ART. XIII.—*Earthquake-origins in the South-west Pacific in 1910.*

By GEORGE HOGBEN, M.A., F.G.S.

[*Read before the Wellington Philosophical Society, 4th October, 1911.*]

THE most interesting problems in connection with seismology at the present time are those relating to the paths of earthquake-waves through the earth. The paths of the so-called long waves, which show the maximum amplitude, lie, it is generally agreed, along arcs approximately parallel to the earth's surface, at no great depth below the surface. Their mean velocity of propagation is in almost all cases very near to 3·3 kilometres per second, or 200 kilometres (or 125 miles) per minute. The velocity of the preliminary tremors is much higher—often four times as great, or even more. These waves, being the first to be recorded, must travel by the brachistochronic path from the origin to the places of observation, and, whether this path be approximately rectilinear or not, the high speed of the waves shows that they must be transmitted through a medium or media of much greater elasticity than that possessed by the surface rocks. The determination of the actual path of these preliminary tremors is therefore the point upon which attention is being just now especially directed. The problem is mainly a geometrical problem, and obviously the first step is the determination of the positions of the epicentra of the earthquakes discussed. These epicentra are likely to be most correctly ascertained when the data used are those from observatories so near the origin that it may be reasonably presumed (a presumption to be tested by the agreement of the results) that the medium through which the waves travel is homogeneous, or nearly so, and yet not so near the origin that the ordinary errors of observation can substantially affect the results. If the paths of the preliminary tremors can be ascertained in such a way that we can formulate a general law, then we shall be able to draw, with a reasonable degree of certainty, inferences as to the constitution of the earth's interior —as to the density, elasticity, and thickness of the successive shells of which the earth is made up.

It therefore becomes the duty of the seismological observers in any region of the world to ascertain as nearly as may be the positions of the origins or of the epicentra of the principal earthquakes occurring in that region. Accordingly I have devoted myself during the last twenty years to the determination of earthquake-origins within the New Zealand region, and incidentally, at the request of the Seismological Committee of the Australasian Association, to finding the origins of some other Australasian earthquakes. It will be of more service to the solution of the problems in hand, however, if this work is extended to a wider region, and accordingly the results of systematic inquiry into the earthquake-origins of the whole south-west Pacific are now placed before you. Those in the present paper relate to the year 1910.

The records used are those received from the Milne seismograph stations, which are published twice a year by the British Association Seismological Committee, edited by Dr. John Milne, F.R.S.; also records received from the Directors of the observatories at Apia, Batavia, Manila, and Riverview, Sydney (the instruments at all the last-named observatories are of the Wiechert type). For these I am indebted to the courtesy of the respective Governments of Germany, Holland, and the United States, and to the kind offices of the Rev. Father Pigot, Director of the Riverview Observatory.

The waves used for determining the origins are the preliminary tremors and the long waves; the methods for the most part trial methods, such as the differential method and that based upon the interval between the arrival of the P_1 waves and those of maximum amplitude.

The results for eleven earthquakes in which the data are sufficient to determine the epicentra are given below. Those called "approximate" are epicentra probably correct within the limits of error of the observations; those called "probable" are epicentra for which there are residual errors somewhat in excess of the limits of errors of observation.

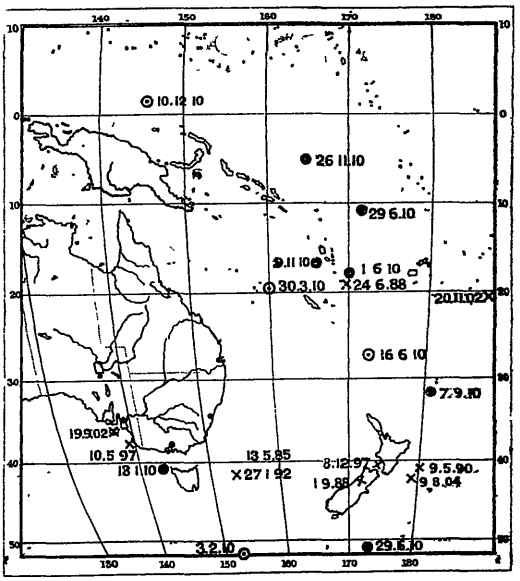

FIG. 1.

