Notes on the Valparaiso and Aleutian Earthquakes of Aug. 17, 1906.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. ***Introduction.*** It is a quite remarkable fact that, on Aug. 17, 1906, almost simultaneously with the great Valparaiso earthquake there was another large shock off the Aleutian Islands. As will be seen from later §§, the Valparaiso shock occurred at 0^h 40^m 05^s (G.M.T.), the approximate position of the origin being $\varphi=$ 31° S, $\lambda=73°$ W. The other earthquake took place 28^m 21^s earlier, or at 0^h 11^m 44^s (G.M.T.), the origin being approximately at $\varphi=50°$ N, $\lambda=175°$ E. As will be seen from Fig. 1, the latter position is on the outer side of the Aleutian Islands arc, where the sea bottom quickly descends to the north Pacific basin whose depth is over 7000 metres. The topography of the vicinity of the origin of the Valparaiso earthquake is also highly characteristic, there being a marked contrast between the depth of the water and the elevation of the mountains. Thus, there is, quite close to the coast, the Chile basin, where the water depth is over 7600 metres, (Fig. 2), while the peak of Aconcagua, in the Andes, reaches an elevation of 6970 metres.

The Aleutian earthquake furnishes an instance of the seismic manifestation along the exterior, or convex, side of an arc formed by a series of islands or mountain chains, such side being generally much steeper than the inner, or concave, side. The Japanese Islands, the Himalayan mountains and the two islands of Java and

Sumatra are other good examples of the relation of the seismic activity to the curvilinear topographical form.*

2. ***Relation between the Valparaiso and Aleutian Earthquakes.*** The centres of the two earthquakes of Valparaiso and Aleutian Islands are separated by an arcual distance of 126° 56′, or by a little more than two-thirds of the earth's semi-circumference. The interesting feature is that these two disturbances were no independent phenomena, but were simultaneous manifestations of seismic energy at both ends of the great earthquake zone extending along the whole Pacific coast of North and South America. The latter zone is indicated, in Fig. 3,‡ by a line marked 5......6, the numerals 1, 2, 3 and 4, indicating the approximate positions of the different previous earthquakes, as follows:—

(1)...........Alaska Earthquakes of 1899 and 1900.

(2)...........Mexico and Central America earthquakes of 1900 and 1902.

(3)...........Panama, Columbia and Equador earthquake of 1906.

(4)...........San Francisco earthquake of 1906.

5 and 6 indicate respectively the origins of the Aleutian and Valparaiso earthquakes. The position of the centre of the first of the last mentioned disturbances is near to the Kuriles and Hokkaido and may be regarded as the approach to the north-eastern part of Japan of the great seismic activity already manifested along the other side of the Pacific. The successive occurrence of large destructive earthquakes along the zone extending from the north

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* These relations have been discussed in detail by the present Author in the *Reports (Japanese) of the Imp. Earthquake Inv. Com., No.* 49. See also the next Article.

Figs. 1 and 2 are based on "Stiller Ozean" edited by Seewarte (Hamburg).

‡ This is a slight modification of Fig. 20, given on page 22, of the *Bulletin*, No. 1.

Mediterranean to the Himalayas, and possibly to Formosa, has already been noted in the *Bulletin*, No. 1.*

3. *Seismograms.* As stated before, the Aleutian earthquake occurred nearly half an hour before the Valparaiso earthquake. The motion due to the latter disturbance was, therefore, in the seismographic records partly confused by that due to the former. In the seismograms obtained at the different Japanese stations, however, this circumstance caused no mistake, as the commencement of the Valparaiso earthquake was clearly indicated by the appearance of small quick vibrations usually marking the 1st preliminary tremor of the seismic motion. The Vicentini seismogram obtained at Manila also shows clearly the vibrations due to the Chilian earthquake.

I have here to express my thanks to the Directors of the Observatories of Osaka, Manila, Ximeniano, Querce, and other places, who have kindly supplied me with the copies of the seismograms relating to the two earthquakes in question.

Most of the observers in Europe have, in the analysis of the seismograms, mistaken the first or Aleutian Earthquake for that of Valparaiso, the only exceptions as far as I know being Padre Alfani and Professor Wiechert. Padre Alfani has written a note on the results obtained at the Ximeniano observatory, giving 0^h 58^m 15^s (G.M.T.) for the commencement of the 2nd (Valparaiso) earthquake.‡ Professor Wiechert gives 1^h 13^m 30^s (G.M.T.) for the corresponding phase of motion observed at Göttingen.

I give next the result of the analysis of the seismograms obtained at Tokyo, Osaka, Manila, and Querce. As usual, the

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* See also next Article.

‡ Padre Alfani: "Appunti sul Terremoto di Valparaiso." *Rivista di Fisica, Matematica e Scienze Naturali* (Pavia), No. 82. 1906.

symbols a, $2a$, and T, will be used to denote respectively the amplitude, double amplitude, and the complete period of vibration. *The times are always given in G.M.T.*

ANALYSIS OF THE SEISMOGRAMS.

1. *Observation at Hongo, Tokyo.*

(i) EW Component. Fig. 5, Pl. XXIV.

Pl. XXIV is a reproduction of the EW Component diagram given by a horizontal pendulum set up in the brick "earthquake-proof house," at Hongo, the instrumental constants being as follows*

Period (complete) of free oscillation=28 sec.

Multiplication of the pointer=10 times.

Weight of the heavy cylinder=14 kg.

Length of the horizontal strut, or the distance between the centre of the heavy cylinder and the point of support=1 metre.

Vertical distance between the points of support and of suspension=2.5 metres.

Aleutian Earthquake. Commencement=$0^h\ 17^m\ 20^s$.

Preliminary Tremor. Duration=$5^m\ 23^s$. During the first $1^m\ 5^s$, the motion was very small, the commencement being slightly uncertain :— T=6.4 sec.

For the next $1^m\ 55^s$, the motion was well defined, forming the most active part in this phase :—

T=8.5 sec., $2a$=0.35 mm.

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* This is one of the horizontal pendulums constructed in 1897, which has been referred to as *A*-apparatus in the *Publications*, No. 5.

The subsequent motion was smaller, consisting of the three following sets of vibrations :—

$$\begin{cases} T=\ 9.0 \text{ sec.,} & 2a=0.27 \text{ mm.} \\ T=\ 4.3 \text{ ,,} & \text{(small).} \\ T=30.9 \text{ ,,} & 2a=0.35. \end{cases}$$

Principal Portion. Commencement=$0^h 2$[illegible]^m 43^s. [1st & 2nd phases.] Duration=2^m 05^s. The very first displacement was a= 1.4 mm., directed towards W. The motion was as follows :—

During the 1st 50 sec .... T=25.0 s., $2a$=2.9 mm.

,, next 1^m 15^s...... $\begin{cases} T=37.5 \text{ s.,} & 2a=2.0 \text{ mm.} \\ T=\ 8.0 \text{ s.,} & \text{———} \end{cases}$

[3rd phase]. Duration=2^m 56^s. The record consists entirely of nearly equal pendulum oscillations as follows :—

T=27.1 sec., max. $2a$=9.8 mm. (2nd vibration).

The very first displacement in this phase was a=4.5 mm., directed towards W.

[4th phase]. Duration=3^m 2^s :—

T=20.2 sec., $2a$=5.6 mm.

The subsequent motion was as follows :—

(i) During the 1st 10^m 00^s :—

$$\begin{cases} T=19.4 \text{ sec.,} & 2a=1.78 \text{ mm.} \\ T=11.1 \text{ ,,} & \text{,,}=1.20 \text{ ,,} \end{cases}$$

(ii) During the next 10^m 55^s :—

$$\begin{cases} T=17.0 \text{ sec.,} & 2a=1.20 \text{ mm.} \\ T=10.5 \text{ ,,} & \text{,,}=1.00 \text{ ,,} \\ T=34.5 \text{ ,,} & \text{———} \end{cases}$$

(iii) During the next 9^m 16^s :—

$$\begin{cases} T=10.5 \text{ sec.,} & 2a=0.55 \text{ mm.} \\ T=18.7 \;\;,, & \;\;,, =0.55 \;\;,, \\ T=\;\;8.3 \;\;,, & \text{(small).} \end{cases}$$

Then there appeared the commencement of the 2nd or Valparaiso earthquake.

Valparaiso Earthquake Commencement $=1^h\ 00^m\ 55^s$.

1*st Preliminary Tremor.* Duration$=18^m\ 58^s$. The commencement of the Valparaiso earthquake was marked by the appearance of small quick movements of T=about 4 sec., mixed with the vibrations constituting the end portion of the Aleutian earthquake. $7^m\ 45^s$ later on there appeared again some small movements, of similar sort which were probably the seismic motion propagated along the major arc between Chile and Tokyo. The elements of motion in this phase, which partly relates to the vibrations belonging to the Aleutian earthquake, were as follows :—

$$\begin{cases} T=\;\;9.3 \text{ sec.,} & 2a=0.53 \text{ mm.} \\ T=14.5 \;\;,, & \;\;,, =0.5 \;\;,, \\ T=29.7 \;\;,, & \text{———} \end{cases}$$

The end of the 1st preliminary tremor was not well defined.

2*nd Preliminary Tremor.* Commencement$=1^h\ 19^m\ 53^s$. Duration $=23^m\ 36^s$. During the first $6^m\ 3^s$, the motion was comparatively small. During the next $3^m\ 15^s$, there were 6 regular vibrations :—

$$T=32.5 \text{ sec.,} \qquad 2a=0.85 \text{ mm;}$$

mixed with small movements of T=9.3 sec.

The subsequent motion was as follows :—

(i) During $2^m\ 48^s$, the motion was small :—

$$\begin{cases} T=\;\;9.7 \text{ sec.,} & 2a=0.32 \text{ mm.} \\ T=18.9 \;\;,, & \;\;,, =0.3 \;\;,, \end{cases}$$

(ii) During 59^s, there were 2 slow vibrations :—

$T=29.5$ sec., $2a=0.6$ mm.

(iii) During $5^m\ 47^s$, motion was small :—

$\begin{cases} T=11.8 \text{ sec.}, & 2a=0.3 \text{ mm.} \\ T=\ 8.7 \ ,, & ,,=0.2 \ ,, \end{cases}$

Then, at $1^h\ 38^m\ 31^s$, the motion became again somewhat more active, possibly corresponding to the propagation along the major arc. The motion during the remaining $4^m\ 43^s$ was as follows :—

$\begin{cases} T=11.2 \text{ sec.}, & 2a=0.42 \text{ mm.} \\ T=\ 8.2 \ ,, & \text{———} \end{cases}$

The end of the 2nd preliminary tremor was not well defined.

