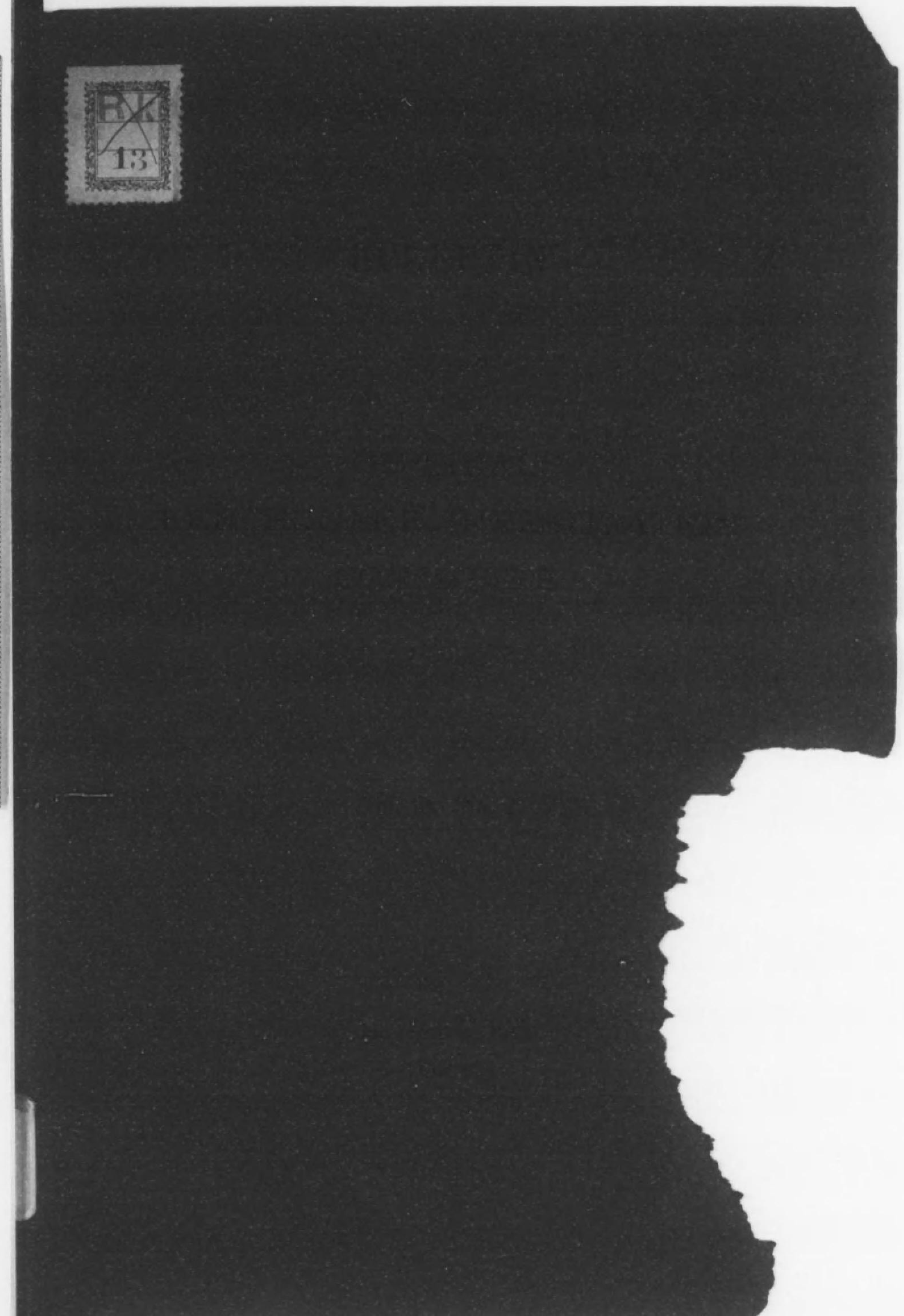
始



BULLETIN

OF THE

IMPERIAL EARTHQUAKE INVESTIGATION COMMITTEE.

