Seismological Investigations.—Seventh Report of the Committee, consisting of Professor J. W. JUDD (*Chairman*), Mr. J. MILNE (*Secretary*), Lord KELVIN, Professor T. G. BONNEY, Mr. C. V. BOYS, Professor G. H. DARWIN, Mr. HORACE DARWIN, Major L. DARWIN, Professor J. A. EWING, Dr. R. T. GLAZEBROOK, Professor C. G. KNOTT, Professor R. MELDOLA, Mr. R. D. OLDHAM, Professor J. PERRY, Mr. W. E. PLUMMER, Professor J. H. POYNTING, Mr. CLEMENT REID, Mr. NELSON RICHARDSON, *and* Professor H. H. TURNER. (*Drawn up by the Secretary.*)

PLATE I.

CONTENTS.

I. *On Seismological Stations abroad and in Great Britain.*

SEISMOGRAPHS of the type recommended by the Seismological Investigation Committee of the British Association have been constructed for and in most instances are already established at the following stations:—

1.	Africa	Cape Town.
2.	,,	Cairo.
3.	Australia	Melbourne.
4.	,,	Sydney.
5.	,,	Perth.
6.	Azores (2 instruments).	
7.	Canada	Toronto.
8.	,,	Victoria, B.C.
9.	Ceylon	Colombo.
10.	England	Shide, Isle of Wight.
11.	,,	Kew.
12.	,,	Bidston.
13.	Germany	Strasburg.
14.	Hawaii	Honolulu.
15.	India	Calcutta.
16.	,,	Madras, Kodaikanal.
17.	,,	,, Vizagapatam.
18.	,,	Bombay.
19	Java	Batavia.
20.	Japan	Tokio.
21.	Mauritius	Royal Alfred Observatory.
22.	Mexico	Mexico.
23.	New Zealand	Wellington.
24.	,,	Christchurch.
25.	Portugal	Coimbra.
26.	Russia	Irkutsk.
27.	,,	Tiflis.
28.	,,	Taschkent.
29.	Scotland	Edinburgh.
30.	,,	Paisley.
31.	S. America	Cordova (Argentina).
32.	,,	Arequipa.
33.	Spain	San Fernando.
34.	Syria	Beyrut.
35.	Trinidad.	
36.	U.S. of America	Philadelphia.
37.	,,	Baltimore.
38.	Antarctic Regions	ss. 'Discovery.'

The last registers issued by the British Association Committee are Circulars Nos. 4 and 5. These refer to Shide, Kew, Bidston, Edinburgh, Strasburg, Toronto, Victoria (B.C.), San Fernando (Spain), Cairo, Cape of Good Hope, Calcutta, Bombay, Kodaikanal, Batavia, Trinidad, Baltimore, Mauritius, Perth, and Irkutsk. To these is added a list of local earthquakes observed in 1901 in Japan. A register of earthquakes observed by Mr. G. Hogben at Wellington, in New Zealand, commencing October 3, 1900, will appear in the next Circular. It is expected that these will be supplemented by a corresponding register drawn up by Mr. Coleridge Farr, of Christchurch, in New Zealand. Mr. Hogben is inclined to the opinion that many of his records refer to disturbances originating in the Antarctic regions, and these he has arranged to exchange by means of the relief expedition with those which may have been obtained by the landing party from the ss. 'Discovery.'

The last instruments despatched were those sent to Mr. F. A. Chaves, Director of the meteorological station at St. Michael, in the Azores. They left the maker, R. D. Munro, Granville Place, King's Cross Road, London, on May 16 of this year.

II. *The Instruments regularly in use at Shide.*

1. A photographing recording horizontal pendulum oriented north and south. This is the type of instrument similar to those in use at the other stations. It is adjusted to have a period of seventeen seconds, and with this adjustment a 4° turn of the calibrating screw results in a deflection of the outer end of the boom of 14 mm. As in all instruments a 1° turn of the screw causes a tilt of $1''{\cdot}9$, the above adjustment means that a deflection of 1 mm. at the outer end of the boom is equivalent to a tilt of $0''{\cdot}54$. This stands on a brick pier 18 inches square and 4 feet high above its footings, which rest on a beds of concrete above the chalk formation.

When a rope is placed round this column 2 inches below its upper edge, and this is pulled, the deflection of the upper surface of the column is equivalent to $0''{\cdot}095$ per 1-lb. pull.

For certain experimental purposes this adjustment of 14 mm. deflection for 4° turn of the calibrating screw is the one now adopted at Kew, Bidston, and Edinburgh (see p. 75). If the instrument is regarded as a 'steady point' seismograph, and records horizontal motion, such motion is theoretically multiplied 6·7 times.

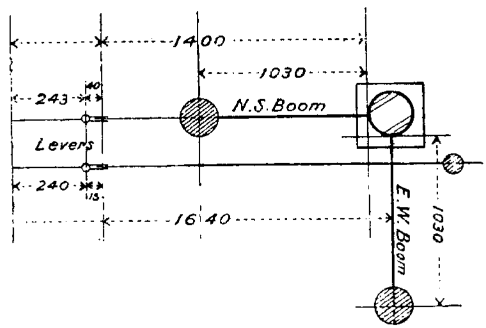
2. A pair of pendulums similar to the above oriented north-south and east-west. This instrument is referred to under the name of its donor, Mr. A. F. Yarrow. The booms of this instrument swing on the same vertical upright. The one recording north-south motion has the same dimensions as those of the type instruments. The other boom, recording east-west motion, is only 5½ inches in length; but there is cranked to it at right angles a light recording pointer, the arrangement being similar to that shown in fig. 1. By this device the records of two components of motion are obtained side by side upon the same band of paper.

This instrument is installed in a building about 50 yards distant from that in which the type instrument is placed. It stands upon a rectangular brick column, the east-west dimension of which is 18 inches, and the north-south dimension is 37 inches. This is 5 feet 3 inches in height above its footings. Its deflection constant, determined as above, is in an east-west direction, 1-lb. pull = $0''{\cdot}14$. In a north-south direction, as inferred from experiments upon other similar columns, the deflection per 1-lb. pull will probably be one quarter of the above, or 0″·035.

