Seismological Investigations.—Second Report of the Committee, consisting of Mr. G. J. SYMONS (*Chairman*), Dr. C. DAVISON *and* Mr. JOHN MILNE (*Secretaries*), Lord KELVIN, Professor W. G. ADAMS, Dr. J. T. BOTTOMLEY, Sir F. J. BRAMWELL, Professor G. H. DARWIN, Mr. HORACE DARWIN, Major L. DARWIN, Mr. G. F. DEACON, Professor J. A. EWING, Professor C. G. KNOTT, Professor G. A. LEBOUR, Professor R. MELDOLA, Professor J. PERRY, Professor J. H. POYNTING, *and* Dr. ISAAC ROBERTS.

CONTENTS.

I. *Report of Work done for the establishment of a Seismic Survey of the World.*

PROFESSOR MILNE has reported to the Committee that on January 31, 1895, he had issued a circular calling attention to the desirability of observing earthquake waves which had travelled great distances, with working drawings of the necessary installations.

Some months later Dr. E. von Rebeur-Paschwitz drew up suggestions for the establishment of an international system of earthquake stations. To this scheme Professor Milne and other members of the Committee lent their names.

After the death of von Rebeur these suggestions were translated into French and issued by Dr. G. Gerland of Strassburg, on his own responsibility.

For this reason, but more especially because individual efforts have not led to any definite results, the Committee have issued a letter to a number of observatories requesting co-operation in the observation of earthquakes which are propagated round and possibly through the earth.

Dr. Michie Smith has informed Professor Milne of the co-operation which might be expected from the Government of Madras. The Kew Committee have decided to establish an instrument.

Mr. Oldham, Director of the Geological Survey of India, has evinced a desire to assist in making observations. It is likely that Professor Turner of Oxford will purchase a seismograph, whilst others have made inquiries respecting the necessary installation. Sir Clement Markham has already offered his hearty support in carrying out a seismic survey of the world, and there were strong reasons for believing that we might expect assistance from both the Royal Geographical and Royal Astronomical Societies.

Letter sent to various Observatories and Persons.

BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE:

Burlington House,
London, W.

....1897.

To..

....

SIR,—It has been established that the movements resulting from a large earthquake originating in any one portion of our globe can, with the aid of suitable instruments, be recorded at any other portion of the same; therefore the Seismological Investigation Committee of the British Association are desirous of your co-operation in an endeavour to extend and systematise the observation of such disturbances.

Similar instruments should be used at all stations; and the one recommended by this Committee as being simple to work, and one that furnishes results sufficiently accurate for the main objects in view, is indicated in the accompanying report (see pp. 2-4) by the letter M; a sketch of the same is shown on p. 7, whilst there is an example of one of its records on p. 49.

We desire to know whether you are disposed to purchase, and make observations with, one of these instruments, the cost of which, including photographic material to last one year, packed for shipment, is about 50*l.* Should you reply in the affirmative, we shall be pleased to arrange with a competent maker for the construction of an instrument for you, and to furnish instructions respecting installation and working. In case an instrument be established at your observatory, we should ask that notes of disturbances having an earthquake character be sent to us for analysis and comparison with the records from other stations. From time to time the results of these examinations would be forwarded to your observatory.

The first object we have in view is to determine the velocity with which motion is propagated round or possibly *through* our earth. To attain this, all that we require from a given station are the times at which various phases of motion are recorded; for which purpose, for the present at least, we consider an instrument recording a single component of horizontal motion to be sufficient. Other results which may be obtained from the proposed observations are numerous.

The foci of submarine disturbances, such, for example, as those which from time to time have interfered with telegraph-cables, may possibly be determined, and new light thrown upon changes taking place in ocean beds.

The records throw light upon certain classes of disturbances now and then noted in magnetometers and other instruments susceptible to slight movements; whilst local changes of level, some of which may have a diurnal character, may, under certain conditions, become apparent.

Trusting that you will find it possible to co-operate in this endeavour to extend our knowledge of the earth on which we live,

We remain, Sir (on behalf of the Committee),

Your obedient servants,

G. J. SYMONS, *Chairman.*

C. DAVISON, J. MILNE, } *Joint Honorary Secretaries.*

It is requested that Replies be addressed to—

THE SEISMOLOGICAL COMMITTEE, BRITISH ASSOCIATION,
BURLINGTON HOUSE, LONDON, W.

Letter sent to the Foreign Office on February 25, 1897.

Shide Hill House, Newport, I.W.,
February 25, 1897.

To the Under-Secretary of State for Foreign Affairs, Whitehall, London.

SIR,—I am directed by the Seismological Committee of the British Association for the Advancement of Science to state that they are anxious to obtain the assistance of the Marquess of Salisbury with a view to ascertaining, through Her Majesty's representatives in the countries mentioned, whether the Governments of the same would be disposed to co-operate in carrying out the observations indicated in the inclosed circular, which are considered of great scientific importance.

The countries with which the Committee desire to communicate are Chili, Peru, Ecuador, Venezuela, U.S. of Columbia, Mexico, Brazil, the Netherlands for Java, Greece, Spain, Portugal for the Azores, Russia for Russia and Siberia, and Japan.

Should his Lordship be pleased to grant the assistance of Her Majesty's Government in this matter, I shall have the honour to forward further copies of the circulars and pamphlets of which specimens are inclosed.

The Committee have learned that the Government of Madras are desirous to establish a station; whilst Admiral Wharton, Hydrographer to the Admiralty, considers the attainment of the objects in view of great practical value to his department.

I have the honour to remain, Sir,
Your most obedient and humble servant,
JOHN MILNE.

Communication with the Colonial Office.

A letter identical with that sent to the Foreign Office, and in which the following colonies were mentioned—Newfoundland, Bermuda, Barbados, Trinidad, Jamaica, Honduras, Guiana, St. Helena, the Falklands, Cyprus, and Malta—was forwarded on February 25, 1897, to the Colonial Office.

Communication with the Under-Secretary of State for India, April 10, 1897.

A letter in terms similar to the two preceding letters was addressed to the Under-Secretary of State for India asking for co-operation in establishing one station at Aden, three in India, and one in Further India.

The results of these three communications have been that the Marquess of Salisbury has granted the co-operation which was asked, a reply is promised from the Colonial Office, whilst the Under-Secretary of State for India has asked for and received more copies of our circulars and reports.

In addition to the above, thirty-one copies of circulars and reports have been distributed as follows :—

List of Observatories, &c., to which Circulars and Reports have been sent.

1. U.S.A. Cambridge, Mass. Harvard University. Professor E. C. Pickering.
2. „ St. Louis, Miss. Washington University. Professor W. S. Chaplin.
3. „ Terre Haute, Ind. Polytechnic Institute. Professor T. Gray.
4. „ Williams Bay, Wis. Yerkes Observatory. Professor G. E. Hale.
5. „ San Francisco, Berkeley, Cal. University of California. Professor Joseph Le Conte.
6. Australia, Perth. The Observatory. Ernest Cook, M.A.
7. „ Adelaide. Sir C. Todd, K.C.M.G., F.R.S.
8. „ Melbourne. The Observatory. *P. Baracchi.*
9. „ Sydney. The Observatory. H. C. Russell, F.R.S.
10. New Zealand, Wellington. Sir J. Hector, F.R.S.
11. Africa, Cape Town. The Observatory. D. Gill, F.R.S.
12. „ Natal. The Observatory. E. Neville Nevill.
13. India, Madras. The Observatory. Dr. Michie Smith.
14. „ Calcutta. Geological Survey. R. D. Oldham.
15. Mauritius, Port Louis. Royal Alfred Observatory. T. F. Claxton.
16. Hawaii, Honolulu. Lieutenant A. G. Hawes.
17. Malta, Gozo. The College. Father James Scoles, S.J.
18. Manila. Meteorological Observatory. Father Saderra, S.J.
19. China, Shanghai, Zikawei. Rev. L. Froc, S.J.
20. „ Hong Kong. The Observatory. Dr. W. Doberk.
21. South America, Argentine. Cordova Observatory. *W. G. Davies.*
22. Canada, Toronto. The Observatory. Professor Stupart.
23. France, Paris, 126, Rue du Bac. M. A. d'Abbadie.
24. „ „ Bureau Central Météorologique. M. Professor Mascart.
25. Roumania, Bucharest. Institut Météorologique. Dr. Hepites.
26. Austria, Vienna. Hohewarte. Professor Dr. J. Hann.
27. Sweden, Upsala. Observatoire Météorologique. Professor H. H. Hildebrandsson.
28. Switzerland, Geneva. Professor F. A. Forel.
29. Spain, Cadiz. W. G. Forster.
30. Belgium, Uccle. Observatoire Royal de Belgique. A. Lancaster.
31. India, Calcutta. Geological Survey. C. L. Griesbach.

Offers for immediate co-operation have been received from Professors E. C. Pickering (No. 1), Dr. D. Gill (No. 11), and Professor Stupart (No. 22); Dr. Hepites (No. 25) will co-operate, using an instrument received from Dr. Tacchini; whilst Dr. J. Hann (No. 26) replies that he is establishing the Ehlert type of pendulum, and later may also use ours. Co-operation may be expected at some future time from Professor G. E. Hale (No. 4) and Mr. Ernest Cook (No. 6).

The applications Nos. 13, 14, and 21 will, it is hoped, receive a reply through the Under-Secretary of State for India.

The replies from Nos. 2, 9, 17, 19, and 30 indicate that co-operation cannot be expected.

From the remainder replies have not yet been received.

II. *Records of the Gray-Milne Seismograph.* *By* JOHN MILNE, *F.R.S., F.G.S.*

The first of the above seismographs constructed in 1883, partly at the expense of the British Association, still continues to be used as the standard instrument at the Central Observatory in Tokio.

I am indebted to the Director of that institution for the following records. The records with which they are continuous will be found in the 'Report of the British Association' for 1895, p. 115.

Catalogue of Earthquakes recorded at the Central Meteorological Observatory in Tokio between May 1895 *and February* 1896.

No.	Month	Day	Time	Duration	Direction	Maximum Period and Amplitude of Horizontal Motion		Maximum Period and Amplitude of Vertical Motion		Nature of Shock
						secs.	mm.	secs.	mm.	
			1895.							
			H. M. S.	M. S.						
1,523	IV.	6	0 30 27 P.M.	—	—	—	—	—	—	slight
1,524	,,	9	6 20 34 P.M.	—	—	—	—	—	—	,,
1,525	,,	14	4 30 48 P.M.	—	—	—	—	—	—	,,
1,526	,,	16	11 46 41 A.M.	—	—	—	—	—	—	,,
1,527	,,	22	2 45 29 P.M.	—	—	—	—	—	—	slight, quick
1,528	,,	25	6 38 43 A.M.	—	—	—	—	—	—	slight
1,529	,,	25	7 08 02 A.M.	—	—	—	—	—	—	,,
1,530	,,	27	5 41 59 A.M.	—	—	—	—	—	—	,,
1,531	,,	28	8 33 36 A.M.	—	—	—	—	—	—	,,
1,532	VI.	2	11 45 19 A.M.	—	—	—	—	—	—	,,
1,533	,,	2	8 38 0 P.M.	1 01	W.N.W., E.S.E.	1·3	0·8	slight		weak, slow
1,534	,,	7	1 13 55 A.M.	—	—	—	—	—	—	slight
1,535	,,	7	2 30 15 P.M.	—	—	—	—	—	—	,,
1,536	,,	11	0 46 23 A.M.	1 07	N.N.W., S.S.E.	0·6	0·4	—	—	weak, quick
1,537	,,	15	4 30 31 P.M.	—	—	—	—	—	—	slight
1,538	,,	16	1 17 38 A.M.	—	—	—	—	—	—	,,
1,539	,,	20	2 51 48 A.M.	—	—	—	—	—	—	,,
1,540	,,	20	11 56 55 A.M.	10 0	S.-N.	0·3	0·2	slight		weak, slow
1,541	,,	24	1 47 57 P.M.	1 28	S.W., N.E.	0·6	0·4	nothing		weak, quick
1,542	,,	29	7 03 27 P.M.	—	—	—	—	—	—	slight
1,543	,,	30	7 16 0 A.M.	—	—	—	—	—	—	,,
1,544	VII.	2	9 12 57 A.M.	—	—	—	—	—	—	,,
1,545	,,	4	8 54 11 A.M.	—	—	—	—	—	—	,,
1,546	,,	3	10 42 07 P.M.	—	—	—	—	—	—	,,
1,547	,,	9	2 26 59 P.M.	—	—	—	—	—	—	,,
1,548	,,	10	11 08 36 A.M.	—		—	—	—	—	,,
1,549	,,	11	3 52 07 A.M.	—		—	—	—	—	,,
1,550	,,	15	9 23 40 A.M.	—	—	—	—	—	—	,,
1,551	,,	17	10 0 8 P.M.	1 25	S.W., N.E.	0·5	0·7	0·3	0·1	rather weak, quick
1,552	,,	18	9 55 42 P.M.	—	—	—	—	—	—	slight
1,553	,,	27	0 09 03 A.M.	0 37	S.-N.	0·5	0·4	slight,	very	weak, slow
1,554	,,	31	4 44 30 P.M.	0 39	E.S.E., W.N.W.	1·0	0·5	—	—	,,
1,555	VIII.	1	3 53 50 A.M.	—	—	—	—	—	—	slight
1,556	,,	1	7 32 35 P.M.	—	—	—	—	—	—	,,
1,557	,,	3	5 36 48 A.M.	—	—	—	—	—	—	,,
1,558	,,	24	11 16 8 P.M.	1 29	S.-N.	0·5	0·4	—	—	weak, slow
1,559	,,	31	9 37 21 P.M.	—	—	—	—	—	—	slight
1,560	IX.	3	8 18 11 P.M.	—	—	—	—	—	—	,,
1,561	,,	6	0 37 26 A.M.	—	—	—	—	—	—	,,
1,562	,,	7	8 02 05 A.M.	—	—	—	—	—	—	,,
1,563	,,	9	9 53 22 P.M.	0 37	S.-N.	0·8	0·4	—	—	weak, slow
1,564	,,	10	0 43 52 P.M.	—	—	—	—	—	—	slight
1,565	,,	18	3 18 54 P.M.	—	—	—	—	—	—	,,
1,566	,,	21	11 24 30 A.M.	—	—	—	—	—	—	,,
1,567	,,	21	11·03 27 P.M.	—	—	—	—	—	—	,,
1,568	,,	24	1 48 10 A.M.	1 08	N.N.E., S.S.W.	0·6	1·7	slight,	very	weak, quick
1,569	,,	25	2 52 12 A.M.	—	—	—	—	—	—	slight
1,570	X.	4	6 01 12 P.M.	—	—	—	—	—	—	,,
1,571	,,	8	1 16 01 P.M.	—	—	—	—	—	—	,, (thing fallen down to south)
1,572	,,	11	3 11 53 P.M.	0 55	S.-N.	0·2	6·1	0·2	1·3	strong, quick
1,573	,,	12	2 18 23 P.M.	—	—	—	—	—	—	slight
1,574	,,	13	8 34 50 A.M.	—	—	—	—	—	—	,,
1,575	,,	13	1 33 57 P.M.	—	—	—	—	—	—	,,
1,576	,,	15	6 35 35 A.M.	—	—	—	—	—	—	,,
1,577	,,	15	3 05 11 P.M.	—	—	—	—	—	—	,,
1,578	,,	17	1 49 26 P.M.	—	—	—	—	—	—	,,
1,579	,,	23	6 56 26 P.M.	0 23	S.-N.	0·4	0·5	slight,	very	weak, quick
1,580	,,	24	6 55 53 A.M.	—	—	—	—	—	—	slight
1,581	,,	24	7 48 17 P.M.	—	—	—	—	—	—	,,
1,582	,,	25	11 30 12 A.M.	—	—	—	—	—	—	,,
1,583	,,	25	8 24 03 P.M.	—	—	—	—	—	—	,,
1,584	,,	27	11 44 23 A.M.	—	—	—	—	—	—	,,
1,585	,,	27	4 33 49 P.M.	—	—	—	—	—	—	,,

CATALOGUE OF EARTHQUAKES—*continued.*

No.	Month	Day	Time	Duration	Direction	Maximum Period and Amplitude of Horizontal Motion		Maximum Period and Amplitude of Vertical Motion		Nature of Shock
						secs.	mm.	secs.	mm.	
			H. M. S.	M. S.						
1,586	X.	28	0 17 51 A.M.	—	—	—	—	—	—	slight
1,587	XI.	7	0 13 28 A.M.	—	—	—	—	—	—	„
1,588	„	8	3 43 34 A.M.	—	—	—	—	—	—	„
1,589	„	11	3 9 39 A.M.	—	—	—	—	—	—	„
1,590	„	19	3 27 23 P.M.	—	—	—	—	—	—	„
1,591	„	22	10 47 54 A.M.	—	—	—	—	—	—	„
1,592	„	28	6 12 55 A.M.	0 43	S.E., N.W.	0·3	0·5	—	—	weak, quick
1,593	XII.	10	11 19 33 A.M.	—	—	—	—	—	—	slight
1,594	„	12	11 15 32 A.M.	—	—	—	—	—	—	„
1,595	„	31	6 04 27 A.M.	—	—	—	—	—	—	„
			1896.							
1,596	I.	1	9 11 23 P.M.	10 0	S.-N.	0·3	0·2	noth	ing	weak, slow
1,597	„	2	6 13 19 P.M.	—	—	—	—	—	—	slight
1,598	„	3	10 12 21 P.M.	—	—	—	—	—	—	„
1,599	„	5	11 24 27 P.M.	—	—	—	—	—	—	„
1,600	„	7	4 10 56 P.M.	—	—	—	—	—	—	„
1,601	„	7	7 0 44 P.M.	—	—	—	—	—	—	„
1,602	„	9	10 17 16 P.M.	9 23	S.-N.	2·2	16·2	0·5	0·6	strong, slow
1,603	„	9	10 42 20 P.M.	—	—	—	—	—	—	slight
1,604	„	9	10 50 37 P.M.	—	—	—	—	—	—	„
1,605	„	9	11 14 49 P.M.	—	—	—	—	—	—	„
1,606	„	10	0 31 42 A.M.	2 15	S.-N.	0·9	0·5	—	—	weak, slow
1,607	„	10	0 39 09 A.M.	—	—	—	—	—	—	slight
1,608	„	10	0 46 17 A.M.	—	—	—	—	—	—	„
1,609	„	10	0 46 32 A.M.	—	—	—	—	—	—	„
1,610	„	10	1 22 01 A.M.	—	—	—	—	—	—	„
1,611	„	10	2 12 51 A.M.	—	—	—	—	—	—	„
1,612	„	10	2 50 24 A.M.	—	—	—	—	—	—	„
1,613	„	10	5 52 20 A.M.	2 43	N.W., S.E.	1·4	1·2	—	—	weak, slow
1,614	„	10	6 41 41 A.M.	—	—	—	—	—	—	slight
1,615	„	10	7 04 21 A.M.	—	—	—	—	—	—	„
1,616	„	10	11 24 29 A.M.	4 22	S.-N.	1·3	1·7	—	—	weak, slow
1,617	„	10	4 42 46 P.M.	4 0	W.N.W., E.S.E.	1·2	1·0	—	—	„
1,618	„	10	8 08 44 P.M.	—	—	—	—	—	—	slight
1,619	„	10	10 21 59 P.M.	—	—	—	—	—	—	„
1,620	„	11	0 33 05 A.M.	—	—	—	—	—	—	„
1,621	„	11	5 50 08 A.M.	—	—	—	—	—	—	„
1,622	„	11	7 06 43 A.M.	—	—	—	—	—	—	„
1,623	„	11	8 49 12 A.M.	—	—	—	—	—	—	„
1,624	„	11	10 36 55 A.M.	—	—	—	—	—	—	„
1,625	„	11	4 47 30 P.M.	—	—	—	—	—	—	„
1,626	„	12	11 06 37 P.M.	36 0	E.-W.	0·2	0·4	0·2	0·2	weak, quick
1,627	„	13	5 26 35 A.M.	—	—	—	—	—	—	slight
1,628	„	15	4 24 54 A.M.	—	—	—	—	—	—	„
1,629	„	16	2 42 31 A.M.	—	—	—	—	—	—	„
1,630	„	16	4 14 25 A.M.	—	—	—	—	—	—	„
1,631	„	19	6 08 22 P.M.	2 10	S.-N.	1·0	0·3	—	—	weak, slow
1,632	„	22	3 11 25 A.M.	—	—	—	—	—	—	slight
1,633	„	22	4 43 40 A.M.	2 50	S.S.E., N.N.W.	0·5	2·3	slight,	very	weak, quick
1,634	„	22	5 28 15 A.M.	30 0	S.S.W., N.N.E.	0·2	0·3	—	—	„
1,635	„	22	7 16 27 A.M.	—	—	—	—	—	—	slight
1,636	„	22	6 16 28 P.M.	—	—	—	—	—	—	„
1,637	„	22	3 30 09 A.M.	—	—	—	—	—	—	„
1,638	II.	2	5 02 06 A.M.	—	—	—	—	—	—	„
1,639	„	5	5 10 17 P.M.	—	—	—	—	—	—	„
1,640	„	9	7 47 21 P.M.	—	—	—	—	—	—	„
1,641	„	12	6 37 44 A.M.	1 09	S.S.E., N.N.W.	0·5	0·3	—	—	weak, quick
1,642	„	14	1 56 11 A.M.	0 40	S.-N.	1·0	0·3	0.3	—	„
1,643	„	14	2 03 44 A.M.	—	—	—	—	—	—	rather weak
1,644	„	15	1 16 20 A.M.	—	—	—	—	—	—	slight
1,645	„	18	about 5 13 0 P.M.	—	—	—	—	—	—	„
1,646	„	18	10 19 27 P.M.	—	—	—	—	—	—	„
1,647	„	23	7 41 47 P.M.	3 55	N., W.S.E.	1·0	3·7	slight.	very	weak, slow
1,648	„	23	9 35 50 P.M.	—	—	—	—	—	—	slight
1,649	„	24	9 56 03 P.M.	—	—	—	—	—	—	„
1,650	„	25	0 59 59 A.M.	—	—	—	—	—	—	„

CATALOGUE OF EARTHQUAKES—*continued.*

No.	Month	Day	Time	Duration	Direction	Maximum Period and Amplitude of Horizontal Motion.		Maximum Period and Amplitude of Vertical Motion		Nature of Shock
						secs.	mm.	secs.	mm.	
			H. M. S.	M. S.						
1,651	II.	25	7 58 25 A.M.	—	—	—	—	—	—	slight
1,652	"	28	9 35 15 A.M.	—	—	—	—	—	—	"
1,653	"	29	5 56 35 A.M.	3 7	E.-W.	0·3	0·2	—	—	weak, quick
1,654	"	29	11 27 02 P.M.	—	—	—	—	—	—	slight
1,655	III.	1	5 29 25 P.M.	—	—	—	—	—	—	"
1,656	"	6	7 40 46 P.M.	—	—	—	—	—	—	"
1,657	"	6	11 51 31 P.M.	2 0	S.W., N.E.	0·6	4·3	0·6	0·4	weak, quick
1,658	"	9	10 16 15 A.M.	—	—	—	—	—	—	slight
1,659	"	10	8 54 48 P.M.	—	—	—	—	—	—	"
1,660	"	12	7 12 16 A.M.	—	—	—	—	—	—	"
1,661	"	13	2 36 23 A.M.	—	—	—	—	—	—	"
1,662	"	14	4 44 32 A.M.	—	—	—	—	—	—	"
1,663	"	14	10 15 32 P.M.	—	—	—	—	—	—	"
1,664	"	14	11 41 48 P.M.	—	—	—	—	—	—	"
1,665	"	16	10 33 16 P.M.	—	—	—	—	—	—	"
1,666	"	17	2 37 08 A.M.	—	—	—	—	—	—	"
1,667	"	20	3 35 57 A.M.	—	—	—	—	—	—	"
1,668	"	20	11 32 20 A.M.	—	—	—	—	—	—	"
1,669	"	26	6 28 49 P.M.	—	—	—	—	—	—	"
1,670	IV.	1	2 53 13 A.M.	—	—	—	—	—	—	"
1,671	"	1	2 50 27 P.M.	—	—	—	—	—	—	"
1,672	"	2	1 41 55 A.M.	1 18	E.-W.	1·2	0·2	—	—	weak, slow
1,673	"	2	11 38 57 A.M.	—	—	—	—	—	—	slight
1,674	"	10	5 39 53 P.M.	0 45	S.-N.	0·5	0·2	—	—	weak, slow
1,675	"	11	10 35 35 A.M.	—	—	—	—	—	—	slight
1,676	"	11	10 59 49 P.M.	2 52	N.W., S.E.	0·3	1·5	0·3	0·2	weak, quick
1,677	"	13	10 05 07 P.M.	—	—	—	—	—	—	slight
1,678	"	13	10 13 47 P.M.	—	—	—	—	—	—	"
1,679	"	15	7 41 39 A.M.	—	—	—	—	—	—	"
1,680	"	15	8 26 27 P.M.	—	—	—	—	—	—	"
1,681	"	19	7 59 02 P.M.	4 07	N.N.W., S.S.E.	1·2	0·9	—	—	weak, slow
1,682	"	20	1 36 17 A.M.	1 50	W.N.W., E.S.E.	1·5	0·6	—	—	"
1,683	"	20	0 23 13 P.M.	—	—	—	—	—	—	slight
1,684	"	21	9 05 03 A.M.	1 57	S.W., N.E.	1·6	0·6	—	—	weak, slow
1,685	"	21	0 19 40 P.M.	—	—	—	—	—	—	slight
1,686	"	23	0 37 41 A.M.	—	—	—	—	—	—	"
1,687	"	23	5 08 45 A.M.	1 21	N.N.W., S.S.E.	0·3	0·5	—	—	weak, quick
1,688	"	26	7 02 37 A.M.	—	—	—	—	—	—	slight
1,689	"	26	10 49 56 A.M.	2 06	S.S.E., N.N.W.	0·7	2·5	0·6	0·2	weak, quick
1,690	"	25 ?	5 28 11 A.M.	—	—	—	—	—	—	slight
1,691	V.	4	7 37 62 A.M.	—	—	—	—	—	—	"
1,692	"	5	3 01 50 A.M.	—	—	—	—	—	—	"
1,693	"	7	2 37 17 P.M.	1 55	W.N.W., E.S.E.	1·3	0·8	—	—	weak, slow
1,694	"	11	11 32 58 P.M.	—	—	—	—	—	—	slight
1,695	"	16	0 26 13 A.M.	1 25	S.E., N.W.	0·4	0·4	0·3	0·1	weak, quick
1,696	"	17	3 39 59 P.M.	2 20	E.S.E., W.N.W.	1·2	1·8	0·7	0·2	weak, slow
1,697	"	21	3 58 33 A.M.	—	—	—	—	—	—	slight
1,698	"	26	6 43 31 P.M.	—	—	—	—	—	—	"
1,699	"	26	8 20 54 P.M.	0 30	S.W., N.E.	0·3	0·3	—	—	weak, quick
1,700	"	29	1 18 50 A.M.	—	—	—	—	—	—	slight
1,701	VI.	1	7 25 52 P.M.	—	—	—	—	—	—	"
1,702	"	4	3 32 52 A.M.	—	—	—	—	—	—	"
1,703	"	5	6 26 41 P.M.	—	—	—	—	—	—	"
1,704	"	7	11 18 15 A.M.	—	—	—	—	—	—	"
1,705	"	7	9 50 09 P.M.	—	—	—	—	—	—	"
1,706	"	8	5 23 36 P.M.	—	—	—	—	—	—	"
1,707	"	11	6 02 17 A.M.	—	—	—	—	—	—	"
1,708	"	11	6 51 59 P.M.	—	—	—	—	—	—	"
1,709	"	14	11 03 08 P.M.	—	—	—	—	—	—	"
1,710	"	15	5 44 43 P.M.	—	—	—	—	—	—	"
1,711	"	15	7 34 14 P.M.	3 48	W.N.W., E.S.E.	1·3	0·8	slight,	very	weak, slow
			about					—	—	slight
1,712	"	15	7 44 0 P.M.	—	—	—	—	—	—	"
1,713	"	15	8 33 53 P.M.	—	—	—	—	—	—	"
1,714	"	15	9 0 38 P.M.	—	—	—	—	—	—	"
1,715	"	15	9 02 31 P.M.	—	—	—	—	—	—	"
1,716	"	15	9 14 14 P.M.	—	—	—	—	—	—	"
1,717	"	15	9 27 35 P.M.	—	—	—	—	—	—	"
1,718	"	15	9 56 39 P.M.	—	—	—	—	—	—	"