Vol. III. No. 2.

November, 1909.
TOKYO.

BULLETIN

OF THE

IMPERIAL

EARTHQUAKE INVESTIGATION

COMMITTEE.

Vol. III. No. 2.

November, 1909.
TOKYO.

CONTENTS.

Preliminary Report on the Messina-Reggio Earthquake of Dec. 28, 1908.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Plates VI–XII.

CONTENTS.

1. *Introduction.* The Messina-Reggio earthquake of Dec. 28, 1908, was, as far as the loss of life is concerned, the great ever recorded in history, and presented to seismologists an ob of study of intense interest. By order of Imperial Gove the present author proceeded to Italy, to make seismolo vestigations respecting the disaster, arriving in Messi middle of February and remaining in the stricken dis the end of April. Professor T. Nakamura, dispatched t also by Government, has studied the effects of the ea from the architectural point of view.

2. *Seismogram and time of occurrence.* According seismographical observations in Tokyo, the Messina-Reggio ea quake was in magnitude about three times larger than the Monteleone (Calabria) earthquake of Sep. 8, 1905. As will be seen from Figs. 1 and 2, the teleseismic movements in Tokyo in the cases under consideration were almost exactly similar to each other, so that the individual vibrations can be identified in the two diagrams. Thus in Tokyo, the earthquake of Dec. 28, 1908, could from the instrumental records be at once ascertained as a great shock, which originated in or near Calabria and consequently produced a large amount of casualty.

In Tokyo, the first preliminary tremor lasted 11m 39 sec., the corresponding calculated (arcual) distance of the earthquake origin being 9930 km. The actual distance between Tokyo and Messina is about 9900 km.

The seismic disturbance reached Tokyo at 1h 32m 08s pm.* (on Dec. 28th). Calculating from the duration of the 1st preliminary tremor, the time interval taken by the vibration of the latter phase of motion in travelling through the distance between Tokyo and the origin is found to be 11m 51s. Consequently, the time of occurrence in the epicentral area ought to have been at 1h 20m 17s of the Central Europe Time. As a matter of
clock in Via Porta Imperiale in the city of Messina and
se of the Railway Station of Villa S. Giovanni were found
the time of about 5h 20m, having been stopped by
quake shock and left untouched during the several
t months. (See Fig. 6.)

Area of disturbance. The motion was distinctly sensible
n area of radius of 200 km or more from the origin. The
strong motion was, however, much smaller; and the city
ania, at an epicentral distance of about 85 km, suffered no

1st Normal Japan Time, which is 8 hours ahead of Central Europe Time.

harm from the shock. The area, within which buildings were entirely destroyed or very heavily damaged, formed, together with the Messina Strait, an elliptical area, parallel N.-S., of a length of about 30 km and of a width of about 20 km. (See Fig. 3.) The regions of violent motion, which was thus quite limited in extension, included amongst others Messina on the Sicilian side and Reggio on the Calabrian side; the populations of the two cities, together with their suburbs, being about 150,000 and 40,000 respectively. This fact accounts for the great superiority of the amount of damage on the present occasion over that of the previous earthquakes in Calabria and Sicily.

4. *Earthquake damage and intensity of motion.* The enormity of the destruction of Messina is really beyond one's imagination. All the buildings in the city were, with a very few exceptions, considerably cracked or absolutely reduced to masses of ruin, which looked like hills of *debris*; even those houses, whose perimetral walls were not overthrown, had their roofs and floors knocked down from top to bottom, so that the inside was filled with *debris*; it being not rare that 15 or more dead bodies were found buried one upon the other in the space of a single sm
room at the ground floor. The city streets, whose maxim
width was less than about 11 metres were covered by th
of the houses, whose height varied from four to six s
from 40 to 60 feet. Especially, the two principal streets,
the Via Cavour and the Via Garibaldi were complete
by the masses of stones and mud, whose average heig
about 5 metres. (See Figs. 7 and 8.) Under such circur
it was certainly impossible for the majority of the people
themselves, even if they had succeeded in escaping out of
The approximate total number of the victims was a little

100,000, of which about 75,000 relate to Messina and the suburbs and the remaining 25,000 relate to Reggio and other places in Calabria.

