REPORTS ON THE STATE OF SCIENCE.

Seismological Investigations.—Eighteenth Report of the Committee, consisting of Professor H. H. TURNER (*Chairman*), Mr. J. MILNE (*Secretary*), Mr. C. VERNON BOYS, Mr. HORACE DARWIN, Mr. F. W. DYSON, Dr. R. T. GLAZEBROOK, Mr. M. H. GRAY, Mr. R. K. GRAY, Professor J. W. JUDD, Professor C. G. KNOTT, Professor R. MELDOLA, Mr. R. D. OLDHAM, Professor J. PERRY, Mr. W. E. PLUMMER, Dr. R. A. SAMPSON, *and* Professor A. SCHUSTER. (*Drawn up by the Secretary.*)

[PLATE I.]

CONTENTS.

I. *General Notes.*

THE above Committee seek to be reappointed with a grant of 60*l.*

The expenditure in connection with seismological work during the last twelve months exceeded 300*l.* This covered the salaries of two assistants, sundry expenses connected with the Observatory at Shide in carrying out the work connected with 58 co-operating stations. Out of the above sum 200*l.* was kindly placed at the disposal of your Secretary by the Government Grant Committee of the Royal Society.

Registers.—During the last year Circulars Nos. 26 and 27 have been issued. They contain 117 pages of entries which refer to the following stations: Shide, Kew, Bidston, Stonyhurst, West Bromwich, Guildford, Haslemere, Eskdalemuir, Paisley, Edinburgh, Cork, Ponta Delgada, Rio Tinto, San Fernando, Valetta, Cairo, Beirut, Ascension Island, St. Vincent, Cape of Good Hope, Fernando Noronha, Trinidad, Toronto, Victoria, B.C., Honolulu, Alipore, Bombay, Kodaikanal, Colombo, Seychelles, Mauritius, Adelaide, Sydney, Wellington, Christchurch.

Mr. Alan Owston, of Yokohama, kindly sends me records of earthquakes he has noted at that place; whilst Mr. Joseph Rippon, of the West India Cable Co., and Mr. Maxwell Hall, of the Weather Office, Jamaica, send records relating to that country. Observers in various parts of the world send from time to time results of their observations.

Visitors.—Baron Kujo; H. M. B. Cooke, Kolas Gold Field, South India; Dr. J. B. A. Treusch, Fanning Island; G. Hewett, Paramaribo; Sir H. B. Donkin; Lord Tennyson; Hon. A. R. D. Elliott; Officers of the Royal Fusiliers; L. F. Richardson, Eskdalemuir; G. F. C. Searle and D. L. Scott, Cambridge; Prof. W. J. Sollas and a party of geological students from Oxford; G. Owen, Liverpool University; Prof. H. H. Turner, Oxford.

Stations.

Fanning Island, 159° 40′ W., 4° N.—This is a Coral Atoll about 30 miles in circumference, no part of which is more than 1000 feet distant from the sea and not more than 10 feet above it. The instrument is in charge of Dr. J. B. A. Treusch.

Agincourt.—In the Report for 1912, page 70, this appeared as if it were a station at which there was a seismograph, which, however, is not the case. Certain of the magnetometers at the Agincourt Observatory are, however, occasionally disturbed by teleseismic motion, which did not happen with the same instruments when they were installed in Toronto.

Toronto.—The seismograph here was first installed in the old Observatory buildings. In March 1908, when these were abolished, it was temporarily erected in a dwelling-house. On September 30, 1909, it was permanently installed in the barograph room in the basement of the new Meteorological Office, which is about half a mile north of the site of the old Observatory.

Shide, Wireless Telegraphy at.—At the end of last year Mr. J. J. Shaw, of West Bromwich, very kindly installed me a wireless telegraphic system, the object of which was to obtain time signals from the Eiffel Tower or North Germany. Up to date it has worked satisfactorily, giving time to within half a second. This it has done in all kinds of weather, when it was impossible to make an observation on the sun or to obtain a Greenwich signal. The cost of an installation for this purpose is less than 10*l*.

II. *Seismic Activity in* 1910.

The following catalogue is a continuation of catalogues published in the British Association Report, 1911, p. 57, and 1912, p. 70.

The number given to an earthquake corresponds to that which is given to the same disturbance in the Shide Registers, published as British Association Circulars. The numbers with an asterisk (*) refer to earthquakes which have disturbed the whole world. Those which are not thus marked have been recorded over areas of not less than two

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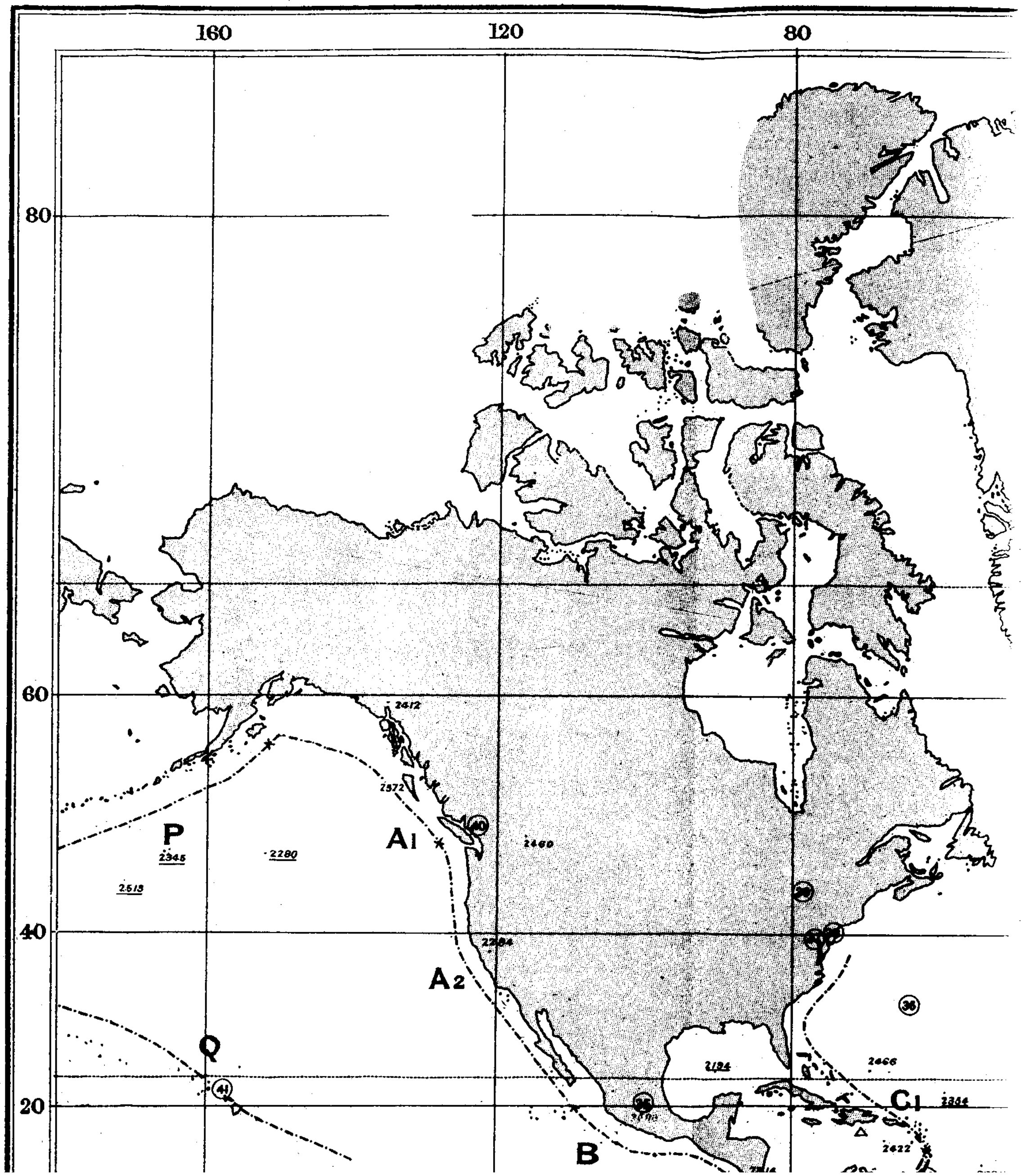
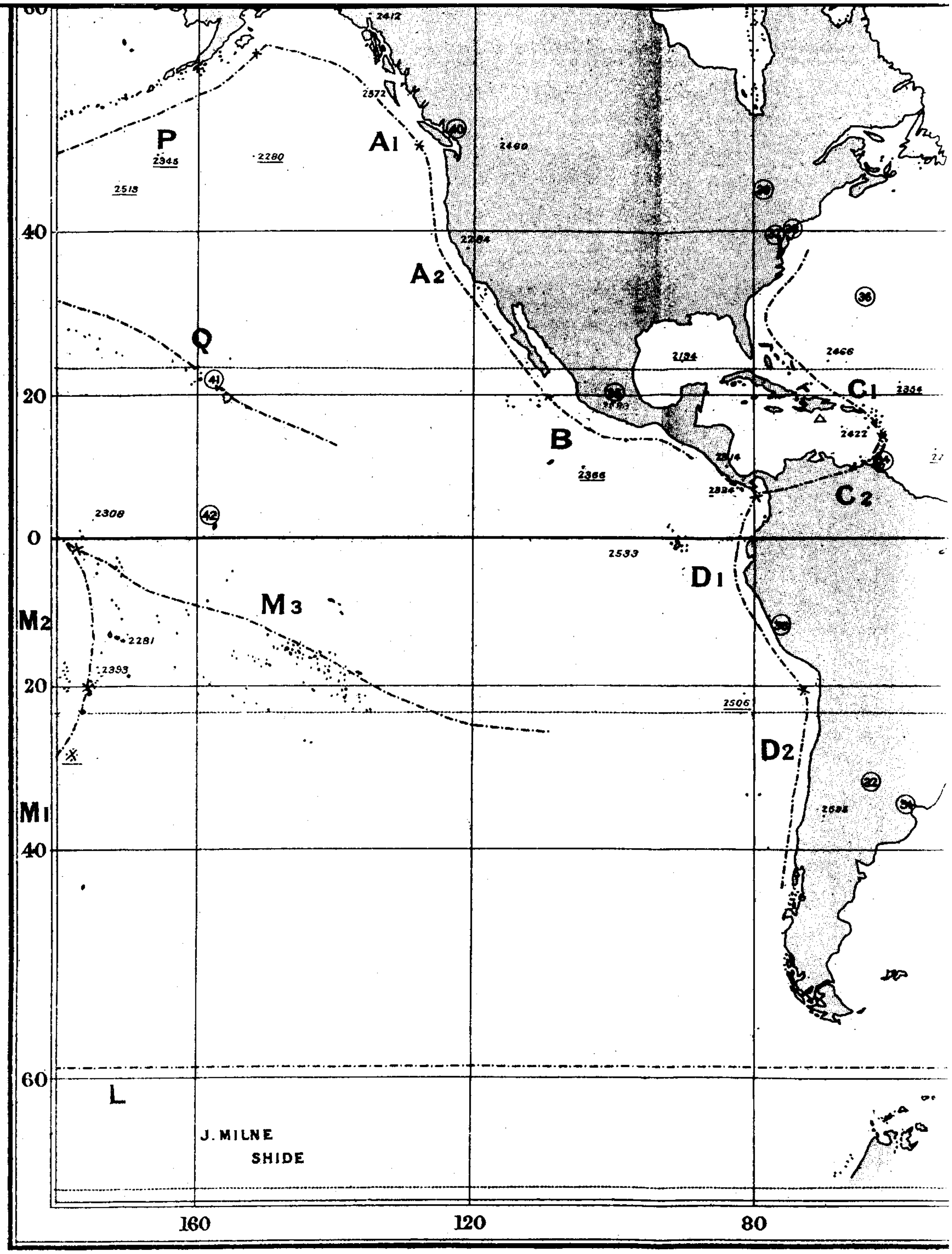
ORIGINS

STATIONS.