CATALOGUE OF EARTHQUAKES—*continued.*

No.	Month	Day	Time	Duration	Direction	Maximum Period and Amplitude of Horizontal Motion		Maximum Period and Amplitude of Vertical Motion		Nature of Shock
						secs.	mm.	secs.	mm.	
			H. M. S.	M. S.						
1,719	VI.	16	0 49 48 A.M.	—	—	—	—	—	—	slight
1,720	"	16	1 05 22 A.M.	—	—	—	—	—	—	"
1,721	"	16	1 32 14 A.M.	—	—	—	—	—	—	"
1,722	"	16	4 16 30 A.M.	4 55	W.N.W., E.S.E.	0·8	0·4	slight,	very	weak, quick
1,723	"	16	5 01 09 A.M.	—	—	—	—	—	—	slight
1,724	"	16	6 40 01 A.M.	—	—	—	—	—	—	"
1,725	"	16	8 01 14 A.M.	3 20	W.S.W., E.N.E.	1·0	0·3	slight,	very	weak, quick
1,726	"	16	8 15 20 A.M.	—	—	—	—	—	—	slight
1,727	"	16	8 16 29 A.M.	—	—	—	—	—	—	"
1,728	"	16	9 32 01 A.M.	—	—	—	—	—	—	"
1,729	"	16	9 47 11 A.M.	—	—	—	—	—	—	"
1,730	"	16	0 0 0 P.M.	—	—	—	—	—	—	"
1,731	"	16	1 26 12 P.M.	—	—	—	—	—	—	"
1,732	"	16	1 28 38 P.M.	—	—	—	—	—	—	"
1,733	"	16	1 29 48 P.M.	—	—	—	—	—	—	"
1,734	"	16	3 11 31 P.M.	—	—	—	—	—	—	"
1,735	"	16	4 23 27 P.M.	—	—	—	—	—	—	"
1,736	"	16	4 44 58 P.M.	—	—	—	—	—	—	"
1,737	"	16	5 46 18 P.M.	—	—	—	—	—	—	"
1,738	"	16	6 31 18 P.M.	—	—	—	—	—	—	"
1,739	"	16	9 58 03 P.M.	—	—	—	—	—	—	"
1,740	"	16	10 33 29 P.M.	1 05	N.N.E., S.S.W.	0·7	0·2	—	—	weak, quick
1,741	"	17	7 47 27 A.M.	—	—	—	—	—	—	slight
1,742	"	17	8 41 19 A.M.	—	—	—	—	—	—	"
1,743	"	17	10 30 20 A.M.	—	—	—	—	—	—	"
1,744	"	17	0 48 28 P.M.	3 25	E.N.E., W.S.W.	1·4	0·4	slight,	very	weak, slow
1,745	"	17	3 13 39 P.M.	—	—	—	—	—	—	slight
1,746	"	18	5 49 38 P.M.	—	—	—	—	—	—	"
1,747	"	22	2 53 59 P.M.	—	—	—	—	—	—	"
1,748	"	24	11 24 17 P.M.	—	—	—	—	—	—	"
1,749	"	25	2 09 19 P.M.	—	—	—	—	—	—	"
1,750	"	26	7 27 06 P.M.	—	—	—	—	—	—	"
1,751	"	30	7 26 03 A.M.	—	—	—	—	—	—	"
1,752	VII.	1	5 30 43 A.M.	—	—	—	—	—	—	"
1,753	"	1	7 13 50 P.M.	—	—	—	—	—	—	"
1,754	"	3	11 38 17 P.M.	—	—	—	—	—	—	"
1,755	"	5	4 59 28 P.M.	—	—	—	—	—	—	"
1,756	"	6	0 25 57 A.M.	—	—	—	—	—	—	"
1,757	"	6	2 21 25 A.M.	—	—	—	—	—	—	"
1,758	"	7	6 35 26 P.M.	—	—	—	—	—	—	"
1,759	"	7	9 39 33 A.M.	—	—	—	—	—	—	"
1,760	"	9	10 03 40 A.M.	—	—	—	—	—	—	"
1,761	"	10	4 49 20 P.M.	—	—	—	—	—	—	"
1,762	"	11	7 44 27 A.M.	—	—	—	—	—	—	"
1,763	"	12	9 35 26 P.M.	—	—	—	—	—	—	"
1,764	"	13	7 53 35 P.M.	—	—	—	—	—	—	"
1,765	"	15	10 31 12 P.M.	—	—	—	—	—	—	"
1,766	"	16	9 43 20 P.M.	—	—	—	—	—	—	"
1,767	"	17	10 41 47 P.M.	—	—	—	—	—	—	"
1,768	"	18	0 59 44 P.M.	1 58	S.S.E., N.N.W.	0·6	0·7	slight,	very	slight, quick
1,769	"	18	3 36 17 P.M.	—	—	—	—	—	—	slight
1,770	"	19	4 12 32 P.M.	—	—	—	—	—	—	"
1,771	"	19	7 44 15 P.M.	—	—	—	—	—	—	"
1,772	"	29	0 56 33 P.M.	—	—	—	—	—	—	"
1,773	"	29	5 63 36 P.M.	2 16	S.W., N.E.	0·8	3·2	slight,	very	weak, slow, stop clock
1,774	VIII.	1	11 49 04 A.M.	2 09	S.E., N.W.	0·8	2·2	0·4	0·3	weak, quick
1,775	"	11	8 23 36 A.M.	20 0	S.W., N.E.	0·8	0·6	slight,	very	rather weak, quick
1,776	"	12	4 31 56 P.M.	—	—	—	—	—	—	slight
1,777	"	13	10 50 37 A.M.	—	—	—	—	—	—	"
1,778	"	14	7 33 28 A.M.	—	—	—	—	—	—	"
1,779	"	14	8 51 21 A.M.	—	—	—	—	—	—	"
1,780	"	17	4 28 48 A.M.	—	—	—	—	—	—	"
1,781	"	20	6 05 37 P.M.	0 50	E.N.E., W.S.W.	0·3	2·9	0·2	0·25	weak, quick
1,782	"	21	1 24 41 A.M.	—	—	—	—	—	—	slight
1,783	"	23	1 37 10 P.M.	—	—	—	—	—	—	"
1,784	"	26	5 49 37 P.M.	—	—	—	—	—	—	"
1,785	"	27	7 25 0 P.M.	—	—	—	—	—	—	"

CATALOGUE OF EARTHQUAKES—*continued.*

No.	Month	Day	Time	Duration	Direction	Maximum Period and Amplitude of Horizontal Motion		Maximum Period and Amplitude of Vertical Motion		Nature of Shock
						secs.	mm.	secs.	mm.	
			H. M. S.	M.S.						
1,786	VIII.	29	7 01 01 P.M.	—	—	—	—	—	—	slight
1,787	”	30	7 32 11 A.M.	—	—	—	—	—	—	”
1,788	”	31	8 38 21 A.M.	—	—	—	—	—	—	”
1,789	”	31	4 42 11 P.M.	—	—	slight, horizontal		—	—	slight, slow
1,790	”	31	5 09 33 P.M.	—	Destructive in Akita		”	slight,	very	”
1,791	IX.	1	2 56 51 P.M.	—	—	—	—	—	—	slight
1,792	”	4	3 15 27 P.M.	—	—	—	—	—	—	”
1,793	”	5	11 07 46 P.M.	—	—	slight, horizontal		—	—	”
1,794	”	10	11 17 53 A.M.	—	—		”	slight,	very	slight, quick
1,795	”	12	8 12 54 P.M.	—	—	—	—	—	—	slight
1,796	”	12	11 16 25 P.M.	—	—	—	—	—	—	”
1,797	”	19	8 59 21 P.M.	—	—	—	—	—	—	”
1,798	X.	1	2 38 07 P.M.	—	—	—	—	—	—	”
1,799	”	7	9 22 35 A.M.	—	—	—	—	—	—	”
1,800	”	8	1 43 08 P.M.	—	—	—	—	—	—	”
1,801	”	10	10 56 01 A.M.	—	—	—	—	—	—	”
1,802	”	28	5 51 26 P.M.	—	—	—	—	—	—	”
1,803	XI.	6	7 42 59 P.M.	—	—	—	—	—	—	”
1,804	”	7	11 07 17 A.M.	—	—	—	—	—	—	”
1,805	”	10	8 06 21 A.M.	—	—	—	—	—	—	”
1,806	”	11	1 36 58 P.M.	—	—	—	—	—	—	”
1,807	”	13	0 13 61 P.M.	—	—	—	—	—	—	”
1,808	”	16	6 06 02 P.M.	—	—	—	—	—	—	”
1,809	”	18	11 08 19 A.M.	2 50	S.S.W., N.N.E.	1·0	0·4	—	—	slight, slow
1,810	XII.	7	10 37 29 A.M.	—	—	—	—	—	—	slight
1,811	”	9	7 56 41 A.M.	—	—	—	—	—	—	”
1,812	”	10	4 44 01 P.M.	—	—	—	—	—	—	”
1,813	”	12	11 22 26 A.M.	—	—	—	—	—	—	”
1,814	”	13	4 02 47 P.M.	—	—	—	—	—	—	”
1,815	”	17	1 17 25 A.M.	0 67	S.S.E., N.N.W.	0·2	1·9	0·3	0·6	weak, very quick
						First begins very slight, and after 5 seconds it shows strong horizontal motion, and continued 9 seconds; then gradually became quieter.				

Other shocks were:—Yokohama, 1h. 17m. 39s., slight; Yokosuka, 1h. 17m. 30s., weak; Maibashi, 1h. 30m. 03s., slight; Gifu, 1h. 20m. 46s., slight. This shock is supposed to represent a landslip in the Bay of Tokio, for it only extends round Tokio.

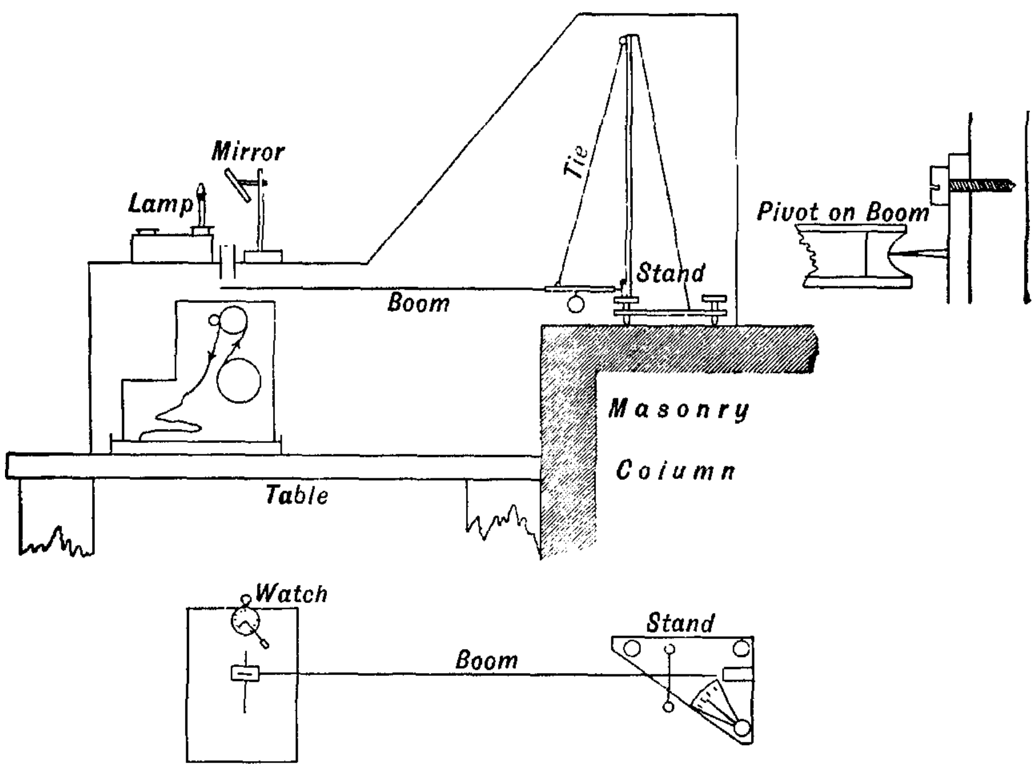
III. *On the Installation and working of Milne's Horizontal Pendulum. By* JOHN MILNE, *F.R.S., F.G.S.*

General Remarks.—As it has been established that the movements resulting from a large earthquake originating in any one portion of our globe can, with the aid of suitable instruments, be recorded in any other portion of the same, the Seismological Committee of the British Association have asked for the co-operation of observers in various parts of the world in an endeavour to extend and systematise the observation of such disturbances. The first object in view is to determine the velocity with which motion is propagated round and possibly through our earth. To attain this, all that is required at a given station is the times at which various phases of motion are recorded, for which purpose, for the present at least, an instrument recording a single component of horizontal motion is sufficient. Other results which may be obtained from the proposed observations are numerous. The foci of submarine disturbances—such, for example, as those which from time to time have interfered with telegraph cables—may possibly be determined, and new light thrown upon changes taking place in ocean beds. The records throw light upon certain classes of disturbances now and then noted in magnetometers and other instruments susceptible to slight movements, whilst local changes in level, some of which may have a diurnal character, may, under certain conditions, become apparent.

The Instrument.—The general features of a type of instrument which the Committee have selected as being sufficient for the attainment of the objects in view are shown in the accompanying sketch.

The instrument consists of an iron bed-plate and stand carried on

FIG. 1.



three levelling screws. Resting against a needle-point or pivot projecting from the base of the stand, and held in a nearly horizontal position by a tie, is a light aluminium boom. Attached to the outer end of this boom there is a small rectangular plate in which there are two slits, one of which is large and the other is small. Partly for the purpose of balancing the weight of the outer end of the boom, and partly for obtaining the 'steady point' of a seismograph between the attachment of the tie to the pivot, a weighted cross-bar is pivoted.

When the boom swings to the right or left, the rectangular plate with its slits passes to the right and left across a fixed slit in the lid of a box, inside which a 2-inch (50 mm.) strip of bromide paper is being driven by clockwork. Light from a lamp is reflected downwards by a mirror to cover the whole of the latter slit. It however only enters the box to the right and left of the floating-plate and through the slits in the same. When the boom is steady, the resulting photogram on the moving bromide paper will be, when developed, that of a white band equal in width to that of the moving-plate, down the centre of which band are two very clearly defined lines, one of which is thick and the other thin (figs. 2, 3, and 5). To the right and left of this white band the paper will have been blackened by the light which entered at the two ends of the fixed slit. On one edge of one of these black bands, at intervals of about 50 mm., there will be seen a series of white marks which have been produced by the minute-hand of a watch, the broadened extremity of which has hourly at the half-hour passed over the end of the fixed slit, and for a period of about one minute eclipsed the light.

Should the clock at any time have failed to drive the bromide strip with regularity this will at once be seen by differences in the distances between successive time marks.

Installation.—The instrument may be placed on any solid pier in an observatory, on a specially constructed pier in the ground-floor of an ordinary dwelling, or in a hut or shed in the open. The room should be dry, which will generally be the case if means are provided for ample ventilation. In order that the photographic paper may be examined or removed at any time, the windows of the room should be provided with shutters, through one of which red light can be admitted. A column or pier of convenient size may be two bricks, or 18 inches (45 cm.) square, which rises 2 feet 8 inches (80 cm.) above the floor. The base of this may rest on a 6-inch (15 cm.) layer of concrete, which in turn rests on a bed of gravel rammed in the natural earth. The top of such a column may be made smooth by a thin facing of cement, whilst its sides should be oriented N.-S. and E.-W. It is convenient to have space to pass round the pier on three sides. The table, which projects from the column in a N.-S. direction and carries the clock-box should be strong, 3 feet 8 inches (1·12 m.) long, 3 feet 7 inches (1·09 m.) broad, and rise 1 foot 8 inches (50 cm.) above the floor of the room. The upper surface of this table is therefore exactly 1 foot (30 cm.) below the top of the column. If an existing pier is used the height of the table must be increased or decreased to maintain the last dimension. The table is made wide to give space for the clock-box, which is run out upon it from its covering-case when removing a film.

The installation may be on an alluvium plain or on solid rock.

Adjustment of the Pendulum.—The instrument is to be so placed that the boom is in the meridian, or points N.-S. The balance weight is to be placed at a distance of $3\frac{1}{2}$ inches (87 mm.) from the pivot, and the attachment of the tie at a distance of about 5 inches (125 mm.). At the latter point, but not shown in the sketch, there is a small upright, from the top of which a thread is carried to within about 9 inches (22 cm.) from the outer end of the boom. This is to prevent the boom from sagging. After the bed-plate of the stand has been made approximately level, the boom is suspended, as shown in the sketch, with its outer end about $\frac{1}{8}$ inch (3 mm.) above the top of the clock-box. To increase or decrease this distance the tie, the last inch or so of which at its upper end is made of unspun silk, may be shortened or lengthened by means of a screw at the top of the stand.

The next point is to give the boom a certain sensibility, which increases as the period of its swing increases. The sensibility which must be arrived at is that which corresponds to an adjustment that results in the pendulum having a period of 15 seconds—that is to say, it is reached when the pendulum makes one complete swing or one back and forward motion in 15 seconds. To make this adjustment the pivot against which the boom abuts may be moved in and out until the desired period is approximately obtained, after which the front screw of the stand may be raised or lowered until the adjustment is completed. To observe the period the observer presses with his hand against the side of the column. This sets the boom in motion. He then goes to the end of the instrument, and, looking downwards through a plate of glass beneath the lamp, watches the rectangular plate on the end of the boom and notes with a watch how many seconds it takes for the boom, as it slowly moves across the scale of millimetres fixed in the top of the clock-box parallel to the slit in the same, to complete a back and forward motion. For various reasons it seems that in all forms of horizontal pendulums this quantity will not remain constant for any great length of time. It therefore must be noted, say, once a week, and if any marked change has taken place the instrument should be readjusted. For stations founded on rock the pendulum may be adjusted to have a period of 18 seconds; but with a pendulum having this sensibility in a station on alluvium, the diurnal motion may exceed the width of the slit in the clock-box, and with changes of weather and the seasons the wandering of the pendulum to one side or the other will be so great that readjustments will be continually required.

The boom is to be brought into a central position by turning one or other of the two back screws in the bed-plate.

The Sensibility of the Instrument.—The distance between the two back screws of the instrument is 150 mm. The front one of these has 0·5 mm. pitch, so that one complete turn of this would tilt the stand through an angle the tangent of which would be measured by $\frac{1}{2}\times\frac{1}{150}=\frac{1}{300}$. By means of a lever fitting the head of the screw, rather than giving it a complete turn, it may be turned 1°, 2°, or any other fraction of a complete turn that may be desired, this quantity being indicated by a pointer attached to the screw which moves over an arc graduated in degrees. For example, assuming that the boom has a period of 18 seconds, and we find by several trials that a 1° turn of the test-screw corresponds to a deflection of the outer end of the boom of 5 mm., as shown on the scale opposite the slit in the clock-box, and assuming, further, that we can read displacements on the photogram of 1 mm., under these circumstances we can measure tiltings the angular values of which would be

$$\frac{1}{2}\times\frac{1}{150}\times\frac{1}{360}\times\frac{1}{5}=\frac{1}{540000};$$

and because 1 sec. of arc$=1/206265$, it follows that 1 mm. deflection of the outer end of the boom corresponds to a tilt of $0''{\cdot}38$.

If we read deflections to within half a millimetre, to do which there is no difficulty, the sensibility of the instrument is doubled. For the object in view this is not required, and if a deflection of 1 mm. is obtained for a tilt of $1''$ to $0''{\cdot}5$, this will be sufficient.

Clock-box.—This, which can be run on rails in and out of the instrument-case, has a cover which is removed to wind the clock and put new paper in the roll. Once a day, when the lamp is filled and trimmed, and the watch is wound, this cover is removed, and the 3 or 4 feet of paper which has accumulated is roughly rolled up. At this time the date may be written in pencil on the bromide film on the top of the upper roll. The small top roll shown in the sketch should barely touch its neighbour, whilst a corresponding roll in contact with the driving-roll should press somewhat tightly on the latter. These two latter rolls are not shown in the sketch. Should the papers at any time refuse to move freely, it may be necessary to alter the adjustment between these rolls to see that they have not become sticky by contact with the bromide surface, or even to cover the driving-roll with a piece of thin but roughish paper. If moisture is suspected as being the cause of a stickiness of the bromide a saucer of calcium chloride may be placed in the clock-box. The most convenient form in which to use this substance is as cake mixed with asbestos. Every week this can be dried over a strong fire.

Calcium chloride, or other desiccating agents, must not be introduced in the instrument-case, for if they are a circulation of air is set up, and the boom swings to and fro, giving records which have often been called earth-tremors. For earthquake work the driving-roll must be adjusted in its outermost position, when it will turn once per hour. In its inner position it turns once in twelve hours, when it may be used, for example, for studying the diurnal wave.

The Watch.—This must be compared fairly often with a standard timekeeper, and its rate noted. It is particularly important that the time at which its hour-hand commences and ends its eclipse over the slit in the clock-box be noted, as it is from these markings that the times of earth disturbances are measured. This can be done either by watching the hour-hand of the watch by looking down the tube down which the mirror reflects light, or by watching the same when the clock-box is taken out of the instrument-case.

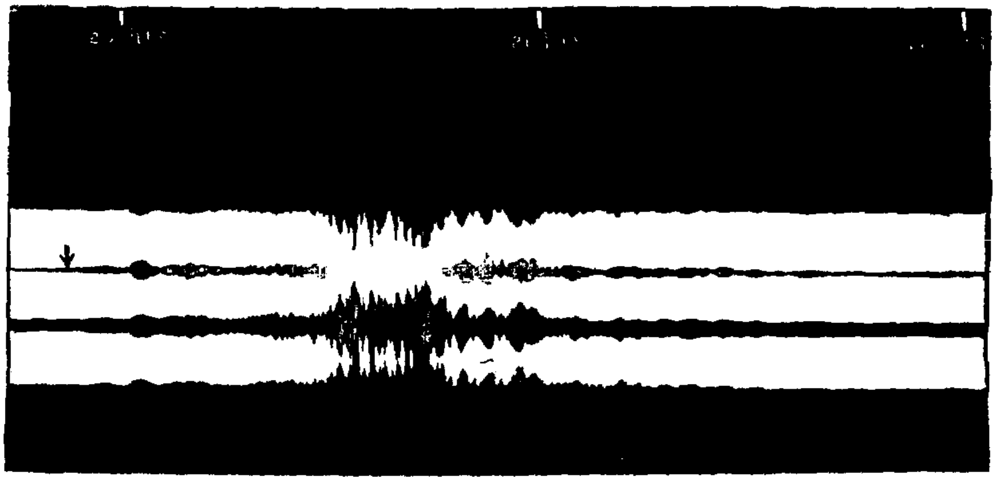
Developing, fixing, and copying the Film.—The films, which are 25 feet in length, are developed once a week. The developer employed has been chosen, because the same solutions may be used for several successive developments. The stock is kept as two separate solutions, made up as follows :—

1st Solution.	Sulphate of soda,	1 oz.	or 1 part by weight.
	Carbonate of potash,	$\frac{1}{2}$ oz.	or $\frac{1}{2}$ " " "
	Bromide of potash,	$\frac{1}{40}$ oz. (10 grs.)	or $\frac{1}{40}$ " " "
	Water,	5 oz.	or 5 " " "
2nd Solution.	Metol,	$\frac{1}{6}$ oz. (75 grs.)	or $\frac{1}{6}$ " " "
	Water,	5 oz.	or 5 " " "

For use one ounce of each of these solutions is to be taken and mixed with about 24 ounces of water, and the whole is then poured into the developing-tray.

The film is doubled backwards and forwards in this solution, and the tray kept agitated until the development takes place, when the solution is poured off into a bottle to be kept until the following week. After the second time of use it may be strengthened with half an ounce of each of the above two solutions, when it will last two weeks longer. It is then thrown away. The next operation is to pour water once or twice into the developing-tray, and to rinse the film, after which it is dragged bodily over the end of the tray into a second tray containing a strong solution of hyposulphite of soda (1 hypo and about 4 water). Whilst in this solution the folds of the film are one by one gently opened to allow the hypo to penetrate. After 10 or 15 minutes, when, by examination of the back of the film, all trace of yellow colour in the film is seen to have disappeared, the hypo is poured back to its bottle and the film is thoroughly washed for at least 15 minutes in several changes of clean water. The

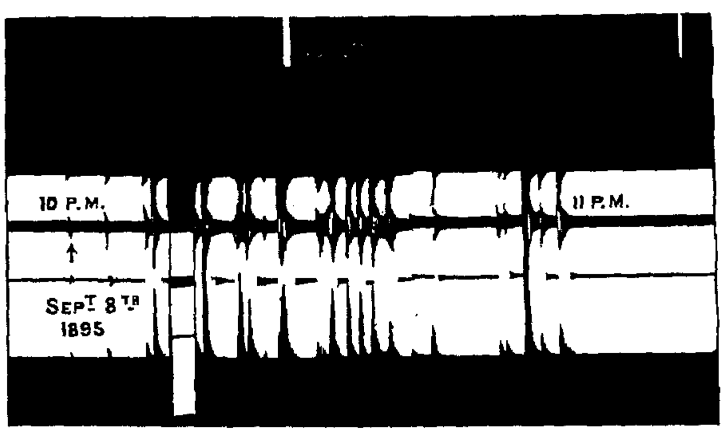
FIG. 2.—Japan Earthquake; Carisbrooke Castle Record.



hypo may be used perhaps twenty times until it has become dirty and ceases to have a saline taste.

The film in its tray of water is then placed on a plank or flat floor. One end of the film is pulled out of the tray and placed face upwards on

FIG. 3.—Displacements on September 10.



the plank or floor, after which the tray is drawn backwards and the film runs out and is left to dry.

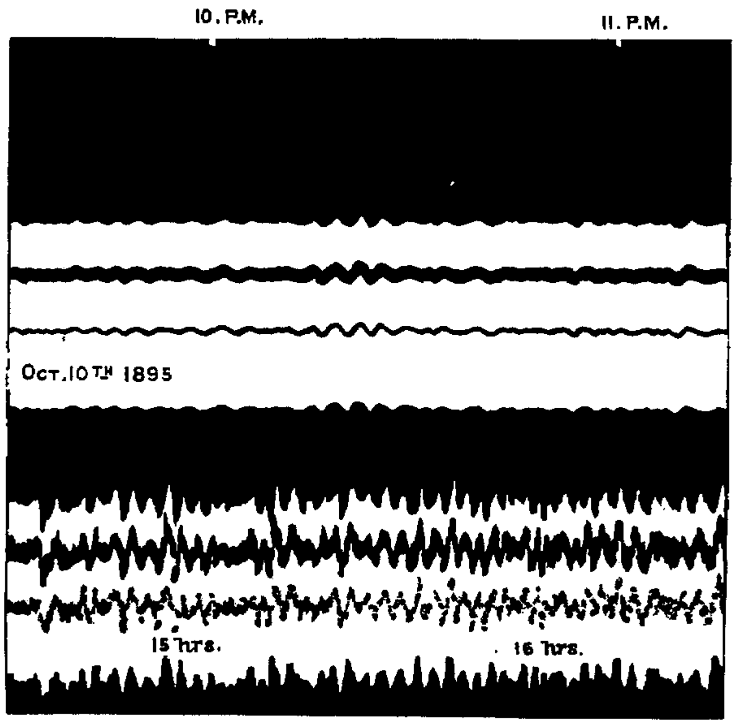
Any particular portion of a film may be reproduced by tracing on tracing-paper, or by photographical printing. For the latter process place the film with its back on a piece of glass or the glass face of a printing frame. A piece of bromide paper is placed with its sensitive surface in contact with the film, and over this a strip of wood or the back of the printing frame, when the whole four are clamped together with springs, clips, or indiarubber bands.

This is held up to the light of an oil lamp or an ordinary gas-burner at a distance of 30 inches for 3 to 10 seconds. Next it is developed in a little fresh but dilute developer. If the developer appears too strong, add water and a few drops of a 10 per cent. solution of bromide of potassium. Too long exposure causes the parts which should be white to become grey. A weak acid bath (citric acid 1 part in 40 of water) tends to remove stains. In warm climates a saturated alum bath may be used. If blisters appear weaken the hypo-bath.

Although photographic reproduction is here referred to, reproduction by tracing is quicker and usually sufficient.

The Photograms.—When the pendulum is at rest the photogram consists of two straight lines, one of which is thin and the other thick, like

FIG. 4.—Commencement and Growth of a Tremor Storm.



those shown over a distance of about a quarter of an inch on the left-hand side of fig. 2 ('British Association Report,' 1896, fig. 19, p. 229,[1]) which is the diagram of an earthquake recorded at Carisbrooke Castle, in the Isle of Wight, but which had its origin in Japan. The reason that two spots of light are used is that for slow movements the fine line gives the best definition, but for rapid movements the light passing through the fine slit is not sufficient to produce an impression on the photographic surface, and therefore, as in the middle of the figure, we have to rely on the image from the large spot.

