events with ionospheric conditions.

OBSERVATIONAL DATA ON TYPE A OSCILLATIONS

In the case of A oscillations it is found more suitable to apply the computed maximum amplitude of the observed field component as the basis for the magnitude scale. The A oscillations are generally of a very regular sinusoidal character and the computation of the field amplitude is, therefore, quite accurate.

The magnitude scale applied is based on the sensitivity of the Palomar recorder and is as follows:

TABLE 9

Magnitude scale for A oscillations.

Maximum amplitude of the north-south field component	Magnitude
0.010 – 0.023 microgauss	I
0.024 – 0.053	II
0.054 – 0.122	III
0.123 – 0.280	IV

A list of all reliable observations of A oscillations observed in California during the period November 1, 1954 to February 28, 1957 is given in *Table 17* where the time of occurrence, record amplitude, period range and the computed magnitude are listed. The list comprises 80 events which occur on 69 days. The data are plotted in Fig. 11 and 12.

Most of the A oscillations exhibit a pronounced beating with periods 50 to 100 sec.

The number of A events and the average period during the interval between equinoxes is given in the following *Table 10*.

The period of A oscillations may have a tendency to be shorter during the summer than during the winter. The relation is, however, somewhat obscure and further data are needed before conclusions can be drawn.

The total number of observed A events is comparetively small. Therefore, in correlating the magnitude and period to the A_p figure only the total recording period from November 1, 1954 to February 28, 1957 will be considered.

The relation between the magnitude and the A_p figure is illustrated in *Table 11*.

Due to the fact that the magnitude groups

TABLE 10

Number of A events observed in California and the average period during intervals between equinoxes.

Interval	Number	Average period
November 1. 54 to March 21. 55	15	1.15 sec
March 22. 55 to September 21. 55	35	1.30
September 22. 55 to March 21. 56	11	1.55
March 22. 56 to September 21. 56	17	1.10
September 22. 56 to February 28. 57	2	1.15
	Sum 80	Average 1.25

I and IV contain only few events *Table 11* may be condensed as shown in *Table 12.*

The relation of the period of A oscillations to the A_p figure is illustrated in *Tables 13* and *14*. The observed period range of the A oscillations of 0.5 to 2.5 sec is divided into 4 subranges in *Table 13* and into two subranges in *Table 14.*

Finally the results of *Table 12* and *Table 14* may be rearranged in the following way in

TABLE 11

Average A_p figures for different magnitudes of A oscillations observed in California.

	Magnitude 0	I	II	III	IV
Nov. 1. 54 to Feb. 28. 57					
Number of days or events	781 d	13 ev	48 ev	14 ev	5 ev
Average A_p (2γ)	14.9	10.9	9.9	12.0	8.4

TABLE 12

Table 11 condensed.

	Magnitude 0	I + II	III + IV
Nov. 1. 54 to Feb. 28. 57			
Number of days or events	781 d	61 ev	19 ev
Average A_p (2γ)	14.9	10.1	11.1

TABLE 13

Average A_p figures for different subranges of the period of A oscillations observed in California.

	Period subrange (a)	(b)	(c)	(d)
Range in sec	0.5—0.8	0.8—1.2	1.2—1.8	1.8—2.7
Nov. 1. 54 to Feb. 28. 57				
Number of events	12	30	31	7
Average A_p (2γ)	16.1	9.7	9.2	8.2

TABLE 14

Table 13 condensed.

	Period subrange (a) + (b)	(c) + (d)
Range in sec	0.5 – 1.2	1.2 – 2.7
Nov. 1. 54 to Feb. 28. 57		
Number of events	42	38
Average A_p	11.4	9.0

Table 15 in order to illustrate a possible correlation between the period and the magnitude.

TABLE 15

Number of A events observed in California grouped with regard to period and magnitude.

	Magnitude I + II	Magnitude III + IV
Perod range (a) + (b)	29	8
(c) + (d)	32	11

The data given in the *Tables 10* to *15* indicate the following relations:

(1) The A oscillations occur definitely on days of lower than average A_p figure, that is, on days of low magnetic activity.

(2) On the other hand, the average A_p for the larger magnitude of the A events is slightly higher than for the smaller magnitudes. However, the difference is so small that it may be insignificant.

(3) The longer periods are associated with slightly lower A_p figures than the shorter periods.

(4) Period and magnitude appear uncorrelated.

There is no obvious correlation between the A oscillations and the events observed on slow-run magnetograms. However, the following observations may be mentioned.

There are 80 A events in the interval November 1, 1954 to February 28, 1957 occurring on 69 days and within an interval of 10 hours of the day.

On the slow-run magnetograms from Tucson, Arizona, there are on the same days and hours a total of 216 events that may be classified as the commencements of magnetic bays.

A total of 14 A events commence approximately simultaneously with the commencements of the bays. Moreover, 14 additional A events appear to have some relation with magnetic bays. A relevant fact is that magnetic bays have a similar preference for days of low magnetic activity as the A oscillations.

At this juncture it is difficult to evaluate the significance of the above observation. Further data are needed.

There may also be a slight tendency of the A oscillations to occur 5 to 10 days after a magnetically disturbed period.

An attempt was made to correlate A oscillations with ionospheric data. Only very incomplete results were obtained. The A oscillations appear to occur preferably simultaneously with the minimum of the f_oF2, that is, the minimum of the spatial maximum electron concentration in the F2 layer of the ionosphere.

SUMMARY OF MAIN DATA ON TYPE A OSCILLATIONS OBSERVED IN CALIFORNIA

(1) *Field amplitude:* Up to 0.3 microgauss. Magnitude scale based on the maximum amplitude of north-south component of the magnetic field.

(2) *Period:* 0.5 to 2.5 sec. Period band of individual events relatively stable and narrow.

(3) *Character:* Sinusoidal oscillations with fairly regular beating of a period 50 to 100 sec.

(4) *Period-magnitude relation:* No correlation.

(5) *Diurnal pattern:* Occur during the night or in the very early morning. Duration ½ to 5 hours.

(6) *Annual pattern:* Frequency of occurrence higher in the summer. Commence at an earlier hour of the day in the summer. Period may possibly be shorter in the summer.

(7) *Relation of distant recording stations:* No differences observed.

(8) *Relation to events on slow-run magnetograms:* Occur on days of a relatively low A_p figure. Larger magnitudes associated with slightly larger A_p averages. Longer periods associated with lower A_p averages. In cases the A events appear to coincide with magnetic bays on the Tucson slow-run magnetograms. The A events may possibly have a tendency to occur 5 to 10 days after a magnetically disturbed period.

(9) *Relation to solar cycle:* Frequency of occurence decreases greatly with the increasing solar activity.

(10) *Relation to ionosphere conditions:* Occur preferably at the time of lowest f_oF2.

(11) *Relation to C, DP and DI oscillations:* No relation.

TABLE 17

Data on A oscillations observed in California Nov. 1. 54 to Feb. 28. 57.

Time given as Pacific Standard Time.