Principal Portion. Commencement$=1^h\ 43^m\ 13^s$.

(i) During the 1st $8^m\ 32^s$:—

$\begin{cases} T=\ 9.2 \text{ sec}, & 2a=0.25 \text{ mm.} \\ T=12.5 \ ,, & 2a=0.25 \ ,, \\ T=37.7 \ ,, \ (?) & \end{cases}$

(ii) During the next $2^m\ 44^s$:—

$T=32.8$ sec., $2a=0.6$ mm.

This part which probably corresponds to the 3rd phase of the principal portion, occurred at $1^h\ 51^m\ 45^s$.

(iii) During the next $8^m\ 33^s$, there were 2 max. groups :—

$\begin{cases} \text{1st group.........Duration}=3^m\ 46^s; & T=22.6 \text{ sec.}, & 2a=2.35 \text{ mm.} \\ \text{2nd} \ ,, \ \text{.........Duration}=3^m\ 58^s; & T=21.6 \ ,, , & 2a=2.0 \ ,, . \end{cases}$

In the minimum part between these two maxima, there were small vibrations of $T=19.3$ sec.

(iv) During the next $11^m\ 40^s$:—

$T=18.3$ sec., $2a=0.74$ mm.

At minimum epochs there were small vibrations of $T=8.8$ sec.

(v) During the next 22^m 15^s :—

$T=19.0$ sec., $2a=0.5$ mm.

Then at 2^h 36^m 59^s, there took place two well defined vibrations :—

$T=20.0$ sec., $2a=0.75$ mm.

These may correspond to the 3rd phase of the principal portion propagated along the major arc. For the next 4^m 14^s :—

$T=22.1$ sec.

Thereafter the motion consisted of quick vibrations and gradually died away, with alternations of maximum and minimum groups. The motion during the subsequent successive epochs was as follows.

(i) During 6^m 34^s :—

$T=16.4$ sec., $2a=0.26$ mm.

(ii) During 6^m 57^s :—

$T=18.2$ sec., $2a=0.29$ mm.

(ili) During 5^m 10^s :—

$T=17.2$ sec., $2a=0$ 1 mm.

(iv) During 9^m 14^s :—

$T=15.8$ sec., $2a$ (small).

At 3^h 52^m 21^s there appeared again some slight slow vibrations of $T=18.3$ sec., which were probably due to the Aleutian earthquake, being the W_3 motion, or the repetition of the motion (3rd phase of the principal portion) first propagated along the minor arc.

(ii) **Vertical Component.** Fig. 6, Pl. XXIV.

Fig. 6, Pl. XXIV is a reproduction of the diagram given by a vertical motion seismograph, whose instrumental constants have been given in the *Bulletin*, No. 1, being as follows :—

Length of the vertical spiral springs = 1.2 metre.

Horizontal distance between the centre of the steady mass and the pivot = 1.2 metre.

Weight of the heavy bob = 9 kg.

Natural oscillation period = 6.0 sec.

Multiplication of the pointer = 12.

Aleutian Earthquake. Commencement = $0^h\ 17^m\ 11^s$.

Preliminary Tremor. Duration = $5^m\ 33^s$. The motion began with quick movements, the vibrations during the successive epochs being as follows.

(i) $1^m\ 5^s$ ....$T=3.3$ sec., $2a=0.05$ mm.

(ii) $2^m\ 20^s$ ......Motion was active :—

$$\begin{cases} T=9.4 \text{ sec.,} & 2a=0.09 \text{ mm.} \\ T=5.2 \text{ ,,} & \text{,,} =0.15 \text{ ,,} \\ T=3.6 \text{ ,,} & \text{(small).} \end{cases}$$

(iii) $2^m\ 8^s$.........Motion was small and nearly uniform :—

$T=3.5$ sec., $2a=0.03$ mm.

Principal Portion. Commencement = $0^h\ 22^m\ 44^s$.

For the first $2^m\ 40^s$, the motion was small, but there were traces of some slow vibrations :—

$$\begin{cases} T=22.8 \text{ sec.,} & \text{———} \\ T=\ 4.7 \text{ ,,} & 2a=0.09 \text{ mm.} \end{cases}$$

Then set in the slow vibration epoch, the motion being most marked for the next $6^m\ 30^s$, as follows :—

(i) $1^m\ 8^s$.........There were 2 slow movements :—

$$\begin{cases} T=34.0 \text{ sec.,} & 2a=0.19 \text{ mm.} \\ T=\ 4.0\ \ ,, & \text{(small).} \end{cases}$$

(ii) $1^m\ 11^s$.........There were 3 well defined vibrations :—

$$T=23.7 \text{ sec.,} \qquad 2a=0.22 \text{ mm.}$$

(iii) $4^m\ 8^k$.........The amplitude gradually decreased :—

$$\begin{cases} T=20.7 \text{ sec.,} & 2a=0.17 \text{ mm.} \\ T=12.4\ \ ,, & \text{———} \end{cases}$$

The subsequent motion was small and regular, the vibrations during the successive epochs being as follows :—

(i)	5^m	5^s	............$T=21.8$ sec.,	$T=10.9$ sec.
(ii)	2	9	............$T=16.1$,,	
(iii)	1	50	............$T=11.0$,,	
(iv)	3	39	............$T=16.9$,,	
(v)	9	54	............$T=11.7$,,	

Valparaiso Earthquake. Commencement=$1^h\ 00^m\ 34^s$.

1st Preliminary Tremor. Duration = about 18^m. The commencement of the Valparaiso earthquake was indicated by the appearance of small quick vibrations :—

$$T=3.5 \text{ sec.,} \qquad 2a=0.12 \text{ mm.}$$

These vibrations existed more or less throughout this phase of motion. There were, however, some increase in amplitude at 6^m 35^s after the commencement of the earthquake, due probably to the propagation along the major arc.

2nd Preliminary Tremor. The motion now consisted entirely of slow vibrations, as follows :—

(i) During the first $7^m 16^s$: $T=11.1$ sec.

(ii) ,, ,, next $7^m\ 28^s$: $T=11.2$ sec.

3rd Phase of the Principal Portion. Commencement $=1^h\ 52^m\ 18^s$. The motion began with slow vibrations of $T=26.8$ sec., which were comparatively small during the first $3^m\ 7^s$. During the next $9^m\ 25^s$, the motion was most active :—

{ (i) For the 1st $3^m\ 44^s$:—$T=22.4$ sec., $2a=0.046$ mm.
{ (ii) „ „ next $5^m\ 41^s$:—$T=19.2$ „ $2a=0.05$ mm.

The subsequent motion was smaller, the T being $=17.1$ sec.

(iii) **EW Component.** Fig. 7, Pl. XXV.

Fig. 7, Pl. XXV gives the earlier part of the EW component of the Aleutian earthquake as recorded by a duplex horizontal pendulum apparatus* in the Seismological Institute, whose instrumental constants are as follows :—

Period of free oscillation $=41.5$ sec.

Multiplication of the pointer $=30$ times.

Weight of the heavy cylinder $=16.5$ kgm.

Length of the horizontal strut $=0.75$ metre.

Vertical distance between the points of support and of suspension $=1$ metre.

Aleutian Earthquake.

Preliminary Tremor. Duration $=5^m\ 5^s$. The very 1st displacement was well marked, being $a=0.04$ mm., directed toward W. For the next $1^m\ 3^s$, the motion was small :—

$T=5.0$ sec., $2a=0.05$ mm.

Then the motion became suddenly large, commencing with a displacement of $a=0.25$ mm., toward W, followed by the counter motion of $2a=0.43$ mm. toward E. During the next $4^m\ 2^s$, T was sec.

* This is a portable form instrument described in the *Publications*, No. 18.

Pricipal Portion. The motion became much larger, the 4 initial displacements being as follows :—

(i) a=0.25 mm., toward W.
(ii) $2a$=0.78 „ „ E.
(iii) $2a$=1.72 „ „ W.
(iv) $2a$=2.57 „ „ E.

Then the pointer went out of the smoked paper, toward W. The period of these vibrations was 31.2 sec., there being also some small movements of T=9.3 sec.

Later on the pointer again entered on the smoked paper, recording the end portion due to the Chilian earthquake :—

T=16.4 sec.

(iv) NS Component. Fig. 8, Pl. XXV.

The record was taken by a long period horizontal pendulum set up in the "earthquake-proof house," whose instrumental constants are as follows :—

Vertical distance between the points of suspension and of support =2 metres.

Effective length of the strut, or the horizontal distance between the point of support and the steady axis=1 metre.

Weight of the heavy bob=46 kgm.

Natural oscillation period=48.5.

Multiplication of the pointer=20.

Aleutian Earthquake.

Preliminary Tremor. Duration=5^m 19^s. The commencement is well defined, the initial displacement being a=0.06 mm., toward S. For the first 1^m 1^s, the motion was small :—

T= 5.1 sec., $2a$=0.06 mm.

Fig. 1. Aleutian Islands and the Surrounding Seas.

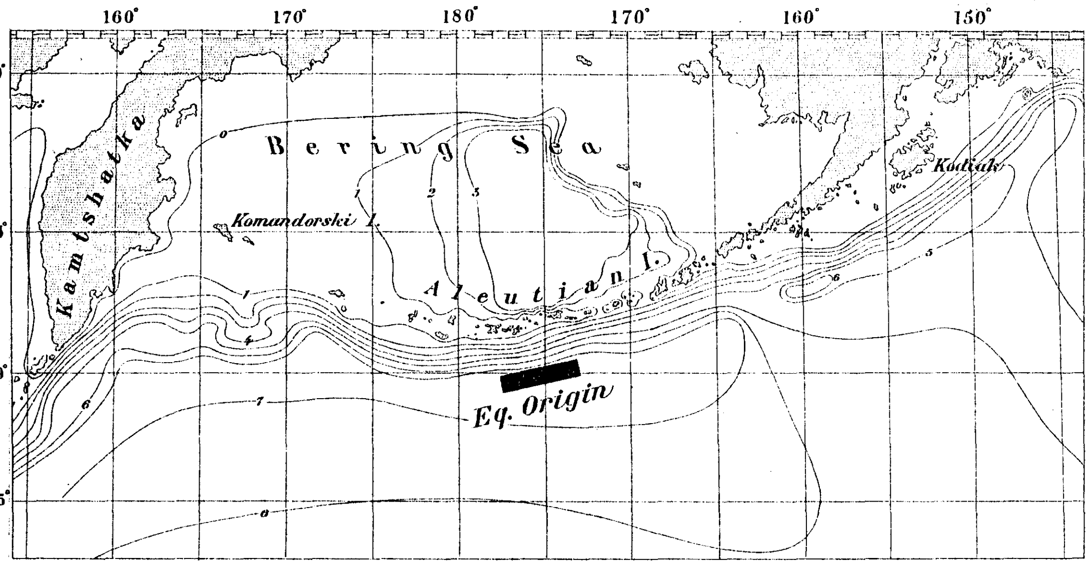


Fig. 2. Showing the Depth of Water off the West Coast of S. America.