Because the watch makes its eclipses at the half-hour the intervals marked as 20 hours, 21 hours, and 22 hours are read as 20·5 hours, 21·5 hours, and 22·5 hours, and then corrected from the known rate of the watch and the observed time of the eclipses. What is chiefly required

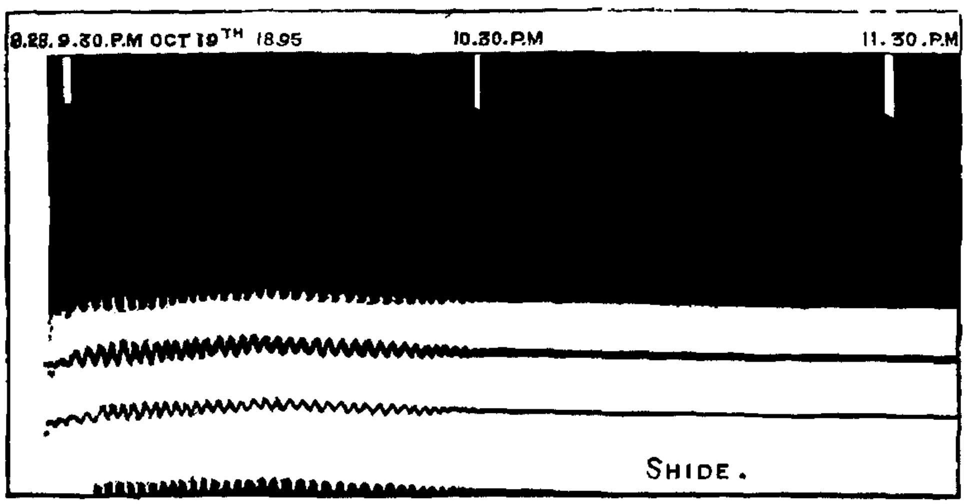
[1] This figure, like the others, having been reproduced from a wood block, is not so clear as the original.

from such a diagram is the Greenwich mean time of the commencement of the preliminary tremors which is near the small arrow, the commencement of decided motion, and the duration of the disturbance. After this, notes may be made of the number of maxima displacements.

Such notes, together with a tracing or photographic reproduction of the diagram, should be sent to the Seismological Committee, British Association, Burlington House, London, W.

In many instances the preliminary tremors, which in the illustration continue over an interval of 34 minutes, may only continue over 5 or 10 minutes, and their duration appears to be connected with the distance at which the disturbance originated. The cause of sudden displacements without preliminary tremors like those shown in fig. 3 ('British Association Report,' 1896, fig. 2, p. 190) is at present unknown. They are rare, and may be due to subsidence beneath the supporting pier. In a dark room, and especially in a warm climate, when removing the clock-box, it is quite possible that now and then a minute spider may find its way

FIG. 5.—Pulsations at Shide.



into the case. If when moving this box the boom is not set in motion, the existence of the work of such an intruder may be suspected, and it and its web must be removed. Such troubles are, however, very rare.

A photogram commencing with intermittent long-period movements, like those shown in the upper part of fig. 4 (' British Association Report,' 1896, p. 200), and increasing until they resemble its lower portion, indicates that the boom has been swinging from side to side under the influence of air currents established inside the case. Such movements, which have been called *earth-tremors* and *microseismic storms*, are at times extremely regular in their character. These latter, with periods of 2 or 3 minutes, are called pulsations (fig. 5. See ' British Association Report,' 1896, fig. 6, p. 201). These movements are frequent during the winter months, and especially at night.

Although they form an interesting study, because they may often eclipse the record of an earthquake, it is necessary that they should be destroyed or avoided. Often they may be destroyed by giving the room in which they are situated a copious and even draughty ventilation. If this does not succeed, the instrument must have a new installation. They are seldom met with in a badly constructed hut or beneath a tent.

Examples of Daily Records.

Date	Light out	Light in	Error of Eclipse Watch	Remarks
1897	h. m.	h. m.	sec.	
Feb. 12	10.41	10.55	−33	Period 18 s. Sensibility 1° = 5 mm. Reset 25° to 30°.
	21.55	21.57		
„ 13	10.30	10.50	−39	Eclipsed light from 10.55 to 10.56, as shown by the eclipse watch.
	21.38	21.40		

&c., &c., &c., up to the end of the week.

From the above records it will be observed that the light has been removed or extinguished twice a day. The times at which this is done is very roughly noted with a pocket-watch. In the morning the lamp is refilled, the eclipse watch wound, and, if necessary, the pendulum, which may have wandered too much on one side, is reset.

The error of the eclipse watch must, relatively to some standard time, be noted accurately. For meaning of 'period' and 'sensibility,' which only need be determined once a week, and which can be expressed in seconds of arc, see pp. 139, 140.

From the mark shown on the developed film when the light is eclipsed the time at which the watch commences to make an eclipse mark can be calculated. These times, as shown on the dial of the eclipse watch, should always be the same, and therefore in order to guard against accident they are only made occasionally. By adding or subtracting the error of the eclipse watch to the time at which an eclipse mark has been made, the exact G.M.T. of this mark is obtained, from which any particular phase of an earth movement may be computed.

Weekly Report.

At the end of the week a report is drawn up of the records, the form of which largely depends upon the movements which have been recorded.

All times must be expressed in Greenwich mean time (civil), the day commencing after 24 hours or midnight. Thus the ordinary notation of June 16, 1.30 A.M., and June 16, 11.30 P.M., becomes June 16, 1.30, and June 16, 23.30.

The most important elements to be noted about an earthquake disturbance are :—

1. The exact time at which preliminary tremors commence.
2. The duration of those tremors.

3. The times at which various maxima of motion are attained, and the tilting they represent expressed in seconds of arc.
4. The total duration of the disturbance.
5. A tracing of the photogram.

IV. *Observations at Carisbrooke Castle and Shide.* *By* JOHN MILNE, *F.R.S.*, *F.G.S.*

In the report for last year it was stated that at about the end of June, through the kindness of Mr. A. Harbottle Estcourt, Deputy-Governor of the Isle of Wight, I had been enabled to establish a second horizontal pendulum at Carisbrooke Castle, and a description of this installation, together with that at Shide, was given in some detail. The object of the second installation was to see how far the records of two similar instruments at some distance apart coincided in character. The Shide records, as already reported upon, consist of movements due to *earthquakes* which have originated at some distance—*displacements*, which show that the boom of the instrument has suddenly been caused to swing or change its zero points ; *tremors*, which are irregular swingings of the boom extending over many hours or several days ; *pulsations*, which are regular back and forth movements of a pendulum, which movements have periods of two or three minutes ; *diurnal waves* and *seasonal wanderings*.

In the following report these movements will be discussed in the order in which they are here mentioned, the Carisbrooke records being taken first.

The Carisbrooke Records.

The Carisbrooke records were obtained between June 16 and August 31, 1896. Because the journey to Carisbrooke and back entailed a walk of four miles, it was only visited once every twenty-four hours. For this reason, together with the fact that the clockwork arrangement often failed to drive the photographic paper—an imperfection which has since been remedied—there were very many interruptions in the continuity of the records. Notwithstanding this, a sufficient number were obtained to compare with corresponding records at Shide, and to indicate the character of Carisbrooke as an observing station.

The *earthquakes* recorded were as follows :—

July 5.—Four exceedingly small, elastic switchings of the boom, the first at 3 hrs. 6 mins. 47 secs., and the last at 3 hrs. 44 mins. 7 secs.

July 21.—At 7 hrs. 3 mins. 53 secs. there was a small elastic disturbance with 5 maxima.

August 30.—A very heavy disturbance (see fig. 2), corresponding in time, points of maxima, and other detail with the Shide record, No. 36. This earthquake had its origin in Japan.

The first two records, which have amplitudes of ·5 to 1 mm., do not correspond with records at Shide, whilst there are similar minute disturbances recorded at Shide which are not visible on the Carisbrooke photograms. The conclusion, for the present, at least, is that these small tremors, which suggest an elastic switching of the end of the boom, are very often of local origin, whilst earthquake movements of a pronounced character are recorded in a similar manner at both stations. The reason that no record was obtained at Carisbrooke on August 26 (No. 35 in the Shide list) was because on that day the recording apparatus was not in operation. The days of such interruptions are indicated on the general list of disturbances, pp. 147, 148.

The *sudden displacements or disturbances* noted at Carisbrooke are given on the list just mentioned. As compared with Shide they are very few in number, and at the two stations there was no agreement in the times at which they took place.

Tremors and *pulsations*, which I am inclined to regard as being due to slow and fairly regular air currents within the covering cases of instrument, were practically absent at Carisbrooke.

Because the observation of the *diurnal wave* and longer-period movements require an adjustment of the clockwork, so that it runs at a slow speed, these were not observed. Inasmuch as readings taken of the position of the end of the boom showed but little change, it is probable that they are small.

Because the latter three classes of movement were frequent at Shide, whilst they were practically absent at Carisbrooke, it is evident that the latter station is the better site for the observation of earthquakes.

Displacements observed at Carisbrooke Castle and Shide in 1896.

l. d. = large displacement; m. d. = moderate displacement; s. d. = small displacement.

Date	Shide				Carisbrooke			
	Time			Character	Time			Character
	H.	M.	S.		H.	M.	S.	
June 16	23	40	0	l. d.		—		—
„ 17	6	29	50	s. d.		—		—
„ 21	6	38	36	s. d.		—		—
„ „	6	55	48	s. d.		—		—
„ „	21	38	36	s. d.		—		—
„ 22	7	4	24	l. d.	5	51	40	l. d.
„ „	18	45	12	l. d.		—		—
„ 23	2	13	5	s. d.	5	34	32	l. d.
„ „	4	33	44	s. d.	19	13	12	s. d.
„ 25	10	18	16	m. d.	Not working			—
„ 26	10	6	26	s. d.	„	„		—
„ 27	6	28	26	s. d.	7	22	21	s. d.
„ „	8	16	0	s. d.	7	32	31	s. d.
„ „	13	31	26	s. d.	7	47	31	l. d.
„ „	17	31	0	s. d.	Not working			—
„ 28	2	53	24	s. d.	„	„		—
„ „	6	47	4	s. d.		—		—
„ „	7	4	16	l. d.		—		—
„ 29	10	8	50	l. d.	Not working			—
July 2	18	51	29	l. d.	„	„		—
„ 3	10	26	47	m. d.	„	„		—
„ „	21	10	41	s. d.	„	„		—
„ „	21	26	41	s. d.	„	„		—
„ 4	19	53	6	s. d.	„	„		—
„ 5	9	47	6	s. d.		—		—
„ 7	9	26	20	l. d.	Not working			—
„ 9	5	43	11	s. d.	„	„		—
„ 12	1	36	40	l. d.	„	„		—
„ „	7	45	40	l. d.	„	„		—
„ 13	0	41	17	l. d.	„	„		—
„ „	18	41	17	l. d.	„	„		—
„ 14	1	3	51	s. d.	„	„		—
„ 17	5	12	42	l. d.	Not working			—
„ 21	5	26	25	l. d.		—		—
„ „	10	8	48	s. d.		—		—

L 2

DISPLACEMENTS OBSERVED AT CARISBROOKE CASTLE AND SHIDE IN 1896—*cont.*

Date	Shide		Carisbrooke	
	Time	Character	Time	Character
July 24 . .	2 20 13	m. d.	—	—
„ „ . .	8 34 45	s. d.	—	—
„ „ . .	10 33 17	s. d.	—	—
„ „ . .	13 21 41	s. d.	—	—
„ „ . .	19 59 41	s. d.	—	—
„ „ . .	21 39 9	s. d.	—	—
„ 25 . .	2 16 18	m. d.	—	—
„ „ . .	9 39 12	l. d.	12 30 10	l. d.
„ 26 . .	13 22 2	l. d.	—	—
„ 27 . .	7 13 3	l. d.	—	—
„ „ . .	10 10 27	s. d.	—	—
„ „ . .	21 40 21	m. d.	—	—
„ 29 . .	2 31 33	m. d.	—	—
„ „ . .	10 7 43	s. d.	—	—
„ „ . .	14 29 55	l. d.	—	—
„ 30 . .	4 14 39	s. d.	2 8 47	—
„ „ . .	10 17 15	s. d.	19 30 7	l. d.
„ 31 . .	2 14 33	s. d.	—	—
„ „ . .	10 21 27	s. d.	—	—
„ „ . .	18 47 3	s. d.	—	—
Aug. 1 . .	2 2 56	s. d.	—	—
„ „ . .	18 54 6	s. d.	—	—
„ 2 . .	18 54 19	s. d.	—	—
„ 3 . .	Not working	—	5 34 0	m. d.
„ 4 to 11 .	—	—	—	—
„ 12 . .	4 35 36	l. d.	—	—
„ „ . .	10 31 56	l. d.	—	—
„ 13 . .	2 15 26	s. d.	—	—
„ 14 . .	15 54 16	l. d.	—	—
„ 15 . .	1 57 46	s. d.	—	—
„ „ . .	13 58 58	s. d.	—	—
„ „ . .	15 32 44	l. d.	—	—
„ „ . .	15 49 0	l. d.	—	—
„ 16 . .	9 10 4	l. d.	—	—
„ „ . .	9 13 22	l. d.	—	—
„ „ . .	21 38 12	l. d.	—	—
„ 17, 18 .	—	—	—	—
„ 19 . .	1 55 32	l. d.	—	—
„ „ . .	17 19 54	l. d.	16 47 48	l. d.
„ 20 . .	2 26 41	l. d.	—	—
„ „ . .	18 59 39	l. d.	—	—
„ „ . .	21 9 41	l. d.	20 7 50	m. d.
„ 21 . .	9 36 37	s. d.	—	—
„ 23 . .	22 26 22	l. d.	8 1 8	l. d.
„ „ . .	—	—	11 51 48	l. d.
„ 24 . .	—	—	4 57 6	—
„ 28 . .	2 7 27	s. d.	—	—
„ „ . .	5 50 45	l. d.	—	—
„ „ . .	10 22 27	l. d.	—	—
„ 30 . .	7 9 16	s. d.	—	—
„ „ . .	22 29 34	l. d.	—	—

Records with an Earthquake-like Character observed at Shide, 1896–97.

For the commencement of the Shide records (August 19, 1895, *to* March 22, 1896) the reader is referred to 'Report of the British Association' for 1896, p. 191, in which shocks and displacements are included in one list. The following list only includes movements which have an earthquake-like character ; but as it is possible that certain small displacements may have been mistaken for earthquakes when examining the list, the following explanatory notes will make it easy to identify records which are doubtful.

The sign >, or a series of such signs, indicates a small movement, or a series of small movements, with an amplitude of about 1 mm., which *commenced suddenly* and ended gradually. It is quite possible that some of them, at least, may be due to some local cause—as, for example, a slight settlement beneath the pier on which the instrument is rested—and therefore are not earthquakes. The sign ⌒, or a series of such signs, indicates a very small movement, or series of movements, which *commenced gradually* and ended gradually. Such movements have a true earthquake character ; but because I have no record where they were nearly simultaneously recorded at Carisbrooke, they must, in many instances, at least, be of local origin.

Disturbances which are 'moderate,' or disturbances which have amplitudes exceeding 2 mm., if these commence gently it may be assumed that they are of earthquake origin.

All large disturbances commencing with decided preliminary tremors are certainly earthquake effects. Those to which an asterisk is attached are described at the end of the list in more or less detail. The materials for their description have been derived from my own observations, observations made in Japan, communications from various observers in Europe and Great Britain, the 'Bolletino della Società Sismologica Italiana,' the columns of 'Nature,' and other sources.

Earthquakes observed at Shide, Isle of Wight, 1896–97. (*All times are given in Greenwich mean astronomical time. Midday or noon* = 0 *or* 24 *hours.*)

No.	Date	Hour of commencement, G.M.T.	Remarks	Observed also at			
				Ischia	Potsdam	Nicolaiew	Edinburgh, from middle of August
			1896.				
		H. M. S.					
1*	June 14	22 30 0	Large ⌒>	—	—	—	
2	„ 22	10 6 26	Small >				
3	„ 24	9 47 56	„ „				
4	„ 27	13 8 35	„ „				
5		13 58 59	„ ⌒				
6		14 30 19	„ >				
7	„ 28	9 27 17	„ „				
8*	„ 29	9 2 26 9 24 45	Four maxima	—		=	
9	„ 30	10 6 0	Small ⌒				
10		18 21 57	„ >				
11	July 1	9 40 1	„				
12		10 26 51	„				
13		11 51 13	„				
14		12 36 53	„				
15	„ 2	8 04 22	„ >				

EARTHQUAKES OBSERVED AT SHIDE—*continued.*

No.	Date	Hour of commencement, G.M.T.	Remarks	Observed also at: Ischia	Potsdam	Nicolaiew	Edinburgh, from middle of August
		H. M. S.					
16		10 11 31	Moderate, commences gently				
17*		18 51 29	,, ,, ,, >				
18	July 8	14 54 14	Small ⌒⌒⌒⌒				
19		17 46 11	,, ⌒⌒				
20	,, 11	10 8 49	Moderate. Four maxima				
21	,, 16	8 12 53	Small				
22	,, 17	19 2 40	Moderate >				
23	,, 18	0 9 48	Small >				
24		18 53 14	,, ⌒				
25		23 52 50	Small. Several maxima >				
26	,, 30	11 25 0 } 13 25 0 }	,, ,, ,, ⌒				
27	,, 31	23 25 0	,, ,, ,, ⌒				
28	Aug. 12	23 53 36	Very small ⌒				
29	,, 14	10 19 50	Small ⌒				
30		11 27 16	,, ,,				
31	,, 23	5 38 52	,, ,,				
32	,, 25	4 27 31	,, ,, ...				
33		5 3 21	,, ,,				
34		12 33 15	,, >				
35*	,, 26	11 23 48	Large preliminary tremors last 1m. 16s. Duration 50m.	—	—	—	—
36*	,, 30	20 23 6	Large preliminary tremors last 34m. Duration nearly 3h.	—	—	—	
37	Sept. 10	0 57 51	Small ⌒⌒				
38		17 36 23	,, >				
39	,, 12	17 44 32	Small preliminary tremors last 5m. 44s. ⌒		—	—	
40		18 52 29	Small ⌒				
41	,, 14	0 51 39	,, > ⌒ >		—		
42	,, 20	4 20 50	,, ⌒				
43		4 29 10	,, >				
44		4 37 21	,, ,,				
45		4 59 10	,, ,, ...				—
46		16 14 48	Moderate				
47*	,, 21	17 2 2	Total duration—35m. 50s. ⌒⌒⌒	—	—	—	—
48*	,, 23	11 59 50	Moderate preliminary tremors 7m. 10s. Duration—28m. 40s.	—	—	—	—
49*	,, 24	10 39 20					
50	,, ,,	11 40 24	Duration—34m. 5s. ⌒ . .			—	—
51	Oct. 6	12 51 27	Twelve separated maxima, ending at 14h. 9m. 18s. > > > &c.	—			
52	,, 13	10 17 52	Small >				
53	,, 14	7 41 25	Moderate				
54	,, 25	5 57 26	Small >				
55	,, 27	10 15 10	> followed at 10h. 28m. 50s. by ⌒⌒. Duration—21m.				
56*	,, 31*	17 18 2	Large preliminary tremors last 13m. 51s. Total duration—3h. to 4h.	—	—	—	
57	Nov. 2	4 9 56	Small >			—	—?

EARTHQUAKES OBSERVED AT SHIDE—*continued*.

No.	Date	Hour of commencement, G.M.T.	Remarks	Observed also at: Ischia	Potsdam	Nicolaiew	Edinburgh, from middle of August
		H. M. S.					
58		8 14 58	Small >				
59		10 20 42	,, ,,				
60	Nov. 4	5 1 46	,, > >				
61		6 27 41	,, >				
62		8 57 47	Moderate				
63		10 11 9	Small ⌒				
64	,, 5	3 40 19	,, >				
65		6 52 19	,, ,,				
66		6 59 35	,, ,,				
67*		9 44 58	Large preliminary tremors last 15m. 16s. Total duration—55m.	—		—	
68	,, 26	9 27 29	Moderate ⌒				
69	Dec. 1	21 55 33	End at 23h. 31m. 20s. ⌒⌒⌒				
70	,, 4	8 7 50	Small ⌒⌒⌒⌒				—
71		8 43 3	,, > > >				
72		9 33 18	,, > > > ⌒				
73*	,, 16	14.30 to 22.0	A series of small tremors. Maxima 17h. 30m.				
74	,, 18	13 12 11					
		16.28 to 18.28	Small tremors				
75	,, 26	11.30 to 22.30	⌒⌒⌒				
			1897.				
76	Jan. 3	2 27 3	Preliminary tremors last 8m. 31s. Maxima motion at 2h. 36m. 53s.				
77	,, 8	22 39 3	Maxima at 22h. 40m. 23s. ⌒ .			—	
78	,, 16	10.8 to 10.29	Small ⌒⌒⌒		—		
79		23 52 47	,, ⌒				
80	,, 17	9 16 2	,, ⌒⌒				
81	,, 18	11.30 to 16.30	Tremors with maxima at 14h. 3m. 50s.				
82	,, 23	9 43 20	Small ⌒				
83*	Feb. 6	19 59 3	Tremors last 26m. 40s. Total duration—1h. 6m.	—	=	—	—
84	,, 7	11 55 7	Small ⌒		—		
85	,, 12	14 8 11	Tremors last 3m. 50s. Duration—13m. 20s.		—	—	
86	,, 13	3 23 36	Moderate. Duration—9m. 20s. ⌒				
87	,, 16	12.30 to 22.30	Small ⌒⌒⌒				—?
88	,, 19	12 17 47	Four moderate maxima, ending 13h. 16m. 27s. From 6h. to 10h. not working.	—	=?	—?	—
89	Mar. 1	14 40 14	Moderate >			—	
90	,, 2	14 49 34	,, >				
91		9 48 11	Small ⌒⌒⌒				
92	,, 13	22 46 56	,, ⌒				
93	,, 15	19 36 27	Moderate. Total duration—29m. 20s.			—	
94	,, 16	4 49 49	Small ⌒				
95	,, 18	1 37 26	,, ,,				

FIG. 6.—August 26, 1896.

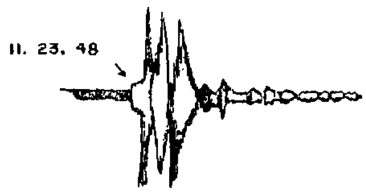


FIG. 7.—September 12, 1896.

FIG. 8.—September 21, 1896.

FIG. 9.—September 23, 1896.

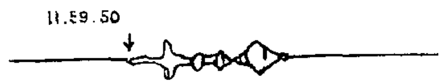


FIG. 10.—October 31, 1896.

FIG. 11.—November 5, 1896.

FIG. 12.

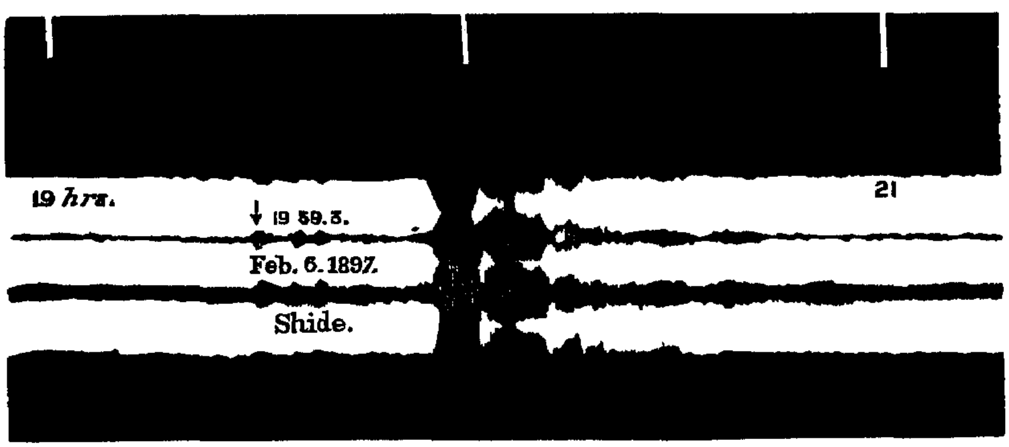


FIG. 13.—Potsdam, February 6, 1897.

V. *Earthquake Records from Japan and other places.* *By* JOHN MILNE, *F.R.S.*, *F.G.S.*

Earthquake No. 1.—*On the Sea-waves and Earthquakes of June* 15, 1896, *in North Japan.*

(Unless otherwise stated, Japan mean time, or G.M.T. + 9 hours, is here used.)

The sea-waves which at about 8 P.M. on June 15, 1896, invaded the north-eastern coast of Nippon were as destructive to life as those which accompanied the well-known eruption on August 26, 1883, of Krakatoa, whilst one of the shocks by which they were preceded was of such severity that it was clearly recorded in Europe, and in every probability caused a disturbance over the entire surface of the globe.

The magnitude of this disturbance, and the sub-oceanic changes by which it was probably accompanied, make it well worthy of record. The sources from which the following notes bearing upon this catastrophe have been derived are various. Amongst the more important are translations from the writings of Professor Kochibe and other officers of the Geological Survey of Japan ; extracts from Japanese newspapers ; the records of the Central Observatory in Tokio, and those from a large number of other observatories at which disturbances were recorded ; and, lastly, the writer's personal knowledge of the devastated districts, and experiences connected with sea-waves and earthquakes which have previously occurred in the same locality.

A full discussion of the phenomena which accompanied this great catastrophe might be divided under two heads, one containing an account of the earthquakes which were recorded, and the other an account of the sea-waves.

Although one or two houses were destroyed by earthquake movement in Yamada, the greatest destruction was that caused by sea-waves, of which the first three were the greatest. The places which suffered most were Kamaishi, Yoshiyama, and neighbouring towns and villages lying in the inlets of the cliff-bound coasts of Rikuzen and Rikuchu, on the N.E. coast of Nippon. Fishermen twenty or twenty-five miles off shore did not observe anything unusual.

List 1.—*Shocks recorded in Japan on June* 15 *and* 16, 1896.

Time (M.J.T.)	Duration	Direction	Remarks	Intensity
H. M. S.				
7 32 30 P.M.	5 m.	E.N.E. W.S.W.	A few houses damaged	slight
7 53 30	The high tide came, and continual shocks were felt.			
8 2 35				
8 23 15				
8 33 10				
8 59 0				
9 31 30				
9 34 5				
9 45 40				
9 50 10				
10 32 10				
11 22 0				
11 33 15				

The first list is that of thirteen shocks noted on June 15 at the Observatory in Miyako, a place lying to the north of Kamaishi and Yamada, where the sea-waves were felt with great force.

The following is a list of shocks noted at observatories in various parts of Japan. The Tokio shocks will also be found in the list of records from the Meteorological Observatory in that city (pp. 135–6, Nos. 1,710 to 1,740). Of these latter, it will be noted that there were only three of marked intensity, and it does not seem that these were connected with the occurrence of the first sea-waves.

List 2.—Earthquakes noted at Observatories in Northern Japan in 1896.

Date	Japan Mean Time	Character of Shock	Place
	H. M. S.		
June 15	5 43 15 P.M.	slight	Fukuoka.
„	5 44 0	„	Choshi.
„	5 44 43	„	Tokio.
„	5 47 13	„	Kofu.
„	7 33 20	weak, slow	Awomori.
„	7 34 0	slight, slow	Fukushima.
„	7 34 14	weak, slow	Tokio.
„	7 30 20	slight, slow	Nemuro.
„	7 34 30	weak	Hakodate.
„	7 34 45	slight, slow	Sakai.
„	7 35 0	weak, slow	Utsunomiya.
„	7 36 21	„	Kofu.
„	7 39 0	slight	Yamagata.
„	7 45 57	„	Fukushima.
„	7 48 43	„	„
„	7 52 0	„	„
„	7 57 0	slight, slow	„
„	8 3 0	„	Awomori.
„	8 7 50	slight	Yamagata.
„	8 5 36	weak, slow	Kofu.
„	8 10 26	slight	Fukushima.
„	8 21 20	„	Awomori.
„	8 27 20	„	Fukushima.
„	8 32 45	„	Awomori.
„	8 33 53	„	Tokio.
„	8 38 10	„	Awomori.
„	8 59 23	slight, slow	„
„	8 59 35	slight	Fukushima.
„	9 0 38	„	Tokio.
„	9 2 31	„	„
„	9 3 45	„	Kofu.
„	9 6 20	„	Yamagata.
„	9 11 37	„	Fukushima.
„	9 13 55	„	Awomori.
„	9 14 14	„	Tokio.
„	9 17 20	„	Kofu.
„	9 19 40	„	Awomori.
„	9 26 18	„	Fukushima.
„	9 27 35	„	Tokio.
„	9 27 52	„	Awomori.
„	9 32 0	„	„
„	9 46 31	„	„
„	9 46 57	„	Fukushima.
„	9 49 30	„	Awomori.
„	9 56 30	„	„
„	9 56 39	„	Tokio.
„	9 59 52	„	Kofu.