F = Flintridge T = Tinemaha
P = Palomar H = Haiwee
MW = Mount Wilson I = Isabella

Date		Begin End	Duration (h–m)	Record ampl. (mm)	Period (sec)	Field ampl. microgauss	Reference station	Other stations	Magnitude
1954									
Nov.	27	02–53							
		03–15	0–22	0.15	1.2	[1]	F	–	II
1955									
Jan.	19	19–23							
		22–00	2–37	0.25	(1.0–1.5)[2]		F	–	III
–	21	02–00							
		02–30	0–30	0.10	1.0		F	–	II
–	23	04–00							
		08–30	4–30	0.15	(0.8–0.9		F	–	II
–	26	05–30							
		06–30	1–00	0.10	0.6		F	–	III
–	27	03–50							
		04–20	0–30	0.15	(1.0–1.2)		F	–	II
–	28	23–20							
		00–53	1–33	0.15	(1.5–1.1)		F	–	II
–	–	03–40							
		05–30	1–50	0.20	1.1		F	–	II
–	–	06–59							
		07–10	0–11	0.15	1.2		F	–	II
–	30	03–00							
		05–00	2–0	0.15	(1.3–1.5)		F	–	II
Feb.	18	03–15							
		03–30	0–15	0.10	1.6		F	–	II
Mar.	5	03–30							
		05–45	2–15	0.15	(1.2–1.5)		F	–	II
–	11	22–45							
		23–30	0–45	0.10	0.9		F	–	II
–	13	04–00							
		05–30	1–30	0.10	(1.0–0.7)		F	–	II
–	21	03–30							
		04–30	1–00	0.15	1.2		F	–	II

1) Field amplitude at Flintridge not accurately known. Therefore magnitude given only.
2) Parenthesis indicate uncertainty.

Date		Begin End	Duration (h–m)	Record ampl. (mm)	Period (sec)	Field ampl. microgauss	Reference station	Other stations	Magni- tude
—	22	01—00 (mainly: 01—35 to 01—45)							
		02—00	1—00	0.30	(1.1—1.2)		F	—	III
—	30	04—45							
		05—45	1—00	0.15	1.2		F	—	II
Apr.	6	00—48							
		01—30	0—42	0.15	1.1		F	—	II
—	8	01—52 (mainly: 02—00 to 02—15)							
		05—00	3—08	0.10	(1.1—1.2)		F	—	II
—	–	22—15							
—	9	01—30	3—15	0.10	1.5		F	—	II
—	–	02—00							
		03—00	1—00	0.10	1.1		F	—	II
—	14	04—00							
		04—45	0—45	0.20	(1.0—1.1)		F	—	III
—	22	03—15							
		04—25	1—10	0.25	(1.3—1.5)		F	—	III
—	29	00—00							
		00—30	0—30	0.05	0.8		F	—	I
May	1	04—00							
		04—30	0—30	0.10	1.2		F	—	II
—	–	10—15							
		10—35	0—20	0.10	1.2		F	—	II
—	3	04—00							
		04—45	0—45	0.10	1.8		F	—	II
—	5	01—30							
		02—45	1—15	0.40	(0.7—1.3)		F	—	IV
—	10	23—15							
		23—45	0—30	0.05	1.3		F	—	I
—	11	03—00							
		04—15	1—15	0.10	1.1		F	—	II
—	13	01—30							
		05—30	4—0	0.20	(1.0—1.4)		F	—	III
—	31	00—00							
		04—00	4—00	0.50	(1.0—1.5)		F	—	IV
June	1	01—00							
		02—00	1—00	0.10	1.2		F	—	II
—	2	00—00							
		00—15	0—15	0.10	1.6		F	—	II
—	–	02—00							
		02—45	0—45	0.40	(1.1—1.3—1.4)		F	—	IV
—	–	at							
		03—15	—	0.05	0.6		F	—	II

Date		Begin End	Duration (h–m)	Record ampl. (mm)	Period (sec)	Field ampl. microgauss	Reference station	Other stations	Magnitude
—	3	22—45 24—00	1—15	0.10	(1.6—1.8)		F	—	II
—	4	03—00 04—00	1—00	0.05	0.8		F	—	I
—	11	01—00 03—00	2—00	0.15	(1.4—1.6—1.2)		F	—	II
—	22	19—08 20—00	0—52	0.35	(1.3—1.5)		F	—	III
—	23	04—10 05—25	1—15	0.10	(0.9—1.1)		F	—	II
July	4	00—00 00—45	0—45	0.10	(1.4—1.5)		F	—	II
—	21	17—35 18—45	1—10	0.30	2.1		F	on P	III
Aug.	9	00—00 04—00	4—00	0.20	(1.6—1.3)		F	P+[1])	III
—	13	02—03 02—18	0—15	0.10	1.3	0.025	P	Fl+	II
—	—	19—15 20—50	1—35	0.10	1.4	0.026	P	Fl+	II
—	—	20—55 21—45	0—50	0.10	2.4	0.035	P	Fl+	II
—	19	02—10 02—40	0—30	0.10	(1.1—1.3)		F	P+	II
—	21	02—30 03—40	1—10	0.15	(1.3—1.4)		F	P+ P Fl	II
Sept.	20	03—23 04—50	1—27	1.00	(1.2—1.4)	0.258	P	Fl P	IV
—	22	02—30 04—00	1—30	0.10	1.5	0.026	P	Fl+	II
—	26	23—30 24—15	0—45	0.05	1.5	0.013	P	Fl	I
—	29	20—53 21—40	0—47	0.05	1.9	0.015	P	—	I
Okt.	16	04—15 04—45 and 07—00	0—30	0.05	2.5	0.018	P	Fl+	I
—	28	00—30 00—45	0—15	0.05	1.1	0.012	P	Fl+	I

1) The + sign indicates that the event has been observed, — sign that it has not been observed.

Date		Begin End	Duration (h–m)	Record ampl. (mm)	Period (sec)	Field ampl. microgauss	Reference station	Other stations	Magni- tude
Nov.	1	23–18							
–	2	01–30	2–12	0.20	(1.2–1.9)	0.059	P	Fl+ MW+	III
–	24	04–00							
		07–00	3–00	0.05	(0.8–1.0)	0.012	P	Fl– MW	I
–	28	23–35							
–	29	00–30	0–55	0.15	(1.4–1.6)	0.042	P	Fl– MW+	II
1956									
Feb.	7	02–15							
		02–40	0–25	0.05	1.5	0.013	P	Fl+	I
–	9	04–45							
		05–15	0–30	0.05	2.5	0.018	P	T > P[1])	I
Mar.	19	23–43							
–	20	00–17	0–34	0.40	(0.6–0.8)	0.102	P	H+ Fl+ P < T	III
Apr.	28	At unknown time one train (1.5–1.8) sec sine waves							
May	12	03–50							
		04–30	0–40	0.10	0.5	0.035	P	H+ Fl+	II
			Ampl. H = 0.25						
			Fl. = 0.25						
–	19	04–00							
		05–30	1–30	0.10	0.6	0.030	P	H+ Fl+	II
–	26	01–59							
		02–50	0–21	0.05	0.6	0.015	P	H– Fl+	I
			Ampl. Fl. = 0.10						
–	30	00–40							
		01–12	0–32	0.10	0.5	0.035	P	H– Fl+	II
June	26	18–00							
		20–15	2–15	0.05	(1.2–1.8)	0.014	P	H+	I
July	1	02–58							
		03–20	0–22	0.05	0.7	0.014	P	H+	I
–	2	03–32							
		04–42	1–10	0.1	0.7	0.027	P	H+	II
–	5	23–30							
–	6	00–45	1–15	0.40	(0.8–1.0)	0.099	P	H+ >	III
–	8	00–05							
		00–47	0–42	1.00	(1.3–1.5)	0.263	P	H+ >	IV
–	–	01–30							
		04–00	2–30	0.1	(1.0–1.1)	0.030	P	H+	II
–	–	04–00							
		05–30	1–30	0.1	2.1	0.031	P	H+	II

1) The signs T>P indicate that the event observed at Tinemaha has a greater amplitude than the event at Palomar.