Earthquake-origins in the South-west Pacific, 1910.
(G. Hogben.)

● Approximate epicentrum.
⊙ Probable epicentrum.
× Origins previously found.

(It should be noted that the method of least squares cannot properly be used unless the physical conditions are approximately the same. For instance, we cannot use it in reference to equations based upon observations from stations varying greatly in their distance from the origin; it should be applied only to deductions from observations of waves passing along the same paths, or, assuming the symmetrical distribution of the various strata of the earth, passing along paths of nearly the same length.)

The origin in each case may, of course, have been a more or less extensive mass below the epicentrum indicated on the map (fig. 1). The map also shows the positions of previously ascertained origins in Australasia.

Date	Position of Epicentrum.			Remarks.
1910.	Lat.	Long.		
13 Jan. ..	41° S.	143° E.	Approximate..	Not recorded in Europe or other distant stations.
3 Feb. ..	52° S.	153° E.	Probable ..	Recorded at near and distant stations.
30 March ..	19° S.	160° E.	,, ..	Ditto.
1 June ..	18° S.	170° E.	Approximate..	,,
16 ,, ..	27° S.	173° E.	Probable .	,,
29 ,, (*a*) ..	11° S.	172° E.	Approximate.	,,
29 ,, (*b*) ..	51° S.	173½° E.	,, ..	Between Campbell Islands and Antipodes Islands All stations.
7 Sept. ..	32° S.	179° W.	, ..	All stations.
9 Nov. ..	17° S.	167° E.	,,	,,
26 ,, ..	5° S.	165° E.	,, .	,,
10 Dec. ..	2° N.	146° E.	Probable ..	,,

The most interesting of all these earthquakes is perhaps that of the 9th November, 1910, the origin of which appears to have been below the ocean, a little to the south-west of Espiritu Santo, in the New Hebrides Group.

The ascertained elements of the preliminary tremors of this earthquake with reference to eleven stations are given in the table below.

Earthquake of 9th November, 1910.

(Epicentrum, 17° S. Lat., 167° E. Long. Time at Origin, 6 h. 03·7 min. G.M.C.T.)

Place of Observation, and Instrument	Latitude	Longitude.	Arcual Distance from Origin (Kilom.).	Chordal Distance (Kilom.).	Time of P_1 6 h. + min.	V_1 (Arc) Kilom. per min.	V_1 (Chord) Kilom. per min.
Apia (Wiechert) ..	13° 48′ S.	171° 46′ W.	2,296	2,284	06·7	765	761
Sydney (Wiechert and Milne)	33° 56′ S.	151° 12′ E.	2,452	2,436	06·9	766	761
Wellington (Milne)	41° 17′ S.	174° 47′ E.	2,800	2,777	07·35	767	·761
Perth (Milne) ..	31° 57′ S.	115° 50′ E.	5,365	5,209	10·6	778	755
Honolulu (Milne) ..	21° 19′ N.	158° 03′ W.	5,711	5,521	10·8	804	778
Batavia (Wiechert)	6° 08′ S.	109° 50′ E.	6,317	6,063	11·7	790	758
Zikawei (Wiechert)	31° 15′ N.	121° 26′ E.	7,235	6,850	12·4	832	781
Victoria, B.C. (Milne)	48° 24′ N.	123° 22′ W.	10,056	9,050	14·6	923	830
Madras (Milne) ..	10° 14′ N.	77° 28′ E.	10,285	9,201	15·1	902	807
Edinburgh (Milne)..	55° 57′ N.	3° 11′ W.	15,667	12,000	22·1	851	652
San Fernando, Cadiz (Milne)	36° 28′ N.	6° 12′ W.	17,889	12,560	22·6	946	665

NOTE.—P_1, preliminary tremors; V_1, velocity of P_1 waves.