3. A pair of horizontal pendulums writing on smoked paper. The booms of these pendulums, which are made of bicycle tubing, are each 1·030 m. in length and carry at their outer ends 80-lb. weights. The vertical support for these pendulums is a lamp-post bedded in concrete. The vertical distance between the top of the ties which carry the weights at the ends of the booms and the points where the inner ends of the booms pivot against blocks attached to the lower part of the lamp-post is 7 feet 11½ inches. As at present adjusted a motion of the outer end of the boom oriented north-south is by means of a light lever multiplied six times, whilst the movement of an arm cranked to the east-west boom is by a similar arrangement multiplied sixteen times.

A plan of the arrangement is shown in fig. 1. The dimensions are in millimetres.

FIG. 1.—Measurements in Millimetres.



From these dimensions it follows that if each boom were tilted equally the diagram for the north-south boom should be 3·1 times greater than that given by the east-west boom.

If the weights carried by the boom be regarded as centres of oscillation the multiplication of horizontal motion can be calculated from the dimensions given in fig. 1.

This instrument takes the place of a pair of horizontal pendulums which carried weights of 10 lb. This instrument, a spiral spring seismograph, and a large balance arranged to record tilting, which are referred to in the Report for last year, are no longer in use. The character of the records obtained from the last two of these instruments is referred to on pp. 70 and 71.

III. *The Records of the Years* 1899, 1900, *and* 1901.

In the Report of the British Association for 1900, on p. 70, a map is given showing the origins from which the earthquakes recorded in Britain during the year 1899 had radiated. These origins were determined by methods explained on pp. 79 and 80 of that report. The accompanying map, fig. 2 (Plate I.), gives a similar distribution—each earthquake being referred to by its numbers in the Shide register—for the records obtained in the years 1900 and 1901. An attempt has been made to place these earthquakes in groups, each group being enclosed by a dotted line. Altogether there are twelve such groups which on the map are indicated by the first twelve letters of the alphabet. A glance at this map shows that certain of these groups, like B and C, overlap, whilst there are many instances where origins are placed outside the boundaries of any of the groups. It is therefore likely that when the data on which these groupings are based become more complete the same will be subjected to modifications. The large numerals indicate the number of earthquakes which originated in the districts marked A, B, C, &c., in the years 1899, 1900, and 1901. The notched bands give the direction of prominent ridges on the face of the globe, whilst the dotted areas are the 'deeps' or depressions in the beds of various oceans exceeding 3,000 fathoms in depth.

That there is a relationship between the distribution of the origins of large earthquakes and the pronounced irregularities on the surface of the earth will be seen from the following notes.

A. *Alaskan Region* (number of earthquakes 25).—The average depth of the water in this bight is about 2,000 fathoms, but in its northern part depths of 2,200 fathoms have been found within sixty miles of the shore. On this shore Mount St. Elias rises to a height of 18,000 feet. An average slope from the land to the sea on a north south line can be found which exceeds 100 feet per mile. This is over a distance of 180 miles.

On the face of this and neighbouring slopes during the last three years it is probable that molar displacements of great magnitude have taken place. On September 10, 1899, in the island of Kanak, opposite Yakuta, a graveyard sank so that on the next day a boat was able to row over the place where it had been, and the tops of the submerged trees could be seen. Many of the earthquakes from this region have yielded large seismograms at the Cape of Good Hope, which is antipodean to Alaska. We have here a district partly belonging to the Alutian ridge, off the southern shores of which within eighty miles of land depths of 4,000 fathoms have been noted, where orogenic processes are now marked the extent of which will probably be gauged by future soundings.

B. *Cordillerean Region* (number of earthquakes 14).—This region forms the western side of the Mexican plateau and the Cordilleras. Just south of the 20° parallel a depth of 2,800 fathoms has been found within forty miles of the shore, whilst depths exceeding 2,000 fathoms have been found a little over 100 miles from the land, somewhat farther to the south. Although there are peaks in these regions rising to heights close upon 18,000 feet, the average height of the ranges does not greatly exceed 6,000 feet. There are, therefore, in this region slopes of 180 to 570 feet per mile, and the instability of these is testified by the frequency of their yieldings.

C. *Antillean Region* (number of earthquakes 16).—Here we have at least two ridges to consider—that of Cuba, Haiti, and Puerto Rico running east and west, and that of Grenada, St. Vincent, Martinique, Dominica, and other islands running north and south. The east-west ridge slopes steeply to the north into water which north of Puerto Rico attains a depth of 4,000 fathoms, and to the south into water 2,500 fathoms in depth. These depths are respectively found at distances of sixty and forty miles off land and indicate slopes of 400 and 375 feet per mile. With the north-south ridge the slopes to the west over a short distance like twelve miles is 1,000 feet per mile, whilst to the eastwards it is comparatively gentle. If these gradients be measured in lengths of 200 miles the slopes are about 70 feet per mile.

D. *Andean District* (number of earthquakes 12).—At many points on the west coast of South America, within fifty miles of the shore, depths of from 2,000 to 4,000 fathoms occur, which correspond to gradients of from 250 to 480 feet per mile. Within a distance of 150 miles from the shore the land rises to a height of 12,000 feet, so that the gradients from them to the bottom of the neighbouring ocean may be taken at 120 to 180 feet per mile.

E. *Japan District* (number of earthquakes 29).—To the east of Northern Japan and the Kuriles, at a distance of about 180 miles off shore, depths of 4,000 and even 4,600 fathoms are found, indicating gradients of 130 to 150 feet per mile, and from observations made in Japan it is known that many of the large earthquakes originate on the face or at the bottom of these slopes.

F. *Javan District* (number of earthquakes 41).—Off the south-west coast of Sumatra and the south coast of Java, at distances of from eighty to 100 miles, depths of from 2,000 to 3,000 fathoms occur. The straits on the opposite shores of these islands are shallow, seldom exceeding thirty fathoms. Eastwards, from Java as far as Ceram, soundings between 1,000 and 2,000 fathoms are frequent. At one point fifty miles south of the latter island there is a depth of 4,000 fathoms. From this particular 'deep' on September 29, 1899, a displacement took place the effects of which were partially visible by subsidences on the southern coast of Ceram. In this district the sub-oceanic irregularities in contour are as irregularly distributed as the islands which form their outcrops.