1. Shide.
2. Kew.
3. Haslemere.
4. Guildford.
5. West Bromwich.
6. Bidston.
7. Stonyhurst.
8. Eskdalemuir.
9. Paisley.
10. Edinburgh.
11. Cardiff.
12. Cork.
13. Paris.
14. Strassburg.
15. Coimbra.
16. San Fernando.
17. Rio Tinto.
18. Azores.
19. Malta.
20. Cairo.
21. Beirut.
22. Tiflis.
23. Seychelles.
24. Mauritius.
25. Cape Town.
26. Accra.
27. Cape Verde.
28. Fernando Noronha.
29. Ascension.
30. St. Helena.
31. Chacarita.
32. Pilar.
33. Lima.
34. Trinidad.
35. Mexico.
36. Bermuda.
37. Baltimore.
38. Philadelphia.
39. Toronto.
40. Victoria, B.C.
41. Honolulu.
42. Fanning Island.
43. Tokio.
44. Irkutsk.
45. Tashkend.
46. Calcutta.
47. Vizagapatam.
48. Bombay.
49. Kodaikanal.
50. Colombo.
51. Batavia.
52. Cocos.
53. Perth.



31. Chacarita.
32. Pilar.
33. Lima.
34. Trinidad.
35. Mexico.
36. Bermuda.
37. Baltimore.
38. Philadelphia.
39. Toronto.
40. Victoria, B.C.
41. Honolulu.
42. Fanning Island.
43. Tokio.
44. Irkutsk.
45. Tashkend.
46. Calcutta.
47. Vizagapatam.
48. Bombay.
49. Kodaikanal.
50. Colombo.
51. Batavia.
52. Cocos.
53. Perth.
54. Adelaide.
55. Melbourne.
56. Sydney.
57. Wellington.
58. Christchurch.
59. Fiji.



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Earthquake Districts are indicated A. B. C., etc. Small numbers refer to Shide Records (see B.A. Circulars). If underlined, were recorded all over the world. Figures in Circles refer to Earthquake Stations.

RIGINS OF LARGE EARTHQUAKES, 19

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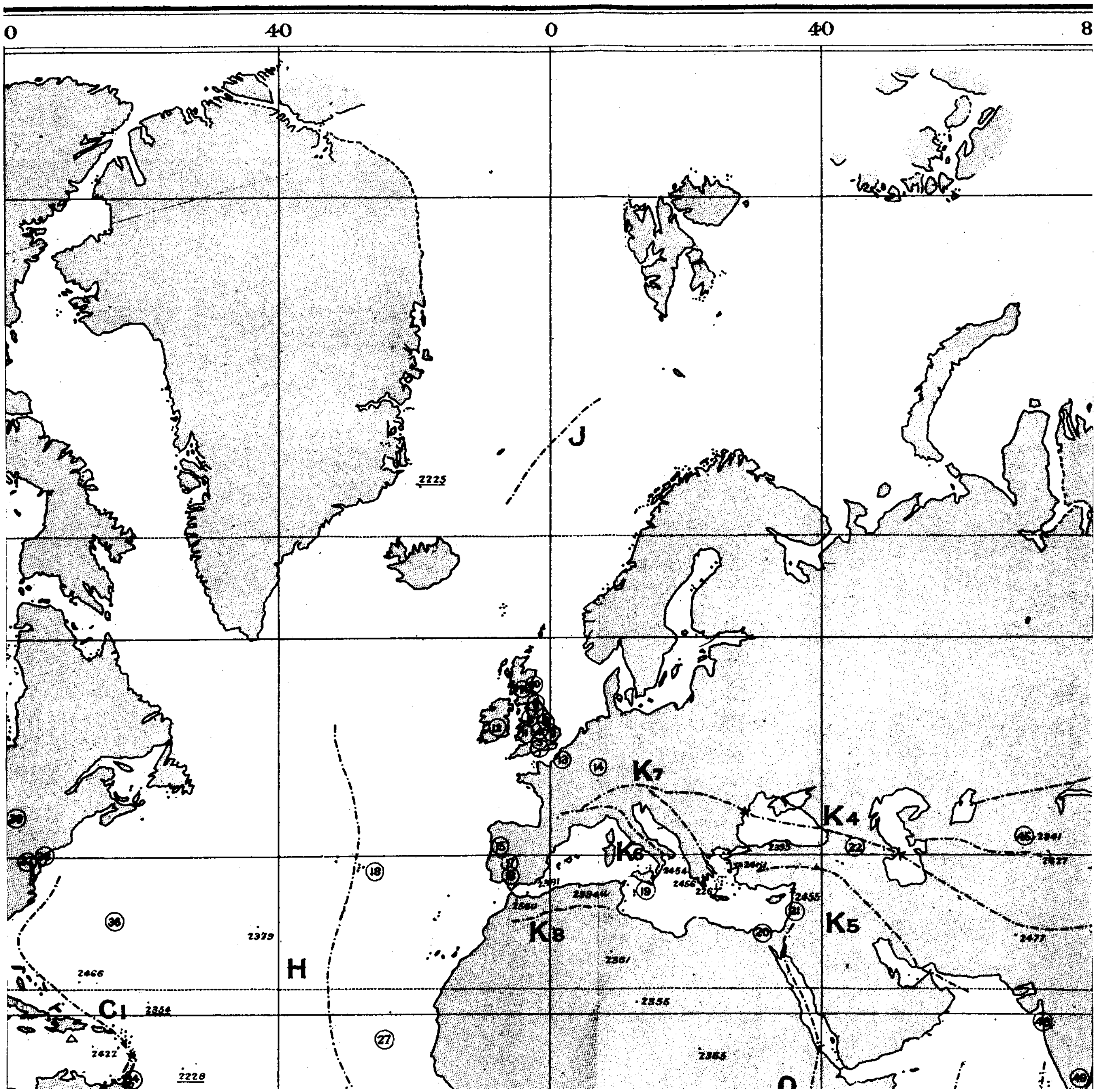