Date		Begin End	Duration (h–m)	Record ampl. (mm)	Period (sec)	Field ampl. microgauss	Reference station	Other stations	Magni-tude
–	18	20–45							
		21–30	0–45	0.10	(1.0–1.1)	0.025	P	H damaged	II
Aug.	3	03–10							
		03–27	0–17	0.10	1.8	0.031	P	H+	II
–	5	00–25							
		00–48	0–23	0.30	(1.1–1.2)	0.075	P	H+ >	III
–	–	01–14							
		02–50	1–36	0.20	1.0	0.049	P	H+ >	II
–	–	04–05							
		04–40	0–35	0.15	(2.0–2.2)	0.049	P	H+ >	II
–	9	04–00							
		05–00	1–00	0.10	1.8	0.029	P	H+	II
1957									
Jan.	8	00–30							
		03–00	2–30	0.30	(1.5–1.7)	0.084	P	H+	III
Mar.	15	23–30							
–	16	04–00	4–30	0.20	0.8	0.051	P	H+ I+	II

Finally, it should be remarked that the A oscillations have a similar period range as the R oscillations which will be discussed below.

OBSERVATIONAL DATA ON TYPE R OSCILLATIONS

The observational data obtained on R oscillations are more meagre than the material in the case of the other types of oscillations. Therefore, only the following results will be given.

The R oscillations are sinusoidal or quasi-sinusoidal oscillations in the period range 0.5 to 3 sec occurring simultaneously with DP and DI oscillations and in rare cases also with C oscillations. The occurrence of R oscillations is marked on the Fig. 3 to 10 by a + sign at the period of the R oscillations.

In 1955 and 1956 there is a total of 62 R events associated with DP and DI oscillations. If the R oscillations are grouped into two groups according to whether the period is smaller or equal to 1.2 sec or larger the following average A_p figures are obtained for the days on which the oscillations occur.

TABLE 18

Average A_p figures for two subranges of the periods of R oscillations observed in California.

	Period $\leq$ 1.2 sec	> 1.2 sec
1955 and 1956		
Numer of events	31	31
Average A_p (2γ)	20.8	17.3

This is a similar pattern as observed in the case of the A oscillations.

A study of the sudden commencements and bays found on the Tucson magnetograms and which are associated with DP and DI oscillations reveals that there is a correlation between the magnitude of the Tucson events and the occurrence of R oscillations. The R oscillations are definitely associated with Tucson events of relatively large magnitude.

OBSERVATIONS IN REYKJAVIK

The magnetic recorder in Reykjavik, Iceland, was installed in 1958 and has since been in operation. An examination of the Reykjavik records reveals that much the same types of oscillations are observed there as in California.

However, some characteristics of the events are strikingly different. This is mainly due to the very disturbed conditions in the auroral zone, but Reykjavik is located within the most active part of this zone.

The Reykjavik records are generally very disturbed, and the level of disturbance does not exhibit a clear diurnal variation as generally observed in California. Relatively irregular C oscillations and very irregular DI trains may occur at any time of the day.

In general the amplitude of C and DI oscillations is one order of magnitude larger in Reykjavik than in California. On disturbed days amplitudes up to several hundred microgauss may be observed.

It is interesting to note that Uppsala, Sweden, stands in a similar relation to Reykjavik as the California stations. The Uppsala records are much less disturbed than the Reykjavik records. It is significant that although the distance between Uppsala and Reykjavik is only about 2,000 km there is practically no detailed correlation between the records. The finer structures of the magnetic field in Reykjavik appear to be dominated by local sources.

Type A oscillations occur relatively frequently in Reykjavik. As in California their frequency increases with decreasing solar activity. They have been observed in Reykjavik nearly daily during the winter 1963. However, their diurnal pattern in Reykjavik differs significantly from California. In Reykjavik type A oscillations are mainly observed between 1000 and 1600 local time. On the other hand, their amplitudes and period are not significantly different from the recordings in California.

REFERENCES

Benioff, H.: Observations of Geomagnetic Fluctuations in the Period Range 0.3 to 120 Seconds. *Journal Geoph. Research, 65,* No. 5, 1413–1422, 1960.

Campbell, W. H. and Matsushita, S.: Auroral-Zone Geomagnetic Micropulsations with Periods of 5 to 30 Seconds. *Journal Geoph. Research, 67,* No. 2, 555–573, 1962.

Kato, Y. and Watanabe, T.: A Survey of Observational Knowledge of the Geomagnetic Pulsations. *Science Reports Tohoku University, Series V,* 1–29, 1957.

Troitskaya, V. A.: Pulsations of the Earth's Electromagnetic Field with Periods of 1 to 15 Seconds. *Journal Geoph. Research, 66,* No. 1, 5–18, 1961.

Westphal, K. O. and Jacobs, J. A.: Oscillations of the Earth's outer Atmosphere and Micropulsations. *Geophys. Journal, 6,* No. 3, 360–376, 1962.

DIAGRAMS

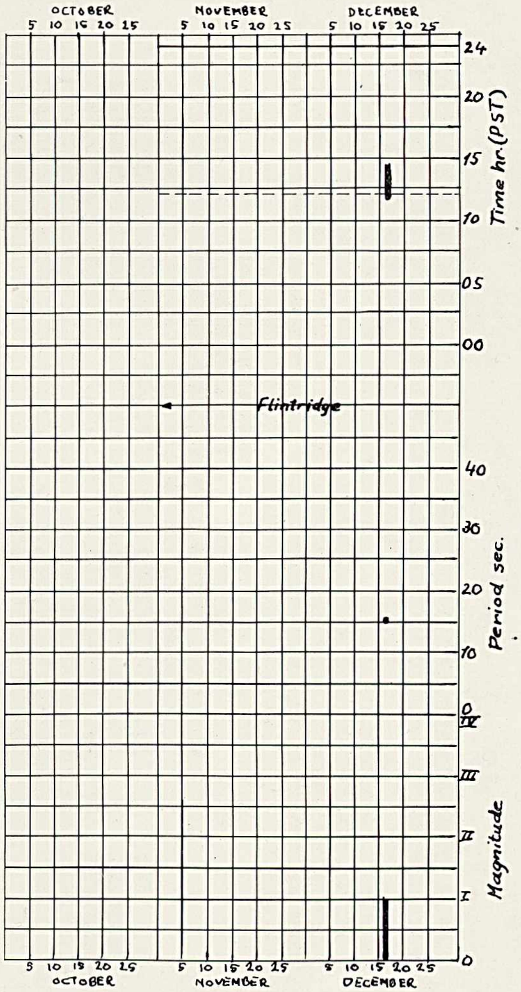

Fig. 3. Observational data on type C oscillations observed in California in 1954. The time of occurence is given as Pacific Standard Time in the upper part of the figure. The period range is given in the middle part, and the magnitude in the lower part. The reference station is indicated above the period section. Figures 3 to 12 are all built up in the same way.