G. *Mauritian District* (number of earthquakes 17).—The origins for this group of earthquakes are not well defined. They are probably related to the depression lying between the ridges represented by the Laccadives and Maldives on the east, and the Seychelles and Mascarine Islands to the south-west.

H. *North-eastern Atlantic* (number of earthquakes 22).

I. *North-western Atlantic* (number of earthquakes 3).

J. *North Atlantic* (number of earthquakes 3).

The earthquakes originating in these districts have been few in number, comparatively small, and their origins are not well defined. Although a ridge is marked as extending up the Atlantic, it is comparatively small, and even in the vicinity of the Azores it is difficult to find a gradient over a distance of 180 miles which exceeds 33 feet per mile.

K. *Alpine, Balkan, Caucasian, Himalayan Districts* (number of earthquakes 14).—Strictly speaking this region, which is the only one from which earthquakes originate on a land surface, might be divided into four or more sub-regions according to the direction of the strike of the ridges which each represents.

The most pronounced foldings are in the eastern part of these districts where in distances of 100 miles gradients of 120 feet per mile can be found, and it is from these steep slopes that the larger earthquakes have originated

IV. *Duration of the First Preliminary Tremors.*

In seismograms from the Milne horizontal pendulum the first preliminary tremors, which usually appear as a thickening of the normal trace, are only seen in connection with fairly large disturbances. The reason for this is at least twofold: first, as a recorder of elastic vibrations the multiplication of the instrument is low, with the result that when these vibrations are minute they may be lost in the thickness of the trace; and second, because as the recording surface only moves at a rate of 1 mm. per minute it is difficult to measure very small intervals of time. For 'near' earthquakes, therefore, the seismograms usually show a disturbance commencing suddenly, and the duration of the preliminary tremors connected with the same can only be inferred by the continuation of the curve of the durations of the movements as recorded at distant stations backwards towards its origin. It is satisfactory to notice that these inferred durations closely agree with actual measurements of the same made by seismographs adapted to record 'near' earthquakes.

The following four tables give the durations of preliminary tremors in minutes for earthquakes originating near Japan, Mexico, Alaska, or in the East Indies as recorded at Shide, Kew, Toronto, Victoria (B.C.), Bombay, Batavia, Mauritius, Madras, and the Cape of Good Hope.

The number following a duration and placed in parenthesis is the number of the earthquake as entered in the Shide register. For districts see map, fig. 2 (Plate I.).

Origins West of Alaska (District A).

Victoria, B.C.	Distant 20°	Durations 3 (344), 2 (345), 7 (454).
Toronto	„ 40°	„ 5 (282), 8 (309), 6 (333), 6 (337), 7 (341), 5 (442), 10 (454).
Shide, I.W.	„ 70°	„ 11 (282), 5 (333), 6 (341), 8 (344), 8 (442), 8 (454).
Kew	„ 70°	„ 8 (333), 7 (337), 9 (338), 10 (442).
San Fernando (Spain)	„ 77°	„ 9 (309), 9 (337), 9 (442).
Bombay	„ 100°	„ 10 (309), 10 (454).
Batavia	„ 108°	„ 9 (454).

Origins in or near Mexico (Districts B and C).

Victoria, B.C.	Distant 30°	Durations 6 (381), 4 (445), 4 (447), 4 (472), 7 (483).
Toronto	„ 34°	„ 5 (250), 3 (294), 6 (381), 6 (407).
		„ 5 (415), 3 (422), 5 (445), 4 (447), 4 (455), 7 (472).
Shide, I.W.	„ 84°	„ 13 (157), 4 (189), 9 (215) 10 (248), 8 (294), 10 (407), 10 (455)
Kew	„ 84°	„ 9 (250), 10 (381), 11 (407), 9 (445), 10 (455).
San Fernando (Spain)	„ 86°	„ 10 (294), 10 (381), 7 445).
Cape of Good Hope	„ 138°	„ 8 (445).
Bombay	„ 148°	„ 10 (483).
Batavia	„ 150°	„ 8 (483).

Origins near Japan (District E).

Victoria, B.C.	Distant 60°	Durations 8 (364), 8 (514), 8 (516).
Bombay	„ 65°	„ 9 (364).
Shide, I.W.	„ 87°	„ 8 (317), 10 (366), 7 (405), 10 (450), 10 (514), 10 (516)
Kew	„ 87°	„ 10 (514).
Toronto	„ 90°	„ 9 (364)

Origins are indicated by their B.A. Shide Register number, and Observing Stations by dots. Earthquake districts are indicated A, B, C, &c., and the number of earthquakes which originated from these districts since 1899 is expressed in large numerals. Ridges. Deeps.