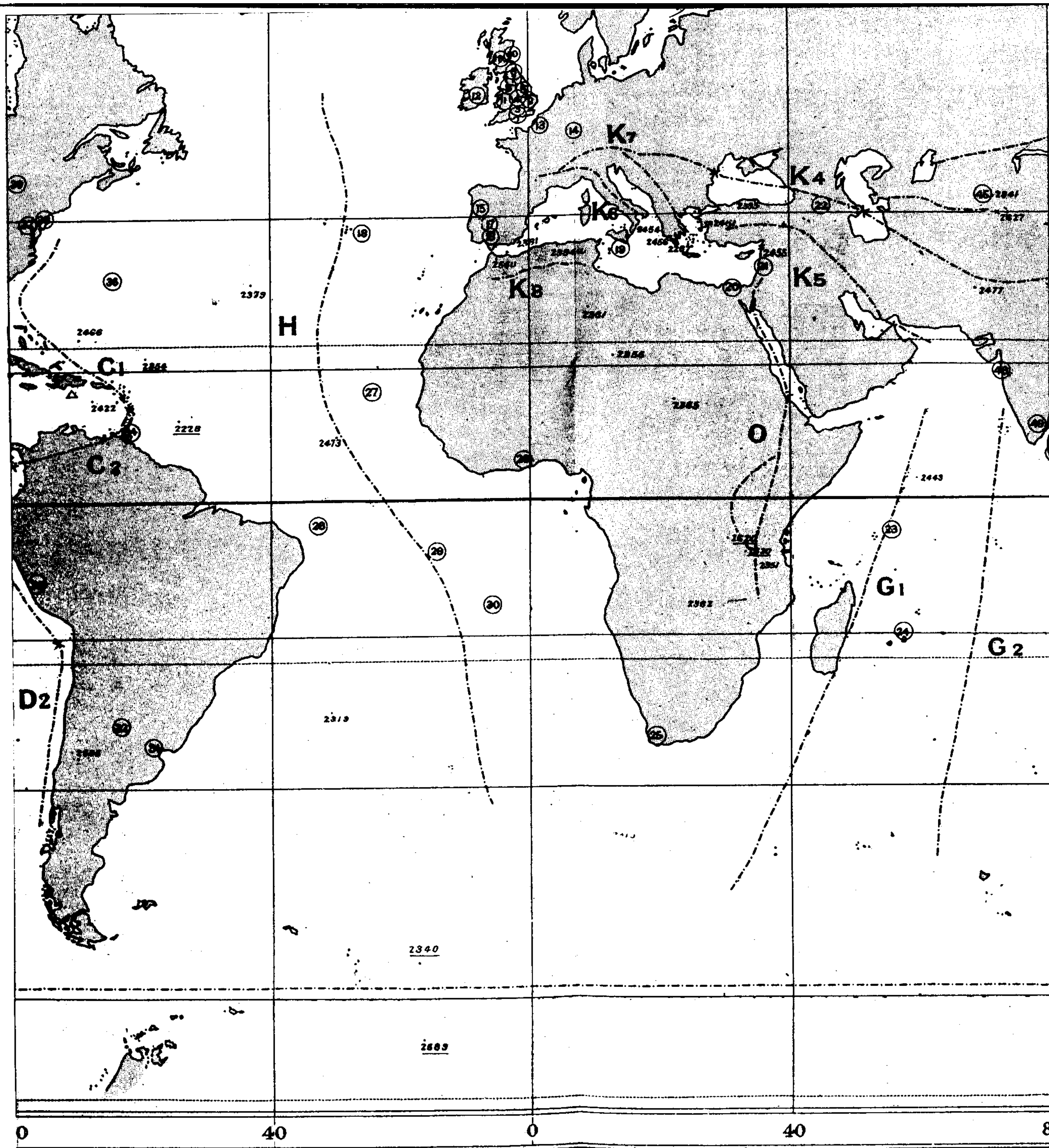

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Records (see
es in Circles

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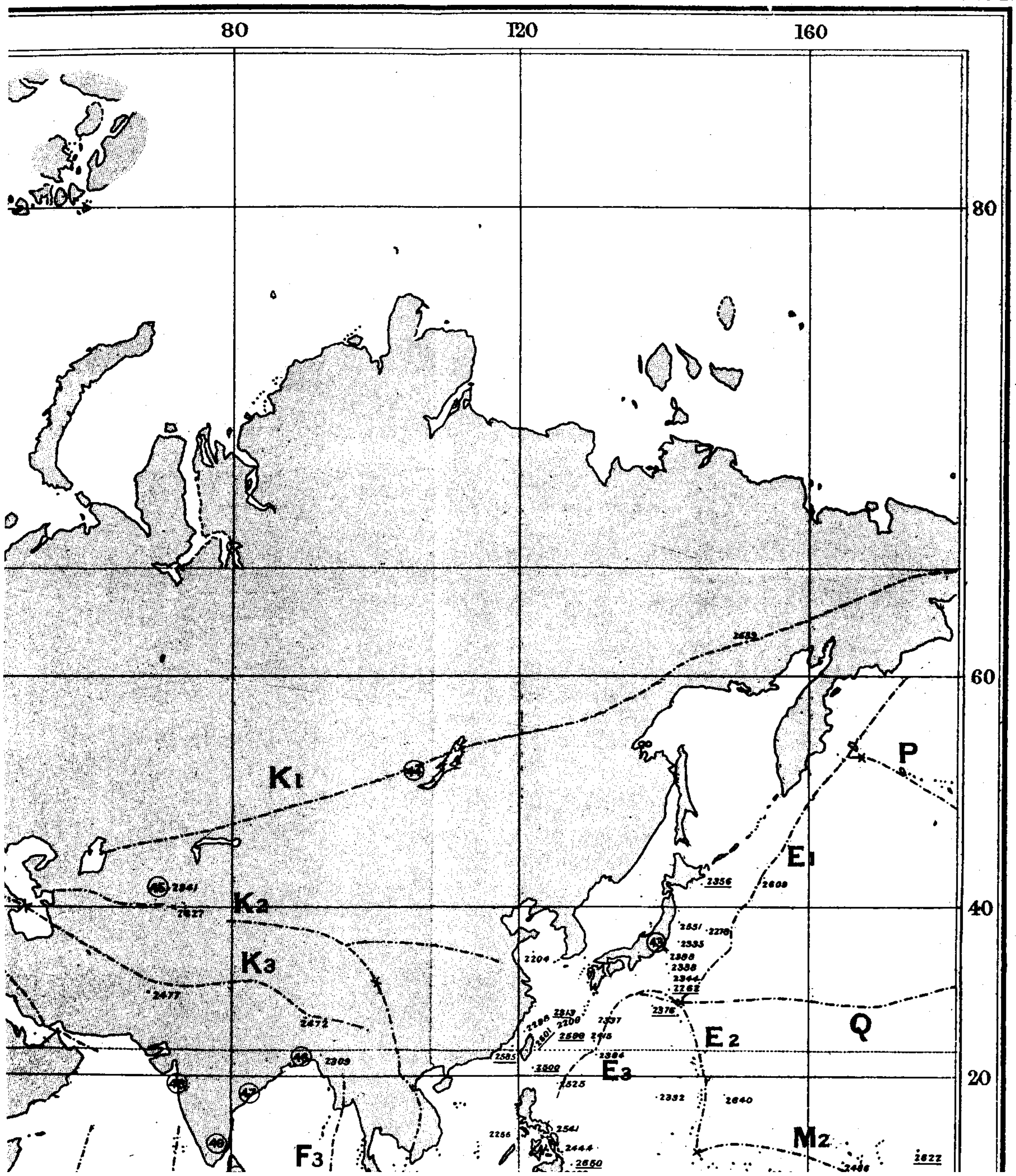
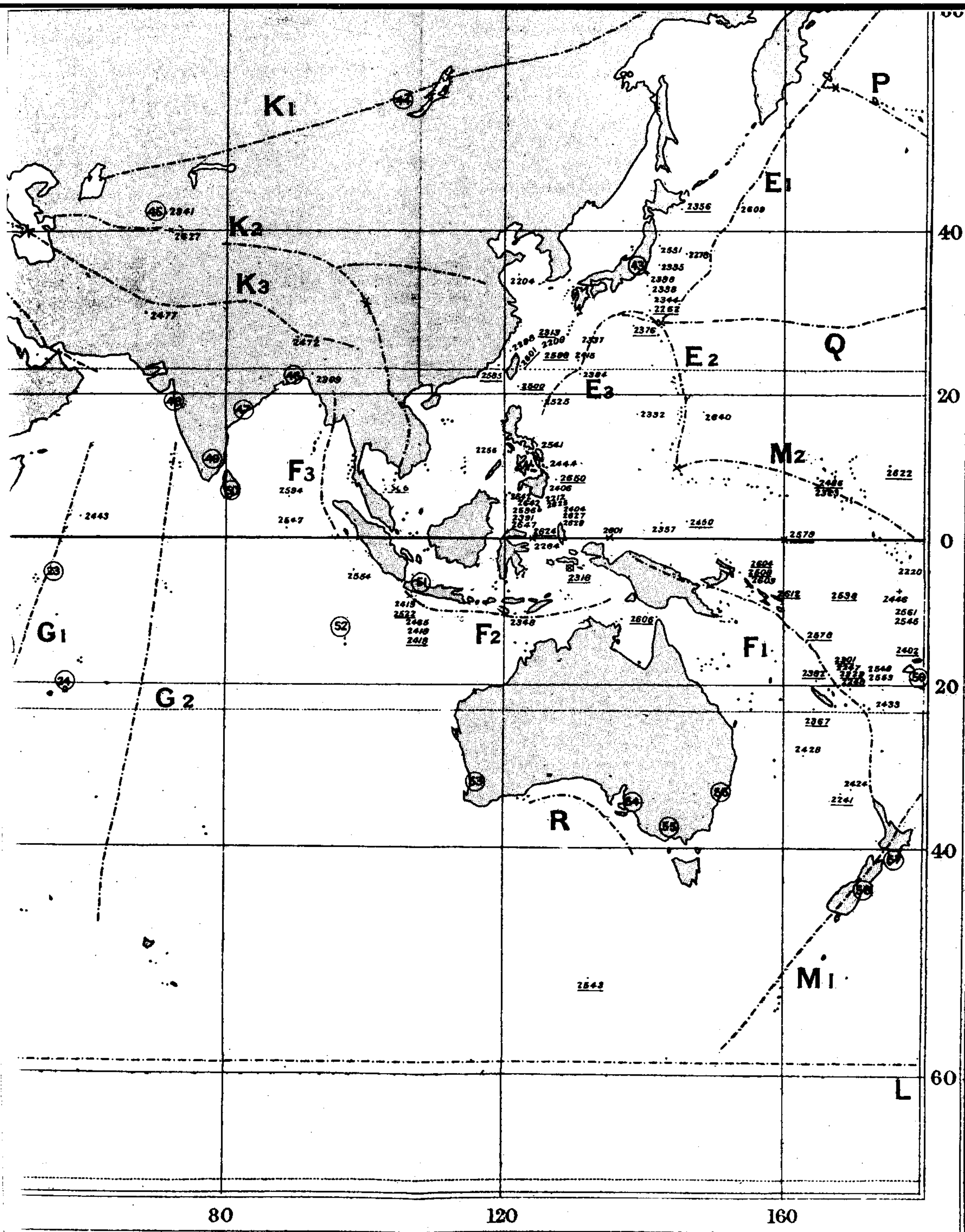
Plate I.





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Illustrating the Eighteenth Report on Seismological Investigations continents. These numbers are reproduced on the accompanying map, and those which are underlined correspond to numbers in the catalogue which carry an asterisk (*). For a description of the methods by which the position of origins has been determined see British Association Report, 1900, p. 79. When the time at which an earthquake originated is followed by plus or minus so many minutes, this means that there is a corresponding uncertainty as to the position of the origin. The names of places at which an earthquake has only been felt is followed by the letter F. If destruction has taken place it is followed by the letter D. The dotted lines on the map are the axes of troughs or ridges from which large earthquakes have originated. In the column for remarks I have made a few references to determination of origins by other investigators. Those given by Prince Galitzin are of interest from the fact that they are made from observations at a single station.[1] The determinations by Dr. Kurt Wegener depend upon observations made at three to six stations.[2]

In connection with my own observations, to make which I frequently had materials from 30 or 40 stations, it is interesting to note that these stations could sometimes be divided into groups, each of which would give different epicentres, the distances between which might be as much as six degrees. One interpretation of this is the assumption that the earthquake originated over an area the dimension of which is indicated by the distances which separate the calculated epicentres.

Date 1910	No.	Time at origin	District	Lat. and long. in degrees	Remarks. F=felt, D=destructive
Jan. 1*	2194	11.2	C_1	90 W. 24 N.	Wegener gives 82 W. 25 N., time 11.2.26. Seismograms evidently refer to two or three disturbances
,, 6	2200	19.54±2	E_3	125 E. 25 N.	Ishigakijima, Loochoo, F.
,, 8	2204	14.48±2	K_2	122 E. 35 N.	In Chili, Kwangsu and Shantung, F.
,, 15	2212	22.15	E_3	125 E. 5 N.	Mindanao, Agusan Valley, F., also Halmahera and Talaud, F
,, 19	2220	14.50±4	M_2	180 E. 4 S.	
,, 22*	2225	8.48	J	19 W. 67 N.	Galitzin gives 17 W. 68 N.
,, 23*	2228	18.48*ca*	C_2	55 W. 12 N.	St. Vincent, Georgetown, Paramaribo, F.
,, 30*	2241	3.45*ca*	F_1	168 E. 33 S.	Probably a dual earthquake.
Feb. 3	2247	16.34*ca*	F_1	168 E. 17 S.	
,, 4*	2248	14.0*ca*	F_1	168 E. 17 S.	Lifu in Loyalty Is., F. Wegener gives 177 W. 18 S., and times 13.59.7, 15.40.2, 17.36.5 and 18.32.5.

[1] See *Bulletin de l'Académie des Sciences de St.-Pétersbourg*, No. 13, 1911, p. 952.
[2] See *d. Kgl. Ges. d. Wiss. math.-phys. Kl.* 1912, Heft 3.

Date 1910		No.	Time at origin	District	Lat. and long. in degrees	Remarks. F=felt, D=destructive
Feb.	7	2255	15.40	E_3	121 E. 13 N.	N. Mindoro at Calapan, F.
,,	12*	2262	18.6	E_1	141 E. 32 N.	Central Japan, F. Galitzin gives 131.5 E. 34.58 N.
,,	13	2264	16.21*ca*	F_1, F_2, E_3	125 E. 0 N.S.	
,,	18	2267	5.11	K_6	24 E. 36 N.	Crete, Varipetro, D.
,,	27	2278	14.27*ca*	E_1, E_2, E_3	145 E. 37 N.	Central Japan, F.
,,	28*	2280	21.0±4	A_1	150 W. 47 N.	
Mar.	1	2281	11.22	M_1	170 W. 13 S.	
,,	11	2284	6.50*ca*	A_2	121 W. 38 N.	Central California, F.
,,	25	2297	15.17±2	D_1, D_2	80 W. 20 S.	Antofagasta, F.(?)
,,	25	2298	18.38	E_3	121 E. 25 N.	N. Formosa, F.
,,	30*	2301	16.55	F_1	168 E. 17 S.	
,,	31*	2302	18.13±3	L	6 W. 71 S.	
April	1		13.46	F_2	129 E. 4 S.	Ambon and Neira, F. Not recorded at Shide.
,,	8	2308	16.28±5	M_2	175 W. 2 N.	Wegener gives 171 W. 16 S. Time 16.34.7.
,,	9	2309	9.27±4	K_3	93 E. 22 N.	
,,	12*	2313	0.22	E_3	124 E. 26 N.	Formosa and Loochoo, F. Galitzin gives 122.55 E. 27.31 N. Wegener gives 122 E. 23 N. Time 0.21.6.
,,	13	2314	6.41	B	84 W. 11 N.	Costa Rica, Cartago, D.
,,	16*	2318	12.30	F_2	130 E. 5 S.	Ambon and Neira, F.
,,	17	2319	0.52*ca*	H	30 W. 30 S.(?)	Possibly 10 W. 65 S.
,,	20	2323	22.12*ca*	M_2	166 E. 8 N.	
May	1*	2329	18.30.4	F_1	170 E. 18 S.	Wegener's determination.
,,	4	2332	15.17*ca*	E_3	137 E. 17 N.	
,,	5*	2334	0.26	B	84 W. 9 N.	Costa Rica, Cartago, D.
,,	9	2335	9.47	E_1	142 E. 36 N.	E. Coast N. Japan, F.
,,	10	2337	9.29	E_3	130 E. 26 N.	
,,	10	2338	13.55	E_1	140 E. 34 N.	
,,	10*	2340	17.42*ca*	L	20 W. 55 S.	Origin doubtful.
,,	11		7.38*ca*	C_1	71 W. 18 N.	Haiti, W. Indies, D. Not recorded at Shide.
,,	11	2341	15.51*ca*	K_2	71 E. 42 N.	Talas Ala-tau in Turkestan.
,,	12	2344	3.21	E_1	141 E. 33 N.	Off Boso, E. Coast Japan, F.
,,	13*	2345	7.57*ca*	P	163 W. 48 N.	
,,	15	2348	16.3±3	F_2	122 E. 10 S.	Maoe Mere in Flores, also in Timor, F.
,,	18	2351	8.58	O	38 E. 9 S.	Tanganyika and German E. Africa, F.
,,	20*	2354	12.9*ca*	C_1	58 W. 22 N.	
,,	21	2355	7.46*ca*	K_8	12 E. 21 N.	
,,	22*	2356	6.25	E_1	145 E. 42 N.	N.E. Japan, Yokohama, Kushiro, F.
,,	23	2357	18.38	F_1	142 E. 3 N.	
,,	27	2361	11.59*ca*	K_8	9 E. 28 N.	
,,	28	2362	6.21*ca*	O	25 E. 14 S.	Rhodesia, Livingstone, F.