The intensity of earthquake motion in Messina was, when estimated from the overturning of bodies, found to be equivalent to an acceleration of about 2000 mm per sec. per sec. This is a little smaller than the seismic intensity in the city of Nagoya on the occasion of the great Mino-Owari earthquake (Japan) of 1891, where the maximum acceleration of motion was 2600 mm per sec. per sec. The population of Nagoya in 1891 was 165,339, which was nearly equal to that of Messina and the vicinity, and of which only 190 were killed in the earthquake. Thus, even supposing the intensity of seismic motion in Messina (1908) to be equal to that in Nagoya (1891), the number of the persons killed in the former city was about 430 times greater than that in the latter. That is to say, about 998 out of 1000 of the number of the killed in Messina must be regarded, when spoken in comparison to a Japanese city, as having fallen victims to seismologically bad construction of the houses. The Mino-Owari disturb-nce was at least 10 times larger in extension, and 4 or 5 times -ater in intensity, than the Messina earthquake; the total of the killed being, however, only 7273.

Origin and cause of earthquake. Judging from the form -ion of the area of violent motion (Fig. 3), the origin be situated in the Messina Strait. Further, the direc- the maximum earthquake motion, deduced from the -ions of overturned bodies, at Messina, Canitello, Villa -nni, Archi, Reggio, Gallina, Pellaro, and Lazzaro, seem as in Fig. 3 to radiate more or less accurately from a point -ed by an *asterisk* in the figure), which is situated in the

Strait and between Messina and Reggio, a little nearer to the latter than to the former; the approximate position of the point or epicentre thus determined being

$$\begin{cases} \varphi = 38^\circ\ 7'\tfrac{1}{2}\ \text{N.} \\ \lambda = 15^\circ\ 35'\ \text{E. of Greenwich, or } 3^\circ\ 9'\ \text{E. from the longitude} \\ \qquad \text{of Rome (Monte Mario.)} \end{cases}$$

Again, according to the seismographic records obtained at the seismological stations of Messina, Catania, Mineo, Mileto, and Valle di Pompei, the direction of the very first displacement of the earthquake motion at each of these places, which was well defined, was *divergent*, that is to say, directed *outwards* from the centre. This is rather contrary to what would take place had the earthquake, as popularly supposed, been caused by a violent volcanic explosion in the Strait; since, in the latter case, the initial motion at a place sufficiently near the centre of disturbance would be directed *inwards*, the second or counter motion being directed outwards.* That the cause of the Messina earthquake was not in a volcanic explosion seems also likely from the relation of the seismic disturbance in question to the other destructive shocks in Southern Italy.

The earthquake was probably caused by the sudden fo- tion or extension of a crack within the earth's crust in a E and WNW direction, whose plane was nearly vertical or incl- slightly towards NEN.

6. Tsunami (maremoto). The seismic disaster was -vated by "tsunami" or tidal waves, which originated i- Messina Strait and attained a considerable violence on both s- of the latter. (See Fig. 9.) From accounts of the eye-wit-

* This characteristic of motion due to an explosion has been verified in the expen- with dynamite at Akabane, Tokyo. See the "Publications," No. 21.

it seems that the waves followed the earthquake shock after a time interval, which varied at the different points on the coasts of the Strait from a few minutes to about 10 minutes.