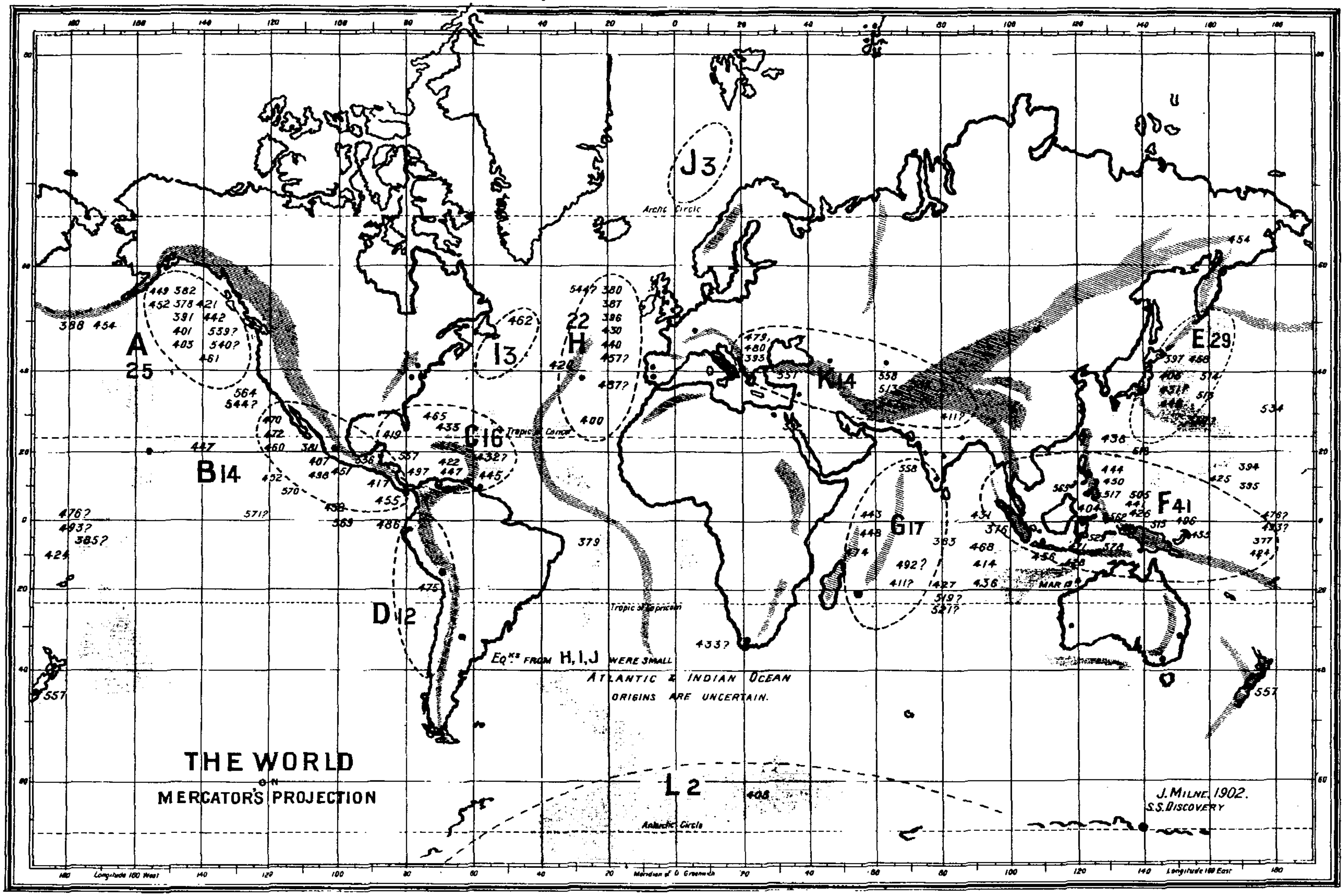


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Fig. 2. *Illustrating the Report on Seismological Investigation.*

Origins in the East Indies (District F).

Batavia . . .	Distant 22° .	Durations 5 (441), 10 (505).
Bombay . . .	" 62° .	" 8 (347), 10 (435), 7 (505).
Mauritius . .	" 73° .	" 10 (324).
Cape of Good Hope	" 105° .	" 12 (377).
Victoria, B.C. . .	" 105° .	" 10 (324), 9 (347), 8 (354) 9 (377).
Shide, I.W. . .	" 121° .	" 7 (133), 4 (134), 10 (324), 5 (347), 10 (355), 12 (404), 13 (460).
Kew	" 121° .	" 14 (505).
Toronto . . .	" 136° .	" 10 (324).

Average values for the above durations which represent the intervals in minutes by which the preliminary tremors have outraced the second phase of motion at distances of 20, 30, 40, 50, 60, 70, 80, 90, and 100 degrees from their origins are, 4, 4·5, 6·5, 7·2, 8, 8·5, 9, 9·5, and 9·7 minutes. The materials to continue plotting the curve represented by these figures, which is shown in fig. 3, indicate that ten minutes is approximately the limit by which the second phase of motion is outraced by the preliminary tremors, and this limit is reached at a distance of ninety to 100 degrees from an origin.

V. *Time Curves for the Earthquakes recorded during four years ending in* 1900.

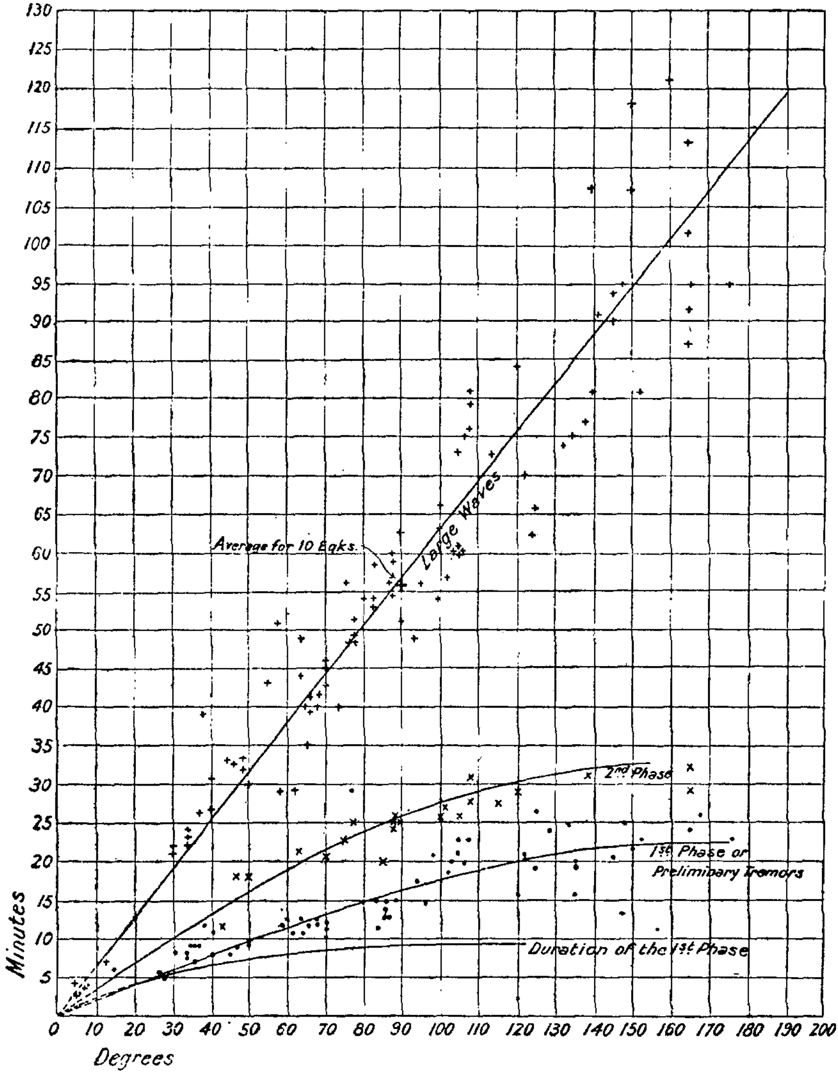
In the British Association Report for 1900, p. 67, time curves for the large waves and preliminary tremors of earthquakes recorded at long distances from their origins are given. These curves are based upon records obtained from Milne horizontal pendulums prior to the year 1900. In fig. 3 similar curves, together with a curve for the second phase of earthquake motion, are given for observations made in 1900. The curve for the second phase of motion, which corresponds to a curve given by Mr. R. T. Oldham,[1] was obtained by adding the time ordinates of the lowest curve in this figure, discussed in the previous section, to those of the time curve for the preliminary tremors. It is of interest to note that this curve would closely correspond with a curve representing the mean position of the signs × which are direct measurements of the time taken by the second phase of motion to traverse varying distances, and are not included in the materials upon which the lowest curve is based.