It will be seen that in this case there is a closer agreement between the velocities (values of V_1) for paths calculated along the chord than for those calculated along the arc; in other words, that the chords represent a closer approximation to the actual paths than the arcs. (It will be understood that the chord cannot be the actual path of a wave passing through layers of varying density, and subject, therefore, to refraction at the bounding surfaces.)

It will be seen that the velocity (P_1) of waves, calculated along the chord, for places not more than 60° from the origin is about 760 kilometres, per minute; that for places between about 60° and 90° from the origin the chordal velocity is greater; that for distances over 90° it is considerably less.

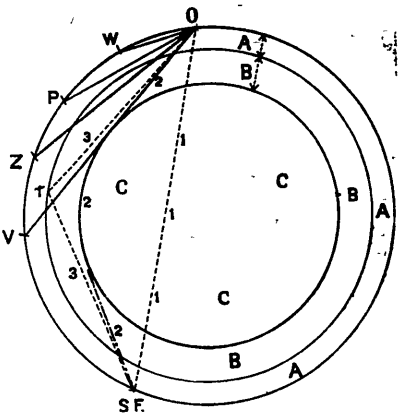

FIG. 2.

Possible Paths of P_1 Waves, 9th November, 1910, to Wellington, OW; Perth, OP; Zikawei, OZ; Victoria (B.C.), OV; San Fernando, 111, or 222, or 3 r 3. O, origin.

This enables us to formulate a hypothesis illustrated by the diagram (fig. 2). Disregarding the surface rocks, which I have elsewhere shown to be not more than twenty-five to thirty miles in thickness, we may assume a shell of much greater density about 500 miles in depth (AAA,)

and below that a shell of still greater density about 630 miles thick (BBB). Below the last-named shell there seems to be a marked change of physical condition—either the density is much less (which is hardly conceivable) or the centrosphere (CCC) is viscous. I have drawn hypothetically the possible paths of preliminary waves reaching the San Fernando Observatory from the origin: (*a*) They may have been transmitted along a path approximating to the chord 1 1 1, but with greatly reduced speed through the central portion; or (*b*) they may have been transmitted along, or nearly along, the path 2 2 2, as internal surface waves for the middle portion of the path—that is, along the surface of the centrosphere; or (*c*) they may have been transmitted along a path 3 *r* 3—that is, along the chords O *r*, *r* S.F., being reflected at *r*.

I put this forward as a mere trial hypothesis, based upon the examination of the records of one earthquake, and examined only partially by other records. It is, however, I think, worth careful examination in the light of all the available data of other earthquakes. I propose to make such an examination (which may last months, or even years), and hope to place the results, whether positive or negative, before you on a future occasion.

I should like to express my appreciation of the kindness of the observers in charge of the Milne seismographs at Sydney, Adelaide, Perth, and Christchurch in sending me copies of their records and seismograms. I regret that I have been unable to obtain any of the records of the instrument at the Melbourne Observatory.

Art. XIV. — *Fluctuations in the Level of the Water in some Artesian Wells in the Christchurch Area.*

By F. W. Hilgendorf, M.A., D.Sc.

[*Read before the Philosophical Institute of Canterbury, 6th December, 1911.*]

As part of the activities of the Artesian Wells Committee of the Canterbury Philosophical Institute, observations on fluctuations in the static height of the water in some flowing wells in the Christchurch artesian area were undertaken early in January, 1910. The records of the wells will be dealt with separately.

(1.) Lincoln College Well.

This well is 341 ft. deep from the ground-level, which is 38 ft. above sea-level. It is a 2 in. pipe, and was sunk in 1893. The water rises to about 8 ft. above ground-level.

There are in the district four other wells of approximately the same depth. The nearest of these is about three-quarters of a mile away, and the next nearest over a mile away.

The observations were taken by means of a glass tube attached to a tap bored into the well-pipe, and the tube was backed by a wooden scale marked in centimetres. The hydraulic rams worked by the well were shut off for the purpose of taking the observations, and the water in the tube