Date 1910		No.	Time at origin	District	Lat. and long. in degrees	Remarks. F=felt. D=destructive
May	30	2365	12.33*ca*	O	22 E. 15 N.	
,,	31*	2366	4.54	B	105 W. 10 N.	Galitzin gives 92.16 W. 23.5 N.
June	1*	2367	5.57±2	F_1	165 E. 23 S.	Wegener gives approximate origin as 170 E. 18 S. at 5.55.1.
,,	9*	2376	11.47	E_1, E_2, E_3	138 E. 28 N.	Bonin Is. and C. E. Japan, F.
,,	14	2379	19.39*ca*	H	44 W. 32 N.	
,,	16	2381	4.15	K_8	2 W. 37 N.	S. Spain, Almeria, Malaga and Algeria, D.
,,	16*	2382	6.30	F_1	166 E. 19 S.	New Caledonia and Loyalty Is., F.
,,	17	2384	5.26	E_3	128 E. 22 N.	Formosa, Pescador Is., Batanes Is., and N. Luzon, F.
,,	23	2391	2.50*ca*	E_3	121 E. 2 N.	Celebes, Posso and Paleleh, F.
,,	23	2393	18.52.5	M_2	174 W. 18 S.	Determined by Wegener.
,,	24	2394*a*	13.27.5	K_8	4 E. 36 N.	Algeria, Aumale, Tablat, D.
,,	25	2395	19.26	K_5	34 E. 41 N.	Asia Minor, Iskelib, F.
,,	26	2398	15.57	E_1	139 E. 35 N.	C. Japan, F.
,,	29*	2402	10.49*ca*	M_2	180 E.W. 15 S.	
,,	29*		14.21*ca*	M_2	178 W. 28 S.	Not recorded at Shide.
,,	29		18.9*ca*	F_2	130 E. 18 S.	Not recorded at Shide.
,,	30	2404	2.55	E_3	127 E. 4 N.	S.E. Mindanao, F.
July	2	2406	5.37	E_3	125 E. 7 N.	Agusan River, E. Mindanao, F.
,,	3	2412	9.9	A_1	135 W. 59 N.	Skagway, F.
,,	5	2415	18.30	E_3	128 E. 25 N.	Loochoo, Naha, F.
,,	7	2417	4.41	A_1	135 W. 60 N.	Skagway, F.
,,	7*	2418	8.17	F_2	108 E. 12 S.	Kediri, Soerakarta, F.
,,	8	2419	3.59	F_2	108 E. 11 S.	Madioen, Pasoeroean, F.
,,	10	2422	15.9*ca*	C_1	69 W. 16 N.	Not recorded at Shide.
,,	11	2424	20.33*ca*	F_1	170 E. 33 S.	
,,	12	2427	7.31(?)	K_2	72 E. 40 N.	Galitzin gives 35.55 N. 69.18 E. N. Afganistan, nr. Hindu Kush Mts.
,,	12	2428	21.6	F_1	163 E. 29 S.	
,,	15	2433	12.1*ca*	F_1	174 E. 23 S.	
,,	21	2443	22.17*ca*	G_1	60 E. 3 N.	
,,	22	2444	14.13	E_3	126 E. 10 N.	Surigao, F.
,,	24	2446	15.19*ca*	M_2	176 E. 7 S.	
,,	29*	2450	10.27±3	F_1	145 E. 3 N.	
Aug.	1	2454	10.43	K_6	19 E. 39 N.	Italy, South, F.
,,	1	2455	22.15*ca*	K_5	35 E. 35 N.	
,,	2	2456	2.35*ca*	K_5	21 E. 37 N.	
,,	5	2460	1.30*ca*	A_1	117 W. 48 N.	Galitzin gives 116.50 W. 39.48 N.
,,	7	2461	20.45	K_5	28 E. 38 N.	Smyrna, F.
,,	10	2465	20.16*ca*	F_2	111 E. 10 S.	
,,	11	2466	16.37	C_1	70 W. 25 N.	
,,	13	2472	21.19	K_3	90 E. 28 N.	

Date 1910		No.	Time at origin	District	Lat. and long. in degrees	Remarks. F=felt, D=destructive
Aug.	14	2473	7.33*ca*	H	32 W. 10 N.	
„	16	—	7.27*ca*	F_2	118 E. 3 S.	Not recorded at Shide.
„	17	2477	11.58	K_3	68 E. 30 N.	Galitzin gives 28.39 N. 67.10 E. Sind and Shikarpur, F.
„	21*	2486	5.20	M_2	165 E. 9 N.	
„	21	2487	16.0*ca*			In the Shide Register the date is given wrongly as Aug. 24. North of India.
Sept.	1*	2500	0.45	E_3	122 E. 21 N.	Galitzin gives 120.22 E. 23.30 N. Taito Taichu and Keelung in Formosa, also in Batanes Is., F.
„	1*	2501	14.20	E_3	122 E. 24 N.	Galitzin gives 119.54 E. 23.13 N. Taihoku Keelung, Tainan, Taichuin, Formosa, F.
„	6*	2506	19.59*ca*	D_1, D_2	82 W. 21 S.	At 20.32±2 a shock originated 5 W. 2 S. At 20.14±3 shocks were noted at Andalgala, in Catamarca, Argentina.
„	7*	2508	7.10±2	F_1	155 E. 5 S.	Wegener gives a locality near to 148 E. 4 S. at 7.10.4.
„	9*	2513	1.11	P	170 W. 45 N.	Galitzin gives 160.24 E. 45.26 N., E. of the Kuriles. Unalaska and Bogoslof Is., F.
„	14	2522	13.53	F_3	116 E. 10 S.	Soembawa and Bali, F.
„	16	2525	23.7	E_3	125 E. 19 N.	N. Luzon, F.
„	24	2533	3.23*ca*	D_1	102 W. 2 S.	Arizona, F.
„	24	2535	15·12*ca*	D_2	69 W. 35 S.	Rioja, San Juan, and Mendosa, in Argentina, F.
Oct.	2	2541	20.33 & 21.15	E_3	123 E. 12 N.	Nueva Caceres and throughout S.E. Luzon, F.
„	4*	2543	22.51*ca*	M_1	132 E. 51 S.	
„	7	2545	6.52	M_2	180 E. or W. 10 S.	
	7	2546	11.54	F_1	171 E. 18 S.	Valparaiso, F.(?)
„	7	2547	16.2	F_3	89 E. 2 N.	
„	13	2551	14.56	E_1	142 E. 38 N.	Eastern part of Central Japan, F.
„	18	2553	2.36	F_1	171 E. 19 S.	
„	20	2554	5.3*ca*	F_2	97 E. 4 S.	Padang, Bovenlanden, Sumatra, F.
„	27	2560	0.59	K_8	5 W. 35 N.	Fez in Morocco, also in Tetuan, Melilla, in Malaga, F.
„	30	2561	7.33	M_2	180 E. or W. 10 S.	
Nov.	6	2572	20.29	A_1	135 W. 53 N.	
„	9*	2578	5.57*ca*	F_1	164 E. 12 S.	Mallicolo, in New Hebrides, F.

Date 1910	No.	Time at origin	District	Lat. and long. in degrees	Remarks. F=felt, D=destructive
Nov. 10*	2579	12.11*ca*	M_2	160 E. 0 N.S.	
„ 14*	2585	7.33	E_3	120 E. 21 N.	N. Formosa, F.
„ 15*	2589	14.18*ca*	L	16 W. 62 S.	
„ 24	2594	15.41*ca*	F_3	90 E. 6 N.	
„ 25	2596*b*	19.12	E_3	125 E. 6 N.	S.E. Mindanao, Sarangani Is., F.
„ 26*	2598	4.39*ca*	F_1	167 E. 8 S.	Not recorded at Shide.
„ 29*	2599	2.24	E_3	125 E. 25 N.	E. coast Formosa, F.
Dec. 1	2601	15.42	F_1	135 E. 0 N.S.	About this time an earthquake was recorded in Tondano in Menado.
„ 3	2603	4.5*ca*	F_1	155 E. 4 S.	Namatani, New Ireland, F.
„ 3*	2604	7.47*ca*	F_1	155 E. 4 S.	
„ 4*	2606	11.0*ca*	F_1	140 E. 10 S.	About this time an earthquake was recorded in Ambon.
„ 5	2609	16.21	E_1	150 E. 42 N.	Off N.E. Japan.
„ 10*	2612	9.25	F_1	159 E. 8 S.	Recorded in Ambon.
„ 13*	2620	11.34	O	33 E. 9 S. or 30 E. 7 S.	
„ 14*	2622	20.27*ca*	M_2	176 E. 10 N.	
„ 16*	2624	14.45	E_3	125 E. 5 N.	S. Mindanao, Sarangani Is., F.
„ 16	2625	18.50	E_3	125 E. 5 N.	S. Mindanao, Sarangani Is., F.
„ 17	2627	6.33	E_3	127 E. 4 N.	N.E. Celebes.
„ 18	2629	2.42*ca*	E_3	127 E. 4 N.	N.E. Celebes, S. Mindanao.
„ 23	2639	0.29*ca*	K_1	150 E. 62 N.	
„ 26	2640	5.34*ca*	E_2	149 E. 18 N.	
„ 27	2642	18.50*ca*	E_3	123 E. 5 N.	
„ 29	2647	13.5	E_3	122 E. 3 N.	Ambon and Mindanao, F.
„ 30*	2650	0.45*ca*	E_3	128 E. 8 N.	Mindanao, Samar, Leyte, Butuan, D.

III. *On the* 443 *or* 452 *Day Period.*

In the Report for 1912, p. 94, I pointed out that marked periods of rest followed groups of megaseisms every 443 days. Professor H. H. Turner increased this period to 452 days. December 14, 1899, is the middle of a rest period, and we find similar periods every successive 443 days. The last period—which, however, is only one of partial quiescence—was about September 3, 1909; we should expect the next one about November 20, 1910. The fact that the accompanying catalogue shows that between November 14 and 24 no large earthquake was recorded verifies the expectation.

IV. *On the Determination of the Position of Epicentres.*

In the British Association Report, 1896, p. 230, I showed by example that the distance of an epicentre could be determined from the duration of preliminary tremors. In 1911 Prince Galitzin showed that not only could a distance be determined from these precursors, but the first of them gave the direction in which we should seek for an origin. In the British Association Report, 1900, p. 79, I gave several methods which I use when mapping the position of epicentres. These methods were dependent on a number of observations made at several more or less widely separated observatories.

As a slight addition to these I submit the following: If we have registers from a number of stations for large earthquakes it is usually easy to read the times of commencements and other phases of motion, together with the amplitudes. An inspection of the records which refer to a given earthquake shows the stations nearest to its epicentre, and any one of these should give us the distance of the same, and if we know this we can easily compute the time at which the shock originated. The difference between this and the arrival of the large waves or the maximum motion at other stations enables us to compute their respective distances from the district from which they radiated. The intersection of arcs, which I draw upon a 'black globe,' which correspond to these distances should represent the epifocal area.

I venture to mention this simple and self-evident way of procedure because it is frequently of use when other methods fail. Preliminary tremors may have been eclipsed by air tremors or microseisms, or they may have died out on their journey, with the result that the seismogram may only present very small records which represent the large waves or maximum motion.

V. *On the Variation of Earthquake Speed with the Variation in the Direction of Propagation.*

In the British Association Report, 1908, p. 74, I showed that megaseismic motion was propagated from its origin farther to the east and west than it was in the direction of a meridian. One explanation for this is that in the former direction the rigidity of the propagating medium may be greater than it is in the latter direction—a suggestion that falls in line with the observations of Dr. Hecker on the gravitational influence of the moon on the crust of our world. If this hypothesis is correct it might be inferred that the velocity of propagation of earth waves would be greatest in an east-west direction.