LIST 2—*continued.*

Date	Japan Mean Time	Character of Shock	Place
	H. M. S.		
June 15	10 2 0	slight	Yamagata.
,,	10 9 25	,,	Awomori.
,,	10 32 36	,,	,,
,,	11 19 7	,,	,,
,,	11 30 18	,,	,,
,,	11 56 30	,,	,,
June 16	0 34 51 A.M.	,,	,,
,,	0 48 45	,,	,,
,,	0 49 0	weak, slow	Ishinomaki.
,,	0 49 48	slight	Tokio.
,,	0 51 8	,,	Kofu.
,,	1 5 22	,,	Tokio.
,,	1 5 45	,,	Awomori.
,,	1 25 33	,,	,,
,,	1 32 14	,,	Tokio.
,,	1 47 2	,,	,,
,,	1 47 36	,,	Kofu.
,,	1 52 0	,,	Yamagata.
,,	1 57 53	,,	Awomori.
,,	2 39 0	,,	,,
,,	3 16 50	weak, slow	Utsunomiya.
,,	4 15 20	slight	Fukushima.
,,	4 16 30	weak, quick	Tokio.
,,	4 16 35	slight, slow	Sakai.
,,	4 17 0	slight	Awomori.
,,	4 18 5	,,	Niigata. Clocks stopped.
,,	4 18 28	weak, slow	Kofu.
,,	4 22 0	slight	Yamagata.
,,	5 1 9	,,	Tokio.
,,	6 1 48	,,	Awomori.
,,	6 40 1	,,	Tokio.
,,	7 17 16	,,	Awomori.
,,	7 51 12	,,	,,
,,	8 0 49	weak	,,
,,	8 0 50	slight	Fukushima.
,,	8 1 14	weak, quick	Tokio.
,,	8 3 4	weak	Kofu.
,,	8 6 0	slight	Yamagata.
,,	8 14 17	,,	Awomori.
,,	8 14 45	,,	Fukushima.
,,	8 15 20	,,	Tokio.
,,	8 16 29	,,	,,
,,	8 20 20	,,	Yamagata.
,,	8 22 57 A.M.	,,	Awomori.
,,	8 58 29	,,	Hikone.
,,	9 30 35	,,	Awomori.
,,	9 32 1	,,	Tokio.
,,	9 46 11	,,	Awomori.
,,	9 47 11	,,	Tokio.
,,	10 1 7	,,	Hikone.
,,	0 25 26 P.M.	,,	Fukushima.
,,	0 26 12	,,	Tokio.
,,	1 15 3	,,	,,
,,	1 28 38	,,	,,
,,	1 29 48	,,	,,
,,	3 11 31	,,	,,

Nearly all these disturbances were only felt in the northern part of Nippon. Thirty-three were noted in Awomori, 26 were recorded in Tokio, 15 in Fukushima, 10 in Kofu, 7 in Yamagata, and 2 in Sakai. The two shocks recorded at Hikone, which is 450 miles distant from Miyako, were probably of local origin. The fact that the Miyako earthquakes were only sufficient to disturb seismographs in North Japan, whilst the effect of one at least of the series was recorded in Europe, indicates that the origin of these movements was far from land. Had it been a few hundred miles still farther off shore it seems likely that ordinary seismographs, recording on smoked-glass surfaces, would have failed to have given any indications that submarine disturbances had taken place. We have, therefore, here an illustration of the necessity of using horizontal pendulums with photographic recording apparatus, or the equivalent of such instruments, if we desire to study sub-oceanic movements or the effects produced by earthquakes which have originated at great distances.

Sea-waves.—Coast of Rikuzen and Rikuchu (Home Department Report).—First high water at 8.25 P.M. Altogether ten large waves, the first three being at intervals of six minutes.

Miyako.—First high water, 8.20 P.M. Sea retreated about 7.15 P.M.; sea rose about 8.0 and 8.7 P.M. This last tide or wave rose 15 feet, and people and houses were carried away. The tide rose six times.

Tawoi mura.—Sea retreated 1,800 feet.

Hakodate (Yesso).—Tides rose and fell from 10 P.M. on the 15th until 10 A.M. on the 16th. At 4 P.M. on the 16th quiet was restored.

Mororan (Yesso).—High tide at 8 P.M.

Tokachi and Moyori (Yesso).—At 11 P.M. the tide was 10 feet lower than usual. It rose four or five times to heights of 60 or 100 feet.

Kinkazan.—Tide gauge showed changes of 7 or 8 feet.

Bonin Ids.—Tide rose 3 or 4 feet.

Hawaii.—In fourteen hours fourteen tides were noticed, commencing at 7.38 P.M.

Sounds.—Sounds like thunder or the report of a heavy gun were heard at many places, at Miyako before 8 P.M.; at Kitsugawa, in Miyagi Ken; at Tokachi and Moyori, in Yesso, &c.

Unusual Set of Ocean Currents.—Sweeping up the eastern coast of Japan is the great Black Stream, or Kuro Siwo, the strength of which, as indicated by the distance to which it is felt and its position with regard to the coast, is subject to seasonal variation. Along the inundated coast a warm current is felt from spring to autumn, whilst during the winter months the same shores experience a current that is cold. In 1896, spring passed, and yet the cold water hugged the shore, and the fishermen seeking bonito had to go farther than usual from land until they reached warmer waters.

Origin of the Disturbance.—Because the village of Taoi was destroyed by two great waves, one coming from the south and the other from the north, it has been assumed that at a distance of from five to eight miles off the village a submarine landslip had taken place, and the waters rushed inwards towards the scene of dislocation. Because places along 150 or 200 miles of the coast on which Taoi is situated were inundated at about the same time, as Professor Kochibe points out, it is clear that the origin of the convulsion was at a very much greater distance from the land than that just indicated.

Because the sea-waves were preceded by earthquakes it is evident that at least one of the latter must have been accompanied by enormous dislocations in order to have produced the former.

These earthquakes, as recorded on land, were comparatively small, which, from what we know of the dissipation of earthquake energy as it radiates from its origins, indicates that the earth vibrations must have travelled *at least* 100 miles.

The *least* interval of time that we can give between the arrival of the vibratory wave and the sea-waves is that observed at Miyako, which is 21 minutes.

If we assume a mean depth for the ocean off the north-east coast of Nippon, along an easterly line, to the origin of the disturbance at 2,000 fathoms, then the distance from the land to the origin may be expressed

$$\sqrt{12000 \times g} \times 21 \times 60,$$

or about 130 geographical miles.

Again, if we assume v_2 to be the velocity of the sea-wave, which may be taken at 500 feet per second, this being a somewhat low observed velocity for earthquake sea-waves approaching this coast; v_1 the velocity of the vibratory waves, which over a short range has often been observed at 7,000 or 8,000 feet per second; and T the observed interval of time between the arrival of the two waves, then the distance of their origin from the coast is

$$T. \frac{v_1 . v_2}{v_1 - v_2},$$

or in this case about 113 geographical miles.

If we make $v_2 = 600$ feet per second, the distance of the origin becomes about 140 geographical miles.

Because we have taken the least interval that can be assigned to the difference in the times of the arrival of the land and sea-waves, it may be concluded that the origin of the Japan disturbance of June 15 was along a submarine line at a distance of 120 to 140 geographical miles off the coast of North-east Nippon.

Such a locus is at a depth of 4,000 fathoms, and, so far as we know the sub-oceanic contours, exactly at the bottom of the Nippon slope, forming the western boundary of the Tuscarora Deep, a well-known origin for many large earthquakes (see map, fig. 14).

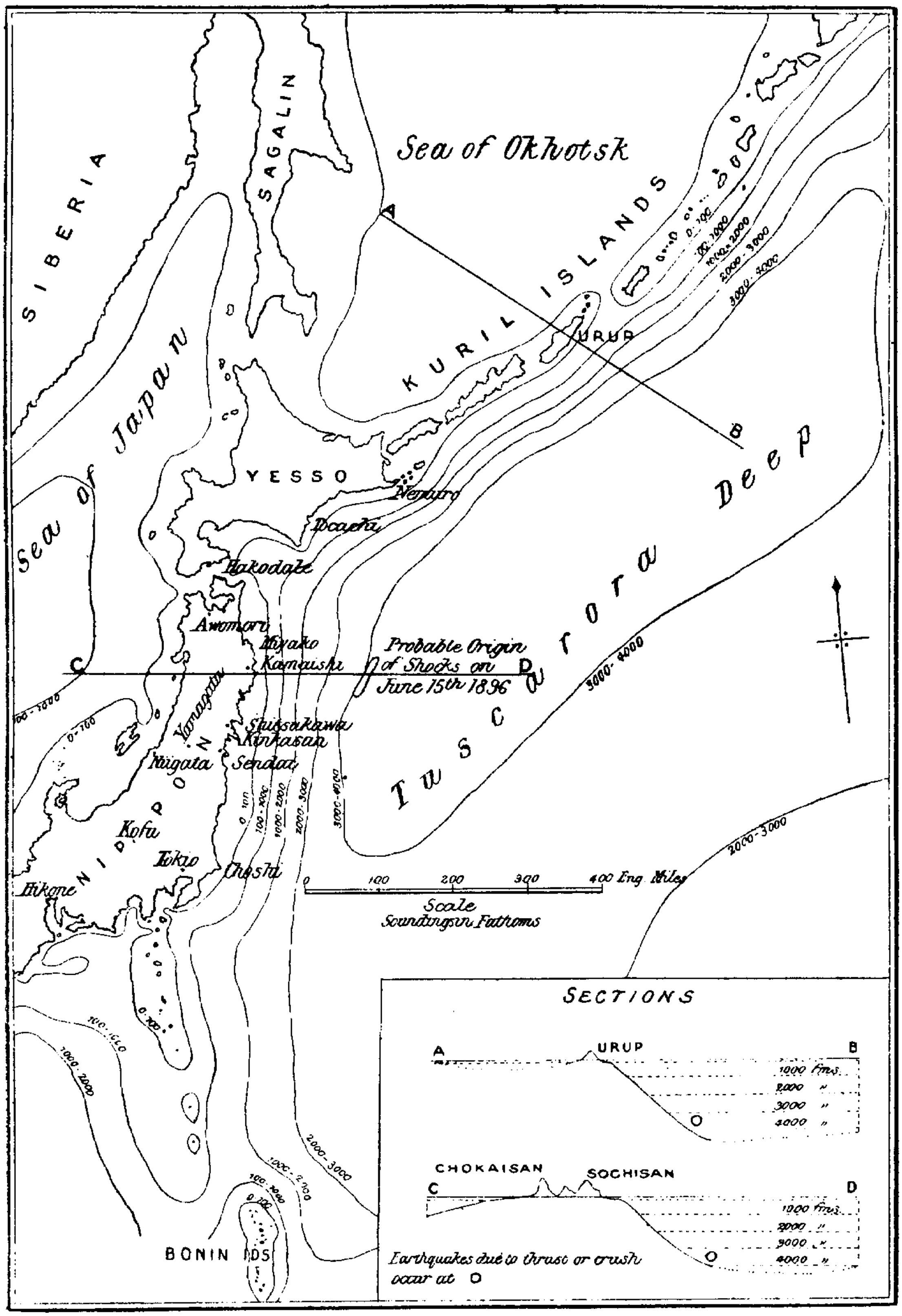
Although much evidence may be adduced to show that early in June 1896 the ocean currents were deranged in direction and intensity, the cause of the submarine dislocation was probably seismic.

Velocity of Propagation of Earth-waves.—Assuming the origin to lie 120 geographical miles east of Miyako, to which place it travelled at a rate of 8,000 feet per second, which fairly well accords with the velocity it travelled from the Miyako isoseist to Tokio, and velocities of propagation of similar earthquakes over short ranges, the time, within a few seconds, at which the earthquake occurred was, in G.M.T., June 14, 22h. 31m. 0s.

G.M.T.—Times at which Preliminary Tremors commenced in Europe.

	H.	M.	S.		M.	S.
Padua	22	46	57	Time to travel	15	57
Ischia	22	49	50	,,	18	50
Rocca di Papa	22	56	18	,,	25	18

Fig. 14.—Map to show submarine earthquake origins near Japan.



The last observation evidently refers to a phase of movement different from that of the first two, and therefore will not be further considered.

Padua .	. 9,320 kms	Velocity .	. 9·7 kms. per sec.
Ischia .	. 9,749 „	„ .	. 8·7 „ „

We should expect to have found these two velocities to have been nearly equal. Their mean value, or the probable rate at which motion was transmitted from Japan to Italy, was

9·2 kms. per sec. on an arc.
And about 8·3 „ „ „ on a chord.

The velocity of transmission to Tokio was about 3 kms. per second.

Earthquake No. 8 (Cyprus).[1]

A severe earthquake took place in Cyprus on June 29, at *about* 8h. 48m. 0s. Other records of this disturbance were as follows :—

	H.	M.	S.
1. Shide	9	2	26
2. Ischia	8	48	20
3. Rocca di Papa	8	48	27
4. Rome	8	48	35
5. Padua	8	49	0
6. Catania	8	50	30
7. Nicolaiew	8	47	0

The observations 2 to 7 clearly indicate a large error in the observation made near the origin in Cyprus. The only calculations of velocity which can therefore be made are on paths between the Nicolaiew isoseist and the first six places.

Places	Distance in Kms. from Cyprus	Distance in Kms. from the Nicolaiew Isoseist	Time of Transit from the Nicolaiew Isoseist	Velocity in Kms. per Sec.
			M. S.	
Nicolaiew .	1,332	—	—	—
Catania .	1,684	352	3 30	1·7
Ischia .	1,813	481	1 20	6·0
Rome .	1,998	666	1 31	7·3
Padua .	2,192	860	2 0	7·1
Shide .	3,404	2,072	15 26	2·2

The first and last determinations may possibly refer to the maximum phases of motion, and the three intermediate ones to the velocity along a path at some depth beneath the surface.

We have here an illustration of high velocities of propagation, which we sometimes find between places each of which are at a distance from an epicentre.

Earthquake in Iceland, No. 35, 1896.

August 26, at about 10.30 P.M. in local time. Very severe shocks, originating in or near the Hekla ridge. Many landslides, four houses thrown down. One fissure on the Oelvus River, 6 miles long. New geysers appeared. Great surface changes.

August 27, 9.15 A.M., also severe.

[1] See *British Association Report*, 1896, pp. 199 and 200.

September 5, 11.30 P.M., also severe.
„ 6, 2.0 A.M. „
„ 19, 11.20 A.M. „ [1]

The above dates and hours, which latter, in all probability, are only approximately correct, become in Greenwich mean time as follows :—

	H.	M.		H.	M.
Aug. 26	11	50	and	22	35
Sept. 5	12	50	„	15	50
„ 19	0	40			

The first of these was recorded at Shide, Edinburgh, Strassburg, Ischia, Potsdam, Nicolaiew, Kew, Paris, and possibly at other places. The remainder were not noted at Shide, because at the hours mentioned the instrument was not working, excepting on the 19th, when there was a heavy tremor storm. The second and third were recorded at Strassburg, and the third and fourth were feebly shown at Edinburgh.

	G.M.T. H.	M.	S.	
Shide Records—				
Commencement	11	23	48	
End of preliminary tremors	11	25	4	
1st max. attained	11	26	12	
2nd „ „	11	27	39	
3rd „ „	11	32	0	
End	12	10	0	
Edinburgh Royal Observatory (Bifilar Pendulum)—				
Commencement	11	10	0	
End	11	30	0	
Kew (Declination Curve)—				
1st small crest	11	27	0	approx.
2nd „ „	11	29	0	„
3rd „ „	11	31	0	„
Paris (*Parc Saint Maur*)—'Magnetic' perturbations observed by M. Moureaux—				
	11	86	0	
	11	42	0	
	11	46	0	

Magnetometers at Greenwich, Falmouth, and Stonyhurst were not disturbed.

	H.	M.	S.
Strassburg (Horizontal pendulum used by Dr. G. Gerland)—			
Commencement	11	22	9
Maximum	11	22	37
Until	12	13	47
End	12	58	37
Rome	11	23	0
Rocca di Papa (15-metre pendulum)	11	26	20
„ „ (7 „ „)	11	36	50
Catania, S.E.–N.W.	11	25	4
„ N.E.–S.W.	11	26	58
Padua	11	30	0
Ischia, E.W.	11	30	54
N. 30° E.–N. 30° W.	11	31	54
N. 30° W.–S. 30° E.	11	31	54

[1] See *Nature*, Oct. 15, 1896, p. 574.

The following table of distances from Hekla, in Iceland, to places where movements were observed, together with the times at which the latter commenced, shows that it is impossible to make any reliable calculations respecting the velocity with which motion was propagated. The causes of the discrepancies are probably to be found in the differences in the form of the instruments employed, and the want of a sufficiently open time scale on many of the record-receiving surfaces :—

	Kms.	H.	M.	S.
Shide	1,831	11	23	48
Strassburg	2,368	11	22	9
Padua	2,775	11	30	0
Rome	3,182	11	23	0
Ischia	3,367	11	30	54
Catania	3,747	11	25	4

Earthquake No. 36 (*N.E. Japan, Nambu*).

For the phases of this earthquake as recorded at Carisbrooke Castle and at Shide, see 'Report of the British Association,' 1896, pp. 229, 230. The photogram is reproduced in this Report, p. 142.

This shock created considerable destruction in the north-west part of Nippon. It was recorded in Tokio as a slow horizontal movement with a slightly vertical component, but the records from ordinary seismographs were too small for accurate measurement. The time of its commencement in Tokio was, in local time, 5h. 9m. 33s. P.M., or in G.M.T., 20h. 9m. 33s.

When this motion was recorded the disturbance would have advanced 4° on its path towards Europe.

The time taken for three of the various phases of motion to reach Shide and the Isle of Wight, and the velocities of propagation, were as follows :—

	H. M. S.	Velocity on Arc. Kms. per Sec.	Velocity on Chord. Kms. per Sec.
Phase 1. Tremors	13 33	11·11	9·46
„ 3. Heavy motion	47 33	3·15	2·68
„ 5. The maximum	1 4 53	2·3	1·96

The following table is a comparison of the Carisbrooke Castle and Strassburg records :—[1]

	Carisbrooke H. M. S.	Strassburg H. M. S.	Difference M. S.
Commencement of tremors	20 23 6	20 17 50	5 16
„ „ max.	20 57 6	20 29 56	27 10
End	23 16 20	23 38 2	21 42
Duration	2 53 20	3 20 12	26 52
Duration of preliminary tremors	34 0	12 6	21 54

Because earthquake movement dies away gradually and fitfully, it is not at all remarkable that there should be nearly 27 minutes difference in the recorded duration of the disturbance as shown at Carisbrooke and Strassburg. The differences between the two records which are noticeable are in the times at which the preliminary tremors commenced and their duration. Because Carisbrooke is not more than 360 kms. farther from North Japan than Strassburg, it might be expected that the preliminary tremors at the latter place would have been observed about half a minute before they reached the Isle of Wight. A difference exceeding five minutes either indicates that the Carisbrooke instrument is less sensitive

[1] *Nature*, April 15, 1897, p. 558.

than that at Strassburg, or else that between the Strassburg isoseist and the Isle of Wight, motion was propagated at only a little over 1 km. per second, which, it may be noted, is a rate of transmission often observed over short ranges near to an epicentre. An inference to be derived from this is, that for purposes of comparison it is desirable that all stations should be furnished with instruments of equal sensibility.

If we accept the Strassburg record of the arrival of the first tremors as correct, then the average velocity of propagation from Japan to that place exceeded on the arc 18 kms. per second, whereas the average of very many other observations on the same path have yielded apparent velocities of half this quantity.

The origin of this disturbance was along two almost north and south lines in the middle of North Nippon. It may be taken as lying to the north and south of a point in 140° 50′ E. long. and 39° 40′ N. lat.

The times at which the shock was automatically noted at various towns were in local time as follows :—

	H.	M.	S.	
Miyako	5	8	55	P.M.
Awomori	5	8	11	
Yamagata	5	8	0	
Ishimaki	5	8	10	
Tokio	5	9	33	

The distance between Tokio and Yamagata is about 150 g.m., and Tokio and the origin 240 g.m. Between the first two places the time taken for the vibration to travel was 90 seconds, indicating a velocity of about 10,000 feet per second. Assuming this to be correct, then the time taken from the origin to Tokio would be 2m. 44s., from which it may be concluded that the shock originated at 5h. 7m. 9s., or, in G.M.T., August 30, 20h. 7m. 9s.

The times at which the commencement of this disturbance was noted in Europe were as follows :—

	H.	M.	S
Shide	20	23	6
Strassburg	20	17	50
Ischia	20	20	30
Rocca di Papa (a maximum by a horizontal pendulum)	21	3	50
„ („ „ 7-metre „)	20	55	0
„ („ „ 15 „ „)	20	41	15
Rome	20	21	15
Catania, N.E.–S.W.	20	25	24
„ S.E.–N.W.	20	21	48
Nicolaiew	20	7	30
Time of origin in North Japan	20	7	9

Omitting the observations at Rocca di Papa and Nicolaiew, the following velocities have been determined :—

—	Shide	Strassburg	Ischia	Rome	Catania
Time of transit	15m. 57s.	10m. 41s.	13m. 21s.	14m. 6s.	14m. 39s.
Distance on arc, in kms.	9,290	9,157	9,468	9,564	9,796
Distance on chord, in kms.	8,532	8,147	8,608	8,698	8,864
Velocity on arc, in kms. per sec.	9·7	14·2	11·8	11·2	11·1
Velocity on chord, in kms. per sec.	8·9	13·1	10·7	10·2	10·0

The previous calculation for Strassburg was from the Tokio isoseist, but even the present result seems very high, whilst that for Shide is a little low.

Earthquake No. 47 (September 21, 1896).

—	Distance from Tiflis	Time, G.M.T.
		H. M. S.
Shide	32° 40′	17 2 2
Fucecchio	—	16 51 50
Rome	23° 18′	16 53 25
Ischia	23° 0′	16 53 58
Padua	24° 0′	16 54 0
Rocca di Papa, E.–W.	—	16 54 0
Catania, N.E.–S.W.	23° 0′	16 54 8
„ S.E.–N.W.	—	16 54 16
Pavia	25° 20′	16 55 30
Nicolaiew	—	16 52 0

The origin may have been near Tiflis.

Earthquake No. 48 (September 23, 1896).

	G.M.T. H.	M.	S.
Shide	11	59	50
Caltagirone	11	50	0
Catania, N.E.–S.W.	11	51	40
„ N.W.–S.E.	11	52	4
Ischia	11	52	8
Rome	11	52	5
Rocca di Papa	11	58	30
Pavia	11	54	0
Nicolaiew	11	52	0

Earthquake No. 49 (September 24, 1896).

	G.M.T. H.	M.	S.
Shide (only partly shown)	10	39	20
Ischia	10	46	33
Rome	10	46	40
Catania, N.E.–S.W.	10	46	50
„ S.E.–N.W.	10	46	47
Nicolaiew	10	49	0

Earthquake No. 56 (October 31, 1896).

	G.M.T. H.	M.	S.
Observations at Shide, Isle of Wight—			
Preliminary tremors commence	17	18	2
„ „ end	17	31	55
„ „ duration		13	53
1. Large waves	17	31	55
2. Maximum	17	53	25
3. Maximum	18	0	35
End of disturbance about	21	0	0
Duration, 3 or 4 hours.			
Nicolaiew, commencement	17	5	30
Ischia, „	17	8	5
Potsdam, shock at	17	21	6

Origin probably Tashkent.

M 2

Earthquake No. 67 (November 5, 1896).

	G.M.T. H.	M.	S.
Shide Records:			
Preliminary tremors commence	9	44	58
" " duration		15	46
Maximum	10	0	47
Duration of disturbance about		55	0
Nicolaiew, commencement	9	39	30
Ischia, "	9	54	17

Earthquake No. 73 (*Severn Valley*).

Shide Records, December 16, 1896.

The earthquake which created so much alarm in the Severn Valley at about 5.30 A.M. on December 17, when chimneys were shattered and certain buildings more or less unroofed, was only barely perceptible in the Isle of Wight. The booms of the seismographs at Shide were not slowly tilted from side to side, as is the case when they record earthquakes originating at a great distance, but merely set in a state of elastic vibration, behaving, in fact, like the pointers of seismographs intended to record movements which we feel. The range of these elastic movements, for the most part, were about 1mm., and did not exceed 3 or 4mm. One marked motion commenced at 17h. 30m. 55s., and lasted 5 minutes.

These tremors, which were intermittent and not continuous, as is the case in an ordinary tremor storm, commenced about 11 P.M. on the 16th, and ended at about 11 A.M. next morning. The duration of each group was from 1 to about 6 minutes, and they were separated by intervals of 5 to 60 minutes. Twenty-two of the tremor groups shown by one instrument apparently closely agree in time with 22 maxima shown by a second instrument in another room.

Because there were certainly movements or phenomena observed indicating movements of the ground before and after the chief shock, the approximate times at which a few of the twenty-two groups of tremors were noted are here given.

December 16: at about 11 hrs.; after 14 hrs.; at 15 hrs., two groups; 16 to 18 hrs. an intermittent series, with a maximum about 17h. 30m.; between 18 to 19 hrs., two groups; and the last at about 22 hrs.

Should it be found necessary, the exact time of each of these may be computed from the original photograms.

Details connected with many observations contained in the first two columns will be found in 'Symons's Meteorological Magazine,' January 1897. These observations indicate that during the night of December 16 and 17 persons living in widely separated districts were from time to time disturbed by what they considered to be a tremulous motion of the ground. Because it was night time, in no instance that I am aware of can it be assumed that accurate time observations were made; and, therefore, a few of them have been bracketed together, as possibly referring to the same disturbance.

The Leicester and Hampshire observations, made between 9.30 A.M. and noon, strangely enough, were the result of observing similar phenomena, namely, the twitching of telegraph wires. In Leicester this was seen by a number of persons, the wires vibrating vertically in an unusual and extraordinary manner, there being no wind or other cause to which the movement could be attributed.

Tremors Observed before *the Shock on December* 16, *at about* 17*h.* 32*m.* 1896.

Place	Time	I.W. Seismograph T	Duration	I.W. Seismograph W	Duration
	H. M.				
Rochdale . . .	after 10 0				
Brixton . . .	11 0				
Bangor . . .	13 42	H. M. S.	M. S.	H. M. S.	M. S.
		14 3 52	4 18	14 4 31	2 47
Near Worcester .	14 10	14 12 28	2 52	14 11 29	2 47
Maidenhead . .	14 55	14 36 38	7 10	14 39 11	4 5
Worcester . .	15 0				
Salop . . .	15 15				
Worcester . .	15 35				
" . .	15 50	15 53 57	4 5	15 50 34	5 45
Wolverhampton .	16 0				
Droitwich . .	16 15				
" . .	16 20	16 25 18	2 44	16 24 3	1 23
Cardiff . . .	16 30				
Hereford . . .	16 50	16 42 2	14 0	16 43 45	max.
Salop . . .	17 0				
Alderley Edge .	17 1				
Hereford . . .	17 20	17 10 2	1 24	17 11 29	max.
" . . .	17 30				

Tremors Observed after *the Shock on December* 16, *at* 17*h.* 32*m.* 1896.

Place	Time	I.W. Seismograph T	Duration	I.W. Seismograph W	Duration
	H. M.	H. M. S.	M. S.	H. M. S.	M. S.
Dulwich . . .	17 50	17 54 33	5 45	17 50 5	6 49
Southampton . .	17 57	18 8 30	13 57	18 5 15	4 5
Leicester . . .	21 30	21 21 3	2 47	21 24 11	5 27
" . . .	23 0	22 42 22	2 52	22 36 27	
	(about)				
Hampshire . .	after 24 0	23 49 2	22 22		

At the time the tremors were recorded Seismograph T was moving under the influence of convection or other air currents. From time to time, however, it showed maxima of rapid motion, which indicates the existence of an influence superimposed upon the slow swing. The times of the commencement of these maxima are therefore not closely defined. Notwithstanding this want of definition, it is worthy of note that eleven of these records closely agree with the commencement of ten groups of tremor records obtained from Seismograph W in another room, and the times at which persons in various parts of England believed that they had been disturbed by slight earthquakes, or had seen evidences of earth movement.

During the night there were altogether thirteen tremors at which the seismographs moved simultaneously; but it must be noted that there were a number of extremely small movements recorded by the two seismographs which did not agree as to their times of occurrence.

Should further comparisons of the records lead to agreements similar to those here indicated, the conclusion will be that England is much more frequently shaken by very small earthquakes than is generally supposed.

Earthquake No. 83 (February 6, 1897).

Shide Records:

	G.M.T. H. M. S.
Preliminary tremors commence	19 59 3
2nd max.	20 5 43
3rd ,,	20 9 43
4th ,,	20 15 3
1st large waves commence	20 15 43
,, ,, ,, end	20 22 23
2nd ,, ,, commence	20 23 43
,, ,, ,, end	20 31 43
1st concluding vibrations	20 33 3
2nd ,, ,,	20 35 43
3rd ,, ,,	20 45 3
4th ,, ,,	20 54 23
Duration of preliminary tremors	26 40
,, disturbance, about	1 6 0

Strassburg Records. (Dr. G. GERLAND *with* Dr. EHLERT'S Pendulums.)

—	Begin H. M. S.	End H. M. S.	After Shocks end H. M. S.
1st Pendulum E. & W.	19 49 50	20 46 19	21 41 39
2nd Pendulum N.W. & S.E.	19 45 25	20 40 20	21 54 0
3rd Pendulum S.W. & N.E.	19 45 25	—	23 30 0

On the third pendulum there were three maxima of tremors.
Duration of preliminary tremors, 38m. 27s.