The individual observations relating to large waves are indicated by small crosses (+), whilst those referring to the preliminary tremors are marked by small circles. It is clear that the concordance between these and their average position as represented by the curves is not so close as could be desired. They do not dispose of the indication based on prior observations that the apparent velocity of large waves is not uniform, but may be at its maximum in quadrantal regions. Also, as has been shown in the time curves published in 1900, we see that the apparent velocity of preliminary tremors may also be increased in regions 60° to 90° from their origin.

Dr. C. G. Knott writes about these observations as follows :—'The other day I took another and more careful look at your curves, and I must confess that they bear out your old view of the large waves being surface waves better than anything else. The large wave curve is a straight line,

[1] *Phil. Trans. Roy. Soc.*, p. 163.

FIG. 3.—Time curves for earthquakes recorded between 1896 and 1900 inclusive.



First phase or preliminary tremors • Second phase × Large waves +

and though we could formulate a law which would make through-earth waves reach the different points of the surface in times proportional to the arcs, yet it would be a most complicated and improbable law. There is no doubt the surface run fits in admirably. I always had great difficulties about it, but "facts are chiels that winna ding," and the most obvious interpretation of your curve is your old view of surface waves. I never could bring myself to believe in the transition of such small oscillations through the heterogeneous crust. It is conceivable, however, that what we observe may be the outcrop of waves running over the surface of the inner more homogeneous nucleus. This may not be necessary. Meanwhile I am compelled to withdraw my antagonism to the surface wave.

'The preliminary tremor curve fits to within the errors of observation the formula time ∝ chord.

'The chord is proportional to sine of half the angle. Tabulating we get :—

Arc	Time observed / Time to Antipodes	Sin ½ Arc	Time observed / Time to Antipodes
20	·17	·174	·20
30	·26	·259	·30
40	·35	·342	·39
50	·44	·423	·487
60	·51	·500	·57
70	·58	·574	·65
80	·64	·643	·72
90	·70	·707	·78
100	·76	·766	·83
110	·82	·819	·87
120	·87	·866	·91
130	·91	·906	·94
140	·95	·940	·96
160	·98	·985	·99

'The fourth column gives the same comparison for the second curve, what you call the second phase. In calculating the ratios of the times I take 23 minutes to be the time to the antipodes in the case of the first phase and 33·5 minutes for the second phase.

'You will see how admirable the agreement is for the first phase. But it is not so good for the second phase. The first phase runs at practically the same rate along the chords. The second phase seems to run a little more quickly the deeper they go.'

Tables of apparent velocities based on observations prior to the end of 1896 are given in the 'British Association Report' for 1897, p. 173. These are discussed in the Report for 1898, p. 221, where a table shows that the apparent *arcual* velocity for preliminary tremors varies with the square root of the average depth of the chord. In the report for the following year, p. 231, the preliminary tremors are referred to as passing *through* the earth with an average velocity which increases with the square root of the average depth of the chord along which they are assumed to travel. Whilst pointing out the inaccuracy of this reference, it must also be observed that the variable velocity it implies is not sustained by observations here published.

VI. *On the Comparison of Records obtained from three Horizontal Pendulums at Shide, the Natural Periods of which have from time to time been altered.*

The instruments referred to are the photographic recording pendulums described on p. 60. Their records are compared in the following table. The type of pendulum which records east-west motion is referred to by the letter A. The pendulum with the short boom, also recording east-west motion, and forming part of the Yarrow instrument, is referred to as B, whilst the north-south boom of the same is called C.

Pendulum A has been kept with a period of 17 seconds, whilst the periods of B and C have from time to time been changed.

The numbers in the first column refer to different earthquakes recorded between January 1 and June 30, 1902, as entered in the Shide Register (see Circular No. 6). In the next three columns are the differences in minutes at which A, B, and C respectively commenced to move.

The first entry for Earthquake No. 572 means that A and B show commencements of movement 4 minutes later than C, beneath which there is a zero.

Amplitudes are also referred to under three columns marked A, B, and C. They indicate half the complete range of the maximum motion. Values less than one millimetre refer to the thickening of the line, and indicate half its width.