In Figs. 1 and 2, the earthquake origins are in each case indicated by a short thick line.

Lines marked 0, 1, 2, ... 7 are the lines of equal depth of 200, 1000, 2000, and 7000 metres respectively

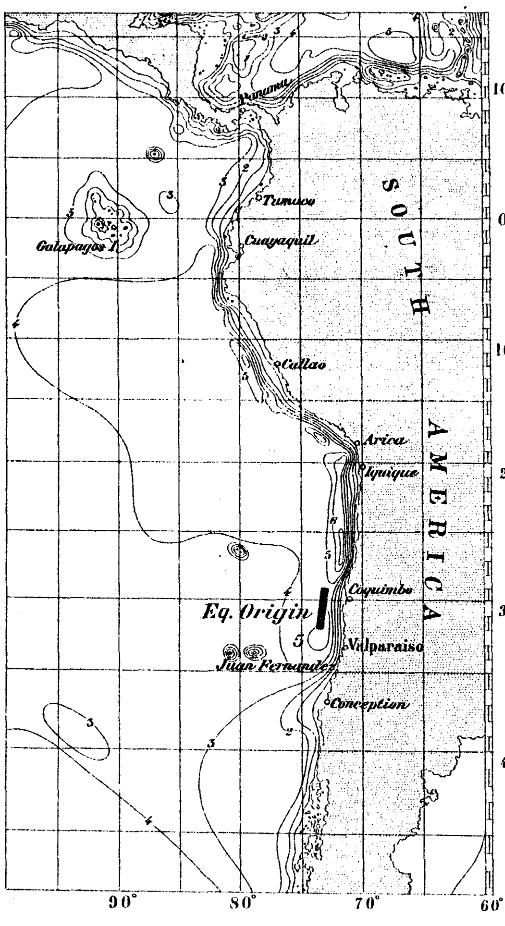


Fig. 3. Map showing the Approximate Positions of the different Great Earthquakes which took place along the West Coast of America.

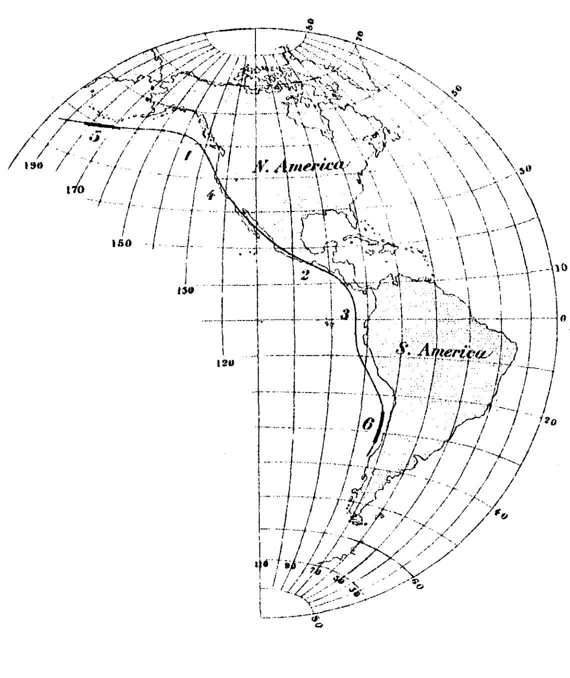
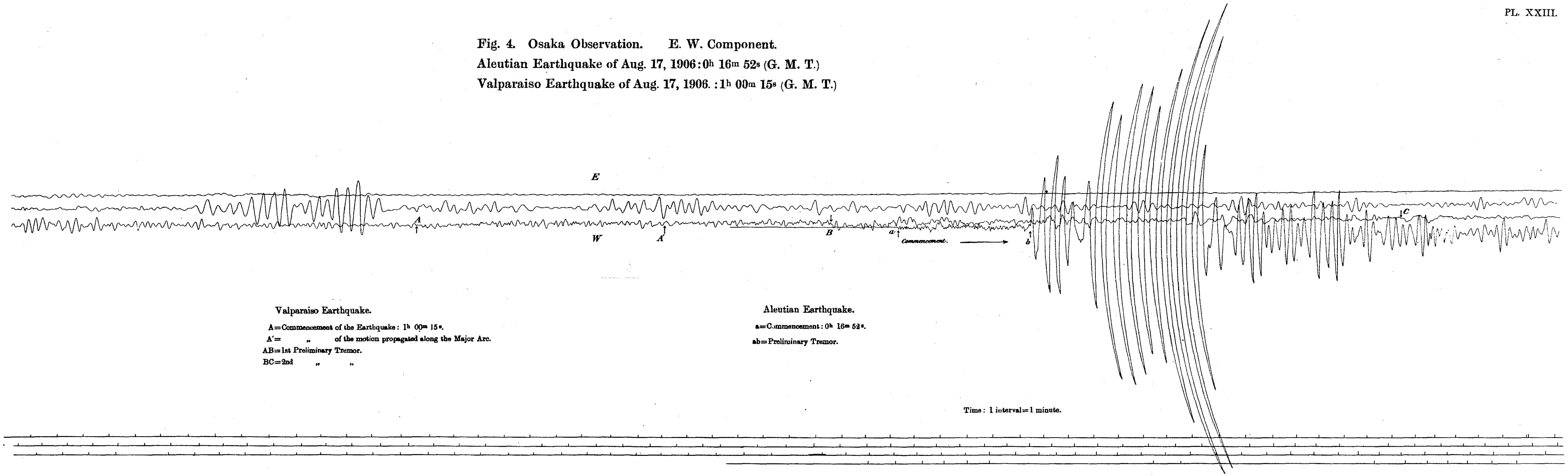


Fig. 4. Osaka Observation. E. W. Component.
Aleutian Earthquake of Aug. 17, 1906: 0h 16m 52s (G. M. T.)
Valparaiso Earthquake of Aug. 17, 1906. : 1h 00m 15s (G. M. T.)



Valparaiso Earthquake.

A=Commencement of the Earthquake: 1h 00m 15s.
A′= „ of the motion propagated along the Major Arc.
AB=1st Preliminary Tremor.
BC=2nd „ „

Aleutian Earthquake.

a=Commencement: 0h 16m 52s.
ab=Preliminary Tremor.

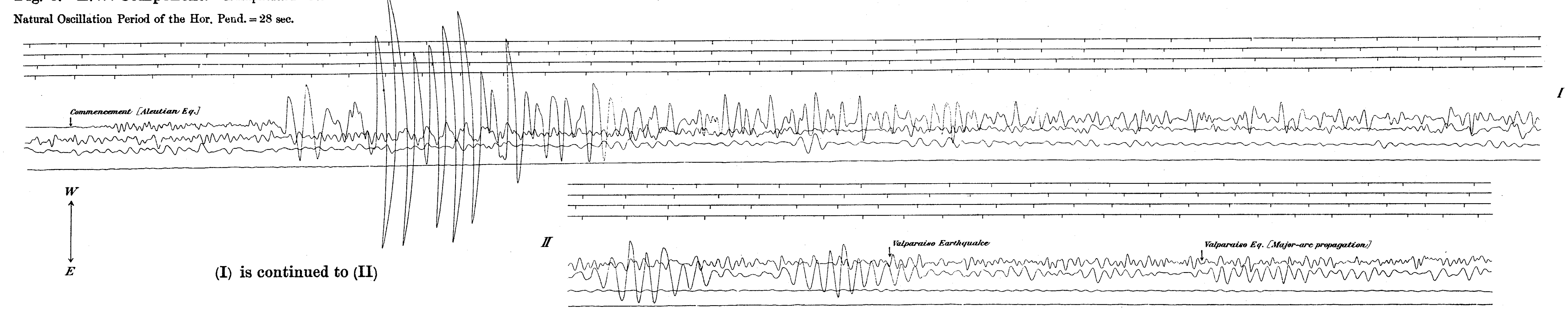
Time: 1 interval=1 minute.

Aleutian and Valparaiso Earthquakes of Aug. 17, 1906. Observed in Tokyo.

Time: 1 interval = 1 minute.

Fig. 5. E.W. Component. Multiplication = 10.

Natural Oscillation Period of the Hor. Pend. = 28 sec.



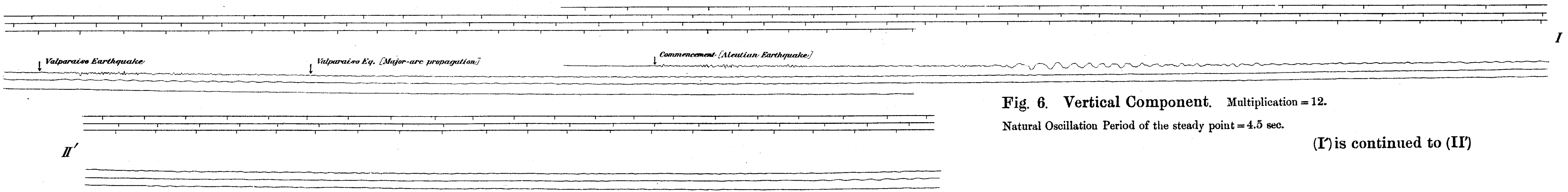


Fig. 6. Vertical Component. Multiplication = 12.

Natural Oscillation Period of the steady point = 4.5 sec.

(I′) is continued to (II′)

Time: 1 interval = 1 min.