Potsdam. Dr. ESCHENHAGEN.

From a photographic reproduction of Dr. Eschenhagen's diagrams the following times are obtained :—

	G.M.T. H. M. S.
Commencement of preliminary tremors	19 50 30
Duration of ,, ,,	29 16
Nicolaiew	19 57 0
Ischia	19 55 0

Earthquake of February 19, 1897. *Origin, Japan* (8h. 49m. 0s. G.M.T.).

This earthquake was not recorded at Shide, the clock of the recording apparatus having stopped. It was recorded at other stations as follows:—

	H.	M.	S.	
Edinburgh	9	30	0	(maximum)
Nicolaiew	8	52	0	
Ischia	8	55	30	
Potsdam	9	4	1	

The following are the times (J.M.T.) at which the shock was noted in Japan:—

Miyako.—5h. 49m., strong and sudden, clocks stopped.
Yamagata.—5h. 49m. 10s., strong and sudden, clocks stopped.
Akita.—5h. 49m. 30s., strong and sudden, clock stopped.
Ishinomaki.—5h. 49m. 30s., strong and sudden, clock stopped.
Niigata.—5h. 46m. 36s., strong, clocks stopped.
Fukushima.—5h. 49m. 48s., strong, clocks stopped.
Utsunomiya.—5h. 50m. 0s., strong, houses shaken.
Mayibashi.—5h. 47m. 56s., strong, clocks stopped.
Tokio.—5h. 49m. 37s., strong and slow, clocks stopped.
Mito.—5h. 50m., strong and slow, clocks stopped.
Kofu.—5h. 50m., strong and slow, clocks stopped.
Choshi.—5h. 51m. 24s., strong and long.
Nagoya.—5h. 52m. 36s., strong, clocks stopped.
Nagano.—5h. 50m. 5s., weak and slow.
K'gaya.—5h. 48m., weak and slow.
Awomori.—5h. 50m., weak and sudden, clocks stopped.
Hakodate.—5h. 59m. 48s., weak and sudden, stopped.
Uwajima.—5h. 52m. 45s., weak and slow.
Yokosuka.—5h. 49m. 57s., weak and long.
Yokohama.—5h. 51m. 20s., weak, clocks stopped.
Hamamatsu.—5h. 7m., weak.
Hikone.—5h. 50m. 27s., weak and long.
Gifu.—5h. 57m. 10s., weak.
Kioto.—5h. 51m. 4s., weak, with rumbling.
Fushiki.—5h. 50m. 45s., slight and slow.
Nemuro.—5h. 40m. 45s., slight and long.
Kushiro.—5h. 50m., 50s., slight, with rumbling noises.

The greatest disturbance appears to have taken place at Sendai and in N.E. Nippon, from which it is not unlikely that the origin of the shock was near to that of June 15, 1896 (see Shock No. 1). This being the case, the rate of travel on paths 9,749, 8,760, and 8,241 kms. to Ischia, Potsdam, and Nicolaiew would respectively be 24, 9·7, and 45 kms. per second! The first and last of these computations we hope to be in a position to correct in some future report.

Examples of earthquakes which have sensibly shaken the whole of North Japan can be found the effects of which do not appear to have reached Europe.

Earth Movements recorded by a Bifilar Pendulum at the Royal Observatory, Edinburgh.

No.	Shide No.	Date	Time, G.M.T.	Remarks.
			H. M.	
1	32	Aug. 25	4 45	Slight tilt to North.
2		" "	5 40	" " South.
3		" "	21 10	Four slight bends in curve, North and South
4		" 26	2 10	alternately.
5	35	" "	11 15	Gap in curve. No photographic effect produced from 11h. 15m. to 11h. 30m.; broadened
		" "	11 50	and badly defined line 11h. 30m. to 11h. 50m.
6		" "	18 35	Tilt to North.
7		" "	22 50	Gap very similar to the one at 11h. 15m.
		" "	23 20	
8		Sept. 20	1 50	
			3 35	Four bends in curve, South and North alter-
	45		5 0	nately.
			6 20	
9	47	" 21	17 5	Trace of diffusion in the curve line. Line slightly bent at several points during the day.
10	48	" 23	11 57	Line distinctly diffused for 20 minutes.
			12 17	
11	51	Oct. 6	20 10	Bend to North.
			20 30	Normal direction resumed.
			22 46	Bend to South.
12	57	Nov. 2	6 48	Tilt to North.
13		" 4	22 35	Line very irregular, sinuous.
14	67	" 5	10 15	
15		" 26	—	Several very slight irregularities during the day. None well marked.
16	70	Dec. 4	8 16	Small tilt to South.
17	83	Feb. 6	19 33	Large tilt to North, about 2″·5.
		" "	20 25	Line diffused, with well-marked widening to
		" "	20 40	South.
18		" 7	5 35	Large tilt to North.
19		" "	13 20	" " "
20	87	" 16	8 12	Strong " "
21		" "	15 17	" " "
22		" 19	9 30	Gap in photographic trace. (At 9h. 30m gap
		" "	9 48	begins abruptly. At 9h. 48m. line is nearly
		" "	10 2	normal for a few minutes Slight diffusion and widening lasts up to 10h. 2m.)
23	88	" "	12 32	Gap in photographic line. (At 12h. 32m. line shows
		" "	12 47	slight trace of diffusion and widening. 12h.
		" "	12 52	47m. to 12h. 52m. line is nearly normal, when
		" "	13 17	the gap begins, and ends sharply at 13h. 17m.)
		Mar. 18	2 54	Small tilt to North.

Records received from Professor Kortazzi, Nicolaiew. The Instrument employed was von Rebeur's Horizontal Pendulum. Time, G.M.T.

No.	Corresponding Shide No.	Date	Time: Commencement	Time: Maximum	Time: End	Remarks.
		1896	H. M. S.	H. M. S.	H. M. S.	
1	1	June 14	—	22 0 0	—	Record spoiled. Japan.
2	8	,, 29	8 47 0	—	9 22 0	Cyprus.
3			9 36 30	—	—	Small. Cyprus.
4	35	Aug. 26	11 22 0	11 37 0	12 22 0	Max. amp. 10mm Also sharp at 11h. 29m. 30s. Iceland.
5	36	,, 30	20 7 30	20 33 0	23 7 0	Also sharp at 20h. 17m. 0s. and 21h. 7m. 0s. Japan.
6	39	Sept. 12	17 12 0	17 32 0	18 12 0	Max. 15mm.
7	47	,, 21	16 52 0	16 59 0	17 32 0	Max. 35mm. Earthquake in Tiflis.
8	48	,, 23	11 52 0	11 57 0	13 52 0	Sharp at 11h. 57m. 30s.
9	49	,, 24	10 49 0	11 35 0	12 10 0	Max. 7·5mm. Sharp at 11h. 6m. 0s.
10	56	Oct. 31	17 5 30	17 19 0	19 0 0	Max. 52mm. Sharp at 17h. 10m. 0s. Djarkent and Przewalsk.
11	57	Nov. 2	3 51 0	3 59 0	4 12 0	Max. 4·5mm.
12	67	,, 5	9 39 30	9 56 0	11 22 0	Max. 18mm. Sharp at 9h. 44m. 30s. and 9h. 52m. 0s.
		1897				
13	74	Jan. 8	22 24 0	22 52 0	24 38 0	Max. 8mm. Sharp at 22h. 48m. 0s.
14	83	Feb. 6	19 57 0	20 16 0	21 22 0	Max. 30mm. Sharp at 20h. 2m. 0s.
15	85	,, 12	14 6 0	14 18 0	15 22 0	Max. 10mm. Sharp at 14h. 16m. 0s.
16	88	,, 19	8 52 0	9 8 0 10 16 0 12 25 0	15 2 0	Separated maxima.
17	89	Mar. 1	14 32 0	14 48 0	15 13 0	Max. 4mm.
18	93	,, 15	18 31 0	19 22 0	20 12 0	Max. 19mm. Sharp at 19h. 9m. 0s. and 19h. 17m. 0s.

Records received from Dr. Giulio Grablovitz, Director R. Osservatorio Geodinamico di Casamicciola, Ischia.

The movements were recorded on smoked paper by means of two horizontal pendulums.

No.	Corresponding Shide No.	Date	Time, G.M.T.			Remarks.
			Commencement	Maximum	End	
		1896	H. M. S.	H. M. S	H. M. S.	
1	1	June 14	22 49 50	23 33 46 23 36 49	0 30 0	Large.
2	—	„ 15	17 38 47	—	—	
3	—	„ „	11 23 33	—	—	
4	8	„ 29	8 48 20	8 56 3 8 59 25	9 17 0	Moderate.
5	35	Aug. 26	11 30 54	11 39 0 11 41 0	12 0 0	Iceland. Large.
6	—	„ „	22 55 30	—	—	„ Moderate.
7	36	„ 30	20 20 30	21 7 0 21 13 0	22 22 0	
8	—	Sept. 5	12 2 43	—	—	Iceland.
9	—	„ 11	20 30 35	—	—	
10	—	„ 17	2 53 40	—	—	Calabria.
11	47	„ 21	16 53 58	16 59 0	17 20 0	Weak.
12	48	„ 23	11 52 8	11 59 0 12 4 0	12 43 0	„
13	—	„ 24	10 46 33	—	—	
14	49 or 50	„ „	11 54 0	12 7 30	Uncertain	Instrument disturbed by strong wind.
15	—	Oct. 29	23 56 35	—	...	
16	56	„ 31	17 8 5	17 31 0 17 34 0	18 32 0	Moderate.
17	67	Nov. 5	9 54 17	10 2 0 10 3 0	10 38 0	„
18	—	„ 9	22 32 8	—	—	
		1897				
19	—	Jan. 10	9 8 0	—	—	Gulf of Persia.
20	83	Feb. 6	19 55 0	20 28 0 20 35 0	21 0 0	Moderate.
21	—	„ 11	11 53 0	—	—	Calabria.
22	—	„ 19	8 55 30	9 45 0	10 20 0	Moderate.
23	88	„ „	12 16 0	13 18 0	14 30 0	

Eleven records refer to the same disturbances noted at Shide.

The following observations have been received from Professor Dr. Eschenhagen, Königliches Meteorologisch-Magnetisches Observatorium, Potsdam :—

Records of Magnetographs.

No.	Corresponding Shide No.	Date	Time, G.M.T.	Remarks.
		1896	H. M. S.	
1	35	Aug. 26	11 29 15	Strong on all three magnetographs at 11h. 34m. 45s.
2	—	„ 27	11 2 57	Weak, but strong at 11h. 7m. 45s.
3	36	„ 31	—	Earthquake, but instrument was also artificially disturbed.
4	—	Sept. 5	12 11 45	From Iceland.
5	39	„ 12	—	Earthquake, but instrument was also artificially disturbed.
6	41	„ 14	—	„ „ „ „
7	47	„ 21	17 6 27	Weak. Strong at 1m. 42s. later. Ends at 17h. 17m. 45s.
8	48	„ 23	12 3 45	Weak for 4m. Also at 12h. 8m. 57s. to 12h. 13m. 27s.
9	56	Oct. 31	17 21 6	Shock, but chief shock at 17h. 27m.
		1897		
10	83	Feb. 6	20 31 57	Duration, 4m. Lloyd's balance.
11	88?	„ 19	9 41 33	„ „
—	—	—	9 43 59	„ „
—	—	—	9 48 33	„ „

Observations with a Conical Pendulum carrying a small Mirror on a Glass Boom 20 cm. in length, and held horizontally by a Quartz Fibre. Period, about 15s. The apparatus is similar to that used for several years in Japan.[1]

No.	Corresponding Shide No.	Date	Approximate Time, G.M.T.	Remarks.
		1897	H. M. S.	
1	—	Jan. 3	11 7 52	Duration, 2h.
2	—	„ 10	9 6 39	„ 1h.
3	—	„ 12	9 6 31	„ 1h.
4	78	„ 16	10 36 29	
5	—	„ 19	14 37 37	
6	83	Feb. 6	20 5 8	„ 2h.
7	84	„ 7	12 5 11	
8	85	„ 12	15 5 23	„ 1h.
9	—	„ 14	3 35 25	
10	—	„ 15	10 5 25	„ 1h.
11	—	„ 19	9 14 31	„ 2h.
12	88	—	12 5 31	„ 2h.
13	—	„ 20	15 50 36	
14	—	„ 23	23 35 50	
15	—	Mar. 2	9 6 10	„ 2h.
16	—	„ 4	12 4 38	„ 1h.
17	—	„ 6	19 5 40	

The lists, it will be observed, are only comparable from January, 1897, after which there are two magnetograph disturbances, corresponding to two movements of the horizontal pendulum. The comparison between these shows considerable differences in time, and indicates the necessity

[1] See *Report of British Association*, 1892.

of obtaining records from similar instruments, each recording on a surface moving with sufficient rapidity to give an open time scale. It is satisfactory to note that twelve of the disturbances were common to North Germany and the Isle of Wight.

The following are more exact determinations of the *commencement* of disturbances, determined from photograms :—

	H. M. S. G.M.T.
No. 4 (Shide 78), Jan. 16	10 2 6
„ 6 („ 83), Feb. 6	19 50 30
„ 11 „ 19	9 4 1
„ 12 („ 88), „ 19	12 20 9

Observations at Rocca di Papa. Dr. A. CANCANI. (These observations reached Shide too late to be used in computations of velocity, &c.)

No.	Shide No.	Date	Commencement	Maximum	Remarks
		1896	H. M. S.	H. M. S.	
1	1	June 14	22 56 0	23 23 15	Period 18 seconds.
2	8	„ 29	8 48 27	8 52 30	Also at 8h. 59m.
3	35	Aug. 26	11 26 40	11 35 0	End at 11h. 46m.
4	36	„ 30	20 21 0	21 3 0	End at 22h. 16m.; the long waves commenced at 20h. 41m.
5	—	Sept. 5	12 6 0	12 15 0	
6	—	„ 11	20 38 20	20 56 0	End about 22h.
7	47	„ 21	17 0 0 (about)	—	Duration 37m.
8	48	„ 23	11 55 0	12 3 0	End about 12h. 20m.
9	56	Oct. 31	17 0 0	17 31 0	End about 18h.
10	67	Nov. 5	9 59 0	10 1 30	Duration 1h.
11	83	Feb. 6	20 24 0	20 27 19	
12	—	„ 19	8 29 0	9 37 20 9 39 30 9 41 20 9 45 10 9 47 0	
13	88	„ „	11 55 0	13 8 0 13 14 0 13 19 0 13 26 0	

VI. *The Highest Apparent Velocities at which Earth-waves are Propagated. By* JOHN MILNE, *F.R.S., F.G.S.*

The following table of the highest apparent velocities with which earthquake motion is propagated over paths of varying length has been drawn up for the purpose of indicating the general character of the information we at present possess bearing upon this subject.

The sources from which information has been derived are various, the more important being as follows :—

'Horizontalpendel-Beobachtungen,' by Dr. E. von Rebeur-Paschwitz ('Beiträge zur Geophysik,' Band II.). These include observations made at Strassburg, Potsdam, Wilhelmshaven, Nicolaiew, Charkof, by the present writer in Japan, by observers in Italy and other places. 'Bollettino della Società Sismologica Italiana,' vols. i. and ii. The catalogues, edited by Professor P. Tacchini, contained in the volumes give prominence to the observations made at Italian stations, whilst observations made in Europe and Japan have not been neglected. 'Transactions of the Seismological

Society,' vols. i.–xx. Seventeen Reports on Seismic Phenomena drawn up by the writer for the British Association, 1881–1896.

With the exception of groups of observations made within a few hundreds of kilometres of an epifocal area, all records which refer to maxima phases of motion, as, for example, those which apparently disturb magnetographs, have been neglected, and therefore, taken as a whole, the velocities given in the following list are based upon the times at which preliminary tremors have commenced to show themselves at various stations.

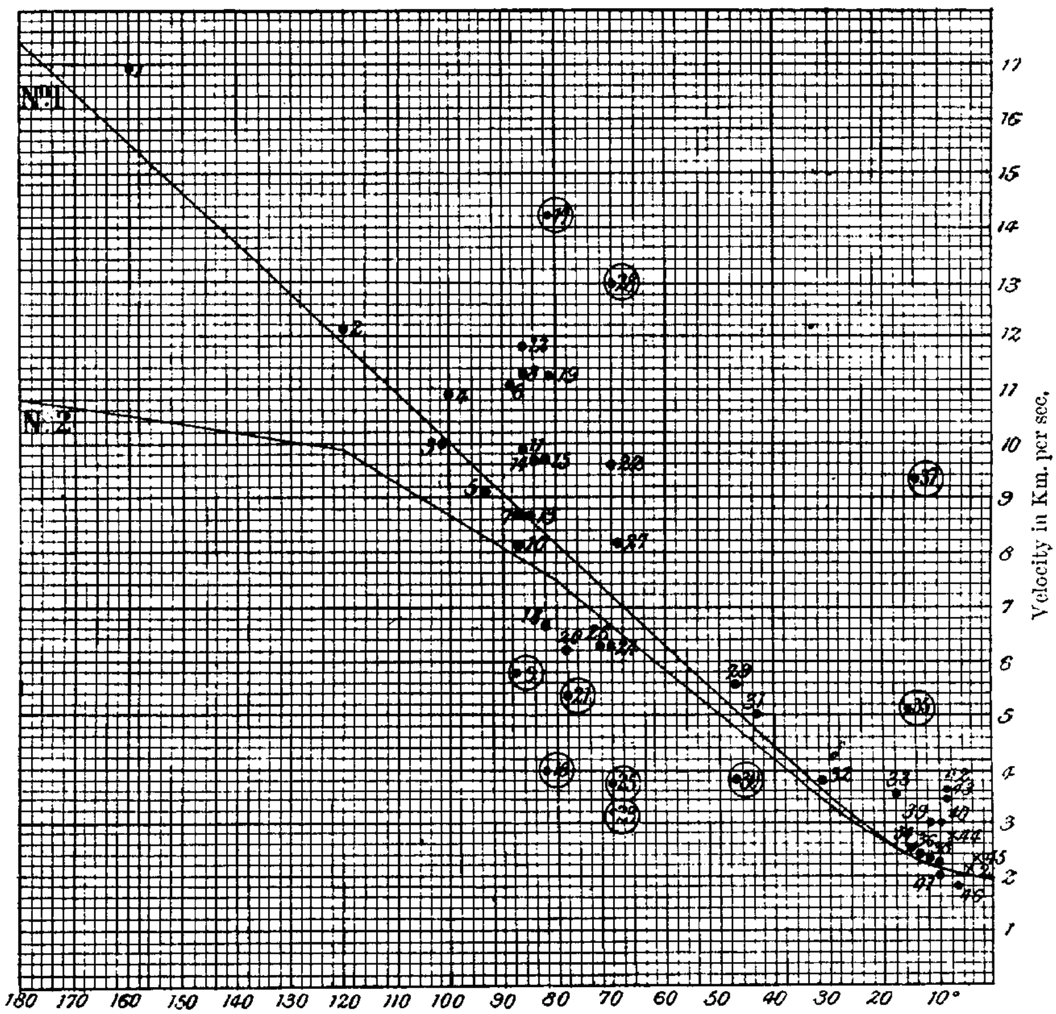
Apparent Velocity of Earthquake Motion along Paths of Varying Length.

Epicentre	Date	Place of Observation	Distance in Degrees	Distance on Arc in Kms.	Velocity in Kms. per Sec. on Arc	—
1. S. A., Santiago	Oct. 27, 1894	Tokio	156	17,400	17·0	Mean of observations at three stations in Tokio.
2. „ „	„	Charkof	119	13,230	12·13	
3. Mexico	Nov. 2, 1894	Nicolaiew	102	11,300	10·0	
4. S. A., Santiago	Oct. 27, 1894	Rome	100	11,200	10·85	
5. Merida Venezuela	Apr. 28, 1894	Charkof	94·8	10,550	9·1	Mean of observations at Charkof and Nicolaiew.
6. Japan, Sakata	Oct. 31, 1896	Catania	88·15	9,796	11·1	
7. „ N.E. Coast	June 15, 1895	Ischia	87·8	9,749	8·7	
8. „ Sakata	Oct. 31, 1896	Rome	86·10	9,564	11·2	
9. „ Tokio	Oct. 18, 1892	Strassburg	86·6	9,520	5·87	
10. „ „	Nov. 4, 1892	„	„	„	8·1	
11. „ Nemuro	Mar. 22, 1893	Rome	86·0	9,500	9·9	
12. „ Sakata	Oct. 31, 1896	Ischia	85·3	9,469	11·8	
13. „ Nemuro	Mar. 22, 1894	S. Russia	85·3	9,477	8·7	
14. „ N.E. Coast	June 15, 1895	Padua	84·4	9,320	9·7	
15. „ Sakata	Oct. 31, 1896	Isle of Wight	83·7	9,290	9·7	
16. California	Apr. 19, 1892	Strassburg	82·7	9,180	3·93	
17. Japan, Sakata	Oct. 31, 1896	„	82·5	9,157	14·2	
18. „ Tokio	Apr. 17, 1889	Wilhelmshaven	81·7	9,070	6·8	
19. „ „	„	Potsdam	80·6	8,950	11·3	
20. Philippines	Mar. 16, 1892	Nicolaiew	78·9	8,758	6·08	
21. „ Luzon	„	„	„	„	5·41	
22. Japan, Tokio	May 11, 1892	„	71·2	7,910	9·55	
23. „ „	Oct. 18, 1892	„	—	—	3·23	
24. „ „	Nov. 4, 1892	„	—	—	6·28	
25. „ „	Mar. 23, 1893	„	—	—	3·72	
26. „ „	Jan. 18, 1895	„	—	—	6·3	
27. „ Nemuro	Mar. 21, 1894	Mid Italy	70·7	7,857	8·2	
28. „ Tokio	Oct. 7, 1894	Charkof	70·4	7,814	13·0	
29. Quetta	Dec. 20, 1892	Strassburg	45·7	5,290	5·65	
30. „	Feb. 13, 1893	„	„	„	3·08	
31. Central Asia, Wjernoje	July 11, 1889	Wilhelmshaven, Potsdam	43·3	4,806	5·00	
32. Quetta	Dec. 20, 1892	—	34·6	3,840	3·86	
33. Asia Minor, Amed	Apr. 16, 1896	Strassburg	18·0	1,990	3·50	
34. Patras	Aug. 25, 1889	Potsdam	15·4	1,732	2·59	
35. Charleston	Aug. 31, 1886	—	15·0	1,678	5·18	
36. Thebes	May 23, 1893	Strassburg	14·8	1,650	2·4	
37. Asia Minor, Amed	Apr. 16, 1896	Padua	14·0	1,580	9·4	
38. Bucharest	Oct. 14, 1892	Strassburg	13·0	1,450	2·35	
39. Valoria, Epirus	June 13, 1893	„	12·1	1,350	3·0	
40. „ „	„	Nicolaiew	11·4	1,270	3·1	
41. Thebes	May 23, 1893	„	10·3	1,150	2·0	
42. Naples	Jan. 25, 1893	Strassburg	9·0	1,000	3·62	
43. Mount Gargano, Italy	Aug. 10, 1893	„	„	„	3·62	
44. Japan, Nemuro	Mar. 22, 1893	Tokio	8·7	965	2·6	Average max. for group of 4 shocks.
45. „ Noto	Dec. 9, 1891	„	2·4	272	2·3	Average for a group.
46. „ Gifu	Oct. 28, 1891	„	2·2	241	2·4	Max. for a group of 18 shocks.

A glance at the above table, or the diagrammatic representation of the same (fig. 15), shows that either there have been great differences in the velocities with which movements have been propagated to points equally distant from given origins, which is unlikely, or that there have been larger errors in the determination of the time at which motion commenced at different stations.

Possible causes for these errors are easily found.

FIG. 15.—Velocities of Earth-waves round or through the Earth.



1. Different instruments; some being horizontal pendulums recording photographically, others being pendulums varying in length and in the frictional resistance of pointers recording on smoked surfaces, may have unequal degrees of sensibility.

2. Similar instruments may be differently adjusted.

3. When a record is received on a surface moving at a rate of about 20mm. per hour, the error in determining the time at which a disturbance commenced may be 1 minute.

4. A local shock may be mistaken for one arriving from a distance.

Examination of Cases where the Velocity has been Abnormally High.

Shock No. 1.—This was recorded at three stations in Japan by horizontal pendulums recording on photographic surfaces. From the fact that ordinary seismographs did not record an earthquake on that day, and because each photogram began with gentle tremors, it is safe to assume that they represented an earthquake originating at a great distance. Unfortunately, the note-books containing the clock corrections were burned, but taking the time determinations direct from the photograms, they lead to the conclusion that motion was propagated to Japan from a place almost at its antipodes at a rate varying between 16 and 19 kms. per second.

The greatest merit in this record is that it falls in line with what we should expect from records taken over shorter ranges.

Shock 17.—Like other Strassburg records, this was obtained on paper moving at a rate of about 1 mm. in three minutes. Independently of this, however, we see that for the same shock at four other observatories velocities of 9·7, 11·1, 11·2, and 11·8 kms. per second have been calculated (Nos. 15, 6, 8, and 12), and it is therefore highly probable that the determination for Strassburg of 14·2 kms. is too high.

Shock 28.—We have here another case of a record from a surface moving at a rate of 1 mm. in about three minutes, whilst the epicentre may have been distant from Tokio.

Shock 37.—Because a delicate seismograph at Catania was disturbed 2 minutes 40 seconds *before* the one at Padua suggests the idea that these Italian records possibly refer to a local disturbance, and not to the one in Asia Minor. This point has been discussed by Professor M. G. Agamennone (see 'Bollet. A. Soc. Sis. Italiana,' vol. ii., No. 8).

Shock 35.—This estimate is based upon a most careful and elaborate analysis of records, none of which, however, were obtained from the automatic indications of seismographs.

Abnormally Low Velocities.

Shocks 9 *and* 23.—We have here two observations for the same shock, and we find that the photograms obtained at Strassburg and Nicolaiew were 'schwach und wenig scharf,' and for the former there was an 'unbestimmter anfang,' from which it may be concluded that the commencement of movement at these places was not determined.

Shock 21.—From the Nicolaiew record it appears that the commencement of this disturbance is thus noted : '5·02 h. (?) Anfang der Storung.' The uncertainty here expressed possibly explains the low velocity recorded.

Shock 16.—Here again there appears to have been difficulty in determining the commencement of movement, owing to the undefined character of the photogram.

Shock 25.—This was observed not only at Nicolaiew, but also at Strassburg, the velocities being 3·72 and 4·2 kms. per second respectively. Although von Rebeur in his 'Horizontalpendel-Beobachtungen,' p. 492, tells us that these velocities are based upon the observation of the time at which the first weak movement is visible, from a table on p. 443 they appear to have been determined from the observation of the instant at which there was a sudden increase in motion, and are used with other observations to determine the *mean* velocity of propagation, which is that of the greatest movements.

Shock 3.—Movement in Europe was extremely small, and no record was obtained at Nicolaiew. Possibly the smallness of the diagram, which began 'little by little,' may have rendered it difficult to make accurate measurements on the time scale.

The general result of the examination of data which have led to the determination of velocities which appear to be either too high or too low, is to find that such data are either imperfect or capable of another interpretation.

The doubtful cases are placed in circles, and to these, based upon a long experience in observing earthquake velocities over ranges up to about 1,000 kms., I should be inclined to add Nos. 33, 39, 40, 43, and 42.

If, therefore, we exclude the computations the accuracy of which is doubtful, the general results towards which the continuation of the observations on the propagation of earth-waves over ranges of varying length point is approximately indicated in the following table :—

Distance from Origin		Apparent Velocity in Kms. per Sec.	
In Degrees	In Kms.	On Arc	On Chord
10	2,200	2 to 3	2 to 3
50	5,500	5	5
80	8,800	8	7·5
100	11,100	10	8·8
120	13,200	12 ?	10 ?
160	17,700	16 ?	10·5 ?

VII. *Diurnal Waves.* *By* JOHN MILNE, *F.R.S.*, *F.G.S.*

Observations made on the Tennis Ground at Shide Hill House. Installation V.

On September 5, 1896, the horizontal pendulum which had been in use at Carisbrooke Castle was brought to Shide, where it was installed on a slate slab resting on an upended earthenware drain-pipe, sunk some inches in the ground, covered by a jointer's tent standing in the middle of a tennis ground. The chief object of this installation was to study the diurnal wave, as shown by the movements of a pendulum so placed that for ten or twenty yards, at least, on all sides of it the surface conditions were fairly similar. The tennis ground is in the middle of a small paddock which slopes towards the west. On the eastern side, at a distance of forty yards, is the building in which instrument T was installed, beyond which the ground quickly rises to Pan Down. The sun, rising on this side, reached the tent over the top of some high trees at about 9 A.M., throwing the shadow of the tent towards the N.W. At about 4 P.M. this shadow, after travelling through N. to the N.E. was lost, as the sun sank behind Mount Joy on the west.

The bromide film was run at a rate of about $3\frac{1}{2}$ inches in twenty-four hours, which was sufficiently rapid to give an easily measurable diagram of the daily movement of the pendulum, the boom of which pointed from its pedestal towards the south.

