Seismological Investigations.—Twentieth Report of the Committee, consisting of Professor H. H. TURNER (*Chairman*), Professor J. PERRY (*Secretary*), Mr. C. VERNON BOYS, Mr. HORACE DARWIN, Mr. C. DAVISON, Sir F. W. DYSON, Dr. R. T. GLAZEBROOK, Mr. M. H. GRAY, Professor J. W. JUDD, Professor C. G. KNOTT, Sir J. LARMOR, Professor R. MELDOLA, Mr. W. E. PLUMMER, Professor R. A. SAMPSON, Professor A. SCHUSTER, Mr. J. J. SHAW, Sir NAPIER SHAW, *and* Dr. G. W. WALKER.

[PLATES I., II., III., IV.]

CONTENTS.

I. *General Notes, Stations, and Registers.*

THE Committee asks to be reappointed with a grant of 60*l.* in addition to the annual grant of 100*l.* from the Caird Fund already voted.

The two years which have elapsed since the death of John Milne provide a sufficient experience for an approximate budget for carrying on the work he had organised, with such natural developments as are mentioned below and had already been initiated by him. The accounts for one year stand thus :

Receipts.				Expenditure.			
(1) Brit. Assoc. Annual Grant	.	£60	(A) Salaries	.	.	.	.	£240
(2) „ „ Printing	.	70	(B) Printing	.	.	.	.	80
(3) Gray Fund	.	40	(C) Rent	.	.	.	.	20
(4) Royal Society	.	200	(D) Shide Station	.	.	.	65
(5) Brit. Assoc. (Caird Fund)	.	100	(E) New machines, &c.	.	.	65
Total	. . .	£470					£470

On the receipts side the items are arranged in historical order. Item (1) dates practically from the appointment of the present Committee (as the fusion of two former Committees of the Association) in 1895 (Ipswich). The first grant to the Committee was 80*l.* Subsequent grants have fluctuated in amount, but the average annual grant in the twenty years 1895–1914 is almost exactly 60*l.*, which has been the uniform grant since 1908. When observing stations had been established over the globe

and it was desirable to print the information received from them in circulars for prompt distribution, the Association sanctioned additional expenditure on the printing of these circulars, which has in recent years been separately mentioned and has stood at the figure quoted—70l. This does not quite cover the cost of the modern bulletins.

Item No. (3) is the annual income from a sum of 1,000l. in Canadian Pacific 4% Stock, presented by Mr. M. H. Gray in aid of Milne's work.

Since some years before Milne's death, the Royal Society have provided, either from the Government Grant Fund or in some other way, an annual sum of 200l. in aid of the work. They have continued this grant during the past two years, but are in no way committed to its future continuance. On Milne's death the Council of the British Association decided to make an additional grant of 100l. annually from the Caird benefaction.

It will be seen that the available income is not only small but somewhat precarious. It is quite insufficient to pay the salary of a competent Director, which would in itself amount to more than the whole sum available. Moreover, items (1), (2), and (4) depend on decisions made from year to year by bodies which are not committed for their future continuance.

Assuming that continuance for the present, the work can be carried on as described below with voluntary superintendence.

For completeness it should perhaps be mentioned that a sum of 1,000l. will ultimately be available for seismological work in accordance with Milne's bequest.

On the expenditure side item (A) chiefly represents the salaries of three people who carry on the work at Shide, viz., Mr. J. H. Burgess (126l. a year), who was already working under Milne's direction. He has a printing business in Newport which claims a portion of his time; the rest he has given enthusiastically to seismology. It is practically owing to him that the continuity of the work remained unbroken by Milne's death. Mr. S. W. Pring (60l. a year) is also in business, but spends his evenings at the Observatory. His interest in the work began through his knowledge of Russian and other languages, which made his help valuable in translating seismological documents, especially the important pamphlets in Russian; but he has gradually made himself acquainted with the whole of the work, so that he can take charge of it on occasions when Mr. Burgess is unavoidably absent. His daughter, Miss K. Pring (36l. a year), gives practically all her time to the work during the day; she is chiefly occupied with the large amount of clerical work involved in copying the records received on to the cards, arranging the cards for the bulletins, proof reading, &c.

This leaves 18l. out of the 240l. entered, chiefly travelling expenses of the present Director, who visits Shide five or six times a year; the remainder being paid to a charwoman for cleaning, &c.

Item (B). The 'Shide Circulars,' which simply reproduced the information received from each station, have been replaced by Bulletins which analyse the results. Expense has been minimised by printing only the results for considerable earthquakes, but even then it is difficult to avoid exceeding slightly the grant definitely available for printing.

Item (C). The rent for the Observatory was fixed by Mrs. Milne's trustees, after consideration of the legal aspect of the question. The

Observatory is annexed to the house in which Mrs. Milne continues to reside, and the Committee has to acknowledge gratefully her kind occasional attention to Observatory matters. The assistants who work in the Observatory all live at a distance, and arrangements are sometimes much facilitated by the help of some one residing on the spot.

Items (D) and (E) are not readily separable because during the past two years part of the work at Shide has been to experiment with new instruments, as described below. Looking backward, item (E) covers expenditure on three or four new machines : the first, constructed by Mr. Shaw at Milne's request and delivered soon after his death, was satisfactorily 'damped' but had not sufficient magnification. To get more magnification, Mr. Shaw preferred to make a new machine rather than alter the former. Meanwhile, Mr. Burgess, with the kind help of Mr. A. E. Conrady, devised another type with optical magnification (instead of mechanical as in Mr. Shaw's), which is being tried side by side with the former. Finally, a Milne-Shaw machine has been made for trial at Eskdalemuir alongside the Galitzin and Wiechert machines. Looking forward it is hoped that at least some such sum as item (E) may be available annually for replacing the existing Milne machines, which scarcely meet modern requirements. The conditions under which many of them were established will be found described in the 1898 Report (Bristol), p. 179. The original Shide instruments were provided from the Government grant; later an improved twin-boom Milne was provided by the generosity of Mr. Yarrow ; the Victoria (B.C.) instrument from the British Association grant (Toronto, 1897), which also provided half the cost of the Mauritius instrument. Other machines were provided by various Governments, observatories, and individuals, but it seems doubtful how far their aid can be again invoked in this way, at any rate until the advantages and working of an improved type of instrument have been demonstrated by a number of good examples.

II. *Stations.—Destruction of Instruments at Cocos.*

A letter, dated April 1, 1915, from Mr. Walter Judd, Electrician-in-Chief of the Eastern Extension, Australasia and China Telegraph Company, informed us that : ' the Seismograph installed at our Cocos Station was destroyed by the landing party from the *Emden* last November.' On April 12 a further letter from the General Manager communicated the following telegram from the Company's Manager at Singapore : ' Meteorological insts. destroyed by *Emden*, Singapore advised 27 March, Straits Government intend replace.'

Probably the replacement must wait for more peaceful times. The Cocos installation dates from 1909, and is due to the generosity of the Company.

New Station at Newport (I. Wight).—In recent bulletins it will be noticed that besides the Shide Station, one at Newport is quoted. This is the station of Mr. W. H. Bullock, a builder in Newport, who did much work for Milne, became keenly interested in Seismology on his own account, and has devised an instrument of his own, with Milne suspension, smoked paper drum and high magnification. It shows the beginnings of the various phases very beautifully. At present there is no damping beyond the friction of the point on the smoked paper, which is effective for small movements, but not for large. Mr. Bullock is experimenting with electro-

P. 54a
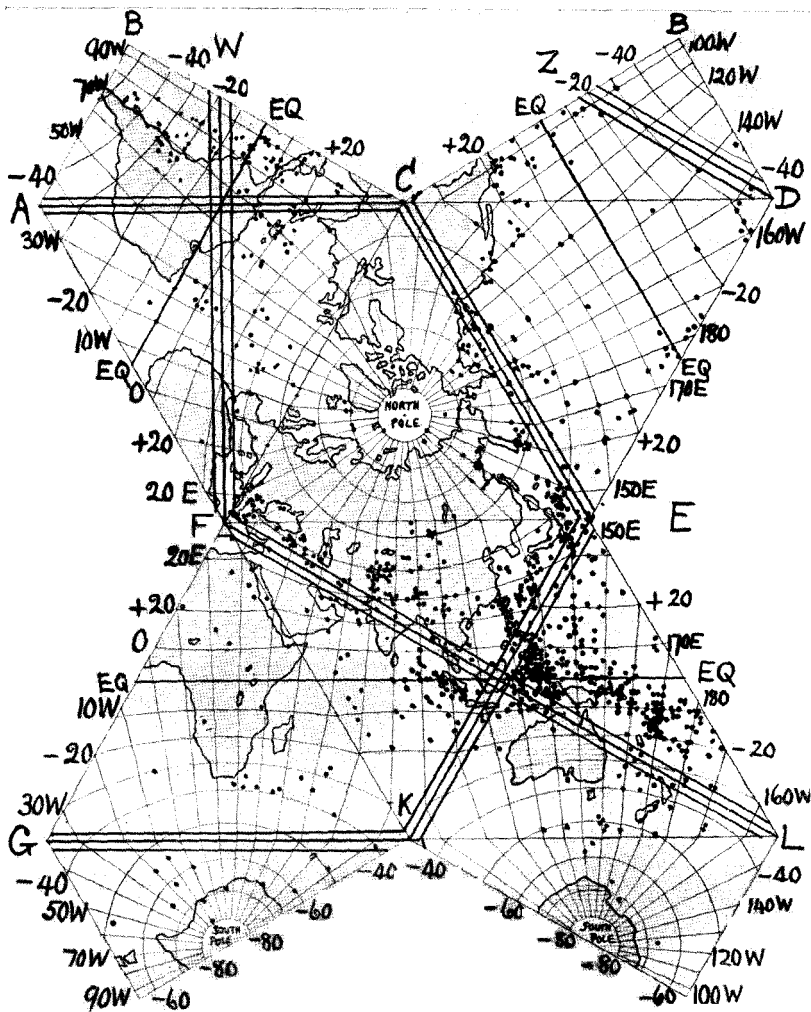
Earthquakes recorded by Milne, 1899–1910.
Small Islands, which might be mistaken for dots, have been omitted.

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magnetic damping, and if he is successful it is proposed to order an instrument from him for use at Shide. It will be especially useful (1) in showing when there has or has not been an earthquake, for guidance in changing the paper of the photographic machines, and (2) for showing to the numerous visitors to Shide the working of a seismograph without disturbance of the photographic machines. In both respects it will replace the large 'lamp-post' machine formerly set up by Milne, but discontinued as too cumbersome.

Time Signal at Shide.—On the outbreak of war, the wireless apparatus used for receiving the time signal from the Eiffel Tower was dismounted in accordance with instructions from the Post Office, and for some months it was difficult to obtain correct time. In December 1914 a small transit instrument, lent by the Royal Astronomical Society, was set up on a disused seismograph pillar near the south window and adjusted as well as possible with a view restricted to altitudes less than 45°. With the kind help of a few telephone exchanges from the Royal Observatory, Greenwich, this sufficed to give clock errors until May 1915, when the Post Office permitted the re-erection of the wireless apparatus. From May 20 this has accordingly been in use again, and has confirmed the accuracy of the transit determinations. On July 23 a storm blew down the aerial, but it was re-erected next day.