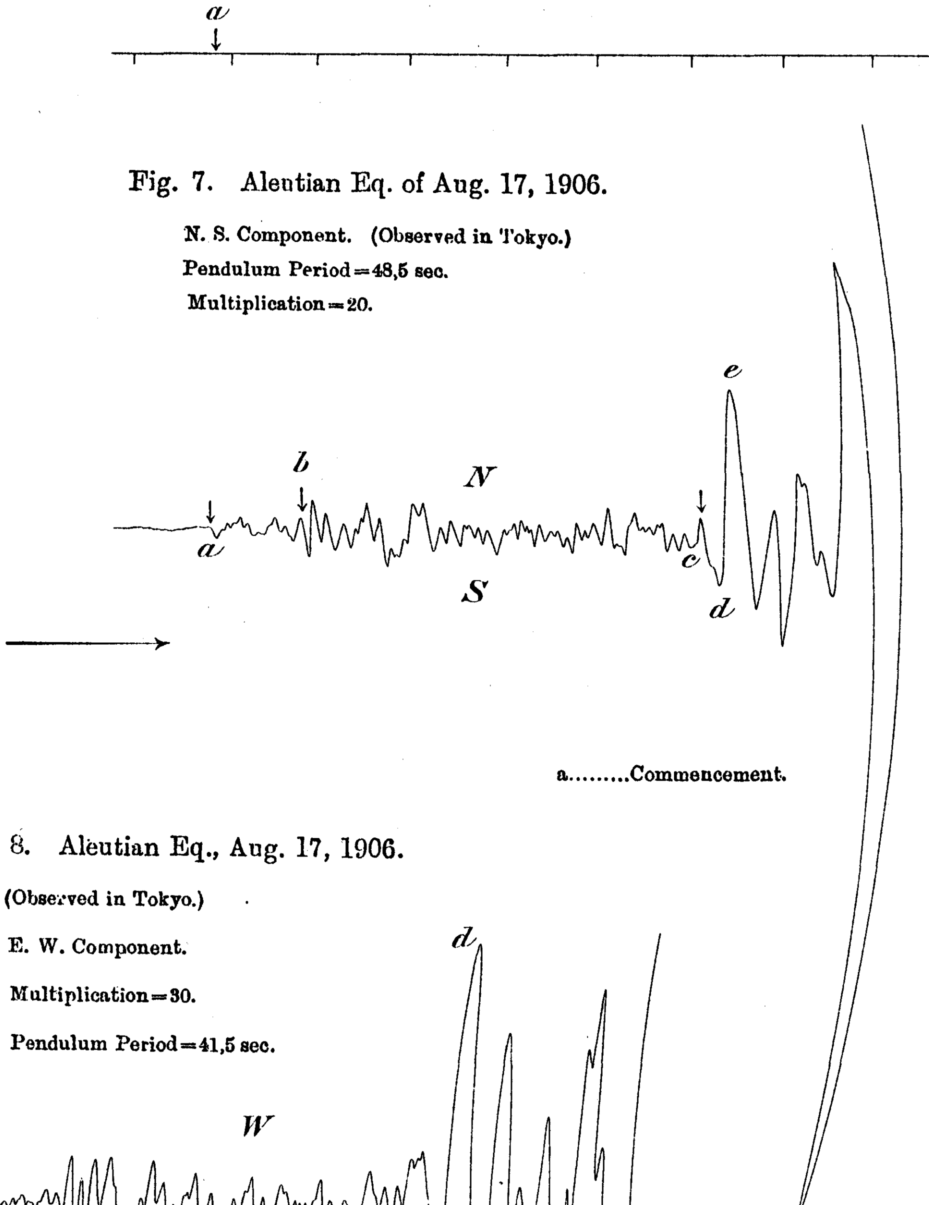


Fig. 7. Aleutian Eq. of Aug. 17, 1906.

N. S. Component. (Observed in Tokyo.)

Pendulum Period = 48,5 sec.

Multiplication = 20.

a.........Commencement.

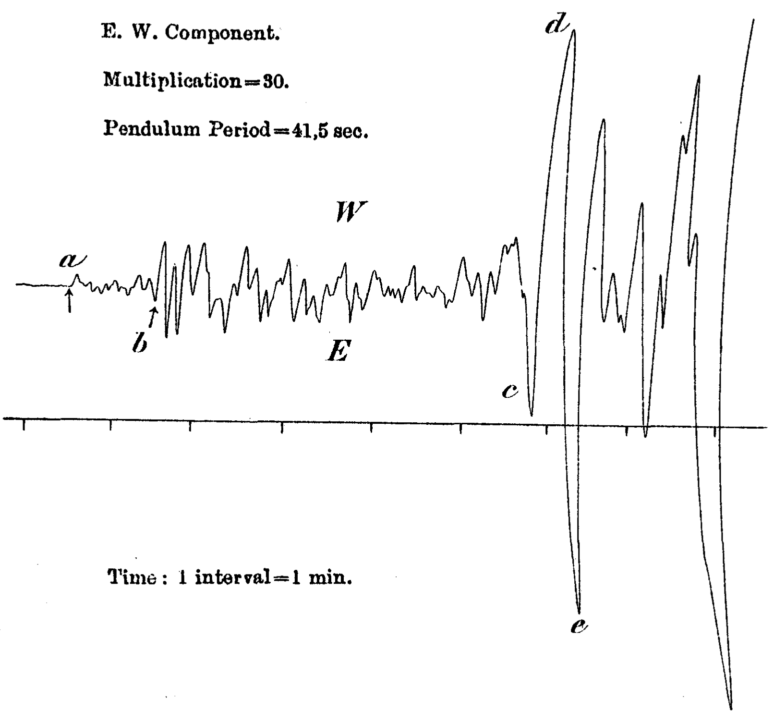
Fig. 8. Aleutian Eq., Aug. 17, 1906.

(Observed in Tokyo.)

E. W. Component.

Multiplication = 30.

Pendulum Period = 41,5 sec.



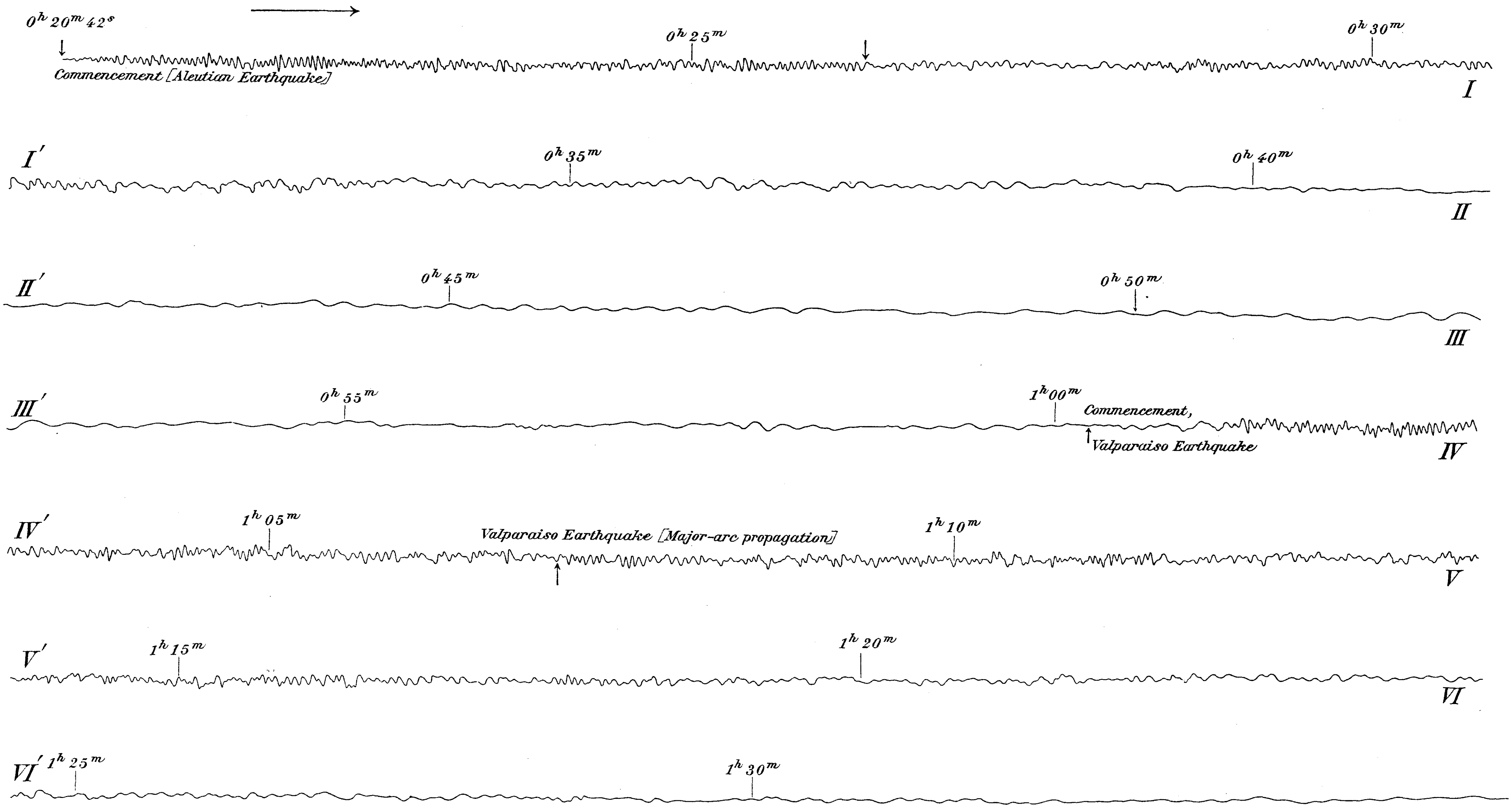
Time: 1 interval = 1 min.

Fig. 9. Aleutian and Valparaiso Earthquakes of Aug. 17, 1906.

Observed at Manila.

ENE—WSW Component.

Vicentini Seismograph. (G. M. T.)



$T=20.3$ sec., $2a=0.14$ mm.

Then the motion became larger, the two first movements being as follows :—

$$\begin{cases} \text{(i)} & a=0.24 \text{ mm, toward S.} \\ \text{(ii)} & 2a=0.38 \text{ ,, ,, } N. \end{cases}$$

The T in the subsequent part was 7.9 sec., there being also some small vibrations of $T=3.9$ sec., $T=18.4$ sec.

Principal Portion. For the first $1^m\ 40^s$, the motion was small comparatively and had a period of $T=30.7$ sec., the three initial displacements being as follows :—

$$\begin{cases} \text{(i)} & a=0.43 \text{ mm, toward S.} \\ \text{(ii)} & 2a=1.3 \text{ ,, ,, N.} \\ \text{(iii)} & 2a=1.4 \text{ ,, ,, S.} \end{cases}$$

At the end of this epoch there took place a vibration consisting of the two following displacements :—

$$\left.\begin{cases} \text{(i)} & a=2.2 \text{ mm, toward N.} \\ \text{(ii)} & 2a=6.35 \text{ ,, ,, S.} \end{cases}\right\} \text{......} T=33.8 \text{ sec.}$$

The next motion was still greater and the pointer went out of the smoked paper, toward N. Later on the pointer again entered on the smoked paper, the vibrations in the end portion of the *Chilian earthquake* being as follows :—

$$\begin{cases} T=19.6 \text{ sec.,} & 2a=0.55 \text{ mm.} \\ T=15.3 \text{ ,,} & 2a=0.20 \text{ ,,} \\ T=10.4 \text{ ,,} & 2a=0.05 \text{ ,,} \\ T=22.9 \text{ ,,} & \text{(small).} \end{cases}$$

5. *Observations at Osaka Meteorological Observatory.*

(i) **EW Component.** Fig. 4, Pl. XXIII.