To test this I took earthquakes Nos. 859, 860, 884, 1111, 1170, 1260, 1363, and 1632 (see British Association Report, 1912, p. 71). I selected these particular disturbances because the positions of their epicentres and times of origin were known, and also because they had been recorded at widely separated stations. For any particular earthquake the only observations considered were those made at stations the bearings of which from the epicentre were within 30 degrees of east and west or within 30 degrees of north and south. The following tables only refer to maximum motion or large waves:—

Earthquake No. 859, June 25, 1904, origin 160° E. 53° N.

					Per sec.
East-West	Bombay,	time to travel 48 m.,	distance 74°,	velocity	2·85 km.
	Mauritius,	,, 68 m.,	,, 114°,	,,	3·10 km.
	Kodaikanal,	,, 48 m.,	,, 77°,	,,	2·93 km.
	Calcutta,	,, 41 m.,	,, 61°,	,,	2·75 km.
				Average . . .	2·90 km.

							Per sec.
North-South	Shide.	time to travel	48 m.,	distance	76°,	velocity	2·92 km.
	Kew,	„	49 m.,	„	75°,	„	2·83 km.
	Bidston.	„	43 m.,	„	72°,	„	3·09 km.
	Edinburgh	„	44 m.,	„	71°,	„	2·98 km.
	Paisley,	„	54 m.,	„	71°,	„	2·43 km.
	San Fernando,	„	55 m.,	„	90°,	„	3·02 km.
	Wellington,	„	80 m.,	„	95°,	„	2·19 km.
				Average .	.	.	2·78 km.

Earthquake No. 860, June 25, 1904, origin 160° E. 53° N.

East-West	Mauritius,	time to travel	68 m.,	distance	101°,	velocity	2·74 km.
	Calcutta,	„	37 m.,	„	60°,	„	3·00 km.
	Bombay,	„	49 m.,	„	72°,	„	2·72 km.
	Kodaikanal,	„	50 m.,	„	76°,	„	2·81 km.
	Honolulu,	„	26 m.,	„	44°,	„	3·13 km.
				Average .	.	.	2·88 km.

North-South	Shide,	time to travel	52 m.,	distance	76°,	velocity	2·70 km.
	Kew,	„	49 m.,	„	75°,	„	2·84 km.
	Bidston,	„	43 m.,	„	72°,	„	3·02 km.
	Edinburgh,	„	43 m.,	„	71°,	„	3·05 km.
	San Fernando,	„	56 m.,	„	90°,	„	2·97 km.
	Christchurch	„	81 m.,	„	97°,	„	2·21 km.
				Average .	.	.	2·79 km.

Earthquake No. 884, August 24, 1904, origin 135° E. 32° N.

East-West	Beirut,	time to travel	55 m.,	distance	79°,	velocity	2·65 km.
	Calcutta,	„	25 m.,	„	42°,	„	3·09 km.
	Kodaikanal,	„	44 m.,	„	57°,	„	2·39 km.
	Cape Town	„	85 m.,	„	129°,	„	2·80 km.
				Average .	.	.	2·73 km.

North-South	Shide,	time to travel	60 m.,	distance	88°,	velocity	2·71 km.
	Kew,	„	59 m.,	„	86°,	„	2·72 km.
	Bidston	„	58 m.,	„	85°,	„	2·75 km.
	Edinburgh	„	59 m.,	„	84°,	„	2·71 km.
	Toronto	„	72 m.,	„	98°,	„	2·51 km.
	Christchurch	„	40 m.,	„	84°,	„	2·88 km.
	Wellington	„	44 m.,	„	82°,	„	3·51 km.
				Average .	.		2·82 km.

Earthquake No. 1111, January 21, 1906, origin 143° E. 34° N.

East-West	Calcutta,	time to travel	23 m.,	distance	49°,	velocity	3·94 km.
	Honolulu	„	38 m.,	„	51°,	„	2·48 km.
				Average .	.	.	3·20 km.

North-South	Baltimore,	time to travel	72 m.,	distance	98°,	velocity	2·51 km.
	Kew,	„	53 m.,	„	89°,	„	3·10 km.
	Bidston,	„	56 m.,	„	88°,	„	2·90 km.
	Perth,	„	37 m.,	„	71°,	„	3·55 km.
				Average .	.	.	3·01 km.

Earthquake No. 1170, April 18, 1906, origin 121° W. 38° N.

					Per sec.
East-West	Cape Town,	time to travel 83 m.,	distance 148°,	velocity	3·29 km.
	Toronto	,, 21 m.,	,, 33°,	,,	2·90 km.
	Batavia,	,, 91 m.,	,, 125°,	,,	2·54 km.
	Perth,	,, 74 m.,	,, 132°,	,,	3·30 km.
	Honolulu,	,, 17 m.,	,, 34°,	,,	3·70 km.
	Samoa,	,, 33 m.,	,, 69°,	,,	3·86 km.
	Manila,	,, 56 m.,	,, 100°,	,,	3·30 km.
			Average . . .		3.27 km.
North-South	Victoria,	time to travel 5 m.,	distance 10.5°,	velocity	3·86 km.
	Mauritius,	,, 98 m.,	,, 158°,	,,	2·98 km.
	Calcutta,	,, 68 m.,	,, 112°,	,,	3·04 km.
	Bombay	,, 82 m.,	,, 121°,	,,	2·73 km.
	Kodaikanal,	,, 74 m.,	,, 127°,	,,	3·17 km.
	Irkutsk,	,, 53 m.,	,, 80°,	,,	2·78 km.
	Cairo,	,, 82 m.,	,, 107°,	,,	2·41 km.
			Average . . .		2·95 km.

Earthquake No. 1260, September 7, 1906, origin 145° E. 35° N. (calculated by Mr. J. Horikawa).

East-West	Bombay,	time to travel 46 m.,	distance 65°,	velocity	2·61 km.
	Calcutta,	,, 34 m.,	,, 50°,	,,	2·73 km.
	Kodaikanal,	,, 44 m.,	,, 65°,	,,	2·72 km.
	Cape Town,	,, 86 m.,	,, 137°,	,,	2·94 km.
	Mauritius,	,, 67 m.,	,, 100°,	,,	2·78 km.
			Average . . .		2·74 km.
North-South	Shide,	time to travel 60 m.,	distance 92°,	velocity	2·64 km.
	Kew,	,, 56 m.,	,, 88°,	,,	2·9 km.
	Bidston,	,, 54 m.,	,, 86°,	,,	2·94 km.
	Edinburgh,	,, 58 m.,	,, 85°,	,,	2·71 km.
	Paisley,	,, 62 m.,	,, 86°,	,,	2·56 km.
	Perth,	,, 59 m.,	,, 72°,	,,	2·25 km.
	Wellington,	,, 63 m.,	,, 82°,	,,	2·40 km.
			Average . . .		2·62 km.

Earthquake No. 1363, April 18, 1907, origin 123° E. 13° N.

East-West	Bombay,	time to travel 31 m.,	distance 48°,	velocity	2·43 km.
	Kodaikanal,	,, 32 m.,	,, 45°,	,,	2·60 km.
	Samoa,	,, 32 m.,	,, 70°,	,,	4·04 km.
	Honolulu,	,, 45 m.,	,, 75°,	,,	3·08 km.
			Average . . .		3·04 km.
North-South	Shide,	time to travel 64 m.,	distance 101°,	velocity	2·91 km.
	Kew,	,, 71 m.,	,, 100°,	,,	2·60 km.
	Edinburgh,	,, 64 m.,	,, 99°,	,,	2·86 km.
	Paisley,	,, 63 m.,	,, 100°,	,,	2·93 km.
	Tokio,	,, 13 m.,	,, 27°,	,,	3·84 km.
	Perth,	,, 33 m.,	,, 46°,	,,	2·57 km.
	Christchurch,	,, 43 m.,	,, 73°,	,,	3·14 km.
			Average . . .		2·98 km.

Earthquake No. 1362, April 18, 1907, origin 124° E. 13° N.

						Per sec.
East-West	Bombay,	time to travel	31 m.,	distance 49°,	velocity	2·92 km.
	Kodaikanal,	,,	40 m.,	,, 45°,	,,	2·08 km.
	Honolulu,	,,	43 m.,	,, 74°,	,,	3·19 km.
				Average .	. .	2·73 km.

North-South	Irkutsk,	time to travel	28 m.,	distance 42°,	velocity	2·77 km.
	Shide,	,,	65 m.,	,, 102°,	,,	2·90 km.
	Kew,	,,	65 m.,	,, 102°,	,,	2·90 km.
	Bidston,	,,	54 m.,	,, 99°,	,,	3·39 km.
	Edinburgh,	,,	59 m.,	,, 99°,	,,	3·07 km.
	Tokio,	,,	14 m.,	,, 27°,	,,	3·56 km.
				Average .	. .	3·09 km.

Earthquake No. 1632, October 13, 1908, origin 102° W. 18° N.

East-West	Honolulu,	time to travel	28 m.,	distance 52°,	velocity	3·43 km.

North-South	Victoria,	time to travel	23 m.,	distance 35°,	velocity	2·81 km.
	Irkutsk,	,,	60 m.,	,, 105°,	,,	3·23 km.
	Tashkend,	,,	60 m.,	,, 122°,	,,	3·76 km.
	Victoria,	,,	23 m.,	,, 35°,	,,	2·81 km.
	Beirut,	,,	82 m.,	,, 114°,	,,	2·56 km.
	Edinburgh,	,,	54 m.,	,, 81°,	,,	2·77 km.
	Bidston,	,,	54 m.,	,, 79°,	,,	2·70 km.
				Average .	. .	2·95 km.

When we look at the averages at the end of the above nine tables, it appears that in seven instances the velocity for East-West motion has been greater than that given for North-South motion. In two instances—viz., those for Earthquakes Nos. 884 and 1362—the reverse has been the case.

If we combine the results for all nine earthquakes we get 35 observations for East-West motion, which give an average velocity of 2·96 km. per second, and 58 observations for North-South motion, the average velocity for which is 2·88 km. per second.

VI. *Comparison of the Amplitudes of East-West and North-South Motion at a given Station.*

At Eskdalemuir during the year 1910 two Milne pendulums, one of which recorded North-South motion and the other East-West motion, had periods which did not differ from each other more than one second. At times they had the same period, but usually the former had a period of 17 seconds and the latter 18 seconds. From this we should expect that, if the displacement of the booms was due to tilting, the amount of this as measured in millimetres would be slightly greater in the East-West direction than in the North-South direction. For 40 earthquakes recorded during this year this was the case, but there are 16 instances in which the boom recording North-South motion showed the greatest displacement. In nine instances the amount of displacement was the same on both pendulums. It may be added that for a short period—viz., from January 1 to February 12—the boom recording North-South motion was as sensitive or more sensitive than the one recording East-West motion. Notwithstanding this, the amplitudes for East-West motion were usually greater than those for the North-South motion.

If, instead of comparing boom displacements measured in millimetres, we convert these into angular units, the conclusion arrived at is that East-West tilting is usually greater than that at right angles.

VII. *On the Direction in which Earthquake Motion is most easily propagated.*

In the British Association Report for 1908, p. 74, I discussed the direction in which megaseismic motion is most freely radiated. Two general conclusions at which I arrived were, first, that the motion of large earthquakes travelled farther westwards than it did eastwards, and, second, that the range of motion across the equator was shorter than it is to the East or West.

In the following note this inquiry has been extended to four groups of earthquakes, the members of each group having origins in the same district. Each earthquake is designated by a number corresponding to entries in the Shide Register, in the Circulars issued by the British Association, and also in a Catalogue published in the Report for 1912, p. 71.

District No. 1.—West Coast of Central America, or approximately 90° W. 5° N.

The earthquakes considered are Nos. 806, 1164, and 1450. As there are only three members in this group no single station can have more than three records.