Durations of the different earthquakes are given in the last three columns. They are expressed in minutes :—

—	Differences in times of Commencement			Amplitudes			Durations		
	A	B	C	A	B	C	A	B	C
Periods . .	s. 17	s. 17	s. 18	s. 17	s. 17	s. 18	s. 17	s. 17	s. 18
	M.	M.	M.	MM.	MM.	MM.	M.	M.	M.
572	4	4	0	1·0	2·0	3·0	115	140	180
573	5	5	0	0·25	0·25	—	5	10	—
574	0	8	6	0·5	0·5	1·0	70	60	65
575	—	not visible		0·25	not visible		10	—	—
576	1	0	0	0·5	0·25	0·25	38	10	45
577	0	1	1	0·25	0·25	0·25	8	5	5
578	97	0	0	0·25	0·5	0·5	45	120	120
579	—	not working		0·25	—	—	5	—	—
580	0	1	1	0·25	0·5	0·5	25	35	35
581	0	3	3	0·5	2·0	2·0	120	230	150
582	0	2	13	0·25	0·5	0·25	45	50	20
583	9	3	0	0·5	0·75	1·0	45	45	55
Periods . .	s. 17	s. 10	s. 10	s. 17	s. 10	s. 10	s. 17	s. 10	s. 10
584	0	3	3	1·0	0·5	0·6	80	65	60
585	0	41	1	1·0	0·25	0·4	60	20	60
586	—	air tremors		0·5	—	—	100	—	—
587	—	,,	,,	0·5	—	—	90	—	—
588	2	0	0	2·0	1·0	1·0	70	60	60
589	—	not working		1·0	—	—	90	—	—

—	Differences in times of Commencement			Amplitudes			Durations		
	A	B	C	A	B	C	A	B	C
Periods	s. 17	s. 12	s. 16	s. 17	s. 12	s. 16	s. 17	s. 12	s. 16
590	7	0	47	0·25	0·25	0·25	44	10	15
591	0	16	58	0·25	0·25	0·25	5	5	5
592	18	0	9	0·5	0·25	1·0	25	30	40
593	9	0	15	0·75	0·5	1·0	90	120	120
594	13 ?	0	0	—	0·25	0·25	—	10	10
595	0	11	air trems.	0·25	0·25	—	25	5	—
596	51	0	46	0·25	0·25	0·25	30	35	120
597	0	3	0	0·5	0·25	0·25	25	5	7
598	0	9	air trems.	0·25	0·25	—	10	5	—
599	6	10	0	1·0	0·75	2·5	50	35	75
600	9	not visible	0	0·25	not visible	0·25	20	—	30
601	37	0	40	1·0	1·2	1·2	140	140	165
602	not visible	—	not visible	—	0·25	—	—	7	—
603	"	—	faint	—	0·25	—	—	5	—
604	0	0	"	0·25	0·25	—	5	5	—
605	3 ?	faint	0	0·5	—	0·75	65	—	85
606	0	0	0	6·0	2·5	8·0	180	90	180
Periods	s. 17	s. 17	s. 12	s. 17	s. 17	s. 12	s. 17	s. 17	s. 12
607	0	32	not visible	0·25	1·0	not visible	5	12	—
608	0	0	faint	1·0	0·75	0·25	40	40	—
609	0	1	6	1·7	1·0	0·25	72 to 85	28	12
Periods	s. 17	s. 20	s. 10	s. 17	s. 20	s. 10	s. 17	s. 20	s. 10
610	0	3	not visible	0·5	0·5	—	20	20	—
611	3	air trems.	0	0·75	—	0·5	35	—	12
612	2	0	2	1·0	1·5	0·5	40	40	25

When examining the above table it must be remembered that pendulum C is oriented at right angles to A and B, that the stiffness of the column carrying A is slightly greater than that carrying B, and also that these two pendulums have not always been so adjusted as to have the same sensibility to the effects produced by tilting. It must also be borne in mind that preliminary tremors are but small movements, and their visibility will vary with the width of the photographic trace, whilst many of the entries referring to amplitudes of 0·25 millimetre are markings so slight that they might easily escape detection.

When the periods of A and B were 17 seconds (572 to 583 and 607 to 609) out of thirteen records, the differences in time at which these instruments commenced to record did not exceed 1 minute in seven cases, and there are two cases where the differences are 2 and 3 minutes. In the remaining four cases the differences are respectively 8, 97, 6, and 32 minutes. When the period of B was changed to 10 and then to 12 seconds, it seems to have been, out of eighteen cases, a matter of chance as to which of the two pendulums first responded to the movement of the ground. Twice they commenced simultaneously, and three times the difference in the commencements was from 2 to 3 minutes. In all other instances these differences are large. The times at which pronounced phases of movement have taken place—for which tables are not given—are practically identical for all the pendulums.

In comparing amplitudes when the periods of A and B were equal (17 sec.), the amplitudes were either equal to each other or that for B was larger by 0·25 mm. The only exceptions are for Earthquakes 608 and 609.

When B was reduced to 10 and then to 12 seconds the amplitudes were for all the larger disturbances, excepting 601, distinctly smaller than those recorded by A. In other instances, relating to small earthquakes, these displacements were equal.

A similar relationship between amplitude and period is seen when comparing C and B.

This result is one which does not accord with the result of a somewhat similar experiment made by Dr. F. Ōmori, whilst it does accord with the hypothesis that the large waves of earthquakes traverse the surface of the earth in undulations.

With equal periods for A and B, generally the latter was caused to move for a longer time than the former, whilst when B was rendered more stable this result was usually reversed. This again suggests that the movements recorded are accompanied by tilting.

VII. *Clinometric Experiments.*

In 1891, whilst resident in Japan, I designed a clinometer to record the tiltings of the ground which take place with severe earthquakes within two or three hundred miles of their origin. The chief feature in this instrument was a balance beam loaded at its extremities, which when its frame was tilted in a direction at right angles to its length was assumed to retain its horizontality. A pointer like that of an ordinary balance attached to this beam acted as a steady fulcrum for the short arm of a lever, the outer end of which rested on a smoked-glass surface.

This is described, and illustrations of its records are to be found in the 'British Association Report for 1893,' and in the 'Seismological Journal,' ii. p. 103.

In 1900 and 1901 at Shide, in the Isle of Wight, I set up a similar but much larger clinometer, with the expectation that it would give some definite information about the so-called large waves which are assumed to accompany large earthquakes when they have radiated to great distances. This 'experiment,' which is referred to in the 'British Association Report' for 1900, p. 83, consisted in observing the movements of a pointer attached to the earth relatively to a pointer, 4 feet in length, attached at right angles to the beam of a balance, the arms of which were 5 feet in length, and each carried a load exceeding 30 lb. Any relative movement of these pointers was shown by the displacement of a spot of light reflected from a mirror hung by a bifilar attachment between the two pointers. Subsequently the record was made mechanically.

With the first installation 1 mm. deflection = 0″·7, and in the second 6″·0.

Although several large earthquakes took place, no record was obtained.