The record was taken by an Omori Horizontal Pendulum Apparatus of portable form, whose instrumental constants are as follows :—

Vertical distance between the points of suspension and of support =86 cm.

Length of the horizontal strut=44 cm.

Weight of the heavy bob=16 kgm.

Period of the free oscillation=27 sec.

Multiplication of the pointer=20 times.

Aleutian Earthquake. Commencement=$0^h\ 16^m\ 52^s$.

Preliminary Tremor. Duration=$5^m\ 36^s$. The motion began quite sharply, the initial displacement being 0.04 mm, toward W. During the first $1^m\ 0^s$, the motion was small :—

T=5.5 sec., $2a$=0.055 mm.

The subsequent motion consisted of several sets of vibrations, as follows :—

	T= 3.6 sec.,	$2a$=0.055 mm.
	T= 9.5 „	$2a$=0.08 „
(?)	T= 5.8 „	$2a$=0.13 „
(?)	T=33.8 „	$2a$=0.23 „

Principal Portion. The two initial displacements were as follows :—

(i) a=0.45 mm, toward E.
(ii) $2a$=1.25 „ „ W.

During the first $2^m\ 20^s$, the motion was small :—

$T=27.5$ sec., $2a=3.3$ mm. (Pend. Osciln s ?)

For the next $5^m\ 22^s$, the motion consisted of 11 gradually increasing pendulum oscillations :—

$T=29.4$ sec., $2a=11.2$ mm. (10th vibration);

The 1st vibration being as follows :—

(i) $a=1.35$ mm, toward E.
(ii) $2a=3.05$ „ „ W.

The subsequent motion became suddenly smaller, the vibrations during the successive epochs being as follows :—

(i)	$5^m\ 55^s$	$T=19.2$ sec.,	$2a=2.15$ mm.
		$T=35$ „	
(ii)	$7^m\ 16^s$	$T=20.4$ sec.,	$2a=0.78$ mm.
		$T=15.0$ „	$2a=1.25$ „
		$T=10.3$ „	$2a=0.48$ „
(iii)	$5^m\ 29^s$	$T=16.1$ sec.,	$2a=0.53$ mm.
(iv)	$12^m\ 02^s$	$T=15.9$ sec.,	$2a=0.25$ mm.
		$T=11.9$ „	$2a=0.13$ „

Then there appeared the earthquake motion due to the Valparaiso disturbance.

Valparaiso Earthquake. Commnecement$=1^h\ 00^m\ 15^s$.

1*st Preliminary Tremor.* Duration$=15^m\ 48^s$. The commencement is well marked by the appearance of small regular vibrations of $T=2.4$ sec., superposed by the following movements :—

$T=13.5$ sec., $2a=0.21$ mm.
(?) $T=6.3$ „ (small).

At $1^h\ 09^m\ 47^s$, or $9^m\ 32^s$ after the commencement of this phase, there was again some slight predominance of quick-vibrations, which were probably the major arc propagation, the movements being as follows :—

$$\begin{cases} T=15.5 \text{ sec.,} & 2a=0.14 \text{ mm.} \\ T=\ 3.9 \ \text{,,} & \end{cases}$$

2nd Preliminary Tremor. Commencement$=1^h\ 16^m\ 03^s$. Duration$=24^m\ 25^s$. During the first $9^m\ 3^s$, the motion was as follows :—

$$\begin{cases} T=12.0 \text{ sec.,} & 2a=0.13 \text{ mm.} \\ T=\ 8.0 \ \text{,,} & \text{,,}\ =0.09\ \text{,,} \\ T=22.3 \ \text{,,} & \text{,,}\ =0.22\ \text{,,} \end{cases}$$

there being at first traces of 3 slow (doubtful) movements of $T=2^m\ 17^s$. Then the amplitude slightly increased, there being, during the next $3^m\ 5^s$, 5 vibrations :—

$$T=37.0 \text{ sec.,} \qquad 2a=0.33 \text{ mm};$$

these were mixed with small vibrations of $T=10.9$ sec. For the next $3^m\ 30^s$, the motion was small :—

$$\begin{cases} T=12.4 \text{ sec.,} & 2a=0.075 \text{ mm.} \\ T=38.2 \text{ sec.,} & \text{(small).} \end{cases}$$

For the next $2^m\ 38^s$ there appeared again 5 large vibrations :—

$$T=31.7 \text{ sec.,} \qquad 2a=0.35 \text{ mm.}$$

During the remaining $6^m\ 28^s$, the motion was smaller :—

$$\begin{cases} T=27.7 \text{ sec.,} & 2a=0.14 \text{ mm.} \\ T=10.0 \ \text{,,} & 2a=0.12\ \text{,,} \\ T=12.4 \ \text{,,} & 2a=0.07\ \text{,,} \end{cases}$$

Principal Portion. Commencement$=1^h\ 40^m\ 24^s$. [1st and 2nd phases.] Duration$=13^m\ 53^s$. The motion began with 2 slow vibrations :—

$T=55.0$ sec., $2a=0.18$ mm.

The subsequent motion was smaller :—

$$\begin{cases} T=19.1 \text{ sec.,} & 2a=0.09 \text{ mm.} \\ T=10.4 \;\;,, & 2a=0.09 \;\;,, \\ (?)\; T=67.4 \;\;,, & \end{cases}$$

[3rd phase, etc.] Commencement $=1^h\ 54^m\ 21^s$. The motion was most active for the first $7^m\ 8^s$:

$T=23.2$ sec., $2a=1.29$ mm.

The subsequent motion was smaller, the vibrations during the successive epochs being as follows.

(i) For $7^m\ 32^s$:— $\begin{cases} T=18.3 \text{ sec.,} & 2a=0.28 \text{ mm.} \\ (?)\; T=45.0 \;\;,, & \end{cases}$

(ii) For the next $4^m\ 55^s$, there was a maximum group :—

$T=17.4$ sec., $2a=0.54$ mm.

(iii) For the next $7^m\ 55^s$, the motion was nearly uniform :—

$$\begin{cases} T=17.4 \text{ sec.,} & 2a=0.36 \text{ mm.} \\ T=15.9 \;\;,, & ,,\ =0.11 \;\;,, \\ T=35.2 \;\;,, & ,,\ =0.20 \;\;,, \end{cases}$$

During the next $26^m\ 30^s$, the motion was more or less active and comprised a series of maximum groups, which occurred at an average interval of $4^m\ 48^s$; the elements of motion in the successive maxima being as follows :—

1st max. group............ $\begin{cases} T=20.3 \text{ sec.,} ......2a=0.36 \text{ mm.} \\ T=12.8 \;\;,, \;\; ......2a=0.075 \;\;,, \end{cases}$

2nd ,, ,, ... $\begin{cases} T=22.7 \;\;,, \;\; ......2a=0.44 \text{ mm.} \\ T=17.8 \;\;,, \;\; ......2a=\text{(small).} \end{cases}$

3rd ,, ,, ... $\begin{cases} T=23.8 \;\;,, \;\; ......2a=0.30 \text{ mm.} \\ T=18.8 \;\;,, \;\; ......2a=0.10 \;\;,, . \end{cases}$

4th max. group............ $\begin{cases} T=19.7 \text{ sec.,......} 2a=0.43 \text{ mm.} \\ T=16.5 \text{ ,, ,......} 2a=0.19 \text{ ,,} \end{cases}$

5th ,, ,, ... $\begin{cases} T=20.8 \text{ sec.,......} 2a=0.30 \text{ ,,} \\ T=14.4 \text{ ,, ,...... ,,} = \text{(small).} \end{cases}$

6th ,, ,, ... $\begin{cases} T=21.1 \text{ sec.,......} 2a=0.30 \text{ mm.} \\ T=16.0 \text{ ,, ,...... ,,} = \text{(small).} \end{cases}$

It will be observed that in each maximum group there were essentially two sets of vibrations, one of which formed the predominating constituent, while the other occurred only at minimum epochs ; the periods belonging to these two sets being as follows :—

(*A*) Larger vib.		(*B*) Smaller vib.	
	T=20.3 sec.		T=12.8 sec
	22.7		17.8
	23.8		18.8
	19.7		16.5
	20.8		14.4
	21.1		16.0
mean	21.4	mean	16.7

The mean value of the (*A*) periods is 21.4 sec., while that of the (*B*) periods is 16.7 sec., (with the single exception of T=12.8 sec.). The difference between these two means is 4.7 sec., correponding probably to the fundamental period which I have denoted by P_1.*

The subsequent motion was much smaller :— T=16.5 sec.

(ii) Diagrams from a Horizontal Tremor-recorder.

The two earthquakes have been registered also by a small Omori Horizontal Tremor-recoder, which was originally designed

* The *Publications*, Nos. 5, 13, 21, etc.

to record small local shocks. Each of the two horizontal component pendulums has a bob of 16 kgm weight, and an oscillation period of about 2 sec., the multiplication ratio being 45.*

The times of commencement of the Aleutian and the Valparaiso earthquakes as recorded by the tremor-recorder were 0^h 17^m 17^s and 1^h 01^m 08^s (G.M.T.) respectively.

NS Component.

Aleutian Earthquake. The preliminary tremor lasted 5^m 30^s, during which the motion was most active and consisted of the following vibrations :—

$$\begin{cases} T=1.9 \text{ sec.,} & 2a=0.062 \text{ mm.} \\ T=5.4 \quad " & \quad " =0.038 \quad " \end{cases}$$

The movements during the earlier parts of the principal portion were as follows :—

(i) For the 1st 2^m 37^s :—

$$T=6.4 \text{ sec.,} \qquad 2a=0.04 \text{ mm.}$$

(ii) For the next 2^m 59^s :— there were 6 slow and nearly uniform vibrations mixed with quick ones :—

$$\begin{cases} T=29\ 8 \text{ sec.,} & 2a=0.022 \text{ mm.} \\ T=\ 5.3 \quad " & \quad " =0.029 \text{ mm.} \end{cases}$$

The subsequent vibrations gradually diminished and were as follows :—

$$T=13.8 \text{ sec.,} \qquad 2a=0.022 \text{ mm.}$$

Valparaiso Earthquake. The commencement was indicated by small vibrations of $T=0.92$ sec.

* This is exactly similar to the instrument which I have described in the *Publications*, No. 18, the only modification being the use of a cylinder for the recording surface.

EW Component.

Aleutian Earthquake. The preliminary Tremor :—

$T=2.3$ sec., $2a=0.067$ mm.