While the apparatus was dismounted and clock error being found by the small transit, Mr. J. J. Shaw visited Shide for regulation of his seismograph, and incidentally compared the Shide clock with his watch, of which he knew the error and rate. To his surprise a large discrepancy developed between the two, and it became clear that the watch was at fault. The cause was traced to the suspension of the watch during the night, which allowed of its vibrating as a pendulum. Attention was drawn to this matter by Lord Kelvin many years ago, but the magnitude of the possible error has scarcely been realised sufficiently. Mr. Shaw recalled attention to the matter, which is of considerable practical importance, in a short paper to the Royal Astronomical Society ('Mon. Not.' lxxv., p. 583).

III. *Seismic Activity in* 1911, 1912, *and* 1913.

Milne carried the list of origins to the end of 1910. From the beginning of 1914 the origins of the larger earthquakes have been specified in the monthly bulletins, at first adopted from the Pulkovo determinations, and later, when it became clear that these could often be profitably corrected, adopted from special determinations made at Shide. The corrections are partly due to errors of the tables, estimated approximately at the end of the last Report, but still under revision. It seemed desirable to await these corrections to the tables before undertaking the computation of origins for 1911–13; but these will shortly be commenced.

IV. *Distribution of Milne's Epicentres*, 1899–1910.

In the last Report a map of the world was given on an octahedral projection, the precise selection of which had been suggested by the study of the epicentres tabulated by Milne for the years 1899–1910. The work of plotting the individual epicentres on this map had not then been completed. When complete (as shown in the accompanying illustration) it showed that the root-idea of the map did not fit the facts in its

original form. The edges of the eight triangles form three great circles at right angles, and it was expected that the epicentres would cluster about these edges. But only one of these great circles, GKECA, fulfils this expectation. Of a second, LKFCD, it was already remarked in the last Report that it was not at present a conspicuous line of earthquake activity, but that the geographical features characterising it (the Red Sea, Italy, the Alps, the American Lakes, California) suggested such activity in the past.

The principal change required by the hypothesis as stated in the last Report concerns the third great circle, which is formed by EF and the boundaries of the map. For this we must clearly substitute a great circle LFW, with ZD, which falls midway between the two now discarded. This makes the general hypothesis really simpler than before, substituting two circles, still at right angles, for the three formerly suggested, and retaining many of the important features of symmetry. The two circles retained have been indicated by a triplet of lines. (A thick line would have obscured some of the epicentre dots.)

The third circle cutting both these at right angles would be along DF, then F to the South Pole, and South Pole to L. There is something to be said for including this in the system, but it does not account for much that is not already accounted for by the other two, so that for the present we may omit it.

We could, of course, suit the great majority of epicentres better by drawing, instead of FL, some line nearer to E; and, instead of FW, some line nearer to C. This means leaving the great circle and substituting some small circle. 'Libbey's Circle,' which was drawn by Milne on the earthquake maps in the Reports for 1903–1909, is approximately a small circle parallel to WFL, at about 20° from it, and would suit the facts very well. But the elementary simplicity of the hypothesis is then lost, and it seems preferable to retain the simple form above indicated for comparison with future facts; and perhaps even with a revised version of the facts already used, for the determinations represented on the diagram are of different values—in some cases well established, in others very uncertain.

## V. *Improvements of the Milne Seismograph.*

Section IV. of the last Report is devoted to a discussion of the times recorded by different seismographs for the beginning of P and S. It is shown that while the probable error of the Milne instrument is distinctly greater than that of modern instruments, the favourable geographical distribution of these pioneer seismographs renders them still capable of giving valuable information. At the same time it is clear that the time has arrived when it is desirable to give the Milne seismographs

　　　　(*a*) a higher magnification;
　　　　(*b*) some form of damping.

The former consideration is put first because seismology is at present very definitely concerned with the determination of the times of arrival of P and S. Not only do the tables for these times of arrival require corrections, but it seems probable that the phenomena themselves are not always rightly identified. It was pointed out that at distances from

British Association, 85th Report, Manchester, 1915.]
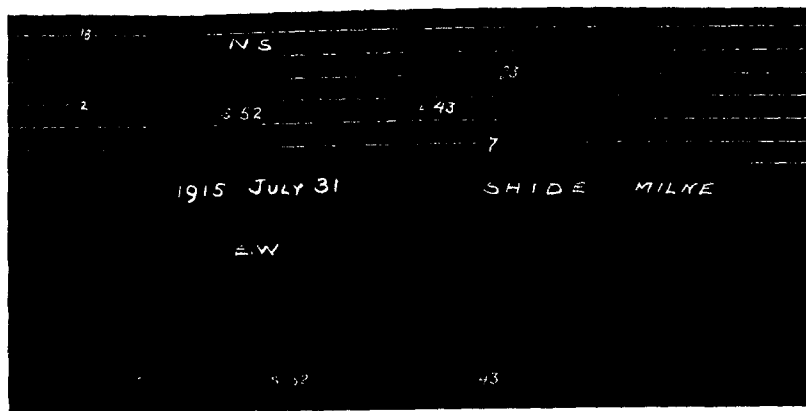
N S

1915 JULY 31 SHIDE MILNE

E.W

Comparison of three types of Earthquake recor
July 31, 1915

White on Black illustrations are negatives of
half full size

5 JULY 31 SHIDE
E W

MILNE.

MILNE-SHA

SR

LARGE WAVES, OR MAX:

MAX. WAVES VIA ANTIPODES
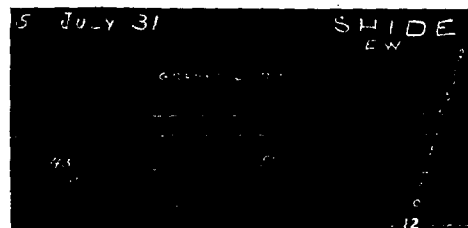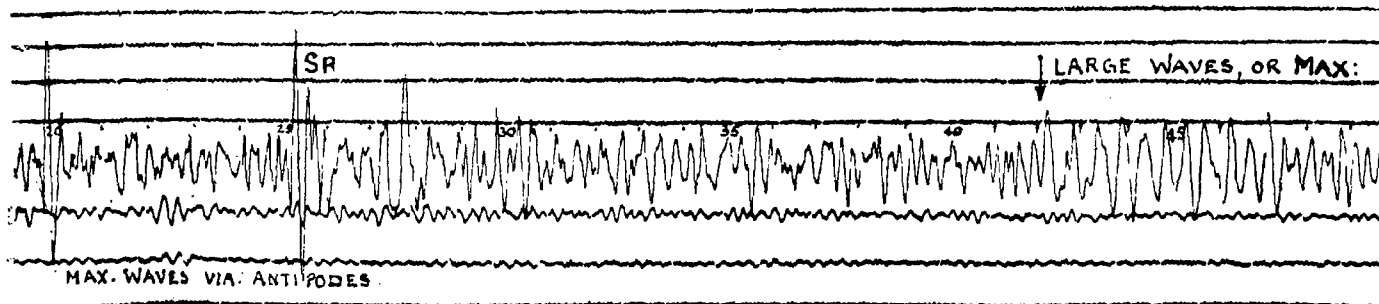
Milne-Shaw record on November 24, 1914, taken at Bidston, England (Director, W. E. Plummer, Esq.). North-South Component. Period
up the paper indicate ground movements to the North C

Comparison of three types of Earthquake records taken at Shide, I.W., England,
July 31, 1915.

White on Black illustrations are negatives of the originals and are reproduced
half full size.
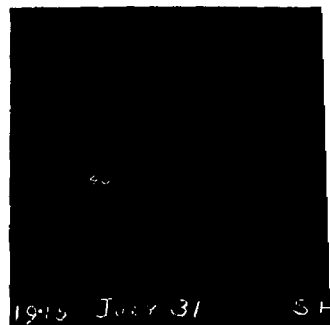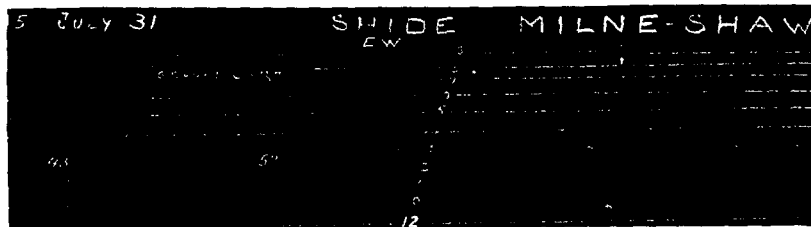
MILNE-SHAW.
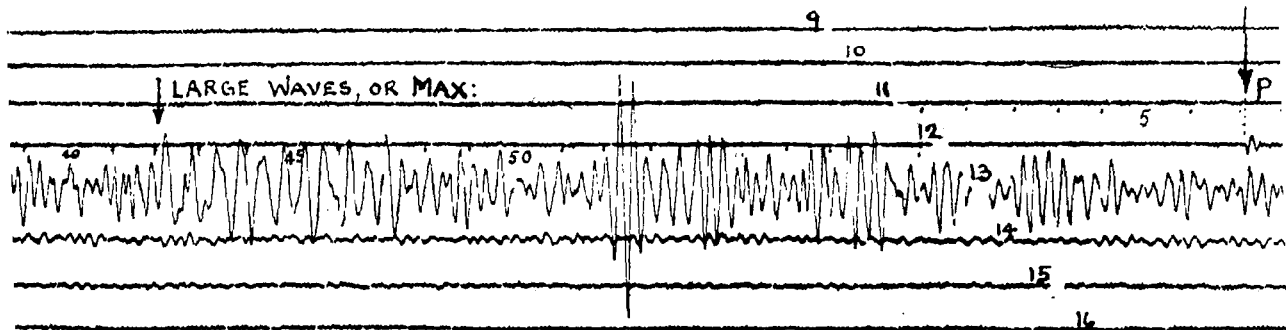
Illummer, Esq.).   North-South Component.   Period of pendulum, 12 seconds.   Damping, Aperiodic; Magnification, 254; Sensitivity to
the paper indicate ground movements to the North Clock 18 seconds fast.   Record reproduced full size.

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P.56c

PLATE II.

MILNE-BURGESS.
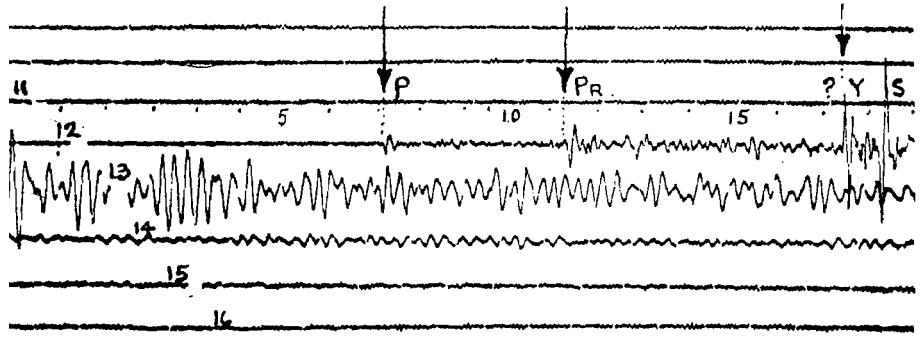
periodic; Magnification, 254; Sensitivity to tilt, 44 mm.   1 second of arc.   Movements
d full size.