On September 13 a heavy tarpaulin (30×30 ft.) was spread over the grass, immediately up to the tent on its west side. On October 13 this was moved to the east side, the object being to see whether such a covering had any effect on the character of the diurnal wave.

The Observations (1896).

1*st week* (*Sept.* 8–14).—From the 8th to the 14th daily waves were marked, but there was such a marked steady displacement towards the valley on the west that adjustments were required almost daily.

On the 8th and 14th it was fairly fine, but on all the other days there was much rain and the weather was dull. The westerly motion, or downward tilting towards the saturated valley, was also marked in the records of T.

2*nd week* (*Sept.* 14–21).—Because the westerly motion had been so great the sensibility of the instrument was reduced, with the result that the daily wave was hardly visible. There was still, however, a westerly tendency. The weather was dull or fine, but there was no heavy rain.

3*rd week* (*Sept.* 21–27) :—

Sept. 21. 15–24 hours slight tremors. Fine. S. wind.
„ 22. 18–20 hours slight tremors. Fine. Strong S.W. wind.
„ 23. Steady. Fine. Strong S.W. wind.
„ 24. 12–19 hours slight tremors. Fine. W. wind. Rain at night.
„ 25. Steady. Strong wind, rain.
„ 26. Steady. Rain, but calm.
„ 27. Steady. Stormy. S.W. wind.

On the 21st, 22nd, 23rd, and 24th there were slight daily waves, but after adjustment on the 25th the movement was barely visible.

It may be inferred that with cloudy weather the daily wave has been small. The shock shown by T on the 21st is not shown.

4*th week* (*Sept.* 28–*Oct.* 2) :—

Sept. 28. East motion completed 4 P.M. Fine. W. wind.
„ 29. East motion completed 4.45 P.M. Rain. S. wind.
„ 30. East motion completed 2·30 to 3.30 P.M. Fine. N. wind.
Oct. 1. East motion completed 3 30 P.M. Fine. W. wind.

For six hours before the above times the motion was easterly, and for six hours after it was westerly. In no instance were the waves large.

Two slight disturbances were noted, but these do not agree in time with displacements observed on T.

5*th week* (*Oct.* 2–9) :—

Oct. 2. East motion completed 5 P.M. West motion completed at 10.50 P.M.

On all other days no movement. This was discovered as being due to a spider, which was caught on Oct. 10.

6*th week* (*Oct.* 9–15) :—

Oct. 9. East motion completed 3.15 P.M., and west at 9 P.M. Amp .9mm. Fine. W. wind.
„ 10. East motion completed 4 P.M. Amp. 3mm. Fine. S. breeze.
„ 11. No record. Dull. N. wind.
„ 12. East motion completed 6 P.M., and west at 18hrs. Amp. 3mm. N. breeze. Dull.
„ 13. Record bad. A large tarpaulin placed on ground on west side of tent. Fine. N. wind.
„ 14. East motion completed about noon. Wave small. Fine. N.E. wind.
„ 15. East motion completed 3 P.M., and west at 6.50 P.M. Amp. 6mm. Little rain. Dull. S. wind.

We have here a case (on Oct. 15), where there has been a fairly large wave on a dull day, and a small one (Oct. 10) on a fine day.

Very small tremors were seen on the following days :—

Oct. 9. 5 to 9 hours.
„ 14. 7 to 14 „
„ 15. 4 to 7 „ and again 11 to 22 hours.

Three displacements were recorded which do not agree in time to those noted by T.

7th week (*Oct.* 16–22) :—

Oct. 16. Very slight wave. Dull. Strong N. wind.
„ 17. East motion completed 2h., and west at 6 P.M. Amp. 6mm. Fine. N. wind.
„ 18. East motion completed 3h., and west at 10 P.M. Amp. 14mm. Fine. N.W. wind.
„ 19 to 20. Practically straight; possibly held fast.

The diurnal waves were marked on fine days.

Slight tremors were only observed on the 16th, 0 to 14 hours. There was one strong deflection on the 16th, which is not shown on T.

8th week (*Oct.* 23–30) :—

Oct. 23. East motion completed 2h. 30m., and west about 8 P.M. Amp. 11mm. Fine. N. wind.
„ 24. East motion completed 1h., and west about 12 P.M. Flat. Rain. S.W. wind.
„ 25. East motion completed 3h. 30m. Fine. N. wind.
„ 26. No record.
„ 27. East motion completed 2h. 30m., and west about 8 P.M. Amp. 14mm. Fine. W. wind.
„ 28. East motion completed 4h., and west about 9 P.M. Amp. 10mm. Fine. W. wind.
„ 29. East motion completed 3h., and west about 7 P.M. Amp. 10mm. Fog. Calm.

It is difficult to say when the west motion is completed. The sharp motion eastwards is from about 8 A.M. to 3 P.M., and westwards 3 P.M. to 8 P.M. Decided waves have been with fine weather, when cloudy and wet, waves have been absent.

Slight tremors were observed as follows :—

Oct. 23. 3 to 7 hours and 18 to 21 hours.
„ 24. 11 to 21 „
„ 25. 8 to 15 „
„ 27. 3 to 8 „
„ 28. 4 to 8 „
„ 29. 3 to 8 „

Tremors, therefore, occurred at night, and whilst there was a rapid westerly displacement. Moderately marked displacements took place on the 23rd to 24th, which are not shown by T.

9th week (*Oct.* 30–*Nov.* 6.) :—

Oct. 30. No record. Moved tarpaulin to the east side of tent.
„ 31. East motion 10 A.M. to 2.30 P.M., west motion 2.30 P.M. to 6.30 P.M. Amp. 8 mm. Fine. N. wind.
Nov. 1. East motion 3 A.M. to 3.0 P.M., west motion 3 to 8 P.M. Wave small. Dull. N.E. wind.
2. No record.

Nov. 3. East motion 5 A.M. to 2.30 P.M., west motion 2.30 P.M. to 6 P.M. Amp. 4 mm. Dull. N. wind.
„ 4. East motion 10 A.M. to 3 P.M., west motion 3 P.M. to 7.30 P.M. Amp. 8 mm. Fine. N. wind.
„ 5. East motion 8.30 A.M. to 3 P.M., west motion 3 P.M. to midnight. Amp. 10 mm. Fine. E. wind.

The greatest movements have been on the fine days.

Tremors were observed on October 30, 3 to 17 hours, of 2 mm. range, and slight tremors on October 31 and November 4.

Three displacements were noted which do not agree with the records of T, but the earthquakes Nos. 55 and 59 shown by T were well recorded.

10*th week* (*Nov.* 6–13.) :—

Nov. 6. East motion from before noon to 2.30 P.M., west motion 2.30 to 8 P.M. Amp. 7 mm. Fine. N. wind.
„ 7. East motion 6.30 A.M. to 3.0 P.M., west motion 3 to 6 P.M. Amp. 1 mm. Fog, frost.
„ 8. No wave, but westerly displacement midnight to 7 A.M. Rain. N. wind.
„ 9. East motion from before noon to 2.45 P.M., west motion 2.45 to 8 P.M. Amp. 7 mm. Fine. N. wind.
„ 10. East motion 9 A.M. to 3.30 P.M., west motion 3.30 to 7 P.M. Amp. 6 mm. Fine. Calm.
„ 11. East motion from before noon to 2 P.M., west motion 2 to 6 P.M. Amp. 1 mm. Dull. W. wind.
„ 12. East motion 9 A.M. to 3 P.M., west motion 3 to 6 P.M. Amp. 8 mm. Dull. S. wind. Afterwards fine.

The diurnal wave is evidently pronounced on fine days, and small or absent when it has been rainy, cloudy, or dull.

Tremors were noted as follows :—

Nov. 6.	4 to 12 hours.	Slight.		
„ 7.	7 to 22 „	Maxima of	2 mm. at	19 hours.
„ 9.	4 to 12 „	„	1 mm. at	6 hours.
„ 10.	6 to 11 „	„	1 „	
„ 11.	18 to 20 „	„	5 „	
„ 12.	4 to 13 „	„	1 „	

Six small displacements were noted, which do not agree with the records of T.

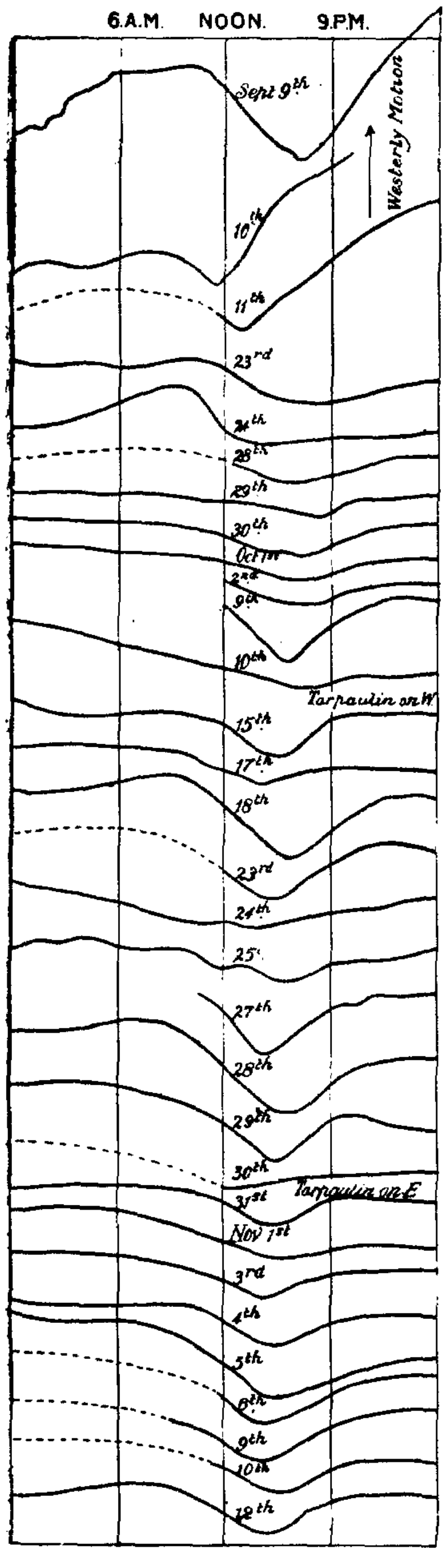
The Diurnal Wave.

Figure 16 shows half-size tracings of daily waves taken from the original photograms. Angular values for these waves may be approximately obtained by assuming that 1 mm. deflection corresponds to a change in inclination of 0·5 sec. of arc. Should accurate measurements of these quantities be required, they can be obtained from my note-books.

Days on which the diurnal wave was very small have been omitted. The curves which are given clearly show that the daily deflection is variable in amount; but whether the ground around the tent was open, or covered by a tarpaulin on the west side or on the east side, the times at which the pendulum commenced, completed, and ended its sharper movements are practically the same. If we commence in the morning, the direction of movement of the pendulum from a north-south line, or its normal position, was such that it tended to approach a position that would place its boom in a line with the sun and the shadow of the tent. That is to say, it swung towards the east, but it continued this motion

N 2

FIG. 16.—Diurnal Waves at Shide, 1896.



until the sun had passed the meridian, or until 2 or 3 P.M. Then it returned, following the sun until 7 or 9 P.M.

The text accompanying these diagrams shows that the movements are practically confined to fine days, from which it may be concluded that the effect is connected with solar radiation.

In previous reports I have suggested that it might be produced by the difference *in load removed by evaporation on* two sides of an installation, such loads from a surface of grass being represented by the removal of 4 or 5 lb. per square yard per day.

The experiment with the tarpaulin-cover placed first on one side of the tent and then on the other, which failed to produce any marked effect on the character of the diurnal motion, indicates not only that this is practically uninfluenced by *differential* evaporation effects, but also by the heat received by the ground on two sides of an installation, these effects being local. We therefore have to look to the instrument, the pier on which it stands, or external effects on a widespread area. *The fact that the diurnal wave is* marked on a brick pier rising from a solid foundation in the middle of a brick building shaded by trees,[1] and also in cellars, in both of which places the changes in temperature have been small, indicates that the movements are *not* to be accounted for by warpings on the pier or portions of the instrument.

The fact that strong and steady westerly deflections corresponding to an increase on the slope of the hill on which T and V stood accompany wet weather, and that reverse movements follow fine weather, indicates that a load in the valley apparently causes this to sink, whilst during the removal *of such a load it apparently rises. It* seems natural to conclude that the diurnal waves are movements with a similar origin. On hot days the valley loses moisture, and therefore it rises,

[1] *British Association Report*, 1896, p. 213.

and the pendulum travels eastwards, whilst at night moisture is accumulated, and it sinks.[1]

VIII. *The Perry Tromometer.* *By* John Milne, *F.R.S.*, *F.G.S.*

A Perry Tromometer, similar to that described in the Report of this Committee for 1896, with photographic recording apparatus, has been constructed, and for some days installed at Shide. Its sensitiveness to elastic tremors was such that it recorded trains moving at a distance of over half a mile, carriages at a distance of a quarter of a mile; and all vehicles passing along a road near to the building in which it was placed. For these reasons it was dismantled, but it may be again used when a site free from the above-mentioned artificial disturbances, to which may be added the sound-waves from heavy guns fired at a distance of five or six miles, can be found.

In conclusion to the preceding sections of the Report the fact that the records of earthquakes and other movements have been continuous has been in consequence of the great interest taken in the observations by my assistant, Shinobu Hirota, who not only understands the working of the instruments in all their details, but has from time to time shown considerable ingenuity in devising and constructing new pieces of apparatus.

IX. *Sub-oceanic Changes.* *By* John Milne, *F.R.S.*, *F.G.S.*

The object of the following notes, which are an epitome of a paper to be communicated to the Royal Geographical Society of London, is to show that beneath seas and oceans there are a certain class of geological changes in operation which are more frequent, and often more intense, than corresponding changes on land.

The sites of these changes are to be found below low-water mark at comparatively shallow depths on submerged plateaus surrounding continents and islands, and on the face, and especially near to the base of the steeper slopes of continental domes, and around submarine banks at depths which may even reach 4,000 fathoms. On the level floor of oceans, where sediments accumulate with immeasurable slowness, and where for years and years ocean cables lie undisturbed, geological changes are, so far as a lifetime is concerned, not recognisable.

The submarine operations to which it is particularly desired to draw attention are those which are seismic and volcanic, the former at least often being accompanied by the displacement as a landslide of such enormous volumes of material that the whole surface of an ocean may be agitated. Evidences that such displacements have had a reality is to be found in the conditions under which cables have been buried, and in the marked change in soundings near to spots where seismic efforts have been exerted.

Other causes leading to displacement of materials on the face and near to the base of submerged slopes are overloading by sedimentation, erosion, the escape of water from submarine springs, and the effects of currents.

The various sub-oceanic phenomena to which it is particularly desired to call attention will be treated in the following order :—

1. *Bradyseismic action.*—Because earthquakes originating beneath

[1] *British Association Report*, 1895, pp. 133–139.

the sea are more numerous and more intense than those originating on land, the inference is that bradyseismic activity and phenomena which accompany earthquakes, like landslides, are also more pronounced beneath the sea than they are on land.

Bradyseismical movements include movements of upheaval or depression, by which rocks are bent, folded, faulted, or displaced, by thrust, together with those which are the result of overloading, and may be exhibited as basal crush. One set of movements involve the idea of elastic and seismic strain, whilst the others a gravitational effect.

2. *Sedimentation and erosion.*—Submarine landslides which in part are due to earthquakes.

The effects of overloading, submarine springs and currents.

3. *Changes evidenced by cable interruptions and soundings.*

4. *Conclusions.*

1. *Bradyseismic Action.*

Earthquakes the Origin of which are Submarine.—The earthquakes which have a submarine origin may be divided into three groups :—

1. Those which have been felt and recorded on land, and which, therefore, may be assumed, in the generality of cases, to have originated on a coast-line or within a few hundred miles off in the ocean.

2. Those which have been recorded on shipboard out at sea, either as tremors or as severe movements. Many of these disturbances are probably volcanic.

3. Those which have not been felt on land, but have been distinctly recorded there. In this group we find many of the earthquakes which shake the world.

As illustrative of the frequency of the first group, I will quote from observations made in Japan.[1] Between 1881 and 1883 in North Japan the writer found that, out of 419 shocks, no less than 218 of them had originated beneath the ocean. There had been 137 which had originated on or near the seaboard, and therefore some of these had been of sub-oceanic origin, whilst only 64 had originated inland. A large number of these earthquakes came from the deep water off the mouth of the Tonegawa, the largest river in Japan, which, as it approaches the sea, crosses the alluvial plain of Musashi.

Between 1885 and 1892 no less than 8,331 earthquakes were recorded in Japan—that is, on the average during this period of eight years there were about one thousand shocks per year.[2] A glance at the map showing the distribution of origins of these disturbances shows that nearly all of them have originated along the eastern seaboard, and have been frequent near the alluvial plains. Between January 1885 and December 1888, when seismic activity was in a normal state—that is to say, when there were no long series of after-shocks—2,018 earthquakes were recorded, of which at least 1,034, or 50 per cent., originated beneath the sea. In Japan, therefore, along a coast-line of 1,140 miles, there has recently been at least about 250 submarine shocks per year. In some years there have been 500.

From a seismic map of the world, I should estimate that round the

[1] 'On 387 Earthquakes observed during Two Years in North Japan,' by John Milne, *Trans. Seis. Soc.*, vol. vii. pt. ii.

[2] *Trans. Seis. Soc.*, vol. xx.

Pacific there are at least ten sub-littoral districts where earthquake frequency may be about half that of Japan. If this is accepted as probable, the sub-littoral seismic activity of the Pacific is represented by 2,500 shocks per year, some of which have been accompanied by submarine landslips and consequent changes in the configuration of the ocean bed. When these latter are great, it is assumed that ocean-waves are created. If we consider the seismic activity round the coasts of the other oceans and seas which cover our globe as being, when taken together, equal to that of the Pacific, then for the world, out of a possible 10,000 shocks per year, 5,000 of them have their origin on the sub-oceanic continental slopes.

To get information about the second group, or earthquakes which have originated far from land, we have to turn to the voluminous catalogues of Perrey, Mallet, Kluge, di Ballore, Fuchs, and other statisticians. Such extracts have been made by Dr. Emil Rudolph in his papers, 'Ueber Submarine Erdbeben und Eruptionen,'[1] who gives us an account of 333 sub-oceanic earthquakes and eruptions. Because the greater number of these shocks are of volcanic origin, they will be more specifically referred to in the next section. The distribution of these is various, but here and there they herd together, indicating localities where changes are comparatively rapid. One favourite locality for submarine disturbances is in the Equatorial Atlantic, about 20° W. long., and again at 30° W. long., near to St. Paul's. For each of these regions Dr. Rudolph gives about thirty-seven shocks, in depths of water exceeding 1,000 and 2,000 fathoms.

The chief source of information for our last group is, however, derived from the records of horizontal pendulums. Taking a list of them published in the 'Transactions of the Seismological Society,' vol. xx., by the late Dr. E. von Rebeur-Paschwitz, out of 301 records obtained in twenty-seven months, there are only 25 which can with certainty be traced to their origin. Out of the 176 which remain, 105 were almost simultaneously recorded at places so widely separated as Potsdam, Wilhelmshaven, Strassburg, Nicolaiew, and Tokio, and therefore cannot be disposed of as being due to some accidental disturbance of an instrument or to small shocks of local origin. Each of them was a disturbance affecting a very large area, and indicates an initial impulse of great magnitude. What is true for the observations in Europe has also been true for my own observations in Japan, and also in the Isle of Wight, the only difference being that in Europe the stations were from 300 to 600 miles apart, whilst in Japan and the Isle of Wight the stations were usually near to each other, and never more than 30 miles apart. In some instances, however, earthquakes of unknown origins were recorded in Japan and Europe, and it is fair to assume that in these instances the whole world had been shaken.

One disturbance noted by the author in Japan on June 3, 1893, had a duration of five and a half hours. It was also recorded in Birmingham, Strassburg, and Nicolaiew, at which latter place the duration of motion extended over eleven hours. Amongst unfelt earthquakes, both for magnitude and duration, it exceeded all that have yet been recorded.

Because the character of the unfelt movements, the origin of which cannot be traced, is identical with the character of those which have been

[1] *Beiträge zur Geophysik*, Band I. and II.

traced to earthquakes originating at great distances, it is, for the present at least, assumed that the cause of the former is similar to the cause of the latter. If this is the case, the only place towards which we can turn to find the origin of the former appears to be beneath our oceans, and when they are of a magnitude approaching that of June 3 their origins must have been very far from land, otherwise a sensible shaking would have been observed upon the nearest shores.

If we take the three classes of records to which we have referred in conjunction, the conclusion to which they point is not simply that the submarine evidences of seismicity are more numerous than those on land, but also that they are very much more intense.

The Character of Submarine Seismic Districts.—If we compare together the characters of the districts where earthquakes of submarine origin are frequent with those where they are practically unknown, the differences are striking. In the former the land, as shown on the seaboard, usually consists of strata which are geologically new ; it exhibits evidences of recent elevation, some of which can be traced to historical times, whilst its average slope from the mountains in the interior down beneath the ocean is, over a considerable distance, relatively very steep.[1] The unit of distance over which such slopes have been measured is taken at 2°, or 120 geographical miles. The following are a few examples of such slopes :—

West Coast, South America, near Aconcagua	1 in 20·2	Seismic districts.
The Kurils from Urap	1 in 22·1	
Japan, west coast of Nippon	1 in 30·4	
Sandwich Islands northwards	1 in 23·5	
Australia generally	1 in 91	Non-seismic districts.
Scotland from Ben Nevis	1 in 158	
South Norway	1 in 73	
South America, eastwards	1 in 943	

The conclusion derived from this is, that if we find slopes of considerable length extending downwards beneath the ocean steeper than 1 in 35, at such places submarine earthquakes, with their accompanying landslips, may be expected. On the summit of these slopes, whether they terminate in a plateau or as a range of mountains, volcanic action is frequent, whilst the earthquakes originate on the lower portions of the face and base of these declivities.

The Cause of Seismic Strain, Deformation, Thrust, and Crush.—We assume that the contours referred to in the last section are mainly the result of rock-movement, and that seismic strain, due to a tendency to further adjustment, is greatest where earthquake origins are most frequent. The home of the volcano is evidently the place where the rocks have been most deformed, whilst that of the earthquake is at the base of steep sub-oceanic slopes where most deformation is in progress. The nature of the forces in operation producing this deformation is twofold. First, there is the horizontal thrust, so strongly emphasised by Lapworth, which may or may not tend to increase the height of the mountain ranges bounding its line of action ; and, secondly, a factor dependent on gravity, which, acting on the side of subaërial and marine denudations, tends to lower them. Earthquakes are for the most part spasmodic accelerations in processes with these characters.

[1] See 'Note upon the Geographical Distribution of Volcanoes,' by J. Milne, *Geol. Mag.*, April 1880. Also address to the Geological Section of the British Association, in 1892, by Professor C. Lapworth, LL.D., F.R.S.

The distortions observed in fossils and pebbles, the difference in thickness of contorted strata, and the 'creep' in coal-mines, all indicate that great pressures may set up movements in stratified materials corresponding to a flow. Mr. William Barlow, in a paper on the 'Horizontal Movements in Rocks,'[1] as evidence of this, calls attention to the contortions and foldings observed in glacial drift produced by a load above, the dip seen on the face of the Grand Cañon of Colorado, and the slight elevation observed in the area surrounded by cliffs known as the 'San Rafael Swell.' These and other appearances may be regarded as instances of 'creep' upon a large scale, when materials have been squeezed out from beneath superincumbent strata.

In studying bradyseismical movement we usually take cognisance of that which is most apparent. This is the vertical component of a displacement, whilst the horizontal movement may be entirely overlooked. The geotectonic structure of many countries, however, shows us that displacements by horizontal thrust have taken place on an enormous scale, and it is not unlikely that these forces, accelerated by the effects of crush, are yet in operation round the basal contours of continental areas. Sub-oceanic earthquakes are therefore announcements that sub-oceanic bradyseismic action is in progress, and because these disturbances are more numerous round the submerged frontiers of continental domes and in mid-ocean than they are on land, it may be concluded that the distortions and displacements due to bending, thrust, and crush are greater beneath the sea than they are upon continents and islands.

Earthquakes and Landslides.—In addition to these bradyseismical effects, which only produce appreciable changes in sub-oceanic contour after the lapse of long intervals of time, there are the effects which accompany the actual shaking, which we may assume are not far different from those effects which we see produced by earthquakes originating on land. Many earthquakes which we feel, although they may create alarm and shatter chimneys, do not produce any effect upon rocks and cliffs. This, however, does not preclude the idea that shakings of equal intensity would not produce effects upon submarine slopes, where, as compared with similar slopes on land, critical conditions may more nearly approach in character to the mechanism of the hair trigger. Severe earthquakes on land are almost always accompanied by great landslides, and mountains which may for ages have been green with forest growth by the sliding away of materials on their sides suddenly present the appearance of having been whitewashed. The probable effect of similar shakings originating beneath the ocean in the vicinity of steep slopes needs no explanation.

Another effect which sometimes accompanies these disturbances, and which may have been their cause, is the creation of a fault 50 or 150 miles in length, by which the country on one side of this, relatively to that on the other, has been suddenly raised or lowered 20 to 30 feet. Earthquakes of this nature, if of submarine origin, would naturally produce similar effects over large areas, and, if the magnitude of the displaced materials, whether by landslides or faulting, were large, as compared with the depth of the superincumbent waters, would also give rise to sea-waves.

One of the most recent examples of effects of this description was that which occurred on June 15, 1896, off the north-east coast of Japan. On

[1] *Quart. Journ. Geol. Soc.*, November 1888.

the evening of that day a submarine earthquake occurred in this locality which was recorded in the Isle of Wight; and, from the magnitude of the diagrams, it may be assumed that the world was shaken from pole to pole. Following this shaking, great sea-waves spread over the North Pacific Ocean. The explanation of these phenomena is that the earthquake was produced by fracture of the rocks, not at a point, but over a considerable length, which movement, being accompanied by the displacement of huge masses of material, gave rise to the sea-waves. The sub-oceanic contour of this locality, where the depth of the water increases at the rate of 1,000 fathoms in 25 miles until the 4,000-fathom line of the Tuscarora Deep is reached, lends itself to this supposition. The only difficulty we experience is to estimate the volume of the material which must have been more or less suddenly displaced at these great depths to have produced so great a disturbance on the surface of the ocean. It is not likely that it was less than that of the greatest landslide of which we have historical record as having occurred upon the surface of the earth.

The data we have for calculating the position of the origin of these great disturbances are numerous and exact. Our knowledge of the dissipation of earthquake energy, as represented by its destructivity as it radiates, indicates that an earthquake which dislodged sufficient material to disturb the whole of the North Pacific Ocean must, at the very least, have originated 100 miles away from Miyako, on the north-east coast of Nippon, at which places a few houses were shattered.

The calculations to be found on p. 157, strangely enough, bring us exactly to the base of the western boundary of the Tuscarora Deep, above which there are 4,000 fathoms of water. This is a place from which many earthquakes have originated, affording evidences, particularly in this instance, of sudden sub-oceanic changes along the basal frontier of a continent the magnitude of which it is difficult to estimate.

Submarine Volcanic Action.—If highly heated rocks saturated with water were the only condition necessary for a display of volcanic action, such activities might be as marked in ocean basins as round their margins. The geological distribution of volcanoes, however, shows that before a volcanic magma can expend and find exit on the surface, the pressure due to superincumbent strata must be relieved, which is apparently obtained when they are sufficiently crumpled upwards to form mountain ridges. If, therefore, we seek for volcanic action beneath the sea, we may expect to find the same along submarine ridges, and if we discover the same, as we do along the central ridge of the Atlantic, the conclusion is that along such a ridge an upward bradyseismical movement is in progress, and not far from the region of eruptions there should be a region of earthquakes.

In certain instances, apparently, as is the case with the Aleutians and the Kurils, so many eruptions have taken place along a submarine ridge that a continuous and almost connected chain of islands has been formed. On the flanks of the most southern of the latter group recent marine strata have been raised, which, taken in conjunction with the fact that hardly a year passes without some new eruption being noted, whilst submarine shocks of earthquakes are frequent, indicates that Japan may in time become connected with Kamschatka.

Any attempt to enumerate the various submarine ridges of volcanic activity at present evidenced by these outcrops would be beyond the scope of the present paper. One curious form of evidence, indicating the existence of volcanic activity entirely hidden in ocean depths, is referred to by

Mr. W. G. Forster, in his paper on 'Earthquake Origin,'[1] from which we learn that cables have, after their interruptions, been recovered from which the gutta-percha had been melted—probably by water at a high temperature. The cables referred to are near the Lipari Islands and between Java and Australia.