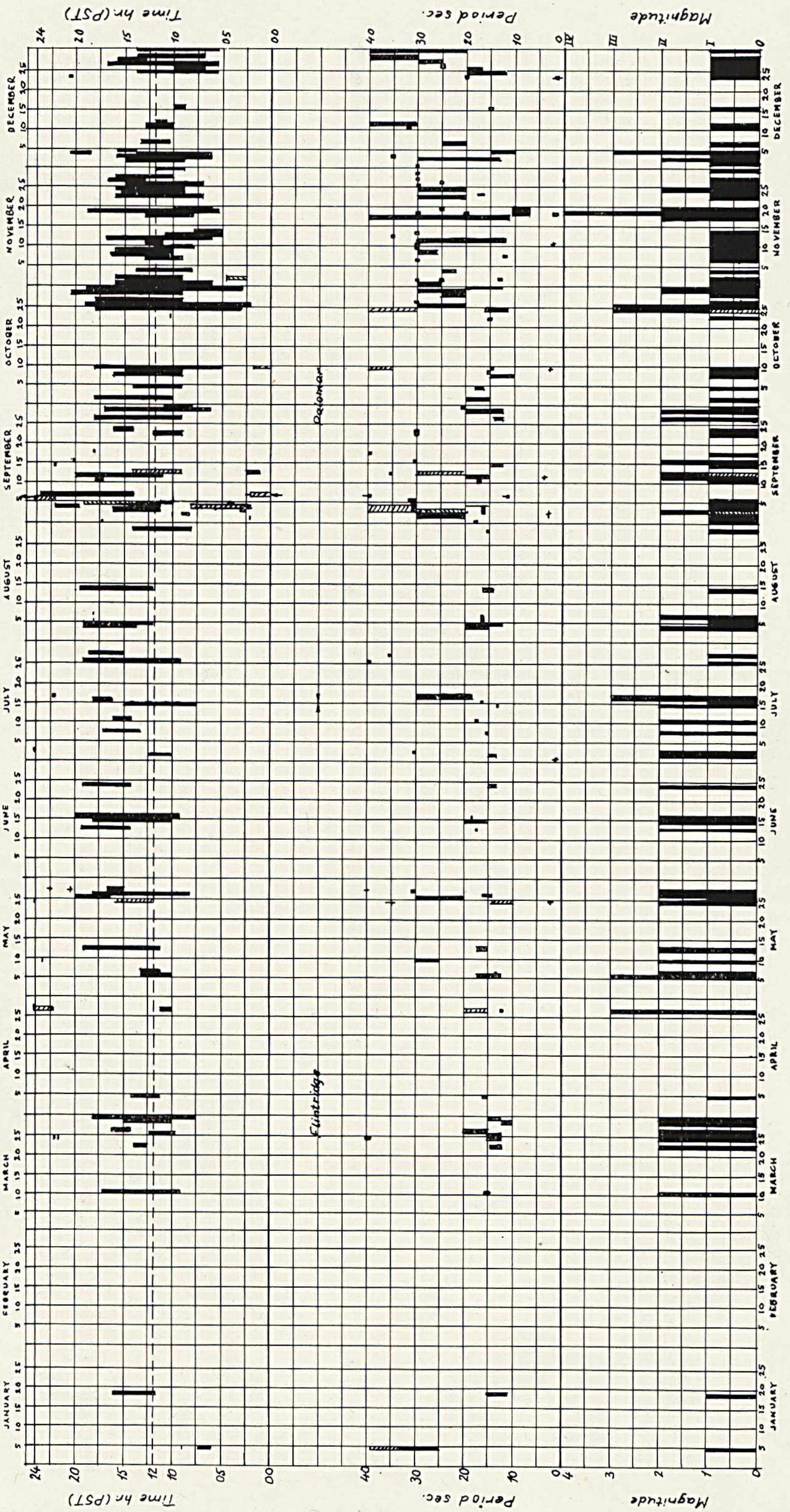

Fig. 4. Observational data on type C oscillations observed in California in 1955.

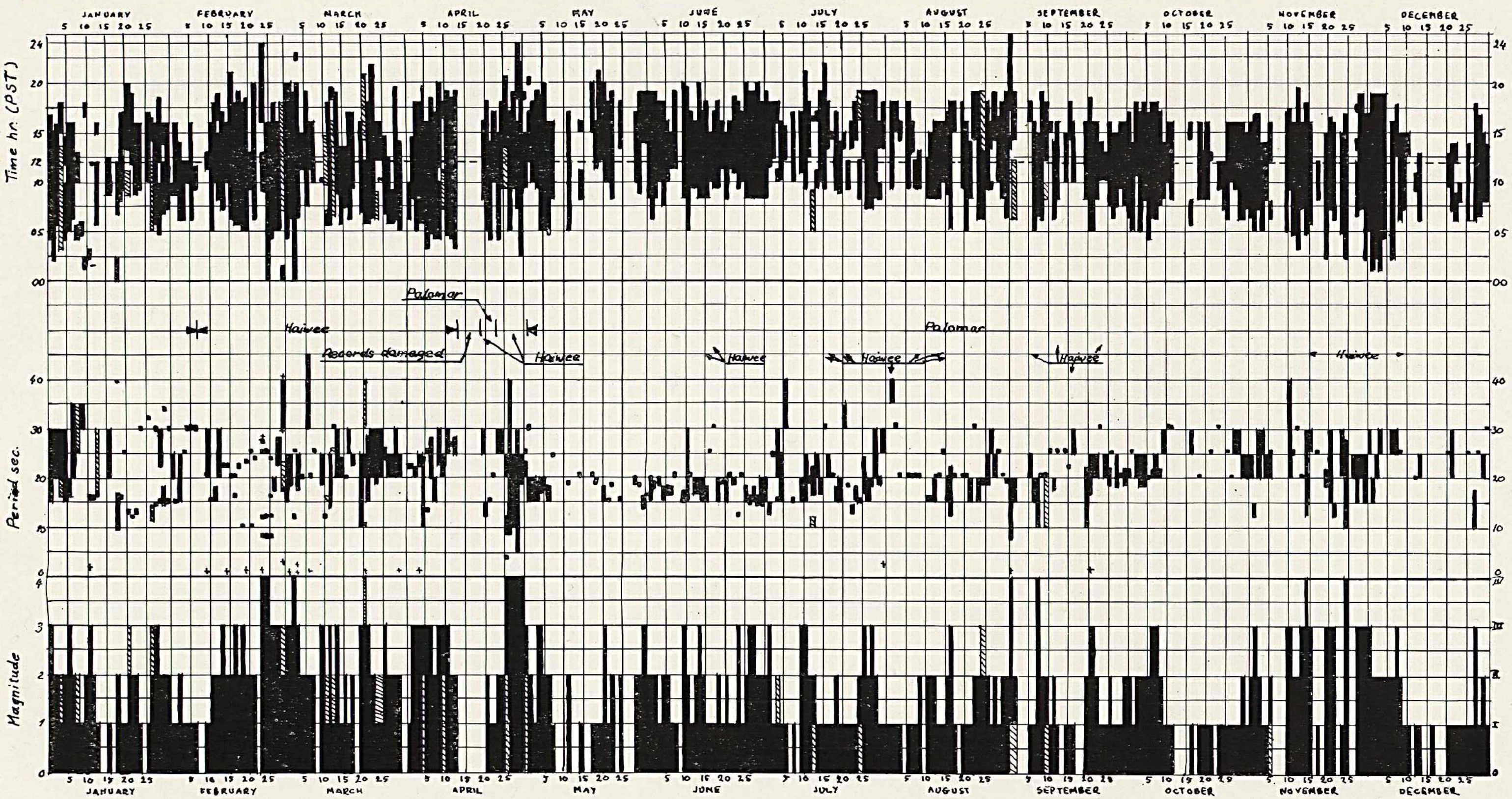

Fig. 5. Observational data on type C oscillations observed in California in 1956.
The sign + given in the period part of the figure indicates R oscillations.