The movements in the successive parts of principal portion were as follows :—

(i) For the 1st $1^m\ 49^s$	:—$T=5.0$ sec.,	$2a=0.022$ mm.
(ii) „ „ next 2 02	:—$T=30.5$ „	$2a=$ (Small).
(iii) „ „ „ 2 12	:—$T=22.0$ „	
(iv) „ „ „ 3 50	:—$T=17.7$ „	

The motion in the E W component was much smaller than in the NS compouent. This may be due to some unequality in the friction existing between parts of the two horizontal pendulums.

Valparaiso Earthquake. During the first 55 sec., the motion was small. Then the vibrations became most active :—

$T=2.2$ sec., $2a=0.033$ mm.

$9^m\ 10^s$ after this maximum there was another slight one, which may correspond to the major arc propagation.

6. *Observation at Manila.* Pl. XXVI. ENE-WSW Component.

The record was obtained by a Vicentini seismograph. In the following analysis, the amplitude is given *unreduced*, or not divided by the multiplying ratio of the pointer.

Aleutian Earthquake. Commencement$=0^h\ 20^m\ 42^s$. For the first $5^m\ 49^s$, the motion consisted of quick vibrations :—

$$\begin{cases} T=2.4 \text{ sec.,} & 2a=3.5 \text{ mm (pendulum oscillation).} \\ T=4.8 \text{ ,,} & \end{cases}$$

For the next $5^m\ 14^s$:—

$$\begin{cases} T=\ 3.8 \text{ sec.,} & 2a=1.5 \text{ mm.} \\ T=\ 2.6 \text{ ,,} & 2a=1.0 \text{ ,,} \\ T=\ 7.9 \text{ ,,} & 2a=2.0 \text{ ,,} \\ (?)\ T=20.8 \text{ ,,} & \end{cases}$$

Thereafter the quick pendulum movements gradually decreased, till they disappeared at $0^h\ 38^m\ 20^s$; the principal vibrations being as follows :—

$$\begin{cases} T=11.2 \text{ sec.,} & 2a=1.4 \text{ mm.} \\ T=17.8 \text{ ,,} & 2a=2.6 \text{ ,,} \\ T=\ 4.7 \text{ ,,} & \text{(small)} \end{cases}$$

For the next $8^m\ 25^s$:—

$$\begin{cases} T=11.4 \text{ sec.,} & 2a=1.0 \text{ mm.} \\ T=\ 7.5 \text{ ,,} & 2a= \text{(small.)} \end{cases}$$

For the next $5^m\ 4^s$:—

$$\begin{cases} T=20.4 \text{ sec.,} & 2a=0.9 \text{ mm.} \\ T=\ 9.3 \text{ ,,} & \text{(small).} \end{cases}$$

Then, at $0^h\ 51^m\ 49^s$, there took place 3 well defined slow vibrations :—

$$T=20.9 \text{ sec.,} \qquad 2a=1.5 \text{ mm.}$$

The subsequent motion was smaller :—

$$\begin{cases} T=17.2 \text{ sec.,} & 2a=1.0 \text{ mm.} \\ T=11.8 \text{ ,,} & 2a=1.4 \text{ ,,} \end{cases}$$

Valparaiso Earthquake. Commencement=$1^h\ 00^m\ 15^s$. The commencement was marked by the appearance of quick vibrations, the motion being small for the first $1^m\ 6^s$. Then, at $1^h\ 01^m\ 21^s$, there appeared most active quick movements, which remained nearly uniform for the next $4^m\ 33^s$:—

T=5.7 sec., $2a$=2.4 mm.

The quick vibrations were indicated distinctly till about $2^h\ 19^m$, and slightly till $2^h\ 29^m$, there being superpositions of slow movements :—

T=2.3 sec.,..................... $2a$=2.0 mm.

T=5.3 sec.; 7.4 sec.; 11.6 sec.; 14.6 sec.

At $1^h\ 07^m\ 06^s$ there was some increase in the amplitude of the quick vibrations (max. $2a$=2.0 mm.), which were probably the major arc propagation.

7. *Observation at the Querce Observatory, Florence.* The following is a note on the lithographic reproduction of the diagrams* obtained at the Querce Observatory, Florence, by a pair of Stiattesi Horizontal Pendulums, whose instrumental constants are :—

Multiplication of the pointer=25.
Weight of the heavy mass=250 kgm.
Mean velocity of the record-receiver=97 cm. per hour.
(Complete) period of free pendulum oscillation=19.6 sec.

Aleutian Earthquake. Commencement=$0^h\ 24^m\ 00^s$.

NW–SE Component.

1st *Preliminary Tremor.* Duration=$10^m\ 53^s$.

The motion consisted of small uniform vibrations.

2nd *Preliminary Tremor.* Commencement=$0^h\ 34^m\ 53^s$. Duration=$11^m\ 41^s$:—

T=17,3 sec., $2a$=0.22 mm.

Principal Portion. Commencement=$0^h\ 46^m\ 34^s$. [1st and 2nd phases] Duration=$13^m\ 30^s$. For the first $7^m\ 47^s$, the motion consisted of slow vibrations :—

T=36.0 sec., $2a$=0.36 mm.

Then there set in large pendulum oscillations, which continued till $2^h\ 27^m$, thereby confusing the movements due to the Valparaiso earthquake. These oscillations were as follows :—

T=18.1 sec., $2a$=6.9 mm. (pend. oscillation).

NE–SW Component.

In this component diagram the pendulum oscillations were much smaller than the other.

1st *Preliminary Tremor.* Duration=$10^m\ 32^s$.

The vibrations were very small.

2nd *Preliminary Tremor.* Duration=$12^m\ 6^s$:—

T= 9.7 sec., $2a$=0.10 mm.; T=14.6 sec.

8. *Summary of the Observations of the Aleutian Earthquake.* The mean values of the different periods of vibrations, which occurred at Tokyo, Osaka, Manila, and Querce, are given in the following table, the periods most frequently occurring being printed in fat characters.

Periods of Vibration.

Tokyo. (EW)	Tokyo. (Vertical)	Tokyo. (NS)	Osaka. (EW)	Osaka. Horiz. Tremor Recorder.	Manila.	Querce.	*Mean.*
sec.	sec.	sec.	sec.		sec.	sec.	sec.
—	3.5	—	—	1.9 (pend. 2.3 oscl.)	2.9	—	—
4.7	4.6	4.5	5.0	5.5	4.8	—	4.7
6.4	—	—	—	—	—	—	—
8.6	9.4	—	—	—	8.2*	9.7	8.8
10.7	11.5	—	10.6	—	11.5	—	11.1
—	—	—	—	13.8	—	—	13.8
18.8*	16.5	18.4	15.9	17.7	17.5*	17.7(P.O.)*	17.4
—	—	20.3	20.0*	—	20.7*	—	20.3
—	22.3*	—	—	22.0	—	—	22.2
26.1*	—	—	28.5(P.O.)*	—	—	—	27.3
30.9	—	30.7	—	30.2	—	—	30.6
36.0*	34.0*	33.8*	34.4	—	—	36.0*	34.8

It will be seen from the above table amongst others that the (mean) periods of 4.7 sec., 8.8 sec., 11.1 sec., 17.4 sec., 20.3 sec., 22.2 sec., 30.6 sec., and 34.8 sec. occurred at Tokyo as well as at one or more of the three other places, namely, Osaka, Manila, and Querce. (See also § 15.) The Tokyo records indicate that there was no special difference in the periods of vibration between the horizontal and vertical movements.

In the following table are collected the times of earthquake occurrence at the above mentioned four places, and at 25 other stations ; the data relating to the latter having been taken from the monthly or weekly reports published by the different seismological observatories. In a few cases, the time of occurrence of the 2nd preliminary tremor and the duration of the 1st preliminary tremor are also given.

* The periods of the predominating vibrations are marked with *asterisks*.
(P.O.) marks the pendulum oscillations.

OBSERVATION OF THE ALEUTIAN EARTHQUAKE.

(Time in G.M.T.)

Place.	Position. Latitude.	Position. Longitude.	Time of occurrence $=t_1$	Time of commencement of 2nd P. T. $=t_2$	Duration of the 1st Preliminary Tremor.
Origin......... *	50° N	175° E	0^h 11^m 44^s		
					(Total P.T.)
Tokyo...........	35° 42′ 29″ N	139°45′53″ E	0^h 17^m 16^s		5^m 20^s
Osaka	34 42 — N	135 31 — E	0 16 52		5 36
Mizusawa	39 08 — N	141 07 — E	0 16 57		
Taihoku(Formosa).	35 02 — N	121 30 — E	0 20 07		
Manila...........	14 34 41 N	120 58 33 E	0 20 42		
Zikawei.........	31 11 33 N	121 10 45 E	0 19 59		
Berkeley, Cal...	37 52 24 N	122 15 11 W	0 18 00		
Washington D.C...	38 54 18 N	77 03 06 W			
Göttingen	51 33 — N	9 58 — E	0 23 43	0 32 30	8 47
Strassburg......	48 35 00 N	7 46 10 E	0 23 01	———	13 33(?)
Heidelberg......	49 23 55 N	5 58 44 E	0 23 08		
Budapest........	47 22 29 N	19 03 55 E	0 23 34		
O'Gyalla.........	47 52 24 N	18 52 32 E	0 22 42		
Zagreb	45 48 54 N	15 58 48 E	0 23 23		
Kremsmünster.....	48 03′ — N	14 08′ — E	0 23 23	0 32 55	9 32
Laibach.........	46 03′ — N	14 31′ — E	0 23 37	0 34 08	10 31
Vienna	48 15′ — N	16 22′ — E	0 22 41	0 37 36	
Triest	45 39′ — N	13 46′ — E	0 23 25		
Tiflis.............	41 43 08 N	44 47 51 E	0 22 54		
Borshom..... .	41 51 — N	43 23 08 E	0 23 45		
Achalkalaki.....	41 25 — N	43 29 09 E	0 23 49		
Upsala...........	59 51 30 N	17 37 30 E	0 22 00		
Belgrad	44 48′ — N	20 09′ — E			
San Fernando (Spain)..........	36 27 40 N	6 12 19 W	0 28 24		
Tortosa	40 49 — N	2 34 — E	0 23 21		
Coats Observatory (Paisley).........	55 51 — N	4 25 — W	0 31 36		
Querce (Florence)..	43 47 18 N	11 16 42 E	0 24 00		
Ximeniano („)...	43 46 40 N	11 15 24 E	0 24 00	0 35 30	11 30

* The position of the origin has been determined by methods given in § 9. For the determination of the time of earthquake origin see § 11.

9. *Determination of the Approximate Position of the Origin of the Aleutian Earthquake.* The approximate position of the earthquake origin may be determined in two different ways, from seismographic observations made at a number of stations, as follows :—

(i) By a comparison of the times of earthquake occurrence ;

(ii) From the epicentral distances deduced from the durations of the preliminary tremors.