The destructive effects of the *tsunami* were manifested along the Calabrian coast for a distance of about 38 km between Cape Pezzo on the north and Saline and Cape dell'Armi on the south; and along the Sicilian coast for a distance of nearly 100 km between Grotto (5 km to the north of Messina) on the north to the vicinity of Catania on the south. The greatest damage was caused at the south-western part of the coast of Calabria between the towns of Pellaro and Lazzaro, both inclusive, where the force of water threw down a railway bridge girder of about 42 metres length; shattered and washed away many dwelling houses, leaving behind only their basements; and carried off the sandy shore ground to a maximum breadth of about 100 metres. This last phenomenon, which was observable also notably at several places between Reggio and Villa S. Giovanni on the Calabrian side, and at Messina and Giampilieri on the Sicilian side, seems to have been more or less combined with the sinking or settlement of ·e soil, such that certain buildings, formerly at some distance . the beach line, are now standing quite close to, or even in, water. On the coast of Sicily the force of the *tsunami* was violent and shattered some number of the houses at Giam- i, which is opposite to Pellaro. A few houses were also yed by the waves at Messina near the mouth of the Torrente legni, at Schiso, and at Riposto.

The *tsunami* was feable in the northern entrance of the Strait, the narrow channel turns towards ENE and makes an of about 60° with the axis of the main portion of the latter.

7. *Cause of tsunami.* In Fig. 4 are indicated the direction

of the *tsunami* at different places on the two sides of the Messina Strait, determined chiefly from the observations of trees bent or broken, and from bodies displaced, by the waves; each of the numbers denoting the height reached by the water.* One remarkable fact is that the *tsunami* was strongest at those places where the earthquake shock was *not* most violent, indicating the probable non-coincidence in position of the origin of the earthquake with that of the *tsunami*. The main centre of the latter phenomenon was probably between Pellaro and Giampilieri, somewhere near the place marked *B*. It is also possible that there existed a secondary centre of the *tsunami* about the epicentre of the earthquake, marked *A*; or, again, that the two centres *B* and *A* formed together a continuous zone of disturbance.

The production of the *tsunami* was probably in a measure due to the communication of the seismic energy to the water of the Strait which forms a sort of fluid pendulum, but principally to the sinking or depression of the ground under the portion of sea in question. This latter action might consist in the settlement through a height of 1 or 2 metres of the loose superficial deposits of the bottom of the Strait, as was actualy verified along t' coasts of the latter.

8. *Relation of Messina-Reggio earthquake to other gr destructive earthquakes in Central and Southern Italy.* In 5 are indicated the position of the area of violent motion (acce tion of the seismic motion=about 2000 mm per sec. per se the Messina-Reggio earthquake and those of the twelve other g destructive shocks which happened since 1638 in Central Southern Italy. The thirteen earthquakes, numbered from

* For many of the exact determinations of the height of water I am indebted to the ness of the zealous *tsunami* investigator, Prof. G. Platania.

13 in order of date, may be divided into three groups *A*, *B*, *C*, as follows :—

Group	No.	Date
Group *A*	1	March 27, 1638.
	2	Nov. 5, 1659.
	4	Jan. 11, 1693.
	8	Feb. 5, 1783.
	9	March 28, „
	12	Sept. 8, 1905.
	13	Dec. 28, 1908.
Group *B*	3	June 5, 1688.
	5	Sept. 8, 1694.
	7	March 29, 1732.
	10	July 26, 1805.
	11	Dec. 16, 1857.
Group *C*	6	Jan. 14, 1703.

These three groups of destructive earthquakes form together a continuous seismic zone, which extends from the neighbourhood of Central Italy, through Calabria, down to the vicinity of Catania. Among the earthquakes of group *A*, the numbers 9 and 12 may regarded as forming a secondary or radial seismic line.

Fig. 5 illustrates very clearly the principle that *great earth- kes* in a given region occur, not everywhere at random, but a definite line of weakness in the earth's crust, namely, a ic zone. Further, the areas of violent motion of the different uakes are almost perfectly exclusive of each other, whence ay be concluded that the great disturbances are not repeated one and the same centre, but happen successively from dif- points or portions along the seismic zone. In other words, places seismically most dangerous in Central and Southern ly are exactly those points along the seismic zone here defined