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To face page 57.

the origin exceeding 90°, PR is often reckoned as P; and it seems at least possible (see Section X) that some hitherto unrecognised phenomenon is sometimes mistaken for S. This was foreshadowed in the last Report from the fact that, though the magnitude of S is usually much greater than that of P, so that its identification might be presumed to be much easier on the whole, nevertheless the probable error of the observed time of arrival of S is considerably greater than that of P. If some other phenomenon is liable to be mistaken for S, this larger probable error is easily explained. Briefly, the proper interpretation of the seismograph trace is essentially dependent on a proper identification of the times of arrival of P and S; so that for the present attention may be profitably concentrated on this problem. It is important to increase the magnification considerably, because the waves of P are particularly small and difficult to pick up ; further, it becomes necessary to provide such magnification that these small movements shall not be blotted out when damped. The importance of damping is second only to magnification, for probably much of the uncertainty in reading S is due to the inability of free pendulums to record the change in character of the ground movement in this phase.

As remarked above, two new forms of the Milne pendulum have been constructed for trial by Mr. J. J. Shaw and Mr. J. H. Burgess, and brief notes on the details are given in the next two sections.

VI. *The Milne-Shaw Seismograph.*

(*Note by* Mr. J. J. SHAW.)

This is a new type of seismograph with high magnification, combined with absolute damping. The magnification is approximately forty times greater than the standard Milne.

It is an established fact that only fully damped machines give any approximation to a true record of the ground movement ; moreover, with damping, the various phases, P, PR, S, SR, and Max, are much more readily determined ; this will be realised by comparing the undamped records with those of the Milne-Shaw for Nov. 24, 1914, illustrated on Plate II.

The Milne-Shaw gives a record strictly comparable with that of a Galitzin,* but with this distinction, that the latter depends upon and gives a measure of the velocity, whereas the former gives a direct measure of the amplitude of the ground movement, and does not involve the use of a galvanometer.

The general principle of the apparatus is to multiply the movements of a short damped boom by reflecting a beam of light by means of a pivoted lens of half a metre focal length.

The boom (16 inches long) carries a mass of 1 lb., together with a damping vane which moves in a strong magnetic field, and brings the boom to rest after each excursion.

The outer end of boom is coupled to an iridium pivoted mirror, which it rotates in an agate setting ; by this means 300 multiplications of the ground movements are obtained. The definition in the trace is a special feature in this machine. The source of light illuminates a vertical cylindrical lens, and the image created is reflected and refocussed by the pivoted reflecting lens on to a second cylindrical lens placed hori-

* Compare illustrations Plate II. and page 70.

zontally, which again refocusses the light into a small intense point. This point falls midway upon a slit ·003 in. wide and only the middle portion is permitted to pass to the film, which is in immediate contact with this slit. Perfect definition is produced in this way, with the result that waves of not more than two or three seconds period are shown quite distinctly on paper moving only 8 mm. per minute, thereby securing both high efficiency and economy.

Special calibrating and adjusting devices were necessary with such high magnification. This has received special attention, and tilts of 1/100 of a second of arc can be applied and registered by a beam of light on a distant calibrating scale. All such operations are performed at a distance from the column, the motion being transmitted by a long flexible cable, so that the movements of the observer shall not enter into the amplitude shown in the trace.

VII. *The Milne-Burgess Seismograph.*
(*Note by* Mr. J. H. BURGESS.)

The Milne-Burgess machine is a modification of the Milne horizontal pendulum, the chief differences being a magnification of 100, about 75 per cent. of artificial damping, and an increased rate of travel.

The registration is photographic. A collimator with a 2 in. objective and 21 in. focus is mounted to produce a real image of an illuminated glass rod 1 mm. thick at a distance of 10 ft. from the object glass. The illuminated line is reflected by means of a piece of sextant mirror attached to the boom just behind the balanced weights through a hole in the wall on to a recording box in another room. In front of the drum a plano-convex cylindrical lens of $\frac{1}{2}$ in. focus is fixed. Behind this lens is a fine horizontal slit, and in this way the reflected line of light is brought to a focus on the recording drum. The drum has a circumference of 40 in. by 6 in. wide, and travels at the rate of 480 mm. per hour. Accurate time-marks are put on the trace every minute by an electric shutter operated by the Observatory clock.

The boom has balanced weights and is artificially damped by means of a copper plate attached to the end of the pendulum which moves between four magnets as shown in the sketch. The induced currents produced when the plate moves retards the motion, and in this way about 75 per cent. of damping is introduced. By the employment of stronger magnets 'periodicity could be obtained.

VIII. *Diurnal Wanderings of the Traces.*

The introduction of a high magnification has brought with it an inconvenience in the unsteadiness of the trace. The trace at Bidston, which with the Milne instrument was a series of smooth lines at equal intervals on the paper, became at once, with the Milne-Shaw, a series of rippling lines crowded in two places and wide in between, the unequal spacing being obviously due to tidal action, and the ripples, the period of which is of the order of 10 sec., being such as appear to disturb all highly magnified traces. At Bidston these ripples appear definitely to be due to wind ; at any rate on a windy day they are largely increased, as will be seen from the portion of the trace for Dec. 4, 1914, given in the illustration. The gusts on this day went up to eighty miles an hour.

P.58a
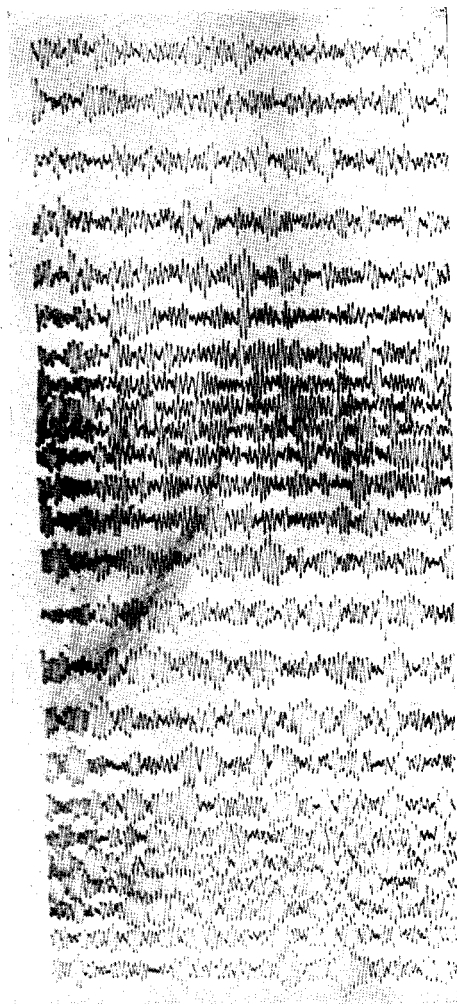
Bidston.   Portion of Trace of Milne-Shaw Seismograph on a Windy Day,
December 4, 1914.

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The diurnal wandering at Bidston is small—much less conspicuous than the tidal or semi-diurnal. At Shide, as described more fully below, the semi-diurnal change is scarcely noticeable, while the diurnal is large and is related to temperature. In view of the investigation which follows, inquiry was made of Mr. Plummer as to what the temperature conditions were. He kindly installed a thermograph and sent the trace for two days, July 31 and August 1, 1915, which showed that the diurnal variation was on one day less than 1° F. and on the next about 1°.5, the external range on the first day being 8° and on the second 14°. If this may be interpreted to mean that the whole chamber is well shielded from the effects of external temperature, the absence of a marked diurnal effect is explained.

At Shide the Milne-Shaw and Milne-Burgess instruments are side by side on separate piers. Their booms are in opposite directions, and when the lines on one are crowded together those on the other are widely separated. There is no conspicuous tidal or semi-diurnal inequality, but there is a very large diurnal inequality, which, though far from constant in its action, usually crowds together the M.-B. trace and expands the M.-S., so that it is apt to run off the drum and be lost. It will be necessary to introduce some modification to meet this disability ; and, in order to investigate its character and possibly to trace its cause, a number of corresponding traces in March 1915 were measured. The quantities tabulated in Table II. below are the measures corrected for the known travel of the drum, so as to represent displacements of the trace from its normal position. The reading at 11 A.M. is adopted as the zero, the paper usually being changed at about 10 A.M.

The numerical sums of the displacements are given at the feet of the columns, as a very rough indication of the relative sensitiveness of the instruments. The totals are 3,338 for the Milne-Shaw and 1,268 for the Milne-Burgess, which are approximately in the ratio of the magnifications, viz., 300 and 100. But we shall find that this ratio is not reproduced in the systematic wanderings.

TABLE II.

Displacements of Trace, in Units of 0·01 in.

| Hour | Mar. 10. | | Mar. 16. | | Mar. 17. | | Mar. 29. | | Mar. 80. | |
	M.-S.	M.-B.	M.-S.	M.-B.	M.-S.	M.-B.	M.-S.	M.-B.	M.-S.	M.-B.
11	0	0	0	0	0	0	0	0	0	0
13	− 54	− 4	− 2	−15	−25	− 4	− 74	+ 1	− 55	− 2
15	−115	+ 3	−25	−32	−54	−14	−128	+13	− 80	− 1
17	−135	+16	−33	−39	−73	−21	−125	+22	−106	+ 2
19	−132	+30	−35	−38	−71	−18	− 96	+33	−113	+13
21	−114	+36	−25	−35	−53	− 9	− 44	+37	− 88	+21
23	−100	+43	−19	−31	−39	− 1	+ 14	+38	− 73	+26
1	− 92	+48	− 7	−27	−29	+ 1	+ 69	+33	− 47	+26
3	− 80	+55	+11	−26	− 9	0	+133	+23	+ 3	+18
5	− 79	+60	+29	−32	+13	− 7	+136	+16	+ 50	+ 7
7	− 53	+70	+33	−35	+27	−12	+103	+15	+ 44	+ 3
9	− 53	+79	+42	−39	+27	−24	+ 56	+13	− 3	− 1
Numl. Sum.	1007	444	261	349	420	111	978	244	672	120

We may now form the first harmonics for these sets of twelve readings, which are as follows :—

TABLE III.

—	Milne-Shaw.	Milne-Burgess.	$-R_B/R_S$	$\theta_B \cdots \theta_S$
	h.	h.		h.
Mar. 10	$- 44 \cos (\theta - 20 \cdot 4)$	$+ 30 \cos (\theta - 3 \cdot 8)$	$+0 \cdot 67$	$+ 7.4$
Mar. 16	$- 34 \cos (\theta - 18 \cdot 9)$	$+ 6 \cos (\theta - 10 \cdot 2)$	$+0 \cdot 18$	$(+15 \cdot 3)$
Mar. 17	$- 47 \cos (\theta - 18 \cdot 9)$	$+ 6 \cos (\theta - 2 \cdot 5)$	$+0 \cdot 13$	$(+ 7 \cdot 6)$
Mar. 29	$-131 \cos (\theta - 16 \cdot 6)$	$+ 17 \cos (\theta - 22 \cdot 7)$	$+0 \cdot 13$	$+ 6 \cdot 1$
Mar. 30	$- 76 \cos (\theta - 18 \cdot 5)$	$+ 14 \cos (\theta - 23 \cdot 7)$	$+0 \cdot 18$	$+ 5 \cdot 2$
Means	$- 66$	$+ 15$	$+0 \cdot 26$	$+ 6 \cdot 2$

The coefficient for the M.-S. machine is given with reversed sign, to make it directly comparable with M.-B. It will be seen that the magnitude of the displacement is much less for the M.-B. machine, though the ratios are not very consistent. A slight correction may be required for error in estimating the hourly travel. This error cannot be large, but there may be

(a) Error in estimating the pitch of the screw, which gives a spiral character to the trace. Thus for the M.-B. machine the screw was seen to have 17 turns in 4 inches. This estimate could not be so much as half-a-turn in error, and since a day uses 12 turns only, we may put the limit of error as less than 12 in our units of hundredths of an inch. Now if we form the first harmonic for the numbers

$$0 \quad 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6 \quad 7 \quad 8 \quad 9 \quad 10 \quad 11$$

we find $-4 \sin \theta - 1 \cos \theta$. Applying this correction with the sign appropriate to making the ratios of M.-S. to M.-B. more accordant, and applying an equal correction to M.-S., guided by the same consideration, we get

TABLE IIIA.—*Being a possible correction to* TABLE III.