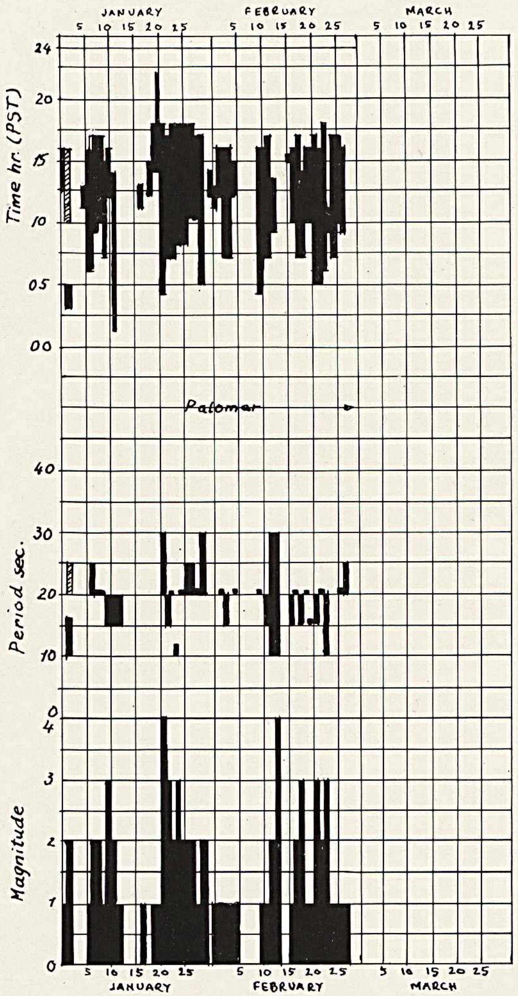

Fig. 6. Observational data on type C oscillations observed in California in 1957.

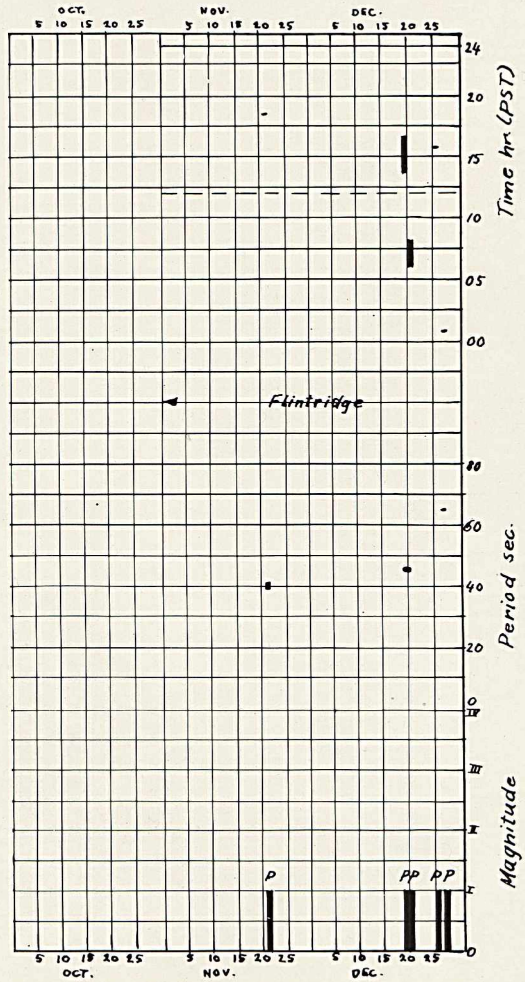

Fig. 7. Observational data on type DP and DI oscillations observed in California in 1954.