At 11 stations lying northwards from this origin 25 records were made, or on the average 2·2 records per station. At five stations lying to the south of the origin eight records were obtained, the average therefore being 1·6 per station.

Inasmuch as all stations within 60 degrees of the origin each obtained the possible three records, I find that if these are omitted when comparing records obtained in the North with those obtained in the South I get the following results:—

Nine northerly stations recorded on the average two shocks. Four southern stations recorded on the average 1·5 shocks.

I also find that the average distance from the origin of the 11 North-lying stations is 98 degrees, whilst that of the five southerly stations is 77 degrees.

From these examinations it would appear that for the three earthquakes considered, two of which were recorded at Batavia, 159 degrees distant from the origin, that motion was transmitted more freely towards the North than in the opposite direction.

If we compare the transmission of motion eastwards with that which is transmitted towards the West we obtain the following:—

At 11 eastern stations 19 records were obtained, or an average of 1·8 per station.

At eight western stations 17 records were obtained, or an average of 2·1 per station.

If we omit the stations lying within 60 degrees of the origin, the above two averages respectively become 1·5 and 2·0.

The average distance from the origin of the eastern stations is 88 degrees, whilst that of the western stations is 90 degrees—two distances which are practically equal.

The inference is that motion is transmitted more freely towards the West than it is towards the East.

District No. 2.—North of India, or approximately 80° E. and 40° N.

The earthquakes considered are Nos. 832, 886, 982, 1070, 1293, and 1468.

The number of records obtained at 9 stations lying to the North of this district was 46; the average per station was therefore 5.1.

At 8 stations lying to the South of this district 29 records were obtained, the average per station therefore being 3·6.

If we only consider stations more than 60 degrees distant from the origin, these two averages respectively become 5·2 and 3·8. Here, again, we are led to the conclusion that motion was propagated more freely towards the North than in the opposite direction.

It must, however, be pointed out that the average distance of these southern stations from the origins was somewhat greater than that of the northern stations, these distances being respectively 65 and 85 degrees.

To the East of long. 80° E. 33 records were obtained at 9 stations, or 3·6 records per station. To the West of this meridian 38 records were obtained at 9 stations, or on the average 4·2 records per station. It would seem, therefore, that in this district, as in District No. 1, motion was propagated more freely towards the West.

The average distances from the origin of these East and West stations are respectively 76 and 75 degrees.

District No. 3.—East Coast of Japan, or approximately 140° E. 40° N.

The earthquakes considered are Nos. 884, 1031, 1266, 1427, and 1510.

Nine stations with northerly bearings recorded 28 disturbances, or on the average 3·1 per station.

Eight stations with southerly bearings noted 20 disturbances, or on the average 2·5 per station.

If we only consider stations more than 60 degrees distant from this district these averages become 3·0 and 2·6.

The average distance from the origin for the southerly stations is, however, somewhat greater than for the northerly stations, these distances respectively being 91 and 77 degrees.

Five stations lying to the East of 150° E. long. gave 13 records, or an average of 2·6 per station.

Eleven stations lying to the West of this same region yielded 34 records, or on an average 3·1 per station. Here again we observe motion has been propagated more freely towards the West.

District No. 4.—North and North-East of New Guinea, or approximately 150° E. and 0° N. or S.

The earthquakes considered are Nos. 977, 1025, 1128, 1190, 1272, 1301, and 1460.

Eleven stations North of the Equator recorded 61 disturbances, or an average of 5·5 per station. Six stations South of the Equator recorded 29 disturbances, or an average of 4·8 per station. If we only consider stations more than 60 degrees distant from an origin these averages respectively become 5·4 and 5.

That the average number of northern records preponderates over those obtained in the South seems more remarkable when we consider the average distances of these two groups of stations from the origin—the former being 95 degrees and the latter 75 degrees.

Six stations lying to the East of long. 150° E. noted 32 disturbances, or on the average 5·3 per station.

Twelve stations lying to the West of this meridian noted 65 disturbances, or an average of 5·4 per station.

This last result suggests that the quantity of motion propagated eastwards is the same as that which is propagated towards the West.

With this exception, the four groups of earthquakes considered indicate that motion travels to greater distances northwards and westwards than it does southwards and eastwards.

If we take the four districts together we find the following:—

40	northerly	stations gave	160	records, or	4·0	per station.
27	southerly	,,	86	,,	3·2	,,
40	westerly	,,	154	,,	3·7	,,
31	easterly	,,	97	,,	3·1	,,

District No. 5.—West of South America, or approximately 80° W. 30° S.

The earthquakes considered are Nos. 1248, 1248B, 1277, 1398, 1851, and 1852.

Each of these six disturbances was recorded at two or more stations in Great Britain, 105 degrees distant from the origin.

Five were noted at San Fernando, Honolulu, and Cape Town, the respective distances of which from the origin are 95, 88, and 78 degrees. The average distance is 87 degrees.

Four were recorded at Toronto, Victoria, Azores, Tokio, Perth, and Zikaiwei. The distances of these from the origin are respectively 73, 83, 85, 145, 115, and 160 degrees. The average distance is 110 degrees.

Three were noted at New Zealand, Mauritius, Bombay, and Calcutta. The distances of these places are respectively 85, 125, 155, and 170 degrees. The average distance is 134 degrees.

Two were noted at Colombo, Kodaikanal, and Irkutsk, the distances of which are 150, 150, and 160 degrees; the average distance is 153 degrees.

One was noted at Sydney, 100 degrees distant.

This examination simply shows that stations near to an origin obtain more records than those at a great distance.

The average number of records for stations lying westwards from the origin is 3·4, and the average distance of these stations from the origin was 105 degrees. The average number of records for stations lying eastwards from the origin was 4·6, and the average distance of these stations was 102 degrees.

The average number of records for stations lying northwards from the origin was 4·6, and the average distance of these stations was 101 degrees.

The average number of records for stations lying southwards from the origin was 3·2, and the average distance of these stations was 95 degrees.

Although the average distance of stations was practically the same, the greater number of records had been obtained at stations lying eastwards and northwards from the origin.

District No. 6.—Near New Zealand, or approximately 180° East or West, 40° South.

The earthquakes considered are Nos. 804, 877, 922B, and 1768.

Each of these four disturbances was recorded in New Zealand, and at approximately 180 degrees distance in Great Britain.

Three were recorded in Toronto, Perth, Honolulu, San Fernando, and India. The distances of these stations from the origin are 122, 52, 65, 180, and 105 degrees; the average distance is 105 degrees.

Two were noted at Victoria, B.C., Cape Town, Irkutsk, Mauritius, Cordova, and Batavia. The distances of these places from the origin are 102, 105, 112, 100, 85, and 72 degrees. The average distance is 96 degrees.

Only one disturbance was noted at Cairo and Sydney, the distances of which from the origin are respectively 150 and 22 degrees.

Ten stations with a northerly bearing recorded on the average 2·4 shocks, the average distance of these stations from the origin being 109 degrees.

Cape Town, which has a southerly bearing from the origin, recorded two shocks; its distance from the origin is 105 degrees.

Material for comparing propagation in these two directions is evidently too scanty.

Three stations to the eastward of the origin recorded on the average 2·3 shocks, the average distance being 103 degrees.

Six stations to the westward of the origin recorded 2·1 shocks, the average distance being 76 degrees.

The result of these examinations does not suggest that earthquake motion is radiated more freely in one particular direction rather than in some other.

For the six groups of earthquakes originating in six different districts it appears that more motion has been propagated towards the North than towards the South. For the first four groups more records were obtained to the westward of an origin than were obtained to the East of the same. For Groups 5 and 6 this is reversed, but it is based on observations which were comparatively few in number.

VIII. *On the Times of Occurrence of Maximum Motion on Pendulums Differently Oriented.*

In the records from certain stations (see British Association Circulars) we observe that the maximum for East-West motion is frequently reached from one to four or even more minutes before that for North-

South motion. A good illustration of this is found in all the registers from Eskdalemuir. In 1910 the East-West and North-South pendulums indicated a maximum 12 times simultaneously; the East-West pendulums, however, had a maximum 41 times in advance of and six times later than the North-South instrument. When the natural period of the pendulums was not identical they did not vary from each other more than one second, the period for the East-West recording instrument being 18 seconds whilst that for the North-South was 17 seconds. This slight difference in sensibility in the two instruments does not, however, explain why the East-West component, although usually giving earlier records, should occasionally give them simultaneously with and sometimes after the North-South instrument.

At San Fernando in South Spain there is a pair of Milne pendulums mounted to record East-West and North-South motion. The natural period of the first of these instruments is 16 secs., and 1 mm. deflection of the outer end of the boom corresponds to a tilt of $0''\cdot43$. The period of the second is 20 seconds, and 1 mm. deflection of the outer end of the boom is equivalent to a tilt of $0''\cdot25$. As regards the displacement produced by tilting, the first of these instruments, which records East-West motion, has only half the sensitiveness of the other. Notwithstanding this, in 1910 the maximum for East-West motion was obtained before North-South motion 17 times. Twice both pendulums recorded maxima simultaneously, while the very sensitive North-South instrument showed maxima 26 times earlier than the East-West boom.

IX. *Disturbances only recorded at Two or Three Widely Separated Stations.*

In the British Association Report for 1858, p. 55, Mallet refers to a number of shocks which had been felt simultaneously, or nearly so, at two distant places. The most remarkable pair are shocks noted at Okhotsk and Quito, places which are nearly antipodal to each other. As these coincidences cannot be assured within several hours, Mallet agrees with Mylne [1] that 'the probability of anything more than mere coincidence is extremely slight.'

In the British Association Reports, 1908, p. 64, and 1909, p. 51, I called attention to 148 small disturbances which had been noted in Jamaica. Fifty-one of these were undoubtedly recorded 43 minutes later at several stations in Great Britain. They were not, however, noted in Europe. This absence of records across the Channel was attributed to a want of sensibility in the seismographs which were there employed. Although we know that the seismograph recording photographically will pick up very small movements which may or may not be visible on the record received on smoked paper, whether a microseism shall or shall not be noted apparently depends not only on the sensibility of the recording instrument but on other conditions not yet defined.

As illustrative of this I called attention to the fact that from time to time Batavia and Cairo have recorded the same earthquake, which, however, has not been recorded at stations lying between

[1] See 'Brit. Earthquakes,' *Edin. Phil. Journ.*, vol. 31.

these places or at any other station in the world. The distance between these places is 80 degrees, and the times taken for compressional, distortional, and surface waves, or P_1, P_2 and P_3, to travel this distance would be 15, 24, and 50 minutes. A disturbance originating in Java might after one of these intervals be recorded in Cairo or it might in the vicinity of Cairo bring into existence a secondary disturbance. There would be practically the same time intervals between the observations at these two places if the primary disturbance had its origin somewhat to the East of Java. Had the origin of the primary been between Batavia and Cairo the time intervals might be anything less than the given three intervals. If the time intervals exceed 50 minutes it is extremely likely that these two records refer to independent earthquakes.

The following are illustrations of records peculiar to Batavia and Cairo made in 1911:—

Feb. 4	at 7.8	in Batavia and	64 m.	later in Cairo.	
Feb. 8	at 4.0	,,	,,	,,	
Feb. 9	at 18.40	,,	42 m.	,,	
Feb. 10	at 17.25	,,	42 m.	,,	
Feb. 11	at 0.54	,,	32 m.	,,	Felt in Sumatra.
March 6	at 9.57	,,	11 m.	earlier in Cairo.	
March 19	at 0.59	,,	41 m.	later in Cairo.	
April 26	at 10.0	,,	16 m.	,,	
Aug. 2	at 10.7	,,	22 m.	,,	
Aug. 19	at 0.49	,,	12 m.	,,	Felt in Sumbawa.
Sept. 14	at 23.16	in Samoa and	19 m.	later in Cairo.	

The fact that with but one exception all these disturbances were recorded at Batavia before they were recorded at Cairo suggests that their origins were nearer to the former place than the latter.