Milne-Shaw	Milne-Burgess	R_B/R_S	$\theta_B-\theta_S$
$+ 43 \cos (\theta-326°)$	$-26 \cos (\theta- 71°)$	$0 \cdot 60$	$105°$
$+ 31 \cos (\theta-292°)$	$- 8 \cos (\theta-198°)$	$0 \cdot 26$	$[266]$
$+ 45 \cos (\theta-304°)$	$- 2 \cos (\theta- 18°)$	$0 \cdot 04$	74
$+127 \cos (\theta-264°)$	$-17 \cos (\theta-288°)$	$0 \cdot 13$	24
$+ 73 \cos (\theta-293°)$	$-13 \cos (\theta-356°)$	$0 \cdot 18$	63

It will be seen that there is no great improvement in accordance of the ratios, while the phases are conspicuously more discordant.

(b) Errors may also arise from the drum not revolving in an exact hour or two hours. These again are not likely to be large, and their general effect would be as for case (a).

(c) Or there may be a real travel of the index during the day, owing to gradual change of temperature, for instance. If we treat this as a uniform change, its general form is still the same as case (a).

Coming to the phases, we see that there is a difference of about 90°, or 6 hours. The inference appears to be that the effect is not due to tilt of the ground, which should affect both instruments at about the same time, but an effect of temperature which acts promptly on the M.-S. instrument but much more slowly on the M.-B. The fact that

Mr. Shaw specially designed his instrument (with a thin metal cover, &c.) so that it might take up the temperature quickly supports this view. But the magnitude of the lag in M.-B., viz. 6 hours, is somewhat surprising, and to test its reality the numbers of Table II. were treated in a different way. Subtracting each constituent from that which follows it, we get the movements for each two hours, and can study the correspondence. It will be convenient to reverse M.-B. for this purpose.

TABLE IV.—*Two-hourly Movements of the Instruments.*

	Mar. 10 Reversed		Mar. 16 Reversed		Mar. 17 Reversed		Mar. 29 Reversed		Mar. 30 Reversed	
	M.-S.	M.-B.	M.-S.	M.-B.	M.-S.	M.-B.	M.-S.	M.-B.	M.-S.	M.-B.
h.　h.										
11—13	−54	+ 4	− 2	+15	−25	+ 4	−74	− 1	−55	+ 2
13—15	−61	− 7	−23	+17	−29	−10	−54	−12	−25	+ 1
15—17	−20	−13	− 8	+ 7	−19	+ 7	+ 3	− 9	−26	− 3
17—19	− 3	−14	− 2	− 1	+ 2	− 3	+29	−11	− 7	−11
19—21	+18	− 6	+10	− 3	+18	− 9	+52	− 4	+25	− 8
21—23	+14	− 7	+ 6	− 4	+14	− 8	+58	− 1	+15	− 5
23— 1	+ 8	− 5	+12	− 4	+10	− 2	+55	+ 5	+10	0
1— 3	+12	− 7	+18	− 1	+20	+ 1	+64	+10	+60	+ 8
3— 5	+ 1	− 5	+18	+ 6	+22	+ 7	+ 3	+ 7	+37	+11
5— 7	+26	−10	+ 4	+ 3	+14	+ 5	−33	+ 1	− 6	+ 4
7— 9	0	− 9	− 9	+ 4	0	+12	−47	+ 2	−47	+ 4

Now, if we try the effect of associating the movement of M.-S.,
(*a*) with the contemporary movement of M.-B.,
(*b*) with the reading of M.-B. two hours later,
(*c*) with the reading of M.-B. four hours later,
and so on, we get, on grouping the results, the means shown in Table V.

TABLE V.—*Effect of Associating M.-S. with M.-B. of Various Times Later.*

M.-S.	Corresponding Movement of M.-B. after time						6^{h}—M.S./8
	h. 0	h. 2	h. 4	h. 6	h. 8	h. 10	
−60	−3	−8	−10	−9	−5	−3	−1
−24	+3	−1	− 4	−6	−5	−2	−3
− 5	+2	+1	− 1	−2	0	+2	−1
+ 4	−8	−8	− 5	0	0	+4	−1
−12	−3	−1	− 1	0	+2	+3	−1
+22	−3	0	+ 3	+4	+5	+2	+1
+54	+5	+6	+ 5	+5	+3	+2	−2

Inspection of these figures indicates that the best correspondence is somewhere between 4 h. and 6 h. later, and nearer 6 h. than 4 h. But it was clearly desirable to have more light on the matter, and, as the next step, a thermograph was installed in the stable which forms the Observatory. It was not a very good thermograph, having been rather roughly treated in some mining experiments; but it gave a pretty fair indication of the temperature for several weeks. The readings May 4–10 and May 31–June 10 were selected for discussion. The traces were

measured with care and discussed at length, but a brief summary will suffice here :

May 4–10.   The mean temperature first rose and then fell.   But it will be convenient to consider first the mean diurnal inequality which came out in degrees Fahrenheit,

$$1°\cdot4 \cos (\theta - 20\cdot8)$$

θ being expressed in hours.   The late hour for the maximum, nearly 9 o'clock in the evening, raises hopes that we may be able to separate the effects of internal and external temperature.   The first harmonics for the two machines were

<div align="center">

mm.   h.

Milne-Shaw $24\cdot2 \cos (\theta - 18\cdot0)$

Milne-Burgess $5\cdot6 \cos (\theta - 20\cdot3)$

</div>

The former measures and coefficients were inadvertently expressed in units of $0\cdot01$ in. ; converted into mm., the former mean values are $16\cdot8$ and $3\cdot8$.   These are smaller than the $24\cdot2$ and $5\cdot6$ now found, but the ratios, $4\cdot4$ and $4\cdot3$, are very nearly the same.

The phases, however, do not differ by nearly so large an amount. M.-S. follows M.-S. by $2\cdot3$ h. only instead of by 6 h. as found in Table V. It will be seen, moreover, that while the maximum of M. B. falls near that of the thermograph, M.-S. precedes the thermograph by a large interval—nearly 3 hours.   Now, if the disturbance of the instruments is due to some temperature effect outside the Observatory—tilt in the valley, for instance—the time of maximum would be different from that of the thermograph.   For instance, if it depended on the Sun's altitude, the maximum should fall at noon.   If the effect is a composite one, the maximum would fall somewhere between noon and $20\cdot8$ h. (internal maximum), as it does in fact.   We have thus a presumption of a composite character.

The presumption is strengthened by the magnitude of the coefficients ; $-1°$ of temperature corresponds to $4\cdot0$ mm. for M.-B. and actually $17\cdot7$ mm. for M.-S.   It seems unlikely that these movements, especially the latter, can be due directly to the $1°$ change in internal temperature.   It seems much more likely that they are due to the much larger external changes, of which the $1°$ internal change is only a fraction.

Further evidence in this direction is afforded by the changes of the mean from day to day, which can be formed when the diurnal change is eliminated.   These were formed for every available day in the two periods May 4–10 and May 31–June 12, and it will suffice to give the mean results :

No. of Days in Group	Mean Change of Temperature	Observed Daily Travel of		Calculated	
		Milne-Shaw	Milne-Burgess	Milne-Shaw	Milne-Burgess
	°	mm.	mm.	mm.	mm.
4	$+4\cdot1$	$- 5\cdot7$	$+5\cdot6$	$-72\cdot6$	$+16\cdot4$
3	$+1\cdot6$	$- 6\cdot5$	$+3\cdot2$	$-28\cdot3$	$+ 6\cdot4$
5	$0\cdot0$	$-16\cdot6$	$+0\cdot7$	$0\cdot0$	$0\cdot0$
4	$-3\cdot2$	$- 7\cdot1$	$-8\cdot6$	$+56\cdot6$	$-12\cdot8$

Under the heading ' Calculated ' are given the daily travels for the temperature change calculated with the coefficients 17·7 mm. and 4·0 mm. for 1° as found above from the diurnal inequalities. The M.-B. machine shows only about half the calculated travel ; the M.-S. machine no sensible travel at all. It should be mentioned that the zero of the latter is adjusted every morning, but this does not affect the above figures, which are deduced (partly by estimation) from the undisturbed daily traces.

A test experiment was made on July 29 as follows :

At 10 a.m. a stove was lit in the Observatory in order to cause a rapid rise of temperature.

At 12.30 p.m. the stove was removed and a large block of ice was introduced in order to cause a sudden fall.
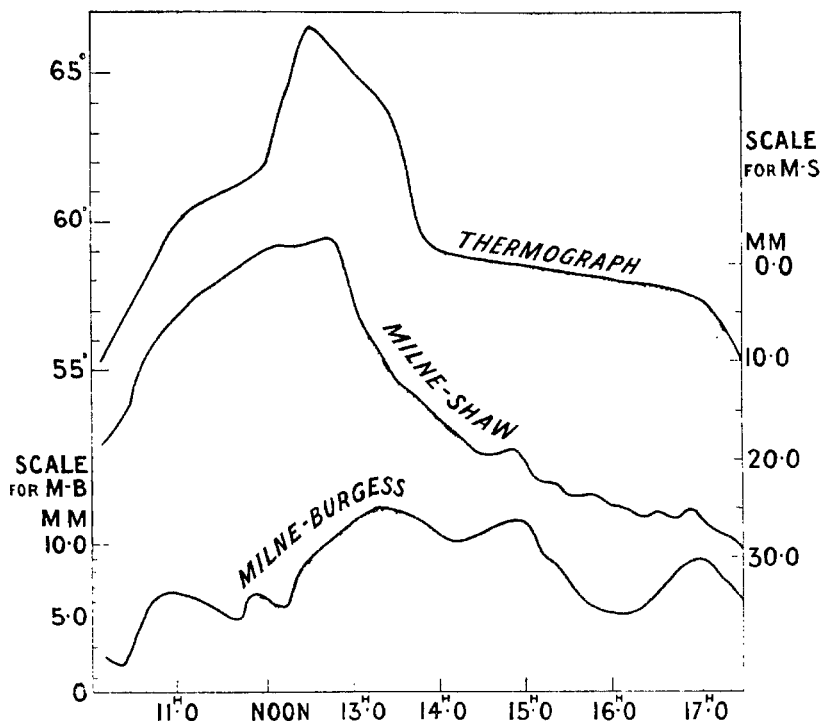
Temperature Experiment at Shide, July 29, 1915.

The readings of the thermograph and the corresponding wanderings of the two machines are shown in the diagram. It will be seen :—

(a) That neither machine responds to the rise of temperature in anything like the degree suggested by the diurnal coefficients. The total rise of temperature is over 10°, and we should expect deflections of 177 mm. and 40 mm. respectively ; instead of which we get about 19 mm. and 11 mm.

(*b*) The Milne-Shaw begins to fall about 15 minutes after the thermograph, and falls pretty rapidly; the fall had not stopped when the observations were closured, and it is clear that the coefficient deduced from the fall would be greater than that found from the rise.