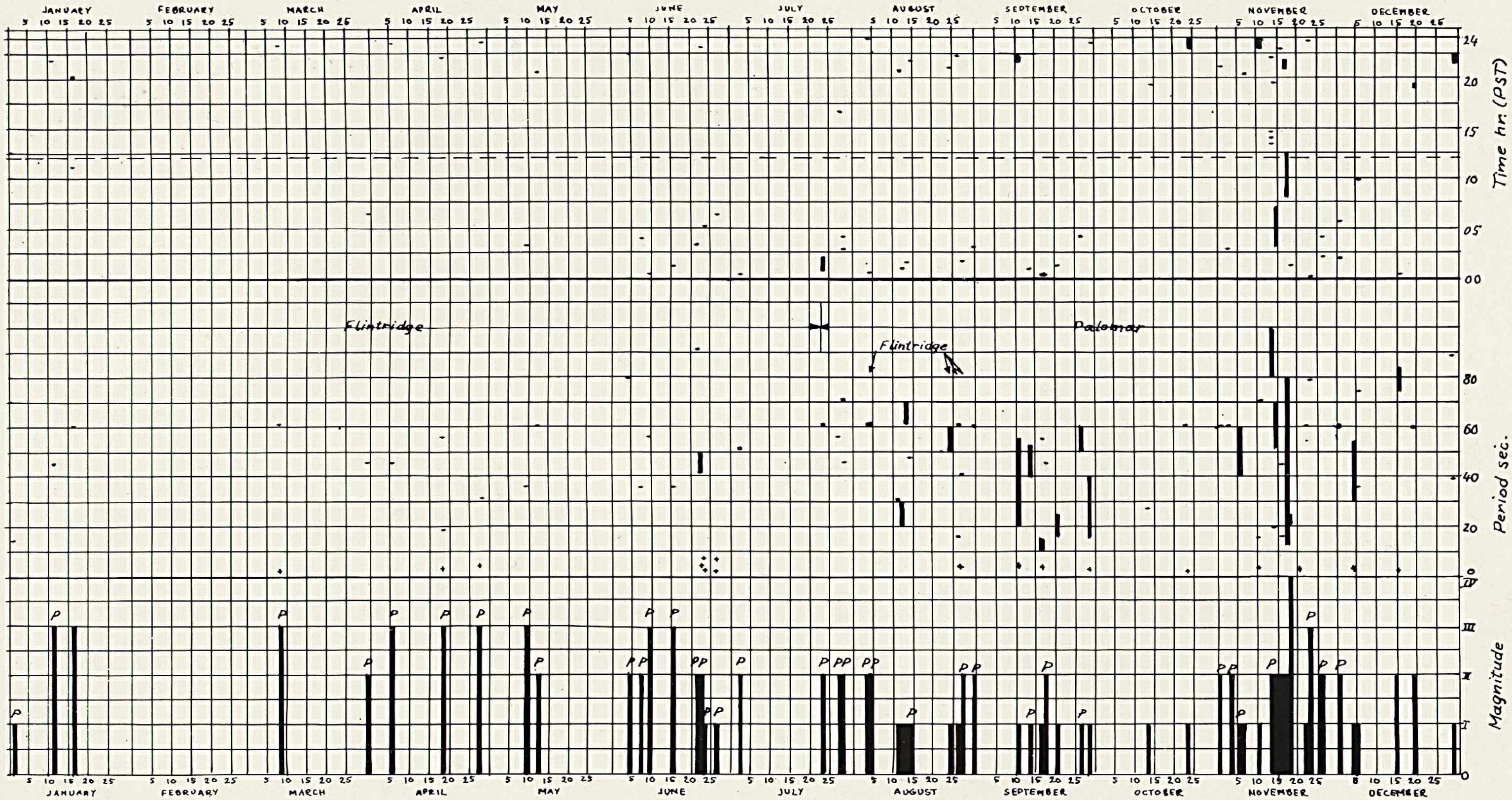

Fig. 8. Observational data on type DP and DI oscillations observed in California in 1955. The sign + given in the period part of the figure indicates R oscillations.

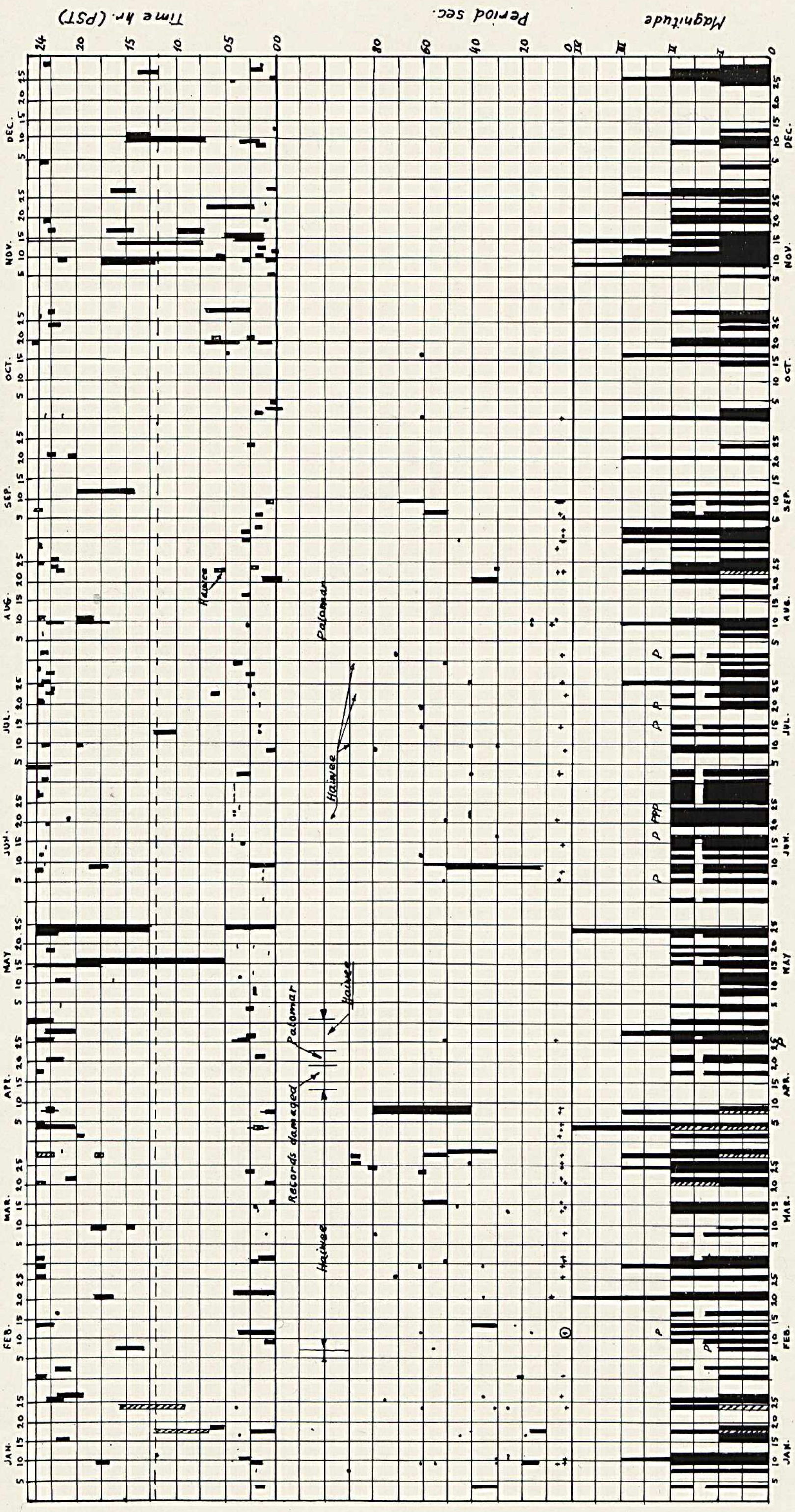

Fig. 9. Observational data on type DP and DI oscillations observed in California in 1956.
The sign + given in the period part of the figure indicates R oscillations.

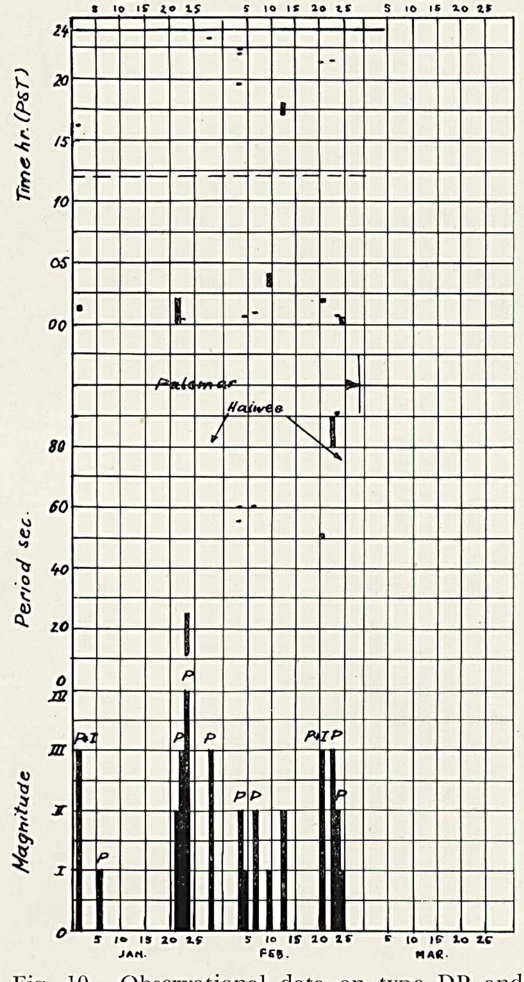

Fig. 10. Observational data on type DP and DI oscillations observed in California in 1957.