Well-equipped stations nearer to Batavia than Cairo, and at which we should have expected to find records of these earthquakes, are the following: Mauritius, Tokio, Irkutsk, Zikawei, Tsing-tau, Calcutta, Bombay, Kodaikanal, Manila, Perth, Sydney, Wellington, Christchurch, Tiflis, Beirut, Harpoot, and Tashkend.

X. *Recurrence of Megaseismic Groups.*

Between 1899 and 1909 I find 88 groups of megaseisms. The number of disturbances in a group varies from 2 to 14, while the number of days over which a group extends varies between 1 and 25. The former numbers divided by the latter give what I call the seismicity of a group period. If three earthquakes have taken place on one day I call the seismicity 3, but if four have happened in 5 days I call it ·8. These seismicities, or earthquake-activity numbers, vary between ·4 and 3. In the following lines I give in the form of numerators and denominators the relationship between seismicities and the average number of days of rest which have followed each group.

$$\frac{\cdot 4}{15}\quad \frac{\cdot 5}{10}\quad \frac{\cdot 6}{16}\quad \frac{\cdot 7}{8}\quad \frac{\cdot 8}{11}\quad \frac{\cdot 9}{7}\quad \frac{1\cdot 0}{8}\quad \frac{1\cdot 2}{9}\quad \frac{1\cdot 3}{8}\quad \frac{1\cdot 5}{8}\quad \frac{1\cdot 6}{11}\quad \frac{2\cdot 0}{8}\quad \frac{2\cdot 5}{10}\quad \frac{3\cdot 0}{6}$$

No definite conclusion can be drawn from these figures, but in connection with them I must call attention to a somewhat similar investigation referred to in the Report for 1910, p. 54, where it is shown that great megaseismic activity is followed by long periods of rest. In that case the intensity of a group was considered independently of the number of days over which it was spread.

XI. *Frequency of Earthquake Followers.*

In the British Association Reports, 1899, p. 227, and 1900, p. 71, under the title of 'Earthquake Echoes,' I discussed the vibrations which follow the main shock or shocks of an earthquake and which bring the same to a conclusion. These occur in groups, and as these rise and fall in amplitude it may be inferred that an earthquake does not become extinguished at a uniform rate, but it dies in surges. I sought for the origin of these surgings, particularly for those groups which resemble each other in form, in the hypothesis of repeated reflection.

Another possible explanation is to assume that these repetitions are interference phenomena consequent on the difference in period between the free swing of the recording pendulum and that of the earth.

Now steady-point seismographs have shown for earthquakes we can feel that their period increases as they die out at a given station, and that it also increases as they radiate from an origin. Assuming this to be correct for megaseismic motion, then beats or recurrences at stations at different distances from an origin should show differences in their frequency. To test this I have compared the time frequency of pulsatory recurrences for disturbances recorded in the Isle of Wight which originated in different localities.

The localities chosen were as follow:—

1. East Coast of Japan, distant from Shide . . . 80° to 85°.
2. West Coast Central America, distant from Shide . 80° to 85°.
3. Central Asia, distant from Shide . . . . . 50° to 60°.
4. Between East New Guinea and Fiji, distant from Shide 130° to 140°.

The earthquakes originating in these four districts, and of which I have seismograms recorded in the Isle of Wight, are referred to by numbers corresponding to the numbers given in the Earthquake Catalogue published in the British Association Reports, 1911, p. 57, and 1912, p. 71.

For *District No.* 1 these numbers were 263, 397, 405, 425, 431, 446, 448, 450, 457, 483, 493, 514, 884, 1031, 1266, 1427, and 1510. The average time interval between successive groups was found to be 2·8 minutes.

For *District No.* 2 the numbers were 248, 264, 407, 415, 417, 432, 447, 536, 576, 606*a*, 642, 806, 924*b*, 1164, 1450. The average time interval for these disturbances was 3·4 minutes.

For *District No.* 3 the numbers were 542, 558, 626, 644, 662, 663, 832, 886, 982, 1064, 1070, 1293, 1468. The average time interval for these disturbances was 2·7 minutes.

For *District No.* 4 the numbers were 351, 352, 354, 377, 435, 515, 530, 581, 977, 1025, 1128, 1190, 1272, 1301, and 1460. The average time interval for these disturbances was 2·8 minutes.

If we compare the time intervals for Districts 1, 3, and 4, it would appear that these are not dependent on the distance at which they are recorded from an origin.

XII. *Large Earthquakes recorded at different Observatories, January to June* 1910.

The total number of large earthquakes, each of which disturbs a continental area, between January and June 1910, was about 166. Each of these was recorded at from 3 to 50 or 60 different observatories, and all extended to a distance of more than 20 degrees from their origin. In the following tables, drawn up by the late Shinobu Hirota, instruments which record photographically are followed by the letter P, whilst those which write mechanically on a smoked surface are marked S. The Milne instruments, unless otherwise stated, are single-boom instruments recording East and West motion only.

DISTRICT I.—*British Islands, Central and Western Europe.*

Station	Foundation	Seismographs	Instrument	No. of Cor. Records
Shide	Disintegrated Chalk	Milne, twin boom	P.	144
Hamburg	Alluvium	Wiechert, Hecker	P. & S.	131
Edinburgh	Andesite Lava	Milne	P.	111
Bidston	New Red Sandstone	Milne	P.	75
Strassburg .	Thick Compact Gravel	Wiechert, Rebeur-Ehlert, Milne, Vicentini, Schmidt, Mainka	P. & S.	68
Göttingen .		Wiechert . . .	P. & S.	64
Vienna . .	Alluvium . . .	Wiechert . . .	S.	64
Paris . .		Wiechert, Bosch-Mainka	S.	59
Kew . .	Thick Alluvium .	Milne	P.	58
San Fernando	Calcareous Rock .	Milne, two machines .	P.	56
W. Bromwich	Thick Alluvium .	Milne	S.	55
Grenada .	Limestone . .	Stiatesi, Wiechert, Vicentini and Omori	S.	50
Laibach .	Alluvium . . .	Vicentini, Grablovitz-Belar, Rebeur-Ehlert	P. & S.	43
Eskdalemuir .	Palæozoic Rock .	Milne, twin boom .	P.	27
Catania . .	Rock	Cancani, Vicentini, Agamennone, Omori	S.	26
Malta . .	Limestone . .	Milne	P.	26
Azores . .	Basalt . . .	Milne	P.	23
Tortosa . .	Alluvium . . .	Vicentini, Grablovitz .	S.	22
Monte Cassino	Limestone . .	Cancani . . .	S.	17

DISTRICT II.—*North America.*

Station	Foundation	Seismographs	Instrument	No. of Cor. Records
Victoria, B.C.	Hard Pan above Igneous Rock	Milne	P	36
Toronto .	Alluvium . . .	Milne	P.	35
Ottawa . .	Boulder Clay . .	Bosch	P.	34
St. Louis, U.S.A.	Alluvium . . .	Wiechert . . .	S.	13

DISTRICT III.—*W. Pacific, Australia, and New Zealand.*

Station	Foundation	Seismographs	Instrument	No. of Cor. Records
Cairo	Eocene Limestone	Milne, two instruments	P.	91
Tiflis	Rock	Milne, Rebeur-Ehlert, Bosch, Zollner and Cancani	P. & S.	85
Adelaide	Thick Alluvium	Milne	P.	76
Batavia	Alluvium	Milne, Rebeur-Ehlert, Wiechert	P. & S.	67
Zikawei	Thick Alluvium	Omori, Wiechert	S.	53
Osaka	Thick Alluvium	Omori	S.	52
Honolulu	Coral Limestone	Milne	P.	52
Riverview, Sydney	Sandstone	Wiechert	S.	51
Manila	Alluvium	Gray-Milne, Bertelli, Cecchi, Vicentini, Omori	P. & S.	48
Sydney	Clay and Ironstone Shale	Milne	P.	45
Tsintau		Wiechert	S.	45
Mauritius	Alluvium on Basalt	Milne	P.	38
Kodaikanal	Rock	Milne	P.	37
Calcutta	Alluvium	Milne	P.	31
Wellington, N.Z.		Milne	P.	34
Colombo	Laterite	Milne	P.	27
Mizusawa	Alluvium	Omori	S.	24
Bombay	Red Earth above Basalt	Milne, Colaba, Omori	P. & S.	22
Tokio	Alluvium	Milne	P.	21
Perth, West Australia	Limestone	Milne	P.	15
Reykjavick	Volcanic Materials	Wiechert	S.	16

A glance at the preceding tables shows that while one station has recorded 144 of the possible 166 disturbances, another station has only recorded 15. These marked differences in the number of records in different places are dependent upon many conditions, and at no two stations are the conditions exactly the same. At one, rapid changes in temperature may be accompanied by air tremors, which may eclipse all but the largest seismic records. In this respect I have found marked differences between adjoining rooms. At certain observatories insects, particularly small spiders, cause trouble. A more important cause leading to differences in the number of earthquakes recorded at stations in the same district is difference in the adjustment of the instrument. If two horizontal pendulums have different periods, the one with the longer period yields the greater number of records. Unfortunately, however, it is the one most influenced by air tremors. The expiring efforts of large earthquakes, which at a distance from their origin may be represented by minute ripples or thickenings in consequence of their smallness, have frequently been overlooked. Proximity to or remoteness from epicentral district has naturally a considerable influence upon the number of records obtained at a station.

Those stations which are in or near to areas in which large earthquakes radiate, as, for example, Batavia, Manila, and Osaka, should obtain more records than Toronto, Ottawa, and St. Louis, which are distant from sites of seismic activity. For this reason stations have been grouped according to their relative distances from seismic regions. The first group refers to stations in the British Isles, Central and Western Europe, the second group is in North America, and the third group is India, the Western side of the Pacific, Australia, and New Zealand.

The average number of records obtained in these three districts is respectively 58, 29, and 41, but why the average for the first of these districts should exceed that for the last is contrary to expectations, and to **explain** it we must look for something more than nearness to or distance from epicentral regions.

If we consider the average number of records given by different types of instruments in different districts, the results we arrive at are as follow:—

In District	1	the average number of	photographic	records was	69
,,	1	,,	smoked-paper	,,	55
,,	2	,,	photographic	,,	35
,,	2	,,	smoked-paper	,,	13
,,	3	,,	photographic	,,	39
,,	3	,,	smoked-paper	,,	45

Districts 1 and 2, together with records from Cairo, Tiflis, and Reykjavick, indicate that with photographic recording apparatus more records can be obtained than with mechanical registration. The same is true if we take all the records, including those for District 3, *en bloc*, but for this latter district by itself the conclusion is reversed.

If we next turn to the character of the foundations we find for Districts 1 and 3 that the average number of records obtained if this was rock was 52, but where it was alluvium it was 50.

Other observations bearing upon this subject will be found in British Association Reports for 1901, pp. 43 and 51; 1902, p. 68; 1903, p. 81; and 1904, p. 42.

XIII. *Seismic and Volcanic Activities.*

In the Report for 1912, p. 102, I pointed out the material in certain catalogues suggested that volcanic and seismic activities in the world increased and decreased independently of each other. From this it might be inferred that if there is any periodicity in volcanic activity it would not be the same as the one exhibited by the megaseisms. With the object of examining this question more closely I asked Mr. Leo Kelley, of Dublin, who has made an extensive collection of materials in connection with volcanoes, to furnish me with a list of eruptions which have taken place during the last 200 years. This he kindly did, but unfortunately in many instances the authors from whom he has quoted only mention the year in which an eruption took place and omit the month and date. In the first column of the accompanying table the year is given, and in the second and third columns the number of eruptions and earthquakes. The earthquake numbers are taken from the 'Catalogue of Destructive Earthquakes,' published in the Report for 1911. In this table we have entries relating to 110 years. When we compare successive years we see, for example, that in 1790 there were 14 eruptions and 11 earthquakes, but in the year following the number of eruptions had fallen to seven, while the number of earthquakes remained constant—volcanic activity had decreased while seismic activity suffered no change.