(*c*) The disturbance of the Milne-Burgess machine is much more complex. There are waves on the rise, and the main maximum which follows that of temperature by nearly an hour is followed by another $1\frac{1}{2}$ hour later, and again another at $4\frac{1}{2}$ hours after the temperature maximum. There may be others later still. A reasonable explanation is that the warmth reaches different parts of the instrument at different times, the separate parts producing separate maxima. This would fully account for the curious discrepancy between the former results, and the large range of values for the interval between M.-B. and M.-S. We have only to suppose that sometimes one part of the instrument is predominantly affected and sometimes another.

The main conclusion is that internal temperature can only be responsible for a part, and probably only a small part, of the diurnal deflections of the instruments. The main cause seems to be external, and is probably the daily opening and shutting of the valley to which Milne drew attention many years ago.

Before leaving these deflections, a word or two may be said as to the tidal effects, so conspicuous on the Milne-Shaw machine at Bidston, but almost hidden by the temperature effects at Shide. Some trouble was taken to disentangle them, and it was found that the lunar tide could be identified by means of the progressive phase. For the Milne-Burgess instrument the coefficient was about 1 mm.; but it is mixed up with temperature effects which may vary widely in character. The tidal coefficient for the Milne-Shaw instrument at Shide is not very much larger than 1 mm.—perhaps 2 mm. at most. But the material available at the time of the discussion was not large and further investigation is desirable.

Finally, some particulars may be given as to the deflections at other stations, where the simple Milne instruments are in use. The magnification being small, the disturbance of the trace by either temperature or tide is not noticeable to a casual glance; but if careful measures are made of the travel at every 2 hours (or 4 hours in some cases) throughout the day, the general nature of the movements can be detected. Such information may be of value in arranging for the setting up of instruments of higher magnification.

The diurnal changes were deduced from the means for all the days measured; as also the semi-diurnal changes.

As regards the lunar tide, the simplest way of detecting it is to form the differences between readings for 2 days separated by any convenient interval from 4 days to 11 days; for in $7\frac{1}{2}$ days the lunar semi-diurnal tide reverses itself, maxima falling on the former minima. We thus get twice the effect by the subtraction. If the interval of 7 or 8 days is not available, the factor will not be so large as 2, but is easily calculated from the relation

$$\text{Cos } (\theta - a) - \cos (\theta + a) = 2 \sin a \sin \theta.$$

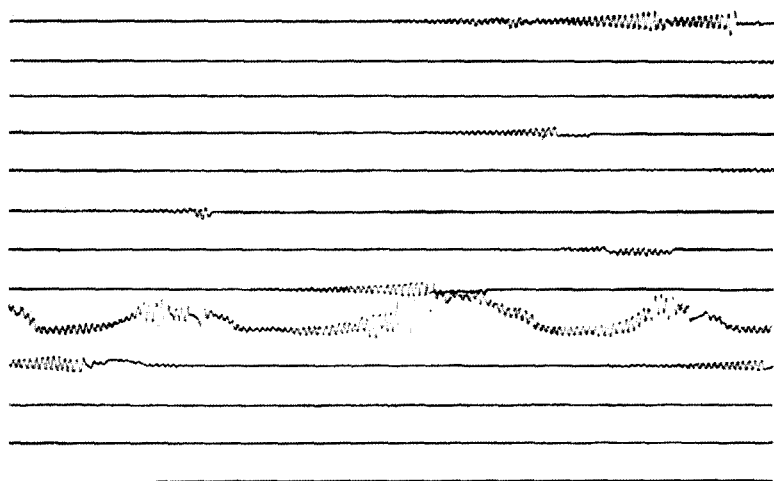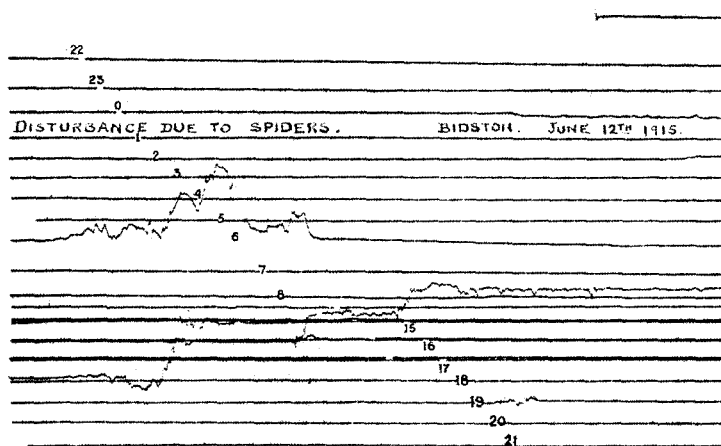For $7\frac{1}{2}$ days, $a = 90°$; for 4 days, $a = 4 \times 90°/7\frac{1}{2} = 48°$.

FIG. A.
St. Helena, May 21-22, 1915.
The effect of insects on a seismograph at St. Helena.   This continued for ten days.

1915.   [Opened June 11, 21, 23.]

[Closed June 12, 21, 16.]
FIG. B.
The work of a spider on the seismograph at Bidston.
He continued for eight days, until removed.

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Hence the factors are as below :—

Days	2	3	4	5	6	7	8	9	10
Factors	0·8	1·2	1·5	1·7	1·9	2·0	2·0	1·9	1·7

An example may make the method clearer. The actual readings of the Seychelles records are given in columns 2, 3, and 4 of Table VI. The unit is 0·01 in.

TABLE VI.

Hour	July			Differences		Diurnal Terms		Differences corrected for diurnal terms	
	12	15	18	15–12	18–15				
10	0	0	0	0	0	0	−3	0	−3
12	14	17	25	+ 3	+ 8	− 2	−4	+5	+4
14	33	31	42	− 2	+11	− 5	−6	+3	+5
16	65	50	59	−15	− 9	−10	−7	−5	+ 2
18	96	78	80	−18	+ 2	−14	+8	−4	−6
20	120	100	105	−20	+ 5	−17	+9	−3	−4
22	139	122	130	−17	+ 8	−18	+9	+1	−1
0	155	145	154	−10	+ 9	−16	+8	+6	+1
2	177	166	177	−11	+11	−13	+7	+2	+4
4	199	187	194	−12	+ 7	− 8	+6	−4	+1
6	228	221	220	− 7	− 1	− 3	+4	−4	−5
8	255	253	253	− 2	0	− 1	+3	−1	−3

In the next two columns the simple differences between July 12 and 15, and between July 15 and 18, are shown. These are clearly affected by diurnal terms, *i.e.*, the diurnal terms differ for different days, as we might expect. To bring out the lunar terms more clearly we remove the diurnal terms, including a suitable constant. The terms found (by harmonic analysis) are shown in the next two columns, and finally the corrected differences, which show the semi-diurnal terms clearly. Analysing these harmonically (as we could of course have done without removing the diurnal terms), we find :—

For July 15–July 12 :

$$\text{in.} \qquad\qquad \text{in.} \qquad\qquad \text{h.}$$
$$0·048 \cos 2\,(\theta - 28°) = 0·048 \cos 2\,(t - 11·9).$$

For July 18–July 15 :

$$0·045 \cos 2\,(\theta - 52°) = 0·045 \cos 2\,(t - 13.5),$$

where θ is the hour angle measured from 10 h., or t is the time in hours measured from 0 h. The hour of maximum has thus advanced 1·6 h. in the 3 days. A purely lunar tide would advance 2·4 h. in 3 days. The discrepancy is partly accidental, partly due to a semi-diurnal temperature effect, which can only be detected or eliminated by a longer series of observations. But we can clearly separate the lunar effect by its advancing phase if we have a long enough series of days.

We proceed to give a few results for stations which had sent films to Shide for examination.

The measures were made in hundredths of an inch, and the travel of each trace is about 0·23 in. per 2 hours. The figures below, being deduced from only a few days' records, must not be taken too seriously,

1915.   F

but will serve to give an idea of the magnitude of the quantities involved.

Station	Dates of Traces Measured	Diurnal and Semi-diurnal changes			Coefficient of lunar tide
		in.	h. in.	h.	in.
Ascension .	1911, Feb. 20–28	·014	cos $(\theta-19\cdot5)+\cdot005$ cos 2 $(\theta-0\cdot0)$		·004
Cocos .	1911, Sept. 5–22	·114	,, 20·0 $+\cdot026$,,	11·5	·028
Eskdalemuir,					
E.-W. .	1911, Feb. 1–22	·002	,, 22·5 $+\cdot021$,,	3·0	·000
Do., N.-S.	,,	·005	,, 22·0 $+\cdot008$,,	5·0	·000
Fernando					
Noronha	1913, Jan. 13–21	·081	,, 19·0 $+\cdot009$,,	6·0	·005
Helwan,					
E.-W. .	1911, Feb. 1–9	·001	,, 7·0 $+\cdot000$,,	—	·000
Do., N.-S.	,,	·002	,, 12·0 $+\cdot000$,,	—	·000
Malta .	1911, July 1–9	·004	,, 18·0 $+\cdot000$,,	—	·000
Seychelles	1911, July 10–19	·035	,, 12·0 $+\cdot050$,,	4·0	·045
St. Helena	1915, Feb. 18–27	·016	,, 17·0 $+\cdot007$,,	2·5	·004
,,	1915, May 15–25	·007	,, 15·0 $+\cdot004$,,	3·5	·009

It will be seen that Eskdalemuir, Helwan, and Malta show no lunar tides ; Seychelles and Cocos have large tides, as well as large diurnal effects.

It may be presumed that 0·001 in. $= 0''\cdot01$ approximately, but in most cases no more precise scale value can be recovered from the records.

IX. *Insect Disturbances of Seismographs.*

An inquiry from St. Helena suggests that it may be useful to other observers to print a note on the disturbances caused by insects.

Mr. J. J. Shaw has kindly drawn up the following :

A difficulty which is frequently met with in practical seismology is to keep the seismograph free from the various insect interferences. An imprisoned moth or fly will often keep the boom in a state of unrest for several days at a time ; but a much more serious nuisance is the ubiquitous spider ; he not only makes havoc with the trace, but also ties up the boom, and very greatly destroys the sensitivity of the apparatus. It is useful to be able to decide from the trace whether the trouble is of the first or second order ; because if of the second it is not sufficient to get rid of the spider, but the web must also be removed.

There is an advantage in making an artificial disturbance each day by standing for about 15 seconds on a selected spot near the side of the masonry column ; a suitable time is just before changing the film, as the boom is then at rest. This will give a standard deflection which can be compared day by day whereby any loss in efficiency is quickly detected. The decrement curve at the commencement of the film is also useful in identifying the cause of these troubles. In instances of the first type the prisoner periodically sets the boom in motion, and occasionally leaves it to come to rest, when the trace will be seen to continue in alignment with its previous position. Confirmation may be looked for in the unimpaired efficiency indicated in the decrement curve. If, however, the disturbances produce permanent displacements in the trace they are probably caused by a spider, or perhaps a moth, whose

wings have been singed in the lamp, and which has fallen down the light aperture and become wedged between the slit plate and the floating vane on the boom. In either case the decrement curve and standard deflection will show considerable deterioration.

A piece of glass over the light aperture is a partial remedy; but more effectual is the addition of about 2 lb. of naphthalene ($C_{10}H_8$) well distributed throughout the cases.

Herewith are given illustrations of first-order trouble from St. Helena and spider trouble from Bidston. The Bidston apparatus is a fully damped Milne-Shaw type and has no decrement curve, but the standard deflection fell from 27 mm. to 9 mm. as a result of the webbing of this spider.

X. *The Identification of* S : *Suggestion of a New Phenomenon* Y.

As shown in the last Report, there are accidental deviations of observation of S from the times assigned by the tables. The mean of the errors discussed is ($+0.73$ minutes or) $+44$ sec. for S, and (±0.31 minutes or) ±19 sec. for P. This is the more remarkable since the amplitude of S is usually much greater than that of P, so that there ought to be less uncertainty in reading. The suspicion is aroused that there is some other phenomenon liable to be mistaken for S; and that many of the errors are due to these mistakes.

A suggestion of this kind is put forward by Dr. G. W. Walker in his ' Modern Seismology,' but is apparently vitiated by an oversight. On p. 41, after considering the first reflected wave PR_1, he next considers a wave which travels as P to the point of reflection and as S subsequently; he points out that there is a lower limit to the possibility of such a wave which he determines as $\Delta=110°$ or 12,000 km.; and he proceeds:

' Now, it has been observed that special difficulty attaches to the identification of S just when Δ is about 12,000 km. Thus with an earthquake in the northern Philippines, which are about 11,000 km. from this country, S usually comes out very clearly, while in the case of an earthquake in the Caroline Islands, about 12,000 km. from us, S is most indistinct, and the tendency is to put it rather late. The result we have obtained throws some light on the matter.'

The oversight which vitiates this explanation is that Mr. Walker is dealing at the moment with the hypothesis of a homogeneous earth, which he soon shows to be quite untenable. His figures are those for a homogeneous earth, and are quite inapplicable to the actual earth. The lower limit he mentions does indeed exist, but instead of being at $\Delta=110°$ it is about $\Delta=35°$. It is readily found numerically by using the existing tables printed on the last page of the Shide bulletins for 1914. Thus when $\Delta=40°$ the times given for a wave to travel

		s.	s.	s.
as P for 1° and S for 39° =	15	+832	=847
P for 2 and S for 38 =	31	+818	=849
P for 3 and S for 37 =	47	+804	=851
P for 4 and S for 36 =	62	+790	=852
P for 5 and S for 35 =	77	+775	=852
P for 6 and S for 34 =	92	+760	=852
P for 7 and S for 33 =	106	+744	=850
P for 8 and S for 32 =	121	+728	=849
P for 9 and S for 31 =	136	+711	=847
&c.			&c.

The sum of the times increases to a maximum of 852 sec., where there is an accumulation which marks the trace (P_1S_1) and then diminishes again.   Since the time for S to travel 40° is by the same tables 847 sec., this P_1S_1 is later than S ; and it is easily found to be always later.   For instance, at

			s.		s.
$\Delta=90°$	we have	S	=1454	P_1S_1	=1507
$\Delta=100$	,,	S	=1556	P_1S_1	=1625
$\Delta=110$	,,	S	=1648	P_1S_1	=1738

But in the above calculation for $\Delta=40°$ the distance travelled as P is only a few degrees ; and as we diminish the value of Δ this distance contracts to zero, marking the limit determined by Mr. Walker in the simple case of a homogeneous earth.

The fact that P_1S_1 is always later than S is an additional reason why it cannot explain the mistakes in identifying S, which require a phenomenon sometimes preceding S, as will be seen from the examples quoted below.   But there is scarcely need of an actual example ; on general principles it is pretty clear that something preceding S is more productive of mistakes than something which follows ; for there is a strong tendency to read the earliest movement in the suitable neighbourhood.

Now, if the phenomenon is to precede S, it seems clear that it cannot travel partly as P and partly as S, since even P_1S_1 is later than S.   We cannot assign a smaller share to S than is represented by P_1S_1, except no share at all.   We are thrown back on P.

A single reflection of P is well known as PR_1, and there is no difficulty in considering two, three, or more reflections of P.   But when the appropriate neighbourhoods in the trace are examined, there seem to be no conspicuous indications there ; certainly nothing likely to be mistaken for S.

The suggestion now put forward is that of a *large number of reflections of* P.   When the number is large, the time of arrival tends to be independent of the precise number, since the times near the origin, whether for P or S, are sensibly proportional to the arcs.   The printed tables give an initial velocity to P of about 1° per 15·5 s.   The facts collated below suggest that this should be altered to 1° per 14·9 s. and this will be adopted for use provisionally.   No large departure from the printed tables is involved—the time at 4·0° would be 59·6 s. instead of 62 s. as printed ; but the times will be assumed for a moment to be accurately proportional to the arcs, at this rate.

On this supposition it is clear that a total arc of 60° is described in the same time by

					s.		s.
15 reflections of 4° each			=15 × 59·6		=894
30	,,	,,	2°	,,	=30 × 29·8	=894
60	,,	,,	1°	,,	=60 × 14·9	=894

And indeed that any number of reflections greater than 15 have the same total time of travel according to the tables.   The simultaneity is only limited by the accuracy of our assumption that the time near the origin is directly proportional to the arc.

There is a difficulty attending this supposition of a theoretical kind. It is remarked by Mr. G. W. Walker on p. 45 of his ' Modern Seismology ' that ' it is impossible to propagate along a plane boundary . . . longitudinal waves with displacement parallel to the surface.'   Now, when

the P waves are many times reflected they must travel so close to the surface as to approximate to this impossible type. On the other hand, C. G. Knott (' Physics of Earthquake Phenomena,' chap. x.) gives, from theory, a total reflection of longitudinal waves at grazing incidence. The theoretical difficulty may disappear on scrutiny ; if not, some other explanation must, of course, be found. But that now offered seems to fit the facts mentioned below, and is therefore put forward for consideration. It amounts to suggesting waves (Y) travelling close to the spherical surface with practically the initial velocity of P, which we take as 14·9 s. per degree. The times would thus compare with those of S as below :

$\Delta=$	60°	70°	80°	90°	100°	110°	120°
	s.	s.	s.	s.	s.	s.	s.
Y=	894	1043	1192	1341	1490	1639	1·788
S=	1103	1226	1343	1454	1556	1648	1729
Y−S=	−209	−183	−151	−113	−66	−9	+59

Mr. J. J. Shaw suggested the name ' polychord ' for the phenomenon considered ; and the letter Y from this term may be used to designate it. It will be seen that Y crosses S near $\Delta=110°$. But in the last Report certain corrections were suggested to the printed tables. It is not yet advisable to alter the figures used, as discussion is proceeding ; but we may indicate in brackets the result of the corrections suggested, which are as below :

$\Delta=$	15°	25°	35°	45°	55°	65°	75°	85°	95°	105°
	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Correction P=	0	0	0	0	0	−1	−3	−8	−15	−24
Correction S=	+5	0	−4	−8	−11	−14	−17	−24	−35	−50

The comparison of Y with S would, with these corrections for S, stand as follows :

$\Delta=$	60°	70°	80°	90°	100°	110°
	s.	s.	s.	s.	s.	s.
Y=	894	1043	1192	1341	1490	1639
(S)=	1090	1210	1323	1424	1514	1588
Y−(S)=	(−196)	(−167)	(−131)	(−83)	(−24)	(+51)

The point of crossing is thus shifted about 8° nearer the epicentre.

The plan of giving corrected figures in brackets will be followed below. The example which first suggested this hypothesis was the Eskdalemuir trace for the earthquake of November 24, 1914, to which attention was drawn by Mr. J. J. Shaw. The lettering on the rough trace shown in the illustration is his. See also Milne-Shaw record Plate II. At the time of examination of this trace no other material was available, and a brief summary may first be given of the argument as it then stood.

It is natural to identify α with P and γ with S. The distance of the epicentre corresponding to

$$S-P=12 \text{ h. } 16 \text{ m. } 55 \text{ s.}-12 \text{ h. } 6 \text{ m. } 43 \text{ s.}=612 \text{ s.}$$

would then be $\Delta=81·3°$ (84·1 corrected tables). The time for PR_1 would then be 12 h. 10 m. 16 s. (12 h. 10 m. 30 s.). But PR_1 can almost certainly be identified with β at 12 h. 10 m. 54 s.*—much later than either the uncorrected or corrected time. Similarly, the time for SR_1 does not fit the trace at all.

If, however, we identify S with δ at 12 h. 17 m. 45 s. we then have

* This is the reading published by Eskdalemuir.

S—P=662 s. and Δ=90·8° (94·8°). The time for PR_1 would then be 12 h. 10 m. 35 s. (12 h. 10 m. 56 s.). For SR_1 we should get 12 h. 24 m. 31 s.
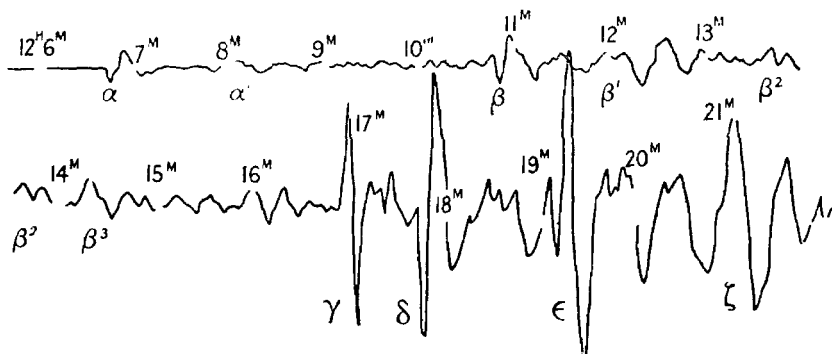
Eskdalemuir (Galitzin) N.S. Component, November 24, 1914.

and there is a notable disturbance on the trace here (though it has not been considered necessary to reproduce that part of it in the diagram).

This argument has been much strengthened since the records of other stations became available. These were collated by Mr. Burgess in the ordinary course of the work at Shide in July 1915 without any knowledge of the suggestion here made. The epicentre selected by him is 21·5° N. 141° E. distant 97·3° from Eskdalemuir ; and the MS. sheet prepared for the Shide Bulletin with this epicentre shows residuals in S of over 100 s. not only for Eskdalemuir and Dyce (Aberdeen), but for Padova, Paris, and other stations. It would appear that γ has been taken instead of δ at such stations, for the above epicentre, though possibly a few degrees in error owing to the conflicting information, suits the near stations (Zi-ka-wei, Batavia, and the Japanese stations), as well as Pulkovo, too well to be so far wrong as must be the case if γ were S.

But if δ is S, what is γ ? Taking Δ=(94·8°) as above, the time for the polychord is 94·8×14·9 seconds=1413 s., following P by (606 s.), and thus affecting the trace at (12 h. 16 m. 49 s.). The Eskdalemuir reading for S (*i.e.*, for γ) is 12 h. 16 m. 56 s.

The full details for this earthquake, which is not at present fully discussed, will be printed in the Shide Bulletin ; but the following figures will show approximately the nature of the results :

Epicentre 24° N., 141° E. *Time*, 1914, Nov. 24, 11 h. 53 m. 15 s.

Station.	Inst.	Δ	P	O – C	S	O – C	O – C for Y instead of S.
		°	h. m. s.	s.	h. m. s.	s.	s.
Zi-ka-wei .	W	18·7	11 58 2	(+22)	12 1 36	(+26)	—
Batavia .	W	41·9	12 1 30	(+ 5)	12 7 48	(+ 5)	—
Pulkovo .	G	79·2	12 5 28	(+ 4)	12 15 17	(+ 8)	+142)
Dyce (Aberd.) .	Ma	93·2	12 6 24	(−10)	12 16 31	(−58)	(+ 8)
Eskdalemuir .	G	95·0	12 6 43	0	12 16 56	(−50)	(+ 6)
Padova .	V	96·7	12 6 51	0	12 17 5	(−55)	(− 9)
Bidston .	MS	96·7	12 6 52	+ 1	12 17 6	(−54)	(− 10)
Paris . .	G	98·3	12 6 59	0	12 17 14	(−60)	(− 15)

Another example is afforded by the earthquake of June 25, 1914, details of which have already been published in the Shide Bulletin for June. Let us first take the following residuals :

	P		O – C	S			O – C
	h.	m.	s.	s.	h.	m.	s.	s.
Eskdalemuir	19	21	15	+ 18	19	32	55	+ 10
West Bromwich	19	21	17	+ 21	19	31	45	– 58

It is clear that if Eskdalemuir is even approximately correct, the S for West Bromwich is sensibly in error. Now, the West Bromwich trace shows, following the printed S at 19 31 45, another disturbance about 45 s. later, say at 19 32 30, which is probably the true S. The printed Δ for West Bromwich is 100·3°, for which Y—(S) would be only —22 s. according to the figures above given. But the position of the epicentre is subject to revision. The printed distance 100·3° would give S—P=11 m. 45 s. (11 m. 22 s. corrected), whereas the West Bromwich trace suggests the smaller value 11 m. 13 s., corresponding to Δ=(98·3°) say : for which Y—(S)=(—35 s.).

For this earthquake the S residuals for Florence, Aachen, Barcelona, Dyce, Honolulu, &c., all accord with a mistake of Y for S. On noticing the above discrepancy between Eskdalemuir and West Bromwich, inquiry was made of Eskdalemuir, and on April 23 Mr. Richardson kindly replied ' the time stated (for S) in our tabulation was the correct one for a certain disturbance on N.-S. But on unravelling the E.-W. trace it is seen to contain a disturbance about a minute earlier. Photo. prints are being sent to you herewith.' A rough tracing of the three records is given in the illustration. It will be seen that Y is small on the N.-S. component ; large on the E.-W. component, and quite noticeable (though S is absent entirely) on the vertical component. These facts seem to accord with a wave of P character, for the epicentre is nearly due east of Eskdalemuir, the azimuth (from the north point) being 82·6 if we accept the epicentre of the June Bulletin (4·5° S., 99° E.). A thrust from this direction would be 7·7 times as much to the W. as to the S. Now measurements of the traces give for the first three south movements in millimetres +8·5, —12·0, +9·0 ; and for the corresponding west movements, +57, —72·5, +65. Dividing the latter by 7·7 we get +7·4, —9·4, +8·4, which are all a little smaller than the former. The ratio (57+72·5+65)/(8·5+12·0+9·0)=6·6 in fact, giving an azimuth for the epicentre of 81·5° instead of 82·6°. The epicentre determined at Eskdalemuir (1° S., 102° E.) gives azimuth 78°, so that the correspondence is thus well within the limits of accidental errors of various kinds. It would be interesting to check this ratio from the S movements, which ought to be, and are, large in the upper trace where Y is small, and small in the lower trace. But, unfortunately, they are masked in the lower trace by the end of the Y movements ; at any rate this is a reasonable interpretation of the trace. In fact, the epicentre is in a particularly favourable azimuth for separating Y from S, and the sentence above quoted from Mr. Richardson's letter takes on a new significance when this is realised. If the azimuth had been nearer 45° or one of the other octants, Y and S might have been mixed up in both traces, and the beginning of Y would probably have been read as the beginning of S. The possible effect of this confusion

on the construction of the tables in use requires very careful considera-
tion, and is an additional reason for deferring the proposal of definitive
corrections.   Indeed, it seems probable that these cannot be made without
a somewhat extensive study of the traces themselves in addition to the
collation of the times published by the various observatories.

There is one further point to be considered—the depth of the focus
below the surface.   If this be at E (see page 73) and $\overline{CEc}$ be the chord
perpendicular to the radius OEK, then all other chords through E are
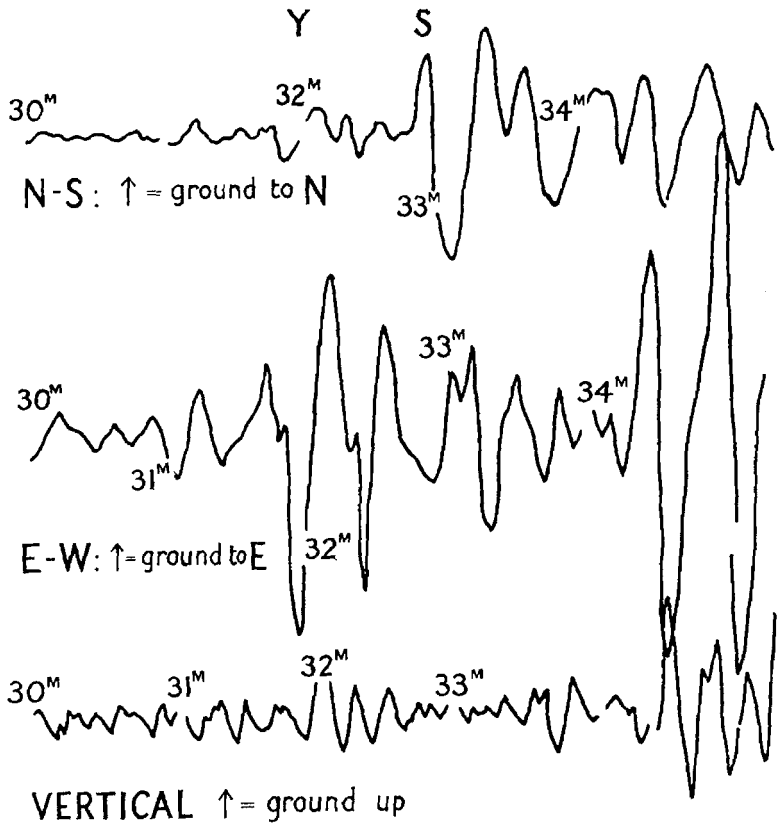
Eskdalemuir, June 25, 1914.

longer than cC, and occur in pairs such as aEA and bEB.   Waves travel-
ling from E by either the path Ea or EB would on reflection travel by
consecutive steps all equal to aA or bB.   Hence, cC represents the mini-
mum step for waves emanating from E, and is larger as E falls further
below the surface.   It seems possible that if E is too near the surface
(or perhaps above it) these nearly tangential reflected waves cannot
occur, and we get no 'polychord' or Y phenomenon.   This may explain
why it has only occasionally attracted notice.   Both the epicentres

above considered are out at sea. It will be interesting to note whether there is a difference between sea and land epicentres in the matter of Y ; but this examination has not yet been made.

In this connection such earthquakes as that of July 4, 1914, may be significant. It is noted in the Shide Bulletin that

a shock at 17 h. 46 m. 30 s. was followed some 100 seconds later by another at another epicentre (12° away) ; but the curious thing is that the nearer stations (Manila, Batavia, &c.) have recorded the second quake and not the first.
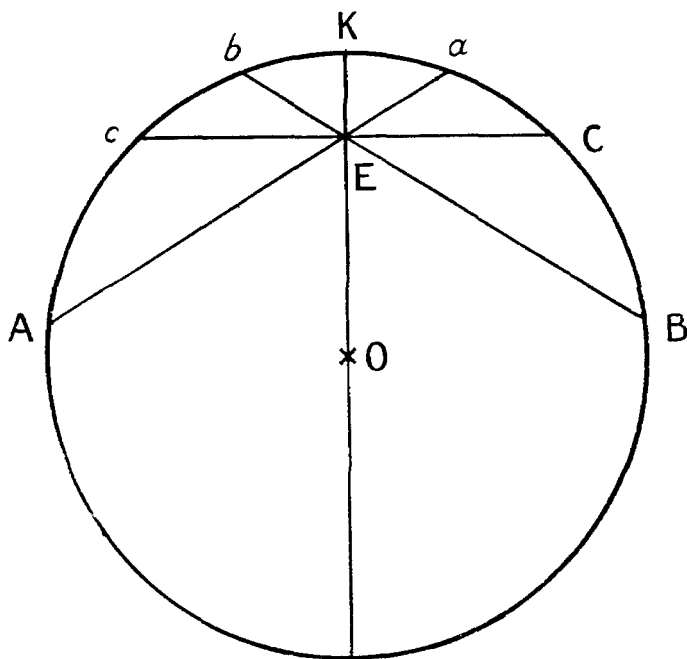
The suggestion now offered is that the first focus was on or even above the surface ; that the path of waves from it has a limiting (minimum) depth, and therefore a limiting (minimum) radius for affected stations, while the second focus was below the surface and was not restricted. If such limits do exist, their application to the possible formation of Y is tolerably obvious.

XI. *Correction of Tables deferred.*

Provisional corrections to the tables for P and S were given at the end of the last Report and are repeated above (p. 67). But the tables printed on the last page of the Shide Bulletins will be used for the present, until a fuller discussion has been made. Meanwhile, the above provisional corrections are made use of in determining epicentres, and they

can be used in studying the residuals. Thus, in the quake of July 4, 1914, the following residuals :

Station.	Machine.	Δ	(O—C) for P.	(O—C) for S.
Graz	W	98·8°	—6 s.	—16 s.
Zagreb. . . .	W	99·4°	—8 s.	—25 s.

are to be considered subject to corrections +19 s. and +41 s. approximately (change sign of tabulated corrections, which apply to the C in O—C). Similarly, those for Pulkovo —9 s. and —28 s. are subject to corrections ($\Delta = 85 \cdot 2°$) + 8 s. and +24 s.

XII. *Shide Bulletins.*

From January 1914 the Shide Bulletins have been arranged with a view to the ultimate discussion of the best material. Earthquakes not observed at many stations appear only on the ' chart' as in the previous year's records ; but for the better observed earthquakes, whereas for 1913 the recorded times were printed without discussion, from January 1914 they have been compared with calculated times. Epicentres were at first adopted from the Pulkovo determination simply ; but as it was found that these were often sensibly in error (owing partly to the errors of the tables) fresh determinations of epicentre have been recently made at Shide.

The preparation of these bulletins has very considerably increased the work at Shide ; but it is hoped that the extra work is profitable.

XIII. *New Method of Computation.*

Some of the labour has been abridged by the adoption of a new method for calculating the distance of a station from an epicentre. If (l, d) be the longitude and latitude of a station, (L, D) those of the epicentre, and if we put

$$a = \cos l \ \cos d \qquad b = \sin l \cos d \qquad c = \sin d$$
$$A = \cos L \cos D \qquad B = \sin L \cos D \qquad C = \sin D$$

then the formula used is

$$2 \text{ versin } \Delta = (a-A)^2 + (b-B)^2 + (c-C)^2.$$

The quantities a, b, c are constants for the stations and have been tabulated. A, B, C are readily formed for each epicentre. A table of squares to 4 figures is amply sufficient to give the $(a-A)^2$, &c., and a table has been formed of 2 versin Δ which saves even the division by 2. A fuller description of the process and the table for 2 versin Δ will be found in ' Mon. Not. R.A.S.,' lxxv. p. 530.

XIV. *Standardizing a Milne-Shaw Seismograph.*

[This section is kindly contributed by the Superintendent of the Meteorological Office. It was written by Mr. L. F. Richardson, of Eskdalemuir, and was completed on September 3.]

This instrument (No. 3) was set up at Eskdalemuir, in July 1915, by Mr. J. J. Shaw. A description of it will be found in Section VI. of this Report.

The pivoted mirror and the link which connects it to the boom are both very light, and in the first instance the instrument has been regarded as a simple boom connected to a massless multiplying device. The theory of such a boom is set out in most text-books on seismology.

The magnification of impulsive horizontal displacements of the ground may be found in two ways :—

(1) The easier way is to obtain it from the period of undamped oscillation, together with the sensitivity to static tilt (' Modern Seismology,' by G. W. Walker, page 23).

According to Mr. Shaw's advice, when observing the period, the damping magnets were entirely removed, not merely tied up to the pillar, lest their weight should bend the latter. The period came to 9·88 secs. for small swings, 10·08 for large ones, and 9·9 has been taken in the subsequent calculation.

The arrangements provided for determining tilt are very convenient. The pitch of the tilting screw, the distances between the feet and the lengths of the path of light, were all measured, and the scale of tilt thus verified to $\frac{1}{2}$ per cent. The sensitivity to static tilt was found to be $6\cdot8_8$ mm. on the paper per 10^{-6} radian. Now the magnification for sudden lateral displacements is

$$\frac{\text{(cms. on paper)} \times 4\pi^2}{\text{(radians tilt)} \times g \times \text{(period)}^2}, \text{ which comes to } 282.$$

(2) As a check, the same magnification was calculated independently from the lengths of the levers and the radius of gyration of the boom about its pivot. In the sketch, BR is the boom pivoted at R. CB is a link, CD a lever pivoted at D, and D is also the mirror. P is the photographic paper.

Lengths of Levers.—The small length CD was measured by a travelling microscope. The distance from the mirror D to the photographic paper was diminished by $\frac{1}{3}$ of the thickness of the cylindrical lens. The length of the equivalent mechanical pointer was taken as $\dfrac{2\,(DP - \frac{1}{3}K)\,(BR)}{CD},$ and came to 30·0 metres. Here K is the thickness of the cylindrical lens.
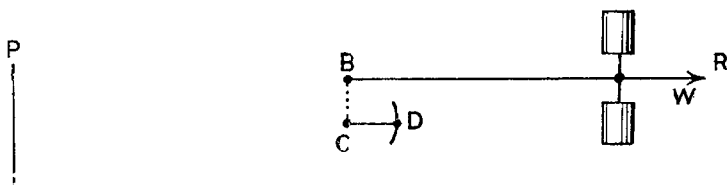

FIG. 1.

Radius of Gyration.—To find this, the moments of inertia about the pivot R of the several parts were measured separately, added up, and divided by the total mass.

The moment of inertia of the boom was found from the position of its centre of mass, together with its period of vibration, when hung up vertically by a short thread attached at W and set to oscillate about a horizontal axis through R.

The heavy dumb-bell shaped mass was at first pivoted upon the boom, as in some Milne instruments ; the intention being to diminish the moment of inertia. The gain in this respect is less than 20 per cent. of the whole moment of inertia of the moving system. On the other

hand, it was found that the freedom of the dumb-bell set up undamped oscillations of the light spot ; so Mr. Shaw clipped the mass rigidly to the boom.   The moment of inertia of the dumb-bell about its centre of mass was measured by hanging up the dumb-bell by a bifilar suspension and observing its time of oscillation.   In this way the radius of gyration l of the whole moving system about the point R was found to be 11·66 cms. The magnification for impulses of lateral displacement is $\dfrac{L}{l} = \dfrac{3000}{11\cdot66} = 257$.

There is an unexplained discrepancy of 10 per cent. between this figure and 282, which might be sought for in the neglected action of the multi-plying lever.   This was not quite perfectly balanced.   In the tilting experiment it remains untilted.

In drawing fig. 2 the mean of 257 and 282 has been used.

Magnification for Long-continued Sinusoidal Waves of Lateral Displacement.—When the period is infinitely short, this is the same as the magnification for impulses.   The diminution of the magnification with increasing period of the earth-wave is determined from the period of the pendulum and the degree of its damping, according to the well-known formula (Walker's 'Modern Seismology,' page 5).   To obtain the damping, a piece of a soft iron nail was attached to the boom.   A small solenoidal coil of wire was fixed on the pillar so that the iron was half inside the coil.   By passing a momentary electric current through the coil the boom was set in motion.   Care was taken that the applied force did not continue for more than a small fraction of the quarter-period of vibration.   As the solenoid had no fixed iron core, there were no after-effects.   As one has to measure the ratio of successive swings, this ratio
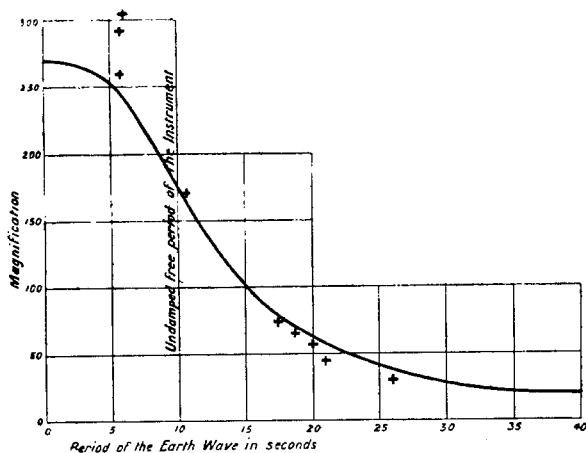

FIG. 2.

Milne-Shaw Seismograph, No. 3.   July 26, 1915.
The full-line curve gives the magnification for long-continued sinusoidal waves of lateral displacement.
Undamped free period of pendulum 9·9 secs.
Damping ratio of successive swings on opposite sides of zero 45 : 1.
The crosses are from the Galitzin instrument.

must not be too large. The measurements were made on the photographic record, and gave 45 : 1 for the ratio of successive displacements on opposite sides of the zero. From these data the curve in fig. (2) was plotted.

Comparison of the Magnification with that of a Galitzin Instrument having Galvanometric Registration.—This was done by selecting a point of time at and near which the natural disturbance was of a regular sinusoidal character on the seismograms of both the Milne-Shaw and Galitzin instruments. The two instruments were in the same room (though on separate piers) and their booms were parallel to one another, so that we may assume that the ground motion was the same for both. The amplitude and period of the Galitzin chart were measured, and from these and from the known constants of the Galitzin instrument the amplitude of the ground motion was deduced. Dividing this quantity by the amplitude on the Milne-Shaw record we get the magnification of the latter instrument. The figures so obtained have been represented by the crosses in fig. 2. The agreement of the crosses, with the curve obtained by consideration of the Milne-Shaw instrument alone, is nearly as good as could be expected, considering the uncertainties involved in measuring the small amplitudes of 1 or 2 mm. on the Milne-Shaw record. The constants of the Galitzin instrument were obtained in May 1915 by the method of tapping the boom (Galitzin's ' Lectures,' ch. vii. § 3) and differ only slightly from those obtained in previous years.

Direction on the Paper.—The boom is suddenly pulled to the west. The light spot therefore moves as if the ground had been jerked to the east. This test is made on every sheet.

Lag of Maximum.—The usual theory of lag begins by assuming that the ground is in a regular and constant state of sinusoidal motion. Each wave is by hypothesis exactly like its neighbours, and therefore it is impossible to distinguish one wave from another, and the lag is indeterminate as to an arbitrary number of whole wave-lengths. This is the only arbitrariness. The theory usually ends, however, in a formula which gives the tangent of the angle of lag, and the angle is therefore unspecified as to a whole number of *half* wave-lengths. On going back and examining the sine and cosine of the angle of lag this uncertainty disappears, in so far as it concerns the phase relations of the quantities represented by the symbols in the theory. But there is still a practical uncertainty of half a wave-length until we have connected the symbols to our practice in reading records, by defining the relation of east and west ground-motion to up and down the record. The definition here adopted is that when all is at rest and the ground suddenly moves, then the initial displacement of the trace on the developed photographic record is conventionally said to be in the same direction as the initial motion of the ground. The actual test is made by pulling the boom in the opposite direction, as stated above.

Now the equation of motion of a ' critically aperiodic ' boom is

$$\left(\frac{d}{dt} + n\right)^2 \theta = -\frac{\ddot{x}}{l}, \quad \ldots \ldots \quad (1)$$

where θ is the angle turned through by the boom.

Here x is the displacement of the ground.

                   n and l are positive constants.

For sudden motions we may neglect n in comparison with $\dfrac{d}{dt}$ and we have left

$$\ddot{\theta} = -\ddot{x}/l.$$

So that the standard relation of signs is $+\theta$ with $-x$.

For very slow motions we may neglect $\dfrac{d}{dt}$ in comparison with n, and we have left

$$n^2\theta = -\ddot{x}/l.$$

Now let $-x = \sin\ pt$,

$$\text{then } \theta = -\ddot{x}/nl^2 = -\frac{p^2}{nl^2}\sin\ pt.$$

Thus θ lags *half a wave-length* behind $-x$. The sign of either side of equation (1) may be changed without affecting this result. Galitzin gives a numerical table for this lag ('Seismometrische Tabellen,' Tabelle VI.), as a function of the degree of damping and of the periods of the pendulum and ground. But as he gives the lag as zero for waves of very long period, instead of half-a-wave as found above, it is clear that he has adopted a different definition of the direction on the paper, and that his definition would give the reversed sign to sudden motions if it were applied to them,
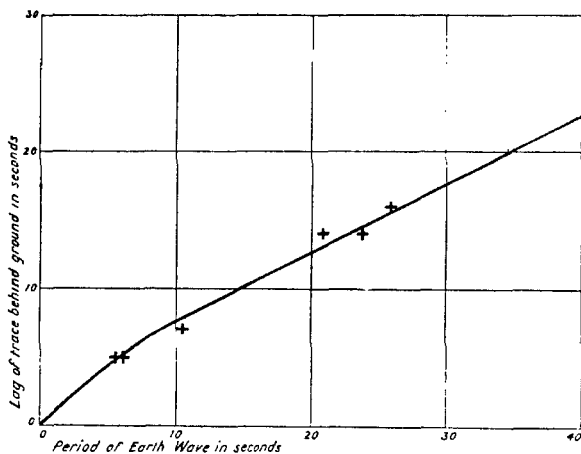

FIG. 3.

Lag of Milne-Shaw Seismograph, No. 3.   July-August 1915.

which probably is not intended.   In preparing fig. 3, the lags in Galitzin's Table VI. have therefore been increased by half the period of the earth-wave.

In order to make an observational comparison between the lag of the Milne-Shaw instrument and that of the Galitzin instrument with galvano-

metric registration, it was necessary to examine the theory of the latter, when the direction on the paper is defined by means of sudden motions from a state of rest. By analysis similar to that given above it may be shown that the numbers for the lag of the galvanometer behind the pendulum, given by Galitzin in his Table VII., are also based on a definition differing by half-a-period from that here taken. So that the sum of the lags given in Galitzin's Tables VI. and VII.—that is to say, the lag of the galvanometer behind the ground—is in agreement with the definition here taken. Of course, it is arbitrary as to a whole number of wave-lengths.

In fig. 3 the crosses indicate the lag found for the Milne-Shaw instrument, taking the lag calculated for the Galitzin instrument as correct.