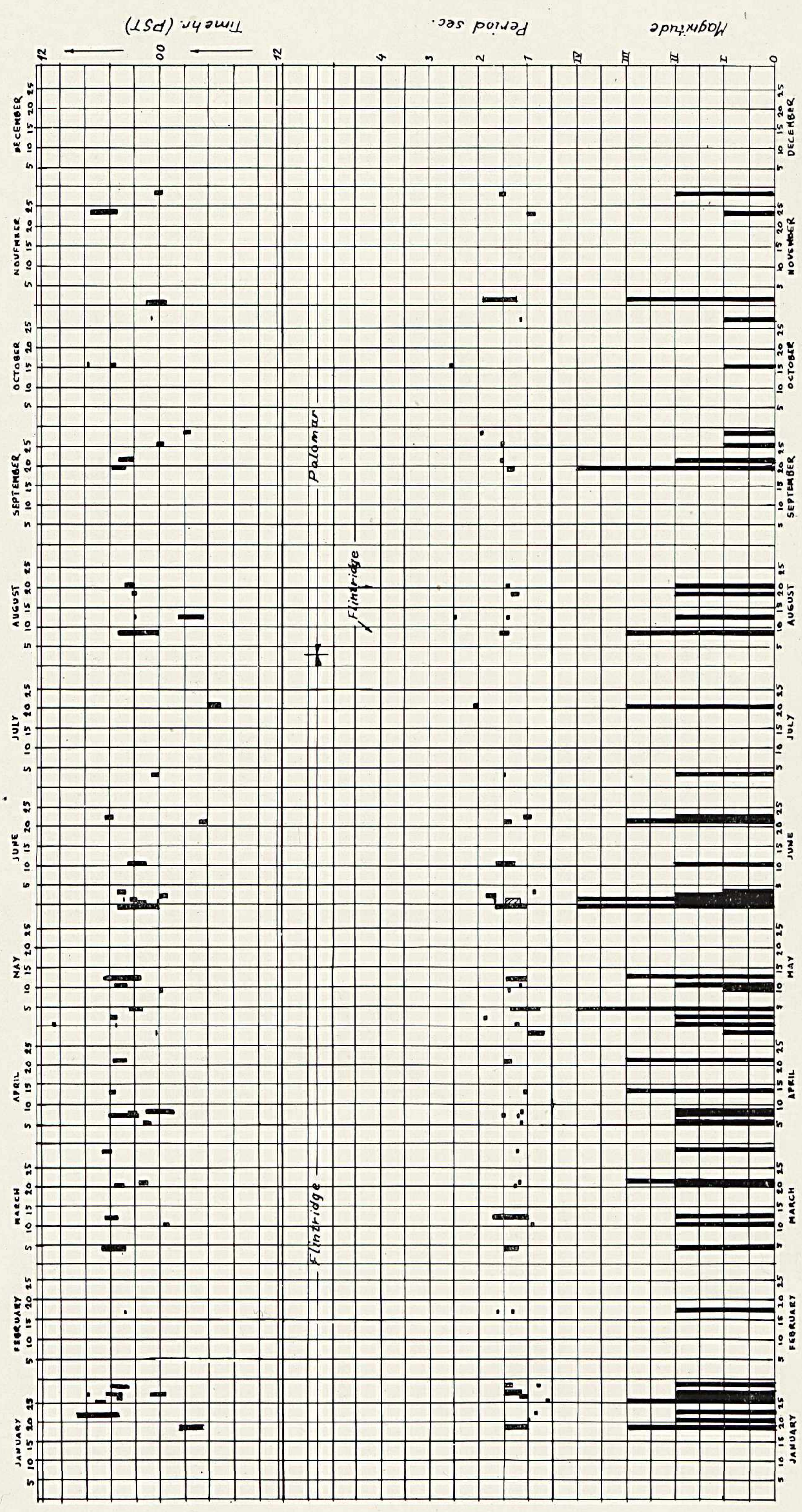

Fig. 11. Observational data on type A oscillations observed in California in 1955.

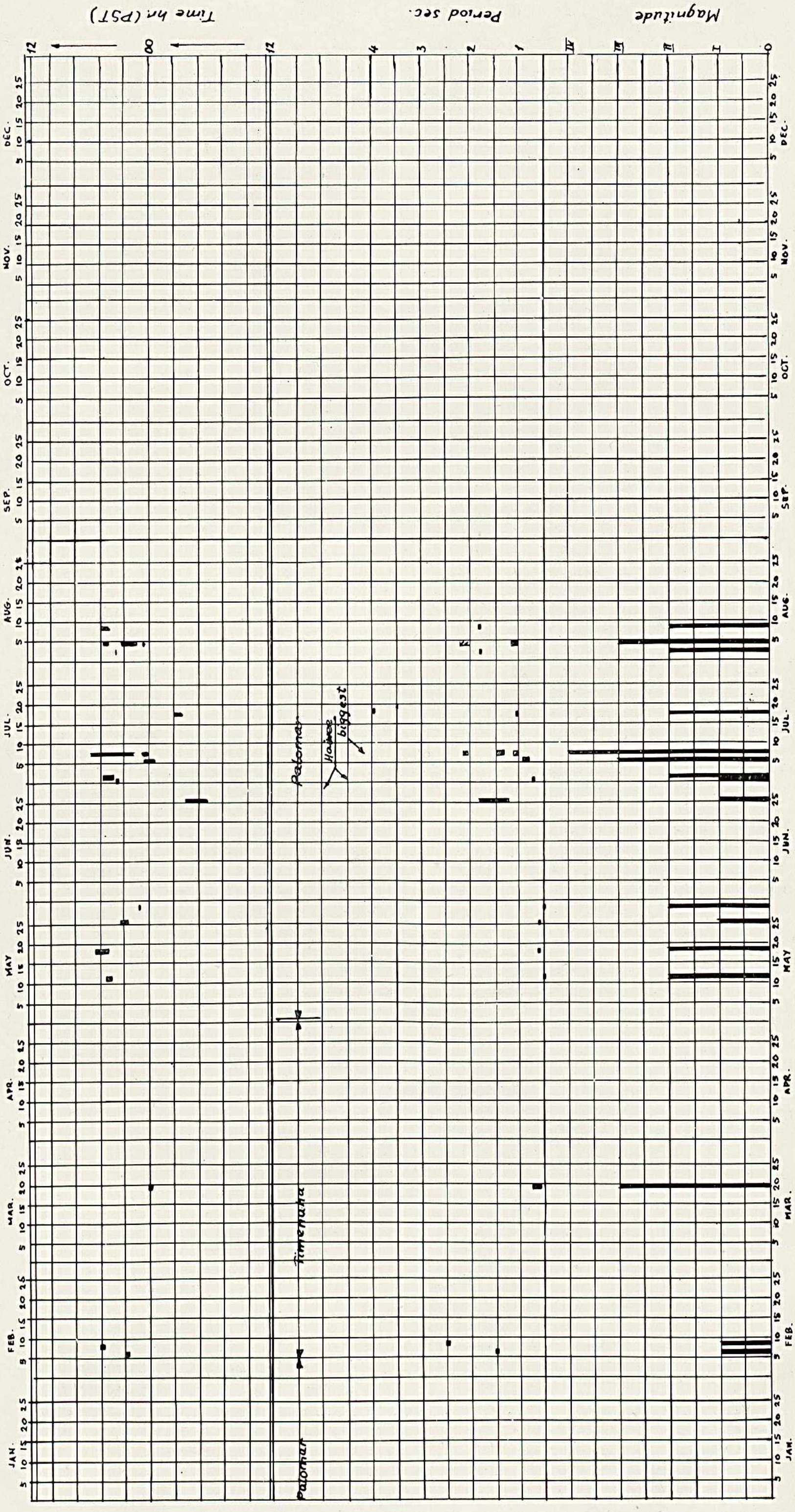

Fig. 12. Observational data on type A oscillations observed in California in 1956.