1*st Method* : *Comparison of the times of occurrence.* As an example, let us take the times ($=t_1$) of earthquake occurrence at Tokyo, Florence, Manila, and Berkeley (California):—

Tokyo................	$t_1=0^h$	17^m	16^s
Florence..............	$t_1=0$	24	00
Manila................	$t_1=0$	20	42
Berkeley..............	$t_1=0$	18	00

It is evident that among the above 4 stations Tokyo was nearest to the origin. As, further, the duration of the total preliminary tremor in Tokyo was 5^m 20^s, which corresponds to an epicentral distance of about 25°, I shall assume a propagation velocity of 13^{km} per sec. for the differential epicentral distances between Tokyo, Berkeley, and Florence (Ximeniano and Querce.) For the comparison of Tokyo and Manila, however, let us take a somewhat lower velocity, say, 10^{km} per sec. Under these suppositions, we obtain the following results :—

Combination of places.	Difference of times of commencement.		Approximate Epicentral Difference.
Florence-Tokyo...........	6^m	44^s	47.°3
Manila-Tokyo..............	3	26	24.3
Berkeley-Tokyo...........	0	44	5.2

A circle drawn about Manila as centre with a radius of 24.°3 passes very nearly through Tokyo, while the locus of equidistance between Tokyo and Florence intersects that between Tokyo and San Francisco at about $\varphi=57°$ N, $\lambda=179°$ W ; this latter point, or the epicentre, being situated, nearly in the same great circle which connects Tokyo and Manila.

2nd *Method : Comparison of the epicentral distances deduced from the duration of the preliminary tremor.* The relation of the epicentral distance (x) to the duration (y_1) of the 1st preliminary tremor, or the total duration (y) of the 1st and 2nd preliminary tremors, is approximately given by either of the two following equations*

$$\begin{cases} \overset{\text{km.}}{x}=\overset{\text{sec.}}{17.1}\ y_1-\overset{\text{km.}}{1360}. \\ x=\ 6.54\,y+720. \end{cases}$$

Taking the observations at Tokyo and Florence, (Ximeniano) for instance, we have :—

$$\begin{cases} \text{Tokyo} \ldots\ldots\ldots\ldots\ y=\ 5^m\ 20^s;\quad x=25°.3 \\ \text{Florence} \ldots\ldots\ldots\ y_1=11\ \ 30\ ;\quad x=94. \end{cases}$$

If two circles be drawn about Tokyo and Florence as centres, with the radii of 25°.3 and 94° respectively, they intersect at about $\varphi=44°$ N, $\lambda=170°$ E.

Taking the mean of the two positions above obtained, we find, for the approximate situation of the earthquake origin,

$$\lambda=\ 50°\ \text{N},\qquad \varphi=175°\ \text{E}.$$

The epicentral distances of some of the observing stations are as follows :—

Tokyo...........................	29°	08′
Osaka......	32	26
Berkeley.........................	45	22
Manila...........................	58	25
Florence.........................	85	09

* The "Publications," No. 5 and No. 13.

10. *Aleutian Earthquake: Direction of Motion in Tokyo.* From a comparison of the descriptions of the EW and NS component diagrams (**iii** and **iv**, § **4**), we see that the displacement occurring at the very commencement of the earthquake was as follows:—

$$\begin{cases} 0.04 \text{ mm, towards W,} \\ 0.06 \;\; ,, \;, \quad ,, \quad \text{S;} \\ \text{Resultant motion} = 0.07 \text{ mm, towards S } 34^\circ \text{ W.} \end{cases}$$

Again the two displacements constituting the first vibration of the principal portion were as follows:—

$$\text{(i)}\ldots\ldots\ldots \begin{cases} 0.25 \text{ mm, towards W,} \\ 0.24 \;\; ,, \;, \quad ,, \quad \text{S;} \\ \text{Resultant motion} = 0.34 \text{ mm, towards S } 46^\circ \text{ W.} \end{cases}$$

$$\text{(ii)}\ldots\ldots\ldots \begin{cases} 0.43 \text{ mm, towards E,} \\ 0.38 \;\; ,, \;, \quad ,, \quad \text{N;} \\ \text{Resultant motion} = 0.57 \text{ mm, towards N } 49^\circ \text{ E.} \end{cases}$$

Taking the mean of these three results, we find that the direction of motion was

$$\text{S } 48^\circ \text{ W}^\circ - \text{N } 48^\circ \text{ E.}$$

This direction points very nearly towards the source of the earthquake disturbance located from the seismographic observations (§ 9), the actual direction of the centre from Tokyo being N 50° E. It will be observed that the initial or first displacement of vibration was directed away from the origin.

11. *Determination of the Approximate Time of Occurrence at the Origin of the Aleutian Earthquake.* The approximate time ($=t_0$) of earthquake occurrence at the origin can be estimated by means of the following equation*:—

$$t_0 = t_1 - 1.165\, y_1^{\text{sec.}}$$

* The *Bulletin*, No. 1.

in which t_1 and y_1 are respectively the time of occurrence and the duration of the 1st preliminary tremor at any given station. Applying, for instance, the above formula to the observations made at Göttingen, Ximeniano, and Laibach, we obtain the following results:—

$$\textit{Göttingen} \dots\dots\dots \begin{cases} t_1 = 0^h 23^m 43^s; \ y_1 = \ 8^m 47^s \\ t_0 = 0^h 13^m 28^s \end{cases}$$

$$\textit{Ximeniano} \dots\dots\dots \begin{cases} t_1 = 0 \ 24 \ 00 \ ; \ y_1 = 11^m 30^s \\ t_0 = 0 \ 10 \ 35 \end{cases}$$

$$\textit{Laibach} \dots\dots\dots \begin{cases} t_1 = 0 \ 23 \ 37 \ ; \ y_1 = 10^m 31^s \\ t_0 = 0 \ 11 \ 19 \end{cases}$$

Taking the mean of the above three values of the t_0, we find:—

t_0, or time of earthquake commencement $= \mathbf{0^h 11^m 44^s}$

12. ***Valparaiso Earthquake.*** According to newspaper reports, the Valparaiso earthquake happened a short time before 8 o'clock in the evening, of the 16th of August. As shown in § 13, the approximate time of occurrence in the epicentral district was probably $0^h 40^m 05^s$ (the 17th) in Greenwich Mean Time, or $7^h 53^m 29^s$ P.M. (the 16th) in the Valparaiso Local Time. At Valparaiso the weather on the day of the earthquake was unusually calm and pleasant.*

The earthquake and subsequent fires produced a considerable amount of damage in the city of Valparaiso; the shock having also caused a great destruction in Vina del Mar, Le Ligna, Limache, Quilque, Arriaca, Palequin, Meripilla, Quillota, Llaillai, Hierro

* A fine and calm weather, which generally corresponds to the rise of the barometric pressure, also characterized most of the great destructive earthquakes in Japan.

Viejo, Aberca, Conchall, Petarda, La Placilla, La Calera, Los Andes, San Felipe, and some other places. There were 30 deaths in the city of Santiago, while the town of Vallenar (300 miles north of the capital) is said to have been badly affected.

The strong motion area seems to have extended from Vallenar on the north to Santiago on the south, over a distance of about 300 miles. The earthquake origin was probably an elongated sub-oceanic zone parallel to the coast, the most central part of which may be assumed *roughly* to be at about 250 km to the NNW of Valparaiso, or at the following position:—

$$\varphi = 31^{\circ}\ \text{S}, \qquad \lambda = 73^{\circ}\ \text{W}.$$

According to a letter of Dr. Ricardo Poenisch, of Santiago, there was no surface manifestation of faults, but apparently the coast was elevated more than 1 metre. The shock was felt on the north as far as Tacna, the northern-most province of Chile, at a distance of about 450 miles from Valparaiso.

The epicentral distances of the different stations, where the distinct commencement of the Valparaiso earthquake was observed, are as follows:—

Tokyo	152° 22′
Osaka	155 51
Göttingen	109 46
Ximeniano	107 07
Manila	159 10

13. ***Observation of the Valparaiso Earthquake.*** The time (t_1) of occurrence observed at the different stations were as follows:—

Tokyo	$t_1=1^h00^m34^s$	
Osaka	1 00 15	
Mean	**1 00 25**	
Manila	1 00 15	
Göttingen	1 13 30	(?) (Vert. Seismograph.)
Ximeniano	0 58 15	

The durations (y_1 and y_2) of the 1st and 2nd preliminary tremors were as follows:—

Tokyo	$y_1=18^m59^s$;	$y_2=26^m05^s$;	$y_1+y_2=45^m04^s$
Osaka	$y_1=15$ 48;	$y_2=24$ 25;	$y_1+y_2=40$ 13
Mean	$y_1=$**17 24**;	$y_2=$**25 15**;	$y_1+y_2=$**42 39**

Time (t_5) of commencement of the 3rd phase of the principal portion was as follows:—

Tokyo	$t_5=1^h52^m18^s$	(Vertical component)
,,	1 58 53	(EW ,,)
Osaka	1 54 21	(,, ,,)
Mean	**1 55 11**	

W_2 Motion. The time intervals between the corresponding epochs in the 1st preliminary tremor of the W_1 and W_2 waves, at Tokyo, Osaka and Manila, were as follows:—

Tokyo	6^m35^s (Vertical)
	7 45 (EW component)
Osaka	9 32
Manila	5 45

The identification of the W_2 motion was in each case extremely difficult, and the intervals of time above given are to be regarded only as rough estimates. Taking the mean, we obtain a time interval of 7^m24^s, corresponding to a mean epicentral distance of $155° 48'$. The theoretical time interval corresponding to the latter value of the epicentral distance, would be, if we suppose a propagation velocity of 13 km per sec., equivalent to

$$\frac{360°-(2\times 155° 48')}{13}=6^m54^s$$

14. ***Estimation of the Time (t_0) of Occurrence at the Origin of the Valparaiso Earthquake.*** Taking the mean of the Tokyo and Osaka observations, we have, according to the equation in § 11,

$$\begin{cases} t_1 = 1^h00^m25^s \\ y_1=17^m24^s \\ t_0 = t_1 - 1{\cdot}165\ y_1 = 0^h40^m05^s \text{ (G.M.T.)} \end{cases}$$

Now the Valparaiso mean local time is that of longitude 71° 39′ W, or $4^h46^m36^s$ after G.M.T. We have, therefore,

$$t_0=7^h53^m29^s \text{ P.M. (Local time).}$$

15. ***Comparison of the Periods of Vibration in the Valparaiso Earthquake with those in the Caracas and Guatemala Earthquakes.*** The following table gives the mean values of the different periods found in the seismograms obtained at Tokyo, Osaka, and Manila, together with those found in the Tokyo seismograms of the Caracas earthquake of Oct. 29, 1900, and the Guatemala earthquake of April 19, 1902; the periods of more frequent occurrence being printed in fat characters.