Some idea of the frequency of earthquakes and volcanic shocks originating in the ocean may be obtained from a paper by Dr. Emil Rudolph.[2] From his descriptions, which are derived from the catalogues of Perrey, Mallet, the archives of the London Meteorological Office, &c., the following table has been drawn up :—

North Atlantic, 1724–1886	28	disturbances.
Azores, 1843–1884	20	,,
Cape Verde Islands, 1854–1883	4	,,
St. Paul's, 1845–1886	22	,,
Equatorial Atlantic, 1747–1878	43	,,
West Indies, Leeward Islands, 1839–1886	17	,,
South Atlantic, 1616–1875	10	,,
West Mediterranean, 1724–1865	11	,,
East Mediterranean, 1820–1886	20	,,
Gulf of Mexico and Caribbean Sea, 1751–1884	17	,,
Indian Ocean, 1818–1883	28	,,
North Pacific, east side, 1790–1885	22	,,
South Pacific, east side, 1687–1885	47	,,
North Pacific, west side, 1773–1681	14	,,
South Pacific, west side, 1643–1885	10	,,
East Indian Archipelago, 1796–1883	20	,,
Total	333	

The records generally are more frequent as we approach modern times, and, to some extent, for those seas and oceans where there have been the greatest number of observers. Dr. Rudolph regards all his records as referring to shocks of volcanic origin, and, if they agree with his definition of *Seebeben*, which are shakings originating in the ocean and propagated as elastic waves, we concur in his views.

2. *Sedimentation and Erosion.*

This section of the paper is a consideration of conditions which lead to the formation of sub-oceanic surfaces of instability which may yield by the continuation of the operations by which they are produced, or by seismic or volcanic actions.

The first fact to be noticed is that the materials resulting from marine denudation round coast-lines and subaërial denudation of continental areas are almost entirely deposited in the ocean, upon an area which is relatively small as compared with that from which they were derived, and therefore the rate of growth on littoral areas per superficial unit is on the average greater than the rate of loss similarly estimated on continents. We know from soundings that the materials derived from land are not always deposited to form a gently sloping submarine plain, but often to form surfaces with steep slopes. Thus, for example, the line of the Congo continued seawards is represented by a gully the sides of which have apparently been built up as a submarine *levée*. Materials thus accumulated under the influence of gravity and hydrodynamic action apparently

[1] *Trans. Seis. Soc.*, vol. xv. p. 73. [2] See p. 183.

result in contours which have reached limits of stability ready to yield as more materials accumulate, by facial slidings, by overloading, by changes in currents, by seismic action, and in other ways.

Forms of Stability.—On land we have many illustrations of natural curves of stability. A volcano mainly consisting of lapilli which have accumulated round a central orifice has a form dependent upon the density and strength as represented by resistance to crushing of its component materials. To increase the height of such a mountain, it would be necessary to increase the area of its base. The upper portion of Mount Fuji has a slope of 30°, but as we proceed downwards the slope becomes less and less until at last it is asymptotic to the plain from which it rises. The *average* slope of this volcano is 15°.

If, therefore, on the face of a bank formed by the accumulation of sediments, soundings, taken at points separated by one or more miles, indicate a certain inclination, it may be inferred that the steepest slope may possibly greatly exceed the quantity thus determined.

The only experiments bearing upon slopes of stability formed beneath water with which the writer is acquainted are a few made by himself. These experiments, which were made with sand and carried out in various manners, pointed to the following general results:—

1. Sediments deposited under the influence of currents accumulate in slightly flatter forms than those of similar materials built up on land.

2. Peaks, edges and corners of loose materials which may be fairly stable on land are beneath water, even when it is still, quite unstable, and quickly become rounded.

3. A mound or bank when thus rounded is very stable even under the influence of strong currents, but the unstable form may be quickly reproduced by the accumulation of new sediments.

The conclusions then are, first, if we find beneath water very short slopes of detrital materials, if they are 2° or 3° less than the angle at which similar materials are self-supporting on land, they have reached a limit of stability; and, secondly, average slopes over distances of one or more miles indicate the existence of much steeper slopes over shorter lengths.

Causes resulting in the Yielding of Submarine Banks.—Because it is not likely that submarine earthquakes the movements of which are felt round the world are the result of volcanic action whenever these are accompanied by sea-waves, it may be inferred that the latter have been produced by the dislodgment of vast masses of material from the faces of steep slopes. Illustrations of such changes will be given in the next section.

That intermittent facial sliding takes place on steep slopes during the accumulation of new materials is rendered likely by what we observe taking place on the faces of a mound of sand, submerged beneath water, as it grows upwards as an accumulation from a fine stream of sand descending from above.

Basal crush with horizontal displacement would only be expected to occur around the lower edges of slopes of great height; and as it is hardly reasonable to suppose that such slopes owe their form simply to the accumulation of sedimentary deposits, then the frequent origin of earthquakes in such localities indicates that the primary cause of crush or thrust is the result of yielding in rocky masses rather than that of detritus. When speaking of cable-interruptions it will be seen that some of these have been attributed to the displacement of materials which have been loosened by the submarine escape of fresh water. Examples of springs of fresh water in bays and along coast-lines are numerous, whilst there is abundant evidence of the absorption of rainfall and even of rivers on continental areas, which in some instances it is suspected find an exit in the sea bottom. Granted the existence of sub-oceanic springs, we see in them at and near their exits a possible cause by which deposits may be loosened and landslips take place. Under certain conditions such dislocations might be expected to be periodical, following, for example, the rainy seasons. Ocean currents which fluctuate in direction and intensity, together with those of temporary character produced by the backing up of water during gales in bays, estuaries, and coasts, may also disturb the isostasy of submarine materials.

For details of these and other operations producing sub-oceanic change reference must be made to the writer's original paper.

3. *Cable Fracture.*

The fact that, on the level plains of ocean beds, cables lie for years and years without disturbance is another testimony to the facts brought together by geologists to show that the flat plains of ocean beds are regions where there is but little change. Directly, however, we approach sub-oceanic banks or the margins of continental slopes, although the depths may be abysmal, the fact that cables after interruption have to be broken away from beneath materials which hold them fast, indicates that regions of dislocation have been reached, and what is true for these great depths is also true for localities nearer land. Sometimes cables are bent and twisted, sometimes they are crushed. Now and again sections are recovered which, from the growth of shells and coral on all sides, show that they have been suspended. Others show that fracture has apparently been the result of abrasions, whilst the ends of wires, one of which is concave and the other convex, slightly drawn out, indicate that yielding has been the result of tension. Needle-pointed ends suggest electrolytic action;[1] but, although cable-interruption may occur in these and other ways, the explanation which best accords with the observations made during cable-recovery generally are those which attribute their dislocation to sudden displacement of the bed in which they are laid, or to their burial by the sliding down of materials from some neighbouring slope.

Sometimes it will be seen that earthquake movement and cable fracture have been simultaneous, whilst many instances will be given where an interruption has occurred at about the same time that an unfelt movement has been recorded on land. These latter records, which in the lists are marked with an asterisk, are unfortunately not numerous, and only refer to days between the following dates:—

1. Observations at Potsdam, Wilhelmshaven, Strassburg, Nicolaiew, Teneriffe, and in Japan. These, which include many of the writer's observations, are published in 'Beiträge zur Geophysik,' Band II., by Dr. E. von Rebeur-Paschwitz, March 27 to October 5, 1889; January 4 to April 27, 1891; February 23, 1892, to August 31, 1893.

2. Observations at Charkow by Prof. G. Lewitzky, August 4, 1893, to October 1894.

[1] This may be due to electrolytic action between the zinc and iron of the sheathing wires, or to the cable having rested on a mineral deposit.

3. Observations by Prof. G. Vicentini, at Padua, February 1 to August 29, 1895.
4. Catalogues of Prof. P. Tacchini, January 1895 to October 16, 1896.
5. Observations at Shide, Isle of Wight, by John Milne, August 19, 1895, to May 1897.

Fracture of Cables in Deep Oceans.

The times of earthquakes are given in G.M.T. astronomical time. *Noon = 24 hours.*

North Atlantic.—Through the kindness of an engineer, whose experience in the laying and repairing of cables has extended over many years, I am enabled to give the dates at which various cables have become ruptured, or been restored to working order. The only case of alteration in depth which he noticed was during the repairs of November 1884, but this was not great. It seemed as if the picked-up cable had to be pulled from under a bank of earth which had slipped down from the eastern slope of the Newfoundland Bank.

The following is a table of North Atlantic cable-interruptions :—

North-eastern Slope of Flemish Cap.—(37° W. to 44° W. long.) July 1894 (about); June 1888 (about); September 1889; September 1881; June 10, 1894*; July 28, 4.40 A.M., 1885; April 18, 8 P.M., 1885; July 25, 8 A.M., 1887; June 1895.

Near South-eastern Slope of the Newfoundland Bank.—(46° W. and 50° W. long.) September 1887 (about); October 3, 9.15 P.M., 1884; October 4, 4.8 A.M., 1884; October 4, 4 and 8 A.M., 1884; September 1889.

An unfelt earthquake was recorded, June 11, 7h. 22m., 1894, very strong at Charkow.

A striking feature connected with these Atlantic troubles is that nearly all have occurred in deep water near to the base of the eastern slope of the Flemish Cap, 330 miles from St. John's, Newfoundland, or the south-eastern slope of the Newfoundland Bank. Off the Flemish Cap in lat. 49° N. and long. 43° E. there is a slope, in a distance of 60 miles, from a depth of 708 fathoms to 2,400 fathoms, or 1 in 35. Another slope, over a distance of 30 miles, is from 275 to 1,946 fathoms, or 1 in 17. Off the eastern side of the Newfoundland Bank, in a distance of 25 miles, the depth changes from 27 to 1,300 fathoms, indicating a slope of 1 in 19.

These slopes are all well within the limits at which from time to time yielding, due to bradyseismical thrust or secular crush, should be expected; and the further a cable can be kept away from the scene of such action, if we may judge from experience, the longer will be its life.

In one case only has the cause of failure been attributed to a landslide, which it is just possible was caused by, or accompanied with, seismic phenomena. A very significant fact is the case when three cables running in parallel lines about 10 miles apart broke, at points nearly opposite to each other, on the same straight lines. This was on October 4, 1884. At first the accidents were attributed to the grapnel of a cable vessel, but as no grappling was done then this hypothesis had to be abandoned. Because three cables broke apparently at the same time in the same locality, one inference is, that the cause resulting in rupture was common to all, and this may have been a sudden change in the configuration of the ocean bed. Such a change does not necessitate any alteration in depth, such as could be detected by sounding, but either a landslip along a line of considerable length or simply a line of fracture like that which was suddenly formed along the Neo valley in Japan in 1891.

When, on the American and English coasts, types of seismometers which will record the unfelt movements of the earth's crust have been established, it seems likely that the cause of cable interruptions may be better understood. Because the fifteen repairs indicated in the previous table possibly cost half a million sterling, the advisability of localising areas that should be avoided, and that we should be able to attribute effects to their real cause, are evidently desiderata of great importance.

St. Louis—Fernando Noronha.—From a paper read at the Institution of Electrical Engineers by Mr. H. Benest, A.M.Inst.C.E., 'On some repairs to the South American Company's cables off Cape Verde in 1893 and 1895,' it seems that the St. Louis—Fernando Noronha cable has been twice broken. The first break occurred on December 26, 1892, about 130 miles from St. Louis du Sénégal, in a depth of 1,220 fathoms, at the time of a heavy gale. The tape covering for 140 fathoms was rubbed bare to the sheathing wires, but on one side only. The sheathing wires at the break were drawn out as if they had been broken in a testing-machine. The Fernando side of the break also showed the effects of rubbing, and the character of the fracture was similar to the other end. In picking up these two ends there was at first a strain in one case not exceeding 2·6 tons, and the other of 4 tons; but as the ends were approached this rose to about 6 tons, when the cable evidently cleared itself from some obstruction, and came easily on board.

Although we have here evidence of what may possibly have been a submarine landslip, I am not aware that at that time any disturbance was noted in Europe.

The second date is March 10, 1895. Here, again, great difficulty was experienced in breaking out the cable from beneath the mud, detritus, or whatever the materials were that had covered it. The position of this break was about 20 miles south-west from that of 1893.

On March 5, at 22 hours G.M.T., a very large unfelt disturbance was recorded in Europe, and one of moderate intensity at several places in Italy on May 10, at 10.4 P.M.

Mr. Benest holds the opinion that these fractures are connected with submarine river outlets and gully formations in the ocean beds. The gradients in the vicinity of the fractures vary from 1 in 34 (1° 30′) to 1 in 7 (8°).

Pernambuco—Cape Verde.—To the north-west of St. Paul's (lat. 2° 41′ 45″ N., and long. 30° 29′ 15″ W.), which is a volcanic centre, two cables broke simultaneously in a depth of 1,675 fathoms, indicating that the rupture was due to a widespread cause. This was on September 21, 1893. Here, in the deep ocean, this was the only failure in nineteen years.

Madras—Penang and *Aden—Bombay.*—These interruptions are referred to on pp. 198, 199.

Interruptions to Cables on or near to Sub-oceanic Continental slopes.

West Coast of Central and South America.—As illustrative of conditions which may exist round many parts of the west coast of South America, where there have been sudden and gradual upliftings of the land within historical time, a portion of a chart showing contours near to the mouth of the river Esmeralda is reproduced. The soundings are in fathoms. Those in ordinary figures are from information received prior to June 1895, whilst those in larger type are from soundings taken in March 1896. Changes from 13 or 20 fathoms to upwards of 200 fathoms in this short interval of time are certainly remarkable; and as the position of the cable-repairing vessel 'Relay,' belonging to the Central and South American Telegraph Company, which made the observations, was ensured by cross-bearings on the land, their general accuracy cannot be doubted.

The figures surrounded by a circle were taken many years ago, and are probably no longer correct. Off the shore, in a distance of 3 miles, there is a depth of 200 fathoms, indicating a slope of 1 in 15, whilst at distances of 10 miles from shore, over a length of 1 mile, slopes of 1 in 3 may be found.

We have evidently here many instances of recent change in sub-oceanic form, and at the same time illustrations of conditions where considerable instability might be expected, and cable interruptions might therefore frequently occur. It will be noted, by reference to the map, that the position of fractures which have taken place are grouped near to the base of these steep slopes, and in this respect follow the rule of similar occurrences in the North Atlantic.

The following is a list of certain interruptions which have taken place off the coasts under consideration :—

La Libertad—Salina Cruz.—November 25, 1890.

Panama—San Juan del Sur.—June 4, 1889*; July 31, 1889*.

Sta. Elena—Buenaventura.—This section is laid off the mouth of the river Esmeralda, at which point many breaks have occurred. Lat. 58′ 20″ N., long. 79° 41′ 25″ W. August 30, 1890; January 25, 1891*; February 13, 1892; December 5, 1893*; December 6, 1893*; December 14, 1893*; December 20, 1893.*

Paita (Peru)—Sta. Elena (Ecuador).—This section passes Talara point, where many breaks have occurred. Lat. 4° 29′ S., long. 81° 17′ W. September 1892; May 19, 1883; September 3, 1886; May 15, 1889*; March 31, 1891*; April 9, 1891*; May 14, 1892*.

Mollendo—Chorillos (Peru).—This section crosses the gully off Pescadores point, lat. 16° 24′ S., long. 73° 18′ W. February 23, 1884; March 24, 1884; April 5, 1884; June 13, 1884; January 30, 1886; August 13, 1886; August 16, 1887; March 25, 1887; December 10, 1887, supposed to have been broken by an earthquake; December 11, 1888; February 21, 1890; March 15, 1890; March 30, 1891*; June 4, 1895*; October 16, 1892*, supposed to have been broken by an earthquake.

Arica—Mollendo.—May 9, 1877, by an earthquake; July 15, 1887; before June 24, 1891; August 13, 1891; June 6, 1895*, shore end broken by waves.

Iquique—Arica.—May 9, 1877, by earthquake; May 7, 1878, by an earthquake; June 12, 1895*, shore end broken by waves.

Caldera—Antofagasta.—July 7, 1886.

Valparaiso, Serena.—July 26, 1877; August 15, 1880, by earthquake; July 8, 1885; before August 19, 1891. July 4, 1895*, by landslide or earthquake.

The *unfelt* earthquakes which were noted in or near Europe were as follows :—

January 25, 1891, 5·01h. A small disturbance was recorded at Teneriffe.

March 26, 1891, 13·6h. to 14·8h. There was an earthquake of moderate intensity noted in Teneriffe.

May 15, 1892. At 2·9h. at Strassburg, and at 3·7h. at Nicolaiew, there was a feeble shock. It is, however, possible that this earthquake may have had its origin at Stavanger, in Norway.

October 13, 1892. At 17·07h., and October 17, at 11·88h. at Strassburg.

December 16, 1893. At Charkow at 13h. 13m. there was a strong disturbance.

June 4, 1895. *At Padova at 18h. 23m., large disturbance.*

July 5, 1895, 5h. 32m. At Padova, origin evidently at a great distance.

Whether these seven unfelt movements recorded on the eastern side of the Atlantic were connected with seismic disturbances on the western side of South America leading to cable interruptions, it is impossible to speak with confidence until we know the *hours* at which these interruptions took place. In the meanwhile, all that we can say is, that it is worthy of note that out of fourteen cable interruptions, seven of them took place about the times when delicately suspended instruments in or near Europe were set in motion. Six interruptions took place when earthquakes were felt, whilst others were caused by landslips, which in turn may have been the result of mechanical shaking. On certain sections, as for example that connecting Arica and Mollendo, fractures have only taken place in certain months, which in this instance are June, July, and August. Restrictions like this suggest that the cause of fracture has been due to landslips brought about by the escape of fresh water beneath sea-level, the action of currents, or other sub-oceanic phenomena having seasonal maxima.

The interruptions off Pescadores Point (16° S. lat.), although, when recovering cables, branches of almost petrified trees have been brought to the surface, Mr. R. Kaye Gray attributes to the great unevenness of the bottom, there being in that neighbourhood submarine hills 3,000 and 4,000 feet in height.

The following notes bearing upon the above sections were kindly drawn up by Mr. W. E. Parsoné, who has been engaged in cable work on the west coast of South America :—

Arica—Mollendo Section.—This section was laid in 1875. On the night of May 9, 1877, while the cables between Arica and Lima were being used for direct working, a very distinct shock of earthquake was felt by the operator in the Lima office at about 10.30 P.M., during receipt of a message from Arica, and communication ceased a few seconds later. The intermediate station of Mollendo afterwards reported that the shock was also felt there, and at about the same time, and that they were unable to communicate with Arica. Mr. Parsoné located the rupture of the Arica – Mollendo section as close to the shore at Arica, and proceeded by first opportunity to that place, where it was found that a violent earthquake shock on May 9, 1877, had been accompanied by a tidal wave of unusual severity, which had completely wrecked the greater portion of the town. The sea-front and harbour had suffered enormous damage, the iron pier having been washed away, and practically all the craft in the port having parted their moorings or foundered. In undertaking the repair, tons of anchor-moorings and material were picked up with the cable, which had been considerably dragged out of position and twisted for a considerable distance from the shore. Communication on this section was restored on May 24, 1877, and worked without interruption until it was permanently repaired by renewing a portion of the shore-end and intermediate cable on November 17, 1878.

Iquique—Arica Section.—This section was laid in 1875. On May 7, 1878, a severe shock of earthquake was experienced in the neighbourhood of Iquique, after which the cable connecting that place with Arica was found to be interrupted. Mr. Parsoné located the rupture at 6 knots from Iquique on the intermediate cable in 60 fathoms of water, and, after considerable difficulties working with barges, there being no repairing-ship obtainable, succeeded in lifting the cable on the spot. Both ends were recovered, and it was found that the cable (intermediate) had snapped clean through, the compound on either side of the break being undisturbed, except at, say, a distance of 18 inches on either, where the sheathing wires had made one complete turn. There the compound had sprung, and some of the strands parted, and the sheathing wires compressed out of position. But for these comparatively slight indications of the enormous force which must have been exerted to make so clean a break in heavy intermediate type, the cable was in no way damaged, the rest of the cable being in as good condition as the day it left the factory. The earthquake, which was undoubtedly the direct cause of the rupture, was said to have a direction from south-west to north-east, and it was noticed with much surprise that the base of the high cliffs on the fore-shore bore marks of recent disturbance at a spot bearing due north-east from the position of the break. The disturbance referred to had the appearance of a recently formed cavern or tunnel—a few feet above the beach where the base of the hard rock was met—as if some enormous piece of artillery had been fired point-blank into the rock, and this had also caused a falling away of the surface rock above the opening, which peels off in layers like decomposed slate. We could not land at the place to examine it more closely on account of the surf and rocks, but attempted to do so by clambering and crawling over the headland of rock; but large thin sections of decomposed surface slipped away with us continually, and we had to give up the attempt. Communication was restored with a piece of deep-sea cable and permanently repaired with the s.s. 'Retriever' on November 21, 1878.

La Serena—Valparaiso Section.—This cable was laid in 1876, and interrupted off the Limaree River on July 26, 1877, as was thought, by floods from the river, although in its normal condition it is practically a dry bed before it reaches the sea.

This section was again interrupted on August 15, 1880, by an earthquake; and the same section was again interrupted by a landslip on July 4, 1885, presumably due to an earthquake.

Mollendo—Chorillos Section.—This cable was laid in 1875, and was frequently interrupted off Pescadores Point to the north of Mollendo, where considerable inequality of depth is experienced, due presumably to the channels of an extinct or subterranean river, whose estuary may now be some miles at sea, and create periodical submarine convulsions at great depth and at, say, 40 or 50 knots from the coast. In any case, all difficulty has ceased in this locality, since the cable has, for a considerable length, been diverted to close inland and laid as close to the shore as it was safe for a ship to get.

This section was also broken in two different places by an earthquake which occurred on December 10, 1887.

East Coast of South America.—The geological and topographical conditions on the east coast of South America are strikingly different from those met with on the west coast. On this latter coast the land plunges rapidly downwards beneath the sea, as a slope produced by bradyseismic thrust and folding, whilst on the former, when measured over long distances, the slope is gentle, indicating an absence of orogenic activities. Although the land is generally continued seawards at a low angle by the deposition of sediments and the scouring action of currents, here and there declivities may have been produced by such epigenic actions.

On the following sections interruptions have been rare or have not occurred :—

Maldonado—Montevideo.—Since 1875.
Santos—Chuy.—Since 1892.
Chuy—Maldonado.—Since 1875.
Rio Grande do Sul—Chuy.—Since 1875.

From these sections, which lie on the northern side of the Rio de la Plata estuary, as we proceed northwards interruptions have been more and more frequent. They are as follows :—

Montevideo—Buenos Ayres.—October 12, 1889.

Sta. Catharina—Rio Grande do Sul.—June 16, 1890.

Santos—Sta. Catharina.—March 12, 1890.

Montevideo—Rio Grande do Sul.—April 25, 1889; June 11, 1889*; December 4, 1889; May 4, 1890; December 4, 1891.

Chuy—Montevideo.—June 27, 1892; July 10, 1892* (*restored*); November 11, 1892 (date of *interruption* not recorded).

Rio de Janeiro—Santos.—April 16, 1889; April 5, 1890; December 24, 1890.

Bahia—Rio de Janeiro.—January 31, 1889; September 3, 1889*; September 21, 1889*; July 24, 1891; July 31, 1891; September 4, 1896.

Pernambuco—Bahia.—April 1, 1889; July 20, 1889; July 14, 1891.

Ceara—Pernambuco.—April 8, 1890; March 14, 1891*; September 1, 1893*; January 12, 1895; March 3, 1896; March 4, 1897*.

Maranham—Ceara.—May 22, 1889*; April 29, 1890; January 20, 1891; January 28, 1891; March 4, 1891*; March 8, 1891*; November 25, 1891; October 11, 1892*; February 12, 1894*; March 6, 1894*; November 25, 1894; April 28, 1896; December 2, 1896.*

Para—Maranham.—September 6, 1888; November 2, 1888; May 22, 1889*; December 27, 1889; January 10, 1890; July 24, 1890; January 12, 1891; October 19, 1891; December 2, 1891; January 19, 1892; October 15, 1892*; March 20, 1893*; September 1, 1893*; March 24, 1894*; July 23, 1894*; November 1, 1894; November 10, 1894; November 15, 1894; January 7, 1895: February 9, 1895*; October 10, 1895*; December 13, 1895*; December 18, 1895*; July 9, 1896*; August 6, 1896*; October 8, 1896*; May 5, 1897.*

In the above list the thirty-one interruptions marked with an asterisk took place whilst horizontal pendulums were in operation in or near Europe.

The European observations were as follows :—

September 18, 1889. At Potsdam, 6·92h. to 9·3h., there was a large disturbance, which suddenly became great at 7·87h. At Wilhelmshaven the disturbance lasted from 7h. to 9·5h. The origin is unknown.

September 5, 1889. At Potsdam there was a heavy disturbance at 22·67h., with a sudden increase at 23·08h. At Wilhelmshaven similar phases are at 22·5h. and 23·08h. Large disturbances also with unknown origin were noted on August 29 at 18·48h.

October 9, 1892. At Strassburg and Nicolaiew, at about 2·45h. and 2·70h.

March 3, 1891. At Teneriffe, earthquake at 1·79h. Origin unknown.

May 21, 1889. At Potsdam, a heavy disturbance at 10·55h. to 11·1h. Origin unknown.

March 20, 1893. At Strassburg and Nicolaiew, at 5·18h. and 5·27h. At this time there was an earthquake in Catania.

October 13, 1892. In Strassburg 17·07h. to 17·78h. An earthquake on the Donau.

September 1, 1893. At Charkow at 9.35 A.M.

February 12, 1894. At Charkow, a strong disturbance at 1.35.

March 24, 1894. At Charkow, about this time, exceedingly heavy disturbances were recorded. From 17h. 35m. on the 21st to 2h. 48m. on the 22nd; from 9·35h. on the 22nd to 3·35h. on the 23rd; and on the 24th, from 0h. 26m. to 1h. 2m.

July 22, 1894. At Charkow, from 11·35h. to 17·35h.

October 9, 1895, at 13h. 26m. Slight.

July 8, 1896, at 14h. 54m. and 17·46. At Shide.

October 6, 1896, at 21·51h. At Shide.

May 5, 1897, at 10·44h. At Shide.

December 2, 1896, at 10 to 11 A.M. At Shide.

Inasmuch as two of the interruptions took place on May 22, 1889, and two on September 1, 1893, which closely correspond with the unfelt but heavy earthquake in that year, we may say that out of twenty-nine interruptions sixteen of these have approximately coincided with the times at which earthquakes with unknown origins have been recorded in Europe.

Because on the Para—Maranham [1] section interruptions have been frequent in October, November, and December, and on the Maranham—Ceara section in November and in March, in searching for the cause of these interruptions we should look to variations in ocean currents or phenomena with a seasonal change.

West Coast of Europe and Africa.

Mediterranean Lipari—Milazzo Sea.—December 1, 1888; March 30, 1889*; September 15, 1889*; February 9, 1893.*

Zante—Canea.—March 29, 1885.

[1] 'The Para—Maranham cable is, I believe,' a friend writes me, 'laid on a shallow muddy bottom, the mud being so fluid that it is said that a schooner with a fair wind can make a good passage when half in mud and half in water.' If this is so, then the Amazon floods may have much to answer for in connection with cable-interruption.

Patras—Corinth.—September 9, 1888 ; August 25, 1889* (two interruptions).

The earth-movements which were observed were as follows :—

March 28, 1889. At 7·35h. at Wilhelmshaven, fairly large.

September 13, 1889. At 5·50h. at Potsdam and from 7h. to 9·5h. at Wilhelmshaven.

February 9, 1893. At Strassburg 6·23h. to 8·48h., and at Nicolaiew 6·19h. to 8·07h., heavy movement. The epicentre possibly near Samotrace. Two other earthquakes were noted on this day.

August 25, 1889. At Potsdam at 7·62h. and at Wilhelmshaven from 7·53h. to 9h., a large disturbance. Epicentre near Patras.

The Lipari—Milazzo fractures took place in depths of from 400 to 650 fathoms 2 or 3 miles distant from Vulcano, about north-east from Solfatore.

The Zante—Canea interruption occurred about 5 miles west by south off Sapienza Island, in a depth of 1,500 fathoms with a clay bottom. Soundings varied as much as 250 fathoms in the length of the ship, and from 1,350 to 1,834 fathoms in half a mile.

The first of the Patras—Corinth breaks occurred about 2 miles north of Akraia, in mud at a depth of 197 fathoms, whilst one of the second interruptions took place in the same locality, in depths varying between 408 and 270 fathoms within a mile, and the other, in cable No. 2, within half a mile south of Morno point.

Mr. W. G. Forster, writing in the 'Transactions of the Seismological Society,' vol. xv., respecting these districts, tells us that after the Filiatra shock in 1886 it was found, by the broken cable 30 miles away, that some four knots of the same had been covered by a landslip, whilst the depth of the water had increased from 700 to 900 fathoms. In 1867, after the destruction of Cephalonia, the soundings taken after the shock were different from those taken before. Again, on September 9, 1888, at 5.4 P.M., the town of Vostizza, in the Gulf of Corinth, was destroyed, and simultaneously the cable between Zante, Patras and Corinth was interrupted. The cause of this, as deduced from soundings and the appearance of the fractured cable, appears to have been either a sudden tautening caused by the sweeping down of a mass of clay from a 100-fathom bank to a 300-fathom bank, or the actual yielding of the bed on which the cable lay.