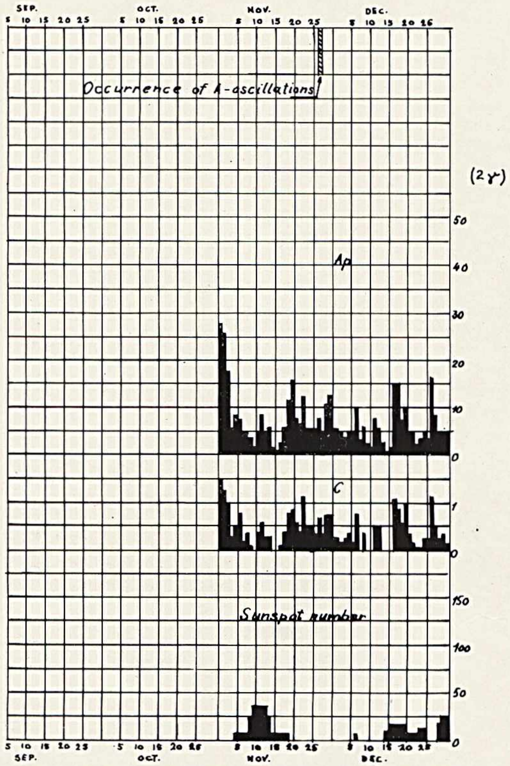

Fig. 13. Sunspot and A_p data for 1954.

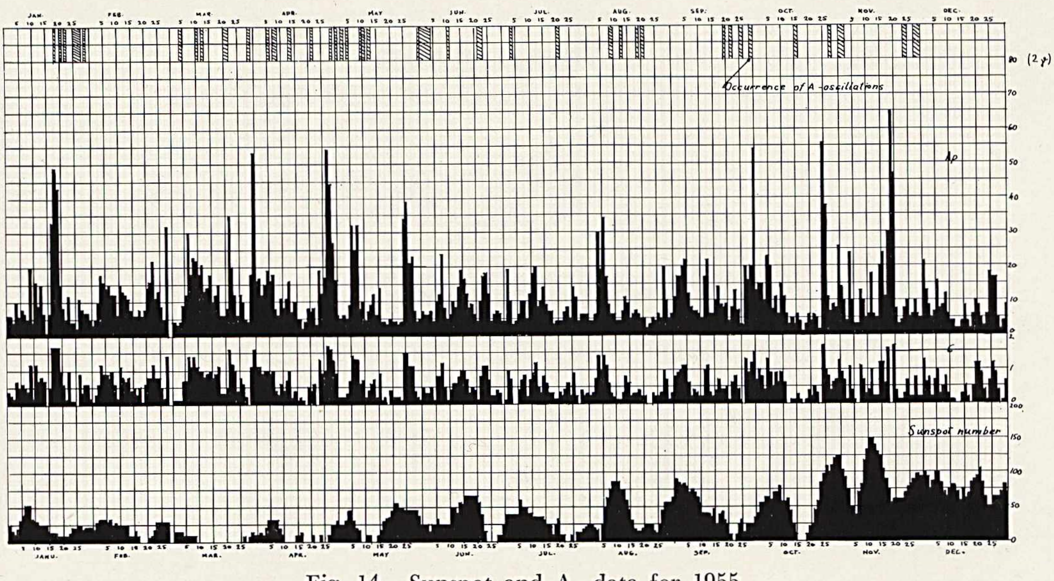

Fig. 14. Sunspot and A_p data for 1955.

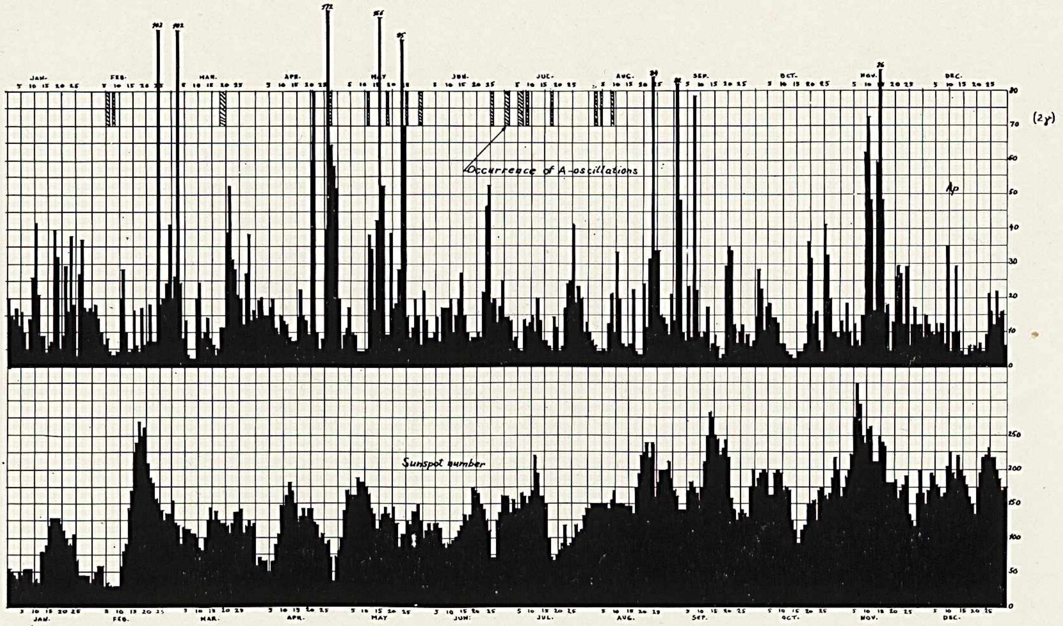

Fig. 15. Sunspot and A_p data for 1956.

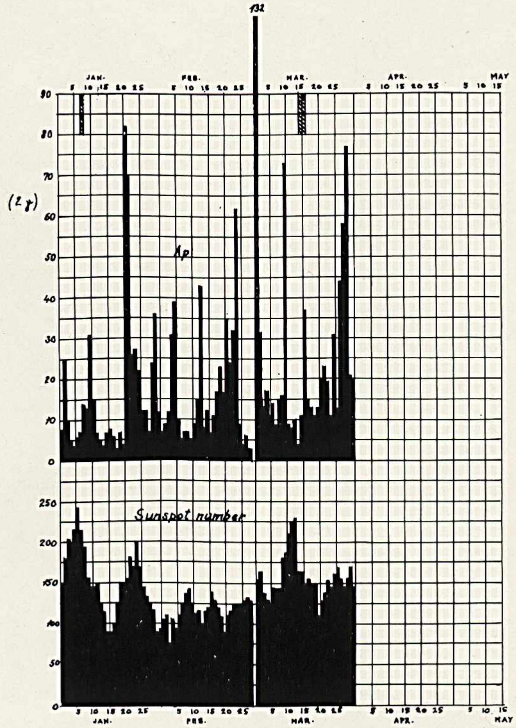

Fig. 16. Sunspot and A_p data for 1957.