Year	No. of Eruptions	No. of Earthquakes	Year	No. of Eruptions	No. of Earthquakes	Year	No. of Eruptions	No. of Earthquakes
1790	14	11	1827	20	16	1864	10	33
1791	7	11	1828	21	23	1865	10	24
1792	7	7	1829	10	15	1866	5	28
1793	12	5	1830	15	18	1867	9	32
1794	5	11	1831	10	14	1868	15	41
1795	5	4	1832	9	7	1869	21	41
1796	10	6	1833	8	9	1870	12	28
1797	11	4	1834	10	11	1871	16	33
1798	5	6	1835	12	11	1872	24	30
1799	8	9	1836	16	11	1873	5	38
1800	5	6	1837	7	9	1874	9	32
1801	5	6	1838	18	7	1875	12	31
1802	5	11	1839	8	16	1876	9	20
1803	7	6	1840	10	11	1877	22	21
1804	6	4	1841	9	23	1878	24	32
1805	7	6	1842	8	7	1879	11	25
1806	10	15	1843	18	15	1880	8	35
1807	6	3	1844	11	14	1881	5	45
1808	6	7	1845	14	21	1882	5	27
1809	4	10	1846	12	26	1883	29	27
1810	3	8	1847	19	29	1884	7	33
1811	7	8	1848	14	20	1885	18	57
1812	11	18	1849	12	17	1886	18	29
1813	2	6	1850	11	14	1887	8	34
1814	7	10	1851	10	30	1888	8	34
1815	7	10	1852	30	35	1889	7	33
1816	4	3	1853	11	35	1890	5	19
1817	7	5	1854	16	27	1891	5	20
1818	9	9	1855	17	36	1892	8	24
1819	8	12	1856	27	30	1893	17	30
1820	13	7	1857	20	32	1894	19	42
1821	9	12	1858	8	36	1895	5	20
1822	22	14	1859	10	24	1896	3	26
1823	12	7	1860	11	26	1897	3	35
1824	8	10	1861	8	35	1898	4	21
1825	17	9	1862	10	43	1899	8	18
1826	10	8	1863	8	34	1900	3	—

Prof. H. H. Turner writes to me about the above table as follows:—

'If we calculate the correlation between these annual totals as they stand, we obtain the coefficient

$$r = +0{\cdot}45 \pm 0{\cdot}05.$$

But there is a systematic effect which should first be eliminated. A mere glance at the figures shows that the number of recorded earthquakes steadily increases; in the first 50 years (1790-1839) there are 471, and in the last 50 years (1850-1899) there are 1555. The number of eruptions also increases, though not so markedly: in the first 50 years there are 465, and in the last 50 years 601. Now it seems probable that these increases are chiefly due to increased facilities for newsgathering; at any rate, a real secular change of this kind would require independent evidence. Further, it is clear that if the two series of numbers are both steadily increasing there will be a tendency for small numbers in one series to be associated with small numbers in the other, and large with large—that is to say, we shall get a spurious correlation (or rather, a spurious increase in the correlation) due to this cause.

'Hence a further computation was undertaken in which the secular effects were eliminated in the following manner:—

'Taking 10 yearly sums, the numbers and their logs are:—

Years	No. of Eruptions	Log.	Calc.	0 – C	No. of Earthquakes	Log.	Calc.	0 – C
1790–9 . .	84	1·92	1·71	+·21	74	1·87	1·67	+·20
1800–9 . .	61	1·78	1·84	–·06	74	1·87	1·81	+·06
1810–9 . .	65	1·81	1·94	–·13	89	1·95	1·95	·00
1820–9 . .	142	2·15	2·01	–·06	121	2·08	2·07	+·01
1830–9 . .	113	2·05	2·07	–·02	113	2·05	2·16	–·11
1840–9 . .	127	2·10	2·10	·00	183	2·26	2·26	·00
1850–9 . .	160	2·20	2·11	+·09	299	2·48	2·34	+·14
1860–9 . .	107	2·03	2·09	–·06	337	2·53	2·41	+·12
1870–9 . .	144	2·16	2·06	+·10	290	2·46	2·47	–·01
1880–9 . .	113	2·05	2·00	+·05	374	2·57	2·51	+·06
1890–9 . .	77	1·89	1·91	–·02	255	2·51	2·55	–·14

'The "calculated" columns are from the formulæ

$$\text{Eruptions} \quad 2{\cdot}10 + n \times 0{\cdot}020 - n^2 \times 0{\cdot}0114,$$
$$\text{Earthquakes} \quad 2{\cdot}26 + n \times 0{\cdot}087 - n^2 \times 0{\cdot}0060,$$

where n is the number of the term, counting from the middle term (1840-9). Part of these assumed secular terms may, of course, be real; but we have no means of testing the point, and for the present we shall assume that they are spurious and therefore to be eliminated.

'When these formulæ are suitably modified and applied to the individual years and the correlation again calculated it is found to be

$$r = 0{\cdot}39 \pm 0{\cdot}05.$$

This is still quite comparable with the former value, and the conclusion seems justifiable that earthquakes and eruptions are affected by the same cause.'

XIV. *Report on an Improved Seismograph.*

Experiments are being made by Mr. J. J. Shaw, of West Bromwich, with a view to increase the efficiency and economy of the Milne-type seismograph.

The improvements it is proposed to incorporate are electro-magnetic damping, more delicate means of calibrating, clearer definition in the trace of seismograms, a still further economic use of the sensitised paper, increased maximum amplitude, adjustable light slits, &c.

Hitherto these pendulums have been quite undamped (except for the natural damping of the mechanism), and herein has partly lain the secret of its very high degree of sensitivity. The fact has long been recognised that most forms of damping, such as the air and liquid systems used on the Continent, would be too crude to apply to so sensitive an apparatus.

The Galitzin method of electro-magnetic damping seemed to offer the best opportunities for development; but the lightness and delicacy of the Milne booms is such that the addition of heavy copper plates was impracticable. Tests have been made with aluminium foil, and it has been found that this metal is superior to copper for the purpose, in so far that its conductivity is higher than that of copper, weight for weight.

Partly due to the feeble inertia of these pendulums and partly to the efficiency of the aluminium as a damping medium, it is found that a strong magnetic field acting upon five grains of the metal will give a damping effect of 8:1. Any lower value is readily obtained by a sliding adjustment.

The new calibrating device will obviate the usual disturbance of the apparatus in the process, either by opening cover cases or walking round the pedestal. The usual calibrating screw is fitted with a worm and wheel; one whole turn of the worm produces a 2-degree turn of calibrating screw, which gives a tilt of 2″ of arc.

The worm is operated from the vicinity of the clock-box by means of an intervening length of flexible cable, and the movement of the calibrating screw is read on a scale fixed on top of the recording case. The angular motion is read by means of a beam of light from a mirror fixed to the calibrating screw. This direct reading eliminates any error due to flexure in the cable or worm.

XV. *Indexing Materials published by the British Association and the Seismological Society of Japan relating to Geophysics.*

Although the British Association has since the year 1841 published fifty-three Annual Reports and other notices about seismology and other branches of geophysics, it is but rarely these are referred to by modern investigators. To make these publications better known and to give to geophysicists an easy means of reference to them, the following index has been compiled. With these a few references are made to the 'Transactions of the Seismological Society of Japan' and the 'Seismological Journal.' The former are indicated by the letters T.S. and the latter by S.J. These for the most part are detailed accounts of investigations which in the Reports of the British Association are only referred to as abstracts.

Authors' names are attached to all reports and writings, with the exception of those written by myself.

XVI. *Shinobu Hirota.*

Many in the Isle of Wight, and many more outside, will regret to hear of the death of Shinobu Hirota, which sad event took place at his home in Japan on April 24. He came to England in 1895, and within a week of his arrival the seismograph which he brought with him was at work at Shide. To convince those who had doubts as to the possibility of recording an earthquake which had originated even so far away as our antipodes and tó corroborate whatever records might be obtained at Shide, a second instrument was installed at Carisbrooke Castle. To look after this Hirota had, wet or fine, a daily walk of four miles. The fact that these two instruments gave similar records and also that from a single record we could tell the distance from which a megaseism had originated, naturally attracted some attention. Directly it was shown that certain sub-oceanic disturbances had interrupted cables, Colonies desirous of knowing the cause of these sudden isolations from the rest of the world set up seismographs. This was the commencement of the British Association co-operation of seismological stations. To bring this into being Hirota played an active part. He knew personally many of the directors, and gave instruction to their officers. In practical seismometry he made many innovations, some of which have rendered instruments more sensitive. His multiplying levers made of grass stems gathered from 'bents' give pointers exactly one-third the weight of their equivalent in aluminium and yet twice if not three times as stiff. It was by using these that we got at Bidston the first record of rock deformation due to tidal load. In the workshop he was a good all-round workman, and in the Observatory office he kept most careful records. For photographic work he held a gold medal from the Isle of Wight Photographic Society. Above all this, his sharp eyes would find in a seismogram two records where at other stations only one had been discovered.

In view of the great attention and large sums which have been spent, particularly in foreign countries, on the new seismological departure, I feel it my duty to give recognition to an assistant pioneer in these new studies. His work is embodied in annual Seismological Reports for the last seventeen years and twenty-six Circulars, being the records received from observatories. His chief work at Shide was to assist in working up an absolutely new branch of geophysics, which has received recognition throughout the world. He died at the age of forty-three.

XVII. *John Milne.*

The above Report was, as stated in the heading, drawn up by the Secretary of the Committee, and in correcting the proof alterations have been made as sparingly as possible.

It falls to the lot of the Chairman to add a paragraph recording the sudden removal of the mainstay of the work. John Milne died, with but a few days' warning, on July 31. This is not the time or place for an adequate account of his life and work; but it may fitly be recalled that since he became Secretary of this Committee in 1895, seismology has become a new science, largely owing to his own initiative. During twenty years' residence in Japan he became acquainted with earthquakes as disasters, and devoted himself to the study of them at close quarters, with a view to preventing loss of life. On his return to England he looked for a place where these studies at close quarters might be continued on minor disturbances, and Shide was selected after consultation with Professor J. W. Judd, F.R.S., then Chairman of this Committee. But almost simultaneously the possibility of detecting large earthquakes at a distance was realised; at once Milne seized the new opportunity; he devised a simple instrument for collecting such distant records, and stimulated the establishment of stations equipped with this instrument scattered over the globe, especially in British territory. Their records were sent to him at Shide, and he gave them information in return which maintained their interest and enthusiasm. The results are embodied in the annual reports of this Committee, in which the growth of a new department of knowledge can be traced. Facts about the structure of our globe are now familiar which were not only unsuspected in themselves when Milne began work, but to which it was not suspected that we had the means of access. Milne was cordially recognised, at the last meeting of the International Seismological Association, as the pioneer in their discovery.

Such a man cannot be replaced. At a meeting of the Committee held on September 10, 1913, it was determined that the work he had organised should for the present be carried forward as nearly as possible on the same lines as before. Mr. J. H. Burgess, who has for some years past been assisting Professor Milne at Shide (especially since the departure of Shinobu Hirota for Japan last year), will carry on the routine, under the general direction of the Chairman of the Committee. Professor Perry has accepted nomination as Secretary of the Committee, as a purely temporary expedient, which will allow of full consideration of a successor. It will not be easy to raise funds for the proper continuation of the work, even on the present lines, since Professor Milne himself subsidised the work to an unknown amount; but this provision of funds is under consideration.

The following resolution was passed by the General Committee of the British Association on September 17:—

> 'That this Committee desires to put on record its deep sympathy with Mrs. Milne, and its profound sense of the loss which seismology, and especially British seismology, has sustained in the death of John Milne. As Secretary of the Committee from 1895 to his death, he secured the establishment of half a hundred observing stations scattered over the face of the earth; he organised a co-operative scheme of work among them and incorporated the results of it in a series of Reports of this Committee which have revolutionised the science, if indeed they may not rather be said to have created it.'