In 1889 a second cable was laid down in the Gulf of Corinth, but this, when it had been down about three months, was, together with the 1884 cable, fractured at the time of an earthquake on August 25 at 8.51 P.M. The 1889 cable seemed to have been smashed by the movement of a mass of material about a mile in length, whilst the 1884 cable was broken at two points by a slip on a 10 to 450 fathom bottom.

In the districts considered by Mr. Forster, there are, as he points out, great irregularities in submarine contours, the depths within short distances changing from 50 to 300 and then to 1,600 fathoms. By the deposition of silt, and the undermining of steep slopes by bottom currents, the exit of underground springs and even rivers, overhanging shelves, tottering and precipitous rocks, and other unstable arrangements, may suddenly give way and cables suffer rupture.

The facts are that the sub-oceanic contours are such that they might be expected to be unstable, and that these contours, at the time of earthquakes, have suddenly been changed. In one instance there has been an increase in depth of over 2,400 feet, and in another of 1,200 feet; whilst in the case of the 1889 disturbance, eleven and a half minutes later, unfelt earth-waves of considerable magnitude were recorded at Wilhelmshaven, 1,732 kilometres distant. Similar unfelt movements have also been recorded at distant places at about the time when cable-interruptions took place, *in every instance* where we have been able to make comparisons. The conclusion, then, is that in this region earthquakes occur, producing beneath the ocean what is equivalent to the landslips which similar movements produce on land.

Bay of Biscay.—About 1875 the Direct Spanish cable was broken about 150 miles north of Bilbao by what seemed to be a submarine landslip, which may have been produced by an undercurrent produced by the piling up of the surface waters under the influence of a westerly gale. The soundings showing the neighbourhood of the interruption indicate slopes of 1 in 7 and even 1 in 3, and it is therefore a district in which landslides and dislocations might be expected to occur. From Mr. R. Kaye Gray I learn that the 1872 Bilbao cable broke down periodically—usually in the month of March, with or after a heavy north-west gale. This took place about 30 miles to the north of Bilbao, and, when repairing, it was invariably found that 4 or 5 miles had been buried. The cause of these interruptions was attributed to a heavy submarine current caused by the piling-up of surface water, cutting the prolongation of a river-bed with steep walls which, when undercut, fell in masses to bury the cable.

St. Thomé—St. Paul de Loanda.—Interruptions which have been noted on this section were as follows:—

January 22, 1892; September 13, 1892*; November 24, 1892*; February 17, 1893*; April 11, 1893*; May 30, 1893*; February 5, 1894*; January 22, 1895*; January 15, 1896*; May 2, 1896*; June 15, 1896.*

The dates on which unfelt earthquakes were recorded were as follows:—

September 13, 1892. At Strassburg a very large disturbance from 9·54h. to 13·31h. Origin unknown.

February 16, 1893. At Strassburg at 0·08h. Origin possibly in Japan.

April 11, 1893. At Strassburg and Nicolaiew, 18·58h. to 19h. Moderate. On April 8 at these stations there was a heavy movement from 1·87h. to 4·17h. Origin unknown.

May 30, 1893. At the above stations from 4·33h. to 5·32h.; a great movement.

February 5, 1894. At Charkow from 4h. 54m. to 10h. 34m. there was a strong movement.

January 18, 1895, 2h. 37m. At many places in Italy.

January 15, 1896, 7h. 10m. At many places in Italy.

May 2, 1896, 1h. 20m. Strong through Europe.

June 13, 1896, 14h. 54m. Strong through Italy.

June 14, 1896, 22h. 46m. Strong through Italy and at Shide. Origin, Pacific Ocean.

We have therefore ten cases of interruptions on or near to the dates of nine of which large earthquakes were recorded. It is difficult to imagine that this particular district should be characterised by any seismic activity, but it seems possible that, if it is a district where sediments rapidly accumulate to attain an unstable form, these might from time to time give way under the influence of earth-waves originating at a great distance.

On this particular section Mr. R. Kaye Gray points out that, from the mouth of the Congo, extending seawards, there is a difficult gully to cross, the walls of which are 2,000 feet in height! Although the gully widens towards the west, this height is maintained for a considerable distance. The shallowest water is found along the edges of this gully, which therefore has a transverse section not unlike that of a river bounded by a naturally formed levée.

The East Coast of Africa.—The following are interruptions noted in various cable sections along the east coast of Africa :—

Mozambique—Zanzibar.—February 1, 1885; April 2, 1885; September 26, 1894*.

Delagoa Bay—Durban.—October 15, 1890; November 18, 1890; December 10, 1894; January 20, 1896*; July 13, 1896*.

Mozambique—Delagoa Bay (Lorenzo Marquez).—November 11, 1890; November 18, 1890; January 5, 1893*; January 25, 1893*; June 9, 1895*; December 24, 1896.*

Zanzibar—Mombasa.—December 20, 1890; January 25, 1892; September 4, 1894*; September 26, 1894*; March 6, 1896*; August 23, 1896*; September 23, 1896*.

Aden—Zanzibar.—January 8, 1890; May 11, 1891; December 5, 1891; February 20, 1893*; August 9, 1893*; December 21, 1894; September 2, 1895*; December 24, 1895*; January 27, 1896*; March 16, 1896*; March 23, 1897 (?).*

With the nineteen interruptions marked with an asterisk, there are eleven instances where these may have corresponded with the records of unfelt earthquakes. Approximate coincidences with earth-movements are as follows :—

January 22, 1893, at 19·87h. A weak disturbance was noted at Nicolaiew and Strassburg.

September 1, 1894, from 1h. 43m. to 4h. 21m. Moderate at Charkow.

September 25, 1894, 16h. 49m. to 17h. 8m. At Charkow.

February 20, 1893, from 19·23h. to 19·78h. At Strassburg small, origin in Japan.

August 9, 1893, from 17h. 11m. to 19h. 4m. At Strassburg moderate.

March 3, 1896, at 16h. 33m. Recorded through Europe.

August 21, 1896, at 10h. 0m. Recorded at Padua.

September 2, 1895, at 1·3h. to 9·6h. and 19h. At Shide.

March 15, 1896, at 19h. 36m. At Shide.

September 21, 1896, at 16h. 53m. Recorded through Europe.

March 23, 1897. At Shide at 4·29h., slight.

Sir James Anderson, in 1887, speaking about the interruptions off the river Rovuma (11° S. lat.), remarks that, so far as soundings showed, there was an even bottom and all that could be desired as a bed on which to place a cable, yet every year the cable broke. The broken ends suggested that the cable had been suspended until it snapped. Although the cable was shifted further out, and then closer in, it still broke. This happened eight times, and it was noticed that the interruptions occurred at about the same time of the year. Seven of these breaks are fairly on the same line, and Sir James's suggested explanation of this cause was that the time when the interruptions occur is at the termination of the rainy season in the African mountains, at which time fresh-water springs take away the bottom on which the cable lies, and leave it suspended.

Mr. John Y. Buchanan suggests that sometimes a cable may be broken in consequence of its slowly subsiding through ooze, until the catenary strain becomes so great that it eventually snaps.

Aden—Bombay.—Interruptions noted on this section were the following :—

July 11, 1881; June 3, 1885; July 27, 1885; July 11 ,1888 August 11, 1888.

On the second and last of the above dates the two cables connecting Aden with India were simultaneously broken, and the traffic between India, Australia, and the East had to pass over the land lines of Russia, Persia, and Turkey. The fractures took place on an even bottom a few hundreds of miles from Aden. At the time of the 1885 interruption, a fearful cyclone was raging at Aden, and it is therefore possible that the ruptures may be attributed to causes similar to those which seem to have operated on the Bilbao cables (p. 191). The place of fracture was 119 nautical miles from Aden, 20 to 25 miles south of the Arabian coast, at a depth of 870 to 990 fathoms, on an even bottom of mud.

Penang and Madras.—Interruptions noted on this section have been as follows :—

May 12, 1873; November 15, 1875; March 28, 1876; November 9, 878; April 22, 1880; January 31, 1881; June 6, 1883; November 15, 1883; June 13, 1884; September 2, 1886; November 2, 1886; November 14, 1886; September 22, 1888 (?); May 13, 1890.

On the above dates horizontal pendulums or the equivalent instruments were not in operation, but that these interruptions were partly due to sub-oceanic change may be inferred from the fact pointed out by Sir John Pender in the 'Electrical Review' of May 23, 1890, who says that nearly all the interruptions on this line have taken place on very bad ground near the Nicobar Islands.

The following completes the list of interruptions on far eastern lines :—

Rangoon—Penang.—September 4, 1886; May 13, 1890.

Singapore—Penang.—November 20, 1873; August 7, 1876; November 8, 1876; December 20, 1876; July 20, 1877; October 19, 1877; September 30, 1878.

Batavia—Singapore.—March 31, 1873 (?); May 20, 1874 (?); August 13, 1874; August 18, 1874; December 14, 1874; September 2, 1875; November 5, 1875; May 9, 1876; June 28, 1876; October 25, 1876; February 27, 1877; September 28, 1877; November 9, 1877; January 22, 1878; May 2, 1878; August 31, 1878; October 28, 1878; December 28, 1878; September 20, 1879; December 3, 1883.

Port Darwin and Java (Banjoewanji).—June 21, 1872; April 27, 1876; November 8, 1877; September 27, 1878; May 29, 1879; July 4, 1879; March 5, 1883; March 10, 1883; April 6, 1883; October 22, 1883; June 29, 1888 (two cables broken); October 10, 1888 (both cables broken); October 22, 1888 (both cables broken); July 11, 1890* (three cables broken, one being to Roebuck Bay); February 23, 1893*; March 22, 1893*; September 27, 1893*; October 25, 1893* (two cables broken);[1] October 26, 1893*.

The horizontal pendulum records are as follows :—

February 22, 1893. At Strassburg, 11·28h. to 11·78h.; also at Nicolaiew. Moderate.

March 20, 1893. At Strassburg, 5·18h. to 5·53h.; also at Nicolaiew. Moderate. Origin probably in Zante.

September 11, 1893. At Charkow, 16h. 13m. to 17h. 50m.

October 22, 1893. At Charkow, 6h. 53m. to 8h. 14m.

The two fractures of June 29, 1888, took place 20 and 25 miles south by west of Mount Dodo, Sambawa, where depths vary from 734 to 1,130 fathoms. Sir John Pender, at the ordinary general meeting of the Eastern Extension Australasia and China Telegraph Company,[2] says that it was found that these breaks resulted from 'volcanic' action; and, curiously

[1] See *Electrician*, November 3, 1893. [2] *Ibid.*, October 12, 1888.

enough, when the cables were recovered, all sorts of things, even the roots of trees, were found attached to them. The whole thing seemed to be a great upheaval of nature. From the same paper, August 20, 1888, we learn that these two interruptions took place at points widely separated. In Port Darwin time, the fractures took place on June 29, at 10.40 P.M. The three interruptions of July 11, 1890, took place, in Banjoewanji time, at 1.35 A.M., on a rough, uneven bottom, between Tafel Hoek (Bali) and Balambangan Point, Java, where the depths vary from 155 to 927 fathoms. The duplicate cable was broken in three places, and overlaid about 65 miles from Banjoewanji. The three cables run along two sides and near the bottom of a gully separating Baly from Java, and are about 7 miles apart. They practically broke on one line, and the cause was 'volcanic' action.[1] In this instance, as in that of June 30, 1888, the submarine displacements extended over an unusually wide area; and, when we refer to a chart, it is seen that at a distance of 9 miles in a south-west direction from Tafel Hoek there is a depth of 1,180 fathoms, indicating a slope of 1 in 7.

The only interruptions which can be compared with the records of horizontal pendulums are the last five, whilst the time of the interruption of March 22, 1893, is not known. The mean Greenwich times and dates at which the remaining four took place in 1893 are as follows:—

1. February 22, between 4h. 20m. and 16h. 20m.
2. September 12, 12h. 20m.
3. October 24, 17h. 5m.
4. October 26, 3h. 0m.

The conclusion is that only the first of these four interruptions took place when an unfelt earthquake was recorded in Europe, but similar disturbances were noted on September 11 and October 22.

The following table is a comparison of the days and hours when earthquakes were felt in Java, with the times at which cables were interrupted:—

Shocks felt in Java and Sumatra in *approximate* G.M.T. (Batavia time – 7 hours)	Date and G.M.T. of cable-interruptions
1872, June 16, 12h. to 14h	June 21.
1876, April 23, 10h. 15m. Sumatra	April 27.
1877, November 3 to 4	November 8.
1878, September 21, 19h. 30m. Sumatra	September 27.
1879, without records.	
1883, March 6, 4h. 45m. Sumatra	March 5.
„ October 18, 17h. 0m. Banjoewanji	October 22.
1888, June 29, 21h. 33m. Batavia	June 29, 3h. 40m.
„ October 8, 12h. 18m. Series of shocks „ „ 9, 12h. 26m.	October 9.
„ „ 21, 12h. 5m. Light shock	October 22.
1890, July 10, 16h. 50m. to 19h. 40m. Series of shocks, some heavy. Java	July 11, 6h. 35m.
1893, February 23, 15h. 15m. Java	February 23, 4h. 20m. and 16h. 20m.
„ March 22, 13h. 32m. Light. Java	March 22 (time unknown).
„ September 9, 22h. 57m. Moderate. Java	September 27, 12h. 20m.
„ October 23, 9h. 53m. Fifteen shocks, very heavy. Java „ October 25. A light shock	October 25, 17h. 25m.

[1] See *Electrician*, October 24, 1890, vol. xxv.

For the interruptions of cables on June 29, 1888, and July 10, 1890, we have the assurance of those connected with their management that

A Tabular Arrangement of the Foregoing Interruptions.

Name of cables	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
North Atlantic . . .	—	—	—	1	—	3	3	—	3	4	—	—	14
St. Louis—Fernando Noronha .	—	—	1	—	—	—	—	—	—	—	—	1	2
Pernambuco—Cape Verde .	—	—	—	—	—	—	—	—	1	—	—	—	1
Luhibestad—Salina Cruz .	—	—	—	—	—	—	—	—	—	—	1	—	1
Panama—San Juan del Sur .	—	—	—	—	—	1	1	—	—	—	—	—	2
Sta. Elena—Buenaventura .	1	1	—	—	—	—	—	1	—	—	—	4	7
Paita—Sta. Elena . . .	—	—	1	1	3	—	—	—	2	—	—	—	7
Mollendo—Chorillos . .	1	2	4	1	—	2	—	2	—	1	—	2	15
Arica—Mollendo . . .	—	—	—	—	1	2	1	1	—	—	—	—	5
Iquique—Arica . .	—	—	—	—	2	1	—	—	—	—	—	—	3
Caldera—Antofagasta . .	—	—	—	—	—	—	1	—	—	—	—	—	1
Valparaiso—Serena . .	—	—	—	—	—	—	3	2	—	—	—	—	5
Montevideo—Buenos Ayres .	—	—	—	—	—	—	—	—	—	1	—	—	1
Sta. Catharina—Rio Grande do Sul . . .	—	—	—	—	—	1	—	—	—	—	—	—	1
Santos—Sta. Catharina . .	—	—	1	—	—	—	—	—	—	—	—	—	1
Montevideo—Rio Grande do Sul	—	—	—	1	1	1	—	—	—	—	—	2	5
Chuy—Montevideo . .	—	—	—	—	—	1	1	—	—	—	1	—	3
Rio de Janeiro—Santos . .	—	—	—	2	—	—	—	—	—	—	—	1	3
Bahia—Rio de Janeiro . .	1	—	—	—	—	—	2	—	3	—	—	—	6
Pernambuco—Bahia . .	—	—	—	1	—	—	2	—	—	—	—	—	3
Ceara—Pernambuco . .	1	—	3	1	—	—	—	—	1	—	—	—	6
Maranham—Ceara . . .	2	1	3	2	1	—	—	—	—	1	2	1	13
Para—Maranham . . .	4	1	2	—	2	—	2	2	2	4	4	4	27
Lipari—Milazzo . . .	—	1	1	—	—	—	—	—	1	—	—	1	4
Zante—Canea	—	—	1	—	—	—	—	—	—	—	—	—	1
Patras—Corinth . . .	—	—	—	—	—	—	—	1	1	—	—	—	2
St. Thomé—St. Paul de Loanda	3	2	—	1	2	1	—	—	1	—	1	—	11
Mozambique—Zanzibar . .	—	1	1	—	—	—	—	—	1	—	—	—	3
Delagoa Bay—Durban . .	1	—	—	—	—	—	1	—	—	1	1	1	5
Mozambique—Delagoa . .	2	—	—	—	—	1	—	—	—	—	2	1	6
Zanzibar—Mombasa . .	1	—	1	—	—	—	—	1	3	—	—	1	7
Aden—Zanzibar . . .	2	1	1	—	1	—	—	1	1	—	—	3	10
Aden—Bombay . . .	—	—	—	—	—	1	3	1	—	—	—	—	5
Penang—Madras . . .	1	—	1	1	1	2	—	—	2	—	5	—	13
Rangoon—Penang . . .	—	—	—	—	1	—	—	—	1	—	—	—	2
Singapore—Penang . .	—	—	—	—	—	—	1	1	—	1	2	1	6
Batavia—Singapore . .	1	1	1	—	3	—	—	3	3	2	2	3	19
Port Darwin—Java . .	—	1	3	2	1	2	2	—	2	5	1	—	19
	21	12	25	14	19	19	23	16	28	20	22	26	245

the cause was volcanic or seismic, whilst the actual or close coincidence in the dates at which the remaining interruptions have taken place with the days on which earthquakes have been felt leads to the belief that the Port Darwin—Java section has suffered more from the effects of sudden sub-oceanic change than from any other cause. The European records of February 22 evidently refer to the disturbance which caused the interruption on that date in Java between the hours 4·20h. and 16·20h.

The above table is a list of the thirty-eight lines just discussed, along which one or more cables are laid. Since these lines were established, the number of interruptions which have occurred have been at *least* 245. For certain lines it would appear that fractures were more frequent at one season than at others, and that therefore a proper analysis of the table or its parts—such, for example, as those to which earthquake statistics have been subjected—might lead to the discovery of periodicities in cable-interruptions. Unfortunately, because the material in our possession is yet so meagre, such discussions must for the present be reserved.

Out of the 245 breaks, 87 of them, each marked with an asterisk, occurred at the times when instruments were in operation which would record unfelt earthquake effects. Fifty-eight of the 87 cable-interruptions occurred at or about the times when Europe was agitated by these unfelt movements. The fractures accompanying earthquake, or, as it is sometimes called, volcanic movement—which could be felt, and which in two instances caused destruction on neighbouring shores—were at least 10 in number, which may be raised to 24 by including the Java records. In three of these instances, two or three cables were broken simultaneously. With the latter the submarine dislocations extended over a wide area; in the Gulf of Corinth great changes in ocean depth were brought about, and from this latter place we know the motion to have radiated so that a few minutes after the interruption well-defined diagrams of earth-waves were obtained at localities 1,000 miles distant, at places where no movement could be felt.

Instances like the latter clearly establish a connection between cable-interruptions, earthquake-motion which has been felt, submarine dislocation, and the records of horizontal pendulums in distant localities. This being the case, and because earthquake-motion cannot be felt at great distances from its origin, it is reasonable to conclude that the records of unfelt earthquakes which approximately coincide in time to those at which cables have been interrupted may sometimes indicate that submarine geological changes have accompanied seismic efforts.

Although certain conclusions arrived at in this paper are definite, until the materials necessary for analysis can be obtained, others remain matters of inference. The records of interruptions for the lines mentioned are, we have reason to believe, incomplete. The horizontal pendulum records with which to make comparisons have not only been few in number, but, because they are confined to Europe, could only be expected to throw light upon disturbances originating at a great distance, which were exceptionally large. The records of earthquakes which have been felt are confined to an imperfect list for Java, a few from the Mediterranean, and a few reported from the west coast of South America. Lastly, the hours, and in some cases even the days, on which cable-interruptions have taken place, together with the probable cause of these interruptions, are unknown. These latter facts are no doubt to be found in the archives of many cable companies, and it would be to the interest of all who desire to increase our knowledge of sub-oceanic change if comparisons could be made between the records of unfelt earthquakes now published, and the times and circumstances at and under which corresponding cable-ruptures have taken place.[1]

[1] The writer, whose address is Shide Hill House, Newport, I.W., England, would be glad to receive any information respecting the day, hour, and probable causes of failure, connected with cable-interruption.

All that it is expected to find is that a certain, and probably a small, proportion of these interruptions may correspond in time with seismic disturbances; and, because we know that certain cables have been lost by landslips and dislocations accompanying earthquake-movement, it is to be hoped that the expectation may be regarded as a reasonable conjecture.

An Attempt to estimate the Frequency of Submarine Dislocations.—If it can be assumed that the majority of cable-interruptions are due to submarine displacements, and not to faults inherent in themselves (which are comparatively of rare occurrence), the swaying of suspended sections under the influence of waves and currents, the movements of marine creatures, the boring of a *teredo*, and other exceptional causes, then the tables which have been given of cable fractures will give some idea of the frequency of such displacements. Because the list of interruptions for a number of the lines mentioned are imperfect, and because each cable follows a path carefully chosen as not being likely to suffer from submarine disturbance, the frequency of dislocation derived from such an assumption is more likely to be a minimum than a maximum. From the known number of interruptions which have occurred on sections of given length in a given number of years, the following table of dislocation frequency per mile of coast per year has been computed.

Cable Dislocation per Mile per Year.

Name of cable	Length in nautical miles	Number of breaks per mile per year
Mollendo—Chorillos	510	0·002
Arica—Mollendo	146	0·003
Iquique—Arica	128	0·0040
Antofagasta—Iquique	250	0·0000
Caldera—Antofagasta	229	0·0004
Coquimbo—Caldera	215	0·0000
Valparaiso—Coquimbo	219	0·001
Santos—Chuy	744	0·000
Maldonado—Montevideo	72	0·000
Chuy—Maldonado	125	0·000
Rio Grande do Sul—Chuy	148	0·000
Montevideo—Buenos Ayres	32	0·004
Sta. Catharina—Rio Grandè do Sul	397	0·0004
Santos—Sta. Catharina	293	0·0005
Montevideo—Rio Grande do Sul	349	0·006
Chuy—Montevideo	201	0·001
Rio de Janeiro—Santos	223	0·009
Bahia—Rio de Janeiro	768	0·0011
Pernambuco—Bahia	404	0·0036
Ceara—Pernambuco	481	0·0018
Maranham—Ceara	408	0·004
Para—Maranham	381	0·008
St. Thomé—St. Paul de Loanda	785	0·003
Delagoa Bay—Durban	348	0·002
Mozambique—Delagoa	971	0·001
Zanzibar—Mombasa	150	0·007
Aden—Zanzibar	1,914	0·0008
	10,891	0·0023 average

The coasts taken are the east and west sides of South America and Africa. The total length considered representing shores which are steep and those which are gently inclined is about 11,000 miles. The general result which is reached is that the dislocations per mile per year, on the coast-lines considered, which may be taken as having on the average a character similar to that of the coast-lines of the world, are represented by the number 0·0023, that is to say, there is on the average one dislocation for every 434 miles per year. If we increase this number to 500 miles, and remember the character of the records and that of the paths to which they refer, although we have attributed *all* the interruptions to submarine change, we are inclined to the opinion that the estimate is not too great. This being granted, then, as there are about 156,000 miles of coast-line in the world, if the same were surrounded by loops of cables, although each section might be laid in the most favourable position, more than three hundred interruptions resulting from submarine disturbance might be expected to occur every year. In deep water on a level soft bottom experience shows that a cable may remain undisturbed and unchanged for long periods of time, indicating, as we have already pointed out, that geological change is proceeding with extreme slowness.

4. *Conclusions and Suggestions for a Seismic Survey of the World.*

Because earthquake origins are more numerous beneath the sea than upon the land, it is fair to assume that the bradyseismical operations resulting in the folding, bending, crushing, faulting, and thrusting of rock masses are more active in the recesses of the ocean than they are upon our continents. Sub-oceanic volcanic activity, as, for example, that which is met with in the mid-Atlantic, probably indicates the existence of bradyseismic movement and a relief of strain. The concentration of detritus derived from continental surfaces along coast-lines on tracts which are comparatively small, indicates that beneath the sea the growth by sedimentation is greater per unit area than the similarly estimated loss is by denudation on the land. This rapid submarine growth, largely under the influence of gravity, but modified by hydrodynamic action, leads to the building up of steep contours, the stability of which may be destroyed by the shaking of an earthquake, the escape of water from submarine springs, the change in direction or intensity of an ocean current, or by other causes which have been enumerated. That submarine landslides of great magnitude have had a real existence is proved for certain localities by the fact that after an interval of a few years very great differences in depth of water have been found at the same place, whilst sudden changes in depth have taken place at the time of and near to the origin of submarine earthquakes (see pp. 193 and 197). Large ocean-waves unaccompanied by volcanic action indicate that there have been very great and sudden displacements of materials beneath the ocean. The most important evidence of sub-oceanic change is, however, to be found amongst the archives of the cable engineer. The routes chosen for cables are carefully selected as being those where interruptions are least likely to occur; and yet, as it has been shown, something which is often of the nature of a submarine landslip takes place and some miles of cable may be buried. Here we seem to have proof positive, especially along the submerged continental plateaus, of sudden sub-oceanic dislocation. Because these changes are frequent, it is reasonable to suppose that sedimentation and erosion and other causes which lead up to the critical conditions are geologically rapid.

Briefly, the foregoing notes and facts indicate that beneath the oceans certain important geological changes are more rapid than they are upon land, whilst new sources from which information respecting these changes may be obtained are pointed out to the student of dynamical geology.

The more important of these sources are the experiences of the cable engineer and the records of seismographs, which are sensitive to unfelt movements. When a number of these instruments have been established round the world, on the borders of great oceans, and on oceanic islands, it is difficult to overestimate the practical and scientific results which will follow.

The greater number of records, as it has been shown, would refer to disturbances which originated beneath the sea. From the times at which earth-waves arrived at different stations, as, for example, on the two sides of the Atlantic, it would be possible to localise their origins, and in time districts would be indicated which it would be well for those who lay cables to avoid. Work of this nature has, by means of ordinary seismographs, been *partially* accomplished for Japan, and the seismic maps of that country [1] show that sub-oceanic disturbances originating *near to the coast* are herded in groups. Should a trans-Pacific cable be landed in that country, to effect this through the middle of one of these groups would be inviting its destruction.

If we had the means of knowing that when an interruption occurred in a cable at the same time an unfelt earthquake had been recorded, we should then be in a position to attribute the fault to its proper cause. The practically simultaneous failure of three Atlantic cables in 1884 led to the hypothesis that they had been broken by the grapnels of a repairing vessel; fortunately for the owners of this vessel, it could not be substantiated.

From the 'Electrician' of August 20 and October 12, 1888, we learn that the simultaneous interruption of the two cables connecting Java and Australia in 1888 cut off the latter from the outside world for nineteen days, and gave a pretext for calling out the military and naval reserves to meet the contingency of war having broken out. In 1890 three cables were simultaneously broken, and telegraphic communication with Australia was cut off for nine days. On these occasions, had there been established in Australia a proper instrument for recording unfelt movements of the ground, it is extremely likely that the cause of the interruption would have been recognised as due to seismic action, and the fear of war and the probable accompanying commercial paralysis would have been averted. Other direct benefits, which have already been derived from the records of instruments such as it is here proposed to establish round the world, are that they enable us to extend, correct, and even to cast doubt upon certain classes of telegraphic information published in our newspapers.

Late in June last year we learned from our newspapers that a great disaster had taken place in North Japan, and that nearly 30,000 people had lost their lives. Seismograms taken in the Isle of Wight not only indicated how many maxima of motion had taken place, but showed that there had been an error in transmission of two days, the catastrophe

[1] See *Seismological Journal*, vol. iv.

having taken place on the evening of June 15, so that all who were to reach the stricken district after that date were in safety.

On August 31 of the same year, the Isle of Wight records showed that a disturbance similar to that which had occurred in Japan had taken place. On account of this similarity, it was stated that we should probably hear of a great earthquake having taken place in or near that country on the above date at 5.7 P.M. Four weeks later this was verified by mail. Another instance occurred some weeks later, when our newspapers announced that a great earthquake had taken place and several thousand lives had been lost in Kobe. No doubt those who had friends and property in that city were filled with anxiety. On this occasion the Isle of Wight instruments were still indicating that nothing of the magnitude described could have occurred. Later it was discovered that the telegram was devoid of all foundation.

If we next turn to the scientific aspect of the proposed investigations, we at once recognise the importance of the results which it is hoped may be obtained for the hydrographer and the student of physical geography and geology.

The greatest result which it is hoped may be achieved is to accurately determine the rate at which earthquake motion is propagated over long distances. In some instances the rates which have already been determined are so high, reaching 12 and more kilometres per second, that the supposition is, that motion does not simply go round our earth, but that it goes *through* the same ; and if this is so, then a determination of these rates of transit will throw new light upon the effective rigidity of our planet.