About the same time Dr. Wilhelm Schlütter (see his 'Inaugural Dissertation,' Göttingen, 1901) experimented with a balance form of clinometer. The records were photographic, but his photograms failed to give any trace of twenty earthquakes recorded by seismographs.

VIII. *Experiments with a Vertical Spring Seismograph.*

With the object of at least detecting the vertical component of the large waves which accompany unfelt earthquakes, in March 1901 I suspended from the wall of my laboratory an ordinary spiral spring, 1 inch in diameter, which, under the influence of a load of 1 lb. 8 oz. and its own weight, was 3 feet 5 inches in length. Its period was then 2 seconds. By the rising or falling of the weight a small mirror was caused to rotate, which displaced a spot of light it reflected upon a moving photographic surface.

'The earthquake of October 9, 1900, caused ripples on the photogram each about 0·5 mm. in range, which would correspond to a change that might have been produced by increasing and decreasing the load by $\frac{1}{700}$ part of itself. The period of motion was approximately 6·5 minutes, which corresponded with the period of maxima in the large waves as in an ordinary seismogram.

The Venezuela earthquake of October 29 gave deflections of half the above, and with periods of about 7 minutes. Other earthquakes caused somewhat similar movements, but usually nothing more than slight blurs upon the photographic traces were to be seen.

The records from the clinometer indicate that earth tilting has not been measurable by the instrument employed, whilst the records from the spiral spring show that there is a possibility that vertical motion may exist, but if it does it is exceedingly minute.'

IX. *On the Nature of Earthquake Movement as recorded at a great distance from its origin.*

In an article in 'Nature,' January 2, 1902, p. 202, after epitomising the various observations which have been made in connection with the large waves of earthquakes, it is said that

'The general inference is that the large waves due to earthquakes originating at a distance, whether they are surface waves or mass waves, actuate horizontal pendulums by horizontal displacements of the ground, rather than by the tilting of the same.'

Observations which support this view are as follows :—

1. Clinometers have hitherto failed to detect any tilting effects.

2. If it is assumed that the records of horizontal pendulums give angular values for tilting, and from the period of the waves causing these tiltings and the velocity with which these waves are propagated on the assumption of simple harmonic motion we calculate their length, we have

all the elements which are required to calculate the heights of these waves.[1] Now these heights are frequently as much as 1 or 2 feet, and apparently represent accelerations $\frac{1}{50}$ of gravity. The magnitude of these quantities is certainly sufficient to create a suspicion that the angular values assigned to large waves has hitherto been exaggerated.[2]

3. The slight evidence of vertical displacements afforded by the experiments described on p. 70.

4. Dr. F. Ōmori's observation that the amplitude of seismograms is not dependent upon the sensibilities of the seismographs to tilting suggests that the movements represented by large waves are horizontal rather than undulatory.

5. The smallness and paucity of records obtained from bifilar pendulums.

On the contrary, observations which support a surface undulation hypothesis are the following :—

1. Surface undulations exist in epifocal districts, and these by the movement of water in ponds and lakes, the movements of the bubbles of spirit levels, the apparent movement of stars in the fields of telescopes, and by other phenomena, have been detected in districts many hundreds of miles beyond the epifocal area.[3]

2. The approximately constant velocity of propagation assigned to large waves (see pp. 65 and 67).

3. Observations which show that the magnitude of a seismogram is dependent upon its sensibility to tilting, p. 70. This conclusion is apparently contrary to that arrived at by Dr. Ōmori.

4. The indications of a vertical component of motion, which have been recorded, p. 71.

With these latter observations before us, it seems reasonable to conclude that the large waves of earthquakes have an undulatory character, but the tilting involved is not so great as generally supposed, and in this sense the above quotation from 'Nature' requires correction.

In the seismograms of a large earthquake we have the records of at least two, and probably three, types of movement, and the manner in which they are presented to us depends upon the character of the instrument by which they were recorded. An ordinary *long* period horizontal pendulum shows the preliminary tremors, which are regarded as compressional waves, which have passed through the earth to be recorded as ripples with a small amplitude ; whilst the large waves, which are assumed to be very flat undulations passing round the earth in or beneath its crust, are shown as large displacements, which are magnified effects due to very slight tilting.

The same disturbance recorded by an apparatus, the natural period of which is *short*, but which is provided with indices having a high multiplication, gives records in which the preliminary tremors are large, whilst the large waves are small, if not entirely absent.[4]

X. *Relationship between Rockfolding, Seismic, and Volcanic Activities.*

Lyell remarks in his 'Principles of Geology,' vol. ii. p. 177 (12th edition), that near the Bay of Naples there appears to be a connection

[1] *Brit. Assoc. Rep.*, 1898, p. 206.
[2] *Ibid.*, 1900, p. 83.
[3] *Ibid.*, 1898, p. 219 ; also 1900, p. 73.
[4] *Ibid.*, 1898, p. 263.

between movements of upheaval and a local development of volcanic heat, whilst periods of depression have been concurrent with periods of volcanic quiescence. A glance at the map, fig. 2 (Plate I.), shows that the districts from which large earthquakes originate, or earthquakes which are accompanied by molar displacements, are those in which geological observations indicate that the land surfaces exhibited as ridges have recently been elevated and where history indicates that elevation is yet in progress.

When this elevation takes place in a ridge, it seems likely that its bounding furrow or furrows should be deepened, and direct evidence that this is the case is sometimes to be found in the records of soundings taken before and after great earthquakes. These records give some idea of the magnitude of the sudden changes in configuration which take place in ocean beds, whilst the dynamical efforts which accompany the same are seen in the disturbances caused in oceanic water and the propagation of vibrations from their origin to their antipodes. Another effect which may accompany these sudden adjustments is to relieve volcanic strain, and no better illustration of this can be found than in the volcanic history of the Antilles, which is briefly as follows :—

1692. Port Royal, in Jamaica, destroyed by an earthquake and land sank beneath the sea. St. Kitts erupted.

1718. Violent earthquake in St. Vincent, accompanied by an eruption.

1766–67. Violent earthquakes in the N.E. of South America, Cuba, Jamaica, and many of the West Indian islands. An eruption in St. Lucia.