Caracas and Guatemala Earthquakes.	Valparaiso Earthquake.				
Tokyo (Horizonal).	Tokyo (Horizontal).	Tokyo (Vertical).	Osaka (EW).	Manila.	*Mean.*
Sec.	Sec.	Sec.	Sec.	Sec.	Sec.
2.9	—	—	2.4	—	—
—	4.0	3.5	3.9	5.5	4.0
7.9	9.0	—	8.0	7.4	8.4
10.2	11.5	11.2	{ 10.4 12.4	11.6	11.4
14.8	15.7	—	{ 14.0 16.0	14.6	15.1
18.4	17.7	18.2	19.1	—	18.3
21.2	22.3	22.4	23.0	—	22.6
		26.8			26.8
26.9	29.7	—	27.7	—	28.7
32.9	32.7	—	31.7	—	32.4
39.5	37.7	—	36.8	—	37.1
45.4	—	—	45.0(?)	—	45.0(?)
56.0	—	—	—	—	—
—	—	—	67.4(?)	—	67.4(?)

From the above table it will be seen that the different periods of vibration, which occurred at Tokyo in the Caracas and Guatemala earthquakes, were almost perfectly identical with those which occurred at Tokyo and Osaka in the Valparaiso earthquake. The Manila seismogram indicates only shorter periods, which are also found in the Tokyo and Osaka records. It is almost certain that, if the Manila seismograph had a long natural period of oscillation, other slow periods would have been likewise registered there. It may be here mentioned that I have taken, for comparison, the

Caracas and Guatemala earthquakes, as the origins of these shocks had, with respect to Tokyo, epicentral distances and azimuths not widely different from those of the Valparaiso earthquake.

By comparing the above table with the list of periods in § 8, it will be seen that the periods of vibration in the Aleutian earthquake also occurred in the Central and South America earthquakes.

The examination of the numerous seismographic records of the great Indian earthquake of April 4, 1905, has also shown the common occurrence of various periods of vibration in different parts of the would.

From the facts like the above, it seems probable that the microseismic or unfelt and slow periods of vibration are approximately the same in different earthquakes and at different stations. I have previously stated a similar conclusion with regard to the *pulsatory oscillations.*

Sea Waves.

16. ***Tidal Disturbances due to the Valparaiso Earthquake.*** The earthquake caused some tidal disturbances, which spread over the Pacific. Thus, in the enclosed Bay of Maalaea, on the island of Maui (Hawaii) the wave is said to have reached a height of 12 feet. An inter-island steamer Noeu, while anchored off the north-eastern coast of the island of Hawaii in a calm sea was carried forward by a sudden undertow, which was so strong that her chain parted and she lost her anchor and forty fathoms of chain. It is, however, noteworthy that there were apparently no sea waves at Valparaiso itself, there being no newspaper account of such disturbances at the Chilian port. The fact seems to be that the tidal waves in the vicinity of Valparaiso did not, owing to the great depth of the water along the coast, attain any considerable amount, failing thereby to produce damage or attract attention.

16. *The Sea Waves observed at Honolulu, San Diego and San Francisco.* The tidal disturbances due to the Valparaiso earthquake, recorded on the tide gauges at Honolulu, San Diego, and San Francisco, whose *direct* arcual distances from the origin of disturbance are respectively 96° 21′, 76° 12′, and 82° 52′, were as follows.*

Honolulu.

$\varphi=21° 18' N$; $\lambda=157° W$.

The time used is that of longitude 157° 30′ W, or 10^h 30^m after G.M.T.

Slight traces of disturbances appeared at about 3 A.M. (Aug. 17th), the period being 33.3^{min}. But the distinct movement began first at 5^h 15^m A.M., and remained active for the next 20 hours :—

$$T=25.5 \text{ min.}, \qquad 2a=0.28 \text{ ft.}$$

In the subsequent portion, (the movement continued more or less active till Aug. 19th):—

$$\begin{cases} T=26.3 \text{ min.}, & 2a=0.15 \text{ ft.} \\ T=45.3 \;\;'' & \end{cases}$$

San Diego.

U.S. Quarantine Wharf. $\varphi=32° 42' N$; $\lambda=117° 10' W$.

The time is the Western States Time, or 8 hours after G.M.T.

The movement was indicated distinctly first at 6^h 30^m A.M., and remained active till about 6^h 40^m P.M. :—

* Denoting by T and $2a$ the complete period and the range, or double amplitude, of the wave motion.

$$\begin{cases} T=21.8 \text{ min.}, & 2a=0.45 \text{ ft.} \\ T=16.2 \quad ,, & \\ T=59.1 \quad ,, & \end{cases}$$

San Francisco.

Presidio. $\varphi=37° 48' N$; $\lambda=122° 30' W$.
Time used : The Western States Time.

The distinct movement began at 7^h 42^m A.M., remaining active till about 11^h P.M. Up to about 8^h 30^m P.M., the predominating oscillations were as follows:—

$$\begin{cases} T=59.1 \text{ mm.}, & 2a=0.28 \text{ ft.} \\ T=21.3 \quad ,, & \end{cases}$$

Thereafter the oscillations were as follows:—

$$\begin{cases} T=41.0 \text{ mm.}, & 2a=0.28 \text{ ft.} \\ T=25.2 \quad ,, & 2a=0.24 \quad ,, \end{cases}$$

17. *The Sea Waves observed at Japanese Coasts.* The sea waves due to the Valparaiso earthquake were also recorded at the different tide-gauge stations on the Pacific coasts of Japan. The following is a short description of the mareogram obtained at Kushimoto, a small sea port situated at the southern extremity of the Kii peninsula.

(i) *Kushimoto.* $\varphi=33° 27' N$; $\lambda=135° 45' E$.
Time used is that of longitude 135° E.

The sea waves began to appear at 9^h 27^m A.M., Aug. 18th. For the first 41^m, there were two small oscillations, of T=20.5 *min.* For the next 2^h 49.5^m, there were 8 oscillations of T= 21.2 *min.*, whose magnitude gradually increased, the 7th having the maximum motion of 44 *cm.* The very initial motion was directed upwards ($2a=6$ *cm.*)

For the next $4^h\ 25^m$, the movement became smaller, the predominating period being shorter:—

$$T = 11.9 \text{ mm.}, \qquad 2a = 10 \text{ cm.}$$

Thereafter the movement became again larger and slower:—

$$T = 22.3 \text{ mm.}, \qquad 2a = 16.5 \text{ cm.}$$

(ii) *Hakodate*: $\varphi = 41°\ 46'$ N; $\lambda = 140°\ 44'$ E.
Ayukawa: $\varphi = 38°\ 18'$ N; $\lambda = 141°\ 31'$ E.
Misaki: $\varphi = 35°\ \ 9'$ N; $\lambda = 139°\ 37'$ E.

The times of commencement of the sea waves at these three places were as follows* :—

Hakodate	10.02 A.M., Aug. 18th.
Ayukawa	9.29 " " "
Misaki...	8.23 " " "

I have also examined the mareograms obtained at the stations on the Japan Sea side. But these gave no clear evidence of the existence of the sea waves due to the earthquake in question.

18. *The Velocity of Propagation across the Pacific.* As is well known, the propagation velocity (v or v') of sea waves may be calculated in two different ways as follows:—

$$v = \frac{s}{\delta t} \quad \ldots\ldots (1)$$

$$v' = \sqrt{gh} \quad \ldots\ldots (2)$$

In (1), s denote the distance between the earthquake origin and a given tide-gauge station, δt being the time interval taken by the sea waves in traversing that distance. In (2), g is the ac-

* Taken from Dr. K. Honda's paper: *On the Velocity of Sea Waves through the Pacific.* Tokyo Sugaku-Buturigakkwai Kizi-Gaiyo. Vol. III, No. 9.

celeration due to the gravity and h the mean sea depth along the distance s.*

Kushimoto. Accorning to § 11, the time of earthquake occurrence at the origin was $0^h\ 40^m\ 05$ (G.M.T.). Hence :—

$$\delta t = 23^h\ 47^m.$$

The great circle connecting Kushimoto with the earthquake origin ($\varphi=31°$S, $\lambda=73°$W) is 155.°5 ($=s$) in length, passing on the whole through deeper parts of the Pacific. The mean depth h is about 4470 metres. We thus obtain:—

$$\begin{cases} v = 202 \text{ metres/sec.} \\ v' = \sqrt{gh} = 209 \text{ metres/sec.} \end{cases}$$

Honolulu. For the Honolulu observation, we have:—

$$s = 96°\ 21' ; \qquad \delta t = 15^h\ 05^m ;$$

s being the distance along the great circle connecting Honolulu with the earthquake origin, along which the mean depth h is about 4150 metres. We have therefore:—

$$\begin{cases} v = \dfrac{s'}{\delta t} = 197 \text{ metres/sec.} \\ v' = \sqrt{gh} = 201.6 \text{ metres/sec.} \end{cases}$$

In these two cases, the agreement between the velocities calculated by the two different methods are in fair agreement with one another.

San Francisco and *San Diego.* The time intervals δt for San Francisco and San Diego were respectively $15^h\ 02^m$ and $13^h\ 50^m$. The great circles between these two places and the earthquake origin, whose lengths (s) are 82° 52′ and 76° 12′, pass very closely off the coast, the mean depths (h), measured a little outward (or

* A correction to the formula (2) has been given by Dr. C. Davison. *Phil. Mag.*, Jan. 1897.

westward) of these arcs, being respectively about 4210 and 4220 metres. We thus obtain:—

San Francisco................. $\begin{cases} v = \dfrac{s}{\delta t} = 170 \text{ metres/sec.} \\ v' = \sqrt{gh} = 203 \quad ,, \quad ,, \end{cases}$

San Diego .... $\begin{cases} v = \dfrac{s}{\delta t} = 170 \quad ,, \quad ,, \\ v' = \sqrt{gh} = 203 \quad ,, \quad ,, \end{cases}$

In each of these two cases, the actual velocity v is much smaller than that deduced from the mean sea depth, the discrepancy being probably due to the inexactness of the assumed wave path, which runs parallel to the coast.

19. *Conclusion.* The foregoing are only fragmentary notes on the Valparaiso and Aleutian earthquakes. A fuller account of the sea waves propagated across the Pacific will be given in a future number of the "Bulletin."

Tokyo. Jan., 1907.