1797. February 7.—40,000 lives were lost in Quito. There were also shocks in the Antilles. Eruption in Guadeloupe.

1802. Severe shock in Antigua. Eruption in Guadeloupe.

1812. Caraccas ruined by an earthquake. November 11, 1811, violents shocks commenced in the Southern States of North America. Eruptions in St. Vincent and Guadeloupe.

1835–36. Violent earthquakes in Chili and Central America. Eruption in Guadeloupe.

1902. April 19.—Large earthquake in Central America, by which towns were destroyed. About this date Mt. Pelée, in Martinique, smoked and rumbled. May 3 it erupted. Cables were broken and the sea receded on this date, and was again disturbed on the 8th, 19th, and 20th. May 7, eruption in St. Vincent. Other cables were interrupted. May 8, violent eruption of Mt. Pelée. With these eruptions there were many small earthquakes.

Practically, therefore, we see that every volcanic eruption in the West Antilles has been connected with some sudden geotectonic change in its own or in a neighbouring ridge.

The small earthquakes, of which there may be 30,000 in the world per year, do not hold any appreciable relationship to the volcanic activity of the districts in which they occur.[1]

XI. *On the Comparison of Earthquake Registers from Shide, Kew, Bidston, and Edinburgh.*

In the 'British Association Report,' 1901, pp. 44–50, reference is made to a series of earthquake records obtained in the early part of 1901 at Kew, Shide, Bidston, and Edinburgh. These registers and their continuations to the end of that year will be found in the British Association Circulars Nos. 4 and 5. The following comparisons of the records

[1] See *Nature*, May 29 and June 11, 1902.

from the above four stations, which are respectively situated on alluvium, chalk, new red sandstone, and a Palæozoic felstone, with the exception of the month of July, when the instrument at Bidston was not working, relate to the remaining eleven months of the year 1901.

Earthquake Frequency.

At Kew	73	records	were	obtained,	63	of which	were noted	at other	stations.
At Shide	107	,,	,,	,,	90	,,	,,	,,	,,
At Bidston	133	,,	,,	,,	94	,,	,,	,,	,,
At Edinburgh	94	,,	,,	,,	85	,,	,,	,,	,,

Earthquake Duration.—During the period under consideration fourteen large earthquakes were recorded at each of the four stations, and were also recorded at many other stations throughout the world. The total number of hours and minutes during which the instruments at the four British stations were caused to move by these disturbances were as follows :—Kew, 27 h. 40 m. ; Shide, 31 h. 56 m. ; Bidston, 30 h. 25 m. ; Edinburgh, 31 h. 59 m.

Amplitudes.—For the above fourteen earthquakes the sum of the amplitudes in millimetres recorded at the four stations were as follows :—Kew, 42·8 mm. ; Shide, $>$58·4 mm. ; Bidston, 56·7 mm. ; Edinburgh, 40·7 mm.

The inferences to be drawn from the above three analyses are by no means clear.

The Frequency Table apparently shows that at Shide and Bidston more earthquakes can be recorded than at Edinburgh and very many more than can be recorded at Kew. Reference to the registers of these four stations shows that the omissions in the Edinburgh and Kew lists relate to earthquakes which were comparatively feeble.

Not only are the records at Kew few in number, but the duration of a given set of earthquakes as recorded at that station is shorter than the duration of the same set of earthquakes as recorded at other stations.

A much more marked difference between these four sets of records is to be seen in the Table of Amplitudes, which it must be noted have been entered as horizontal displacements. From these records the inference is that the extent of movement at Edinburgh and Kew is much less than it is at Shide and Bidston. Inasmuch as the foundations at the first two mentioned stations are respectively harder and very much softer than the foundations at the two second stations, it seems improbable that the differences in amplitude here recorded are to be altogether attributable to the geological character of the materials on which these four stations are situated.

A more likely cause resulting in these apparent differences in amplitude, and we may add also the differences in durations of movement and number of records, is to be found in differences in the sensibilities of the instruments at the four stations.

If as a measure of the sensibility of an instrument we take the angle through which the bedplate of the same has to be tilted to produce a deflection of one millimetre of the outer end of the boom which it carries, then the sensibilities of the instruments at the four stations under consideration have been as follows :—

At Kew	the sensibility has varied from 0″·7 to 0″·8, average 0″·75.
At Edinburgh	,, ,, been 0″·71.
At Shide	,, ,, ,, 0″·47.
At Bidston	,, ,, ,, 0″·4 up to June 30 and subsequently 0″·3.

Inasmuch as the instruments with the least sensibility might fail in recording certain very small earthquakes which might disturb an instrument with a higher sensibility, and that the instruments with the lower sensibility would not move so long or be displaced so far whether the motion was horizontal or angular, as would be the case with instruments the booms of which were more easily displaced, it appears that what has been recorded finds its best explanation in the assumption that the same is due to differences in the sensibilities of the apparatus employed.

If we assume that the amplitudes given in millimetres are quantities to be represented in angular measure, then the displacements at the four stations may be stated as follows :—

Kew, 32″·1 ; Edinburgh, 28″·4 ; Shide, 27″·4 ; Bidston, 19″·0.

One inference from this is that the installations at which it was first supposed there was the feeblest seismic sensibility are those at which it is most marked.

Observations are now being made at these four stations with the instruments so adjusted that a 4° turn of the calibrating screw results in a deflection at the outer end of the pendulum of 14 mm., which means that they have equal sensibilities to tilting although their periods may differ (see p. 60).

XII. *An Attempt to Detect and Measure any Relative Movement of the Strata that may now be taking place at the Ridgeway Fault, near Upway, Dorsetshire. Third Report by* HORACE DARWIN, *August* 1902.

In the last Report a hope was expressed that the alterations made in the apparatus had prevented the water getting into the oil vessels ; this has not been the case, water again having blocked the pipes connecting them. It is probable that water enters in the form of vapour and condenses, and as we saw no way of preventing this we decided to replace the oil by a saturated solution of common salt ; an overflow was arranged, and it is hoped that there will be no more trouble from this cause. It was also discovered that the pipe connecting the vessels was not quite straight, and that slight undulations in it prevented the free flow of the liquid ; this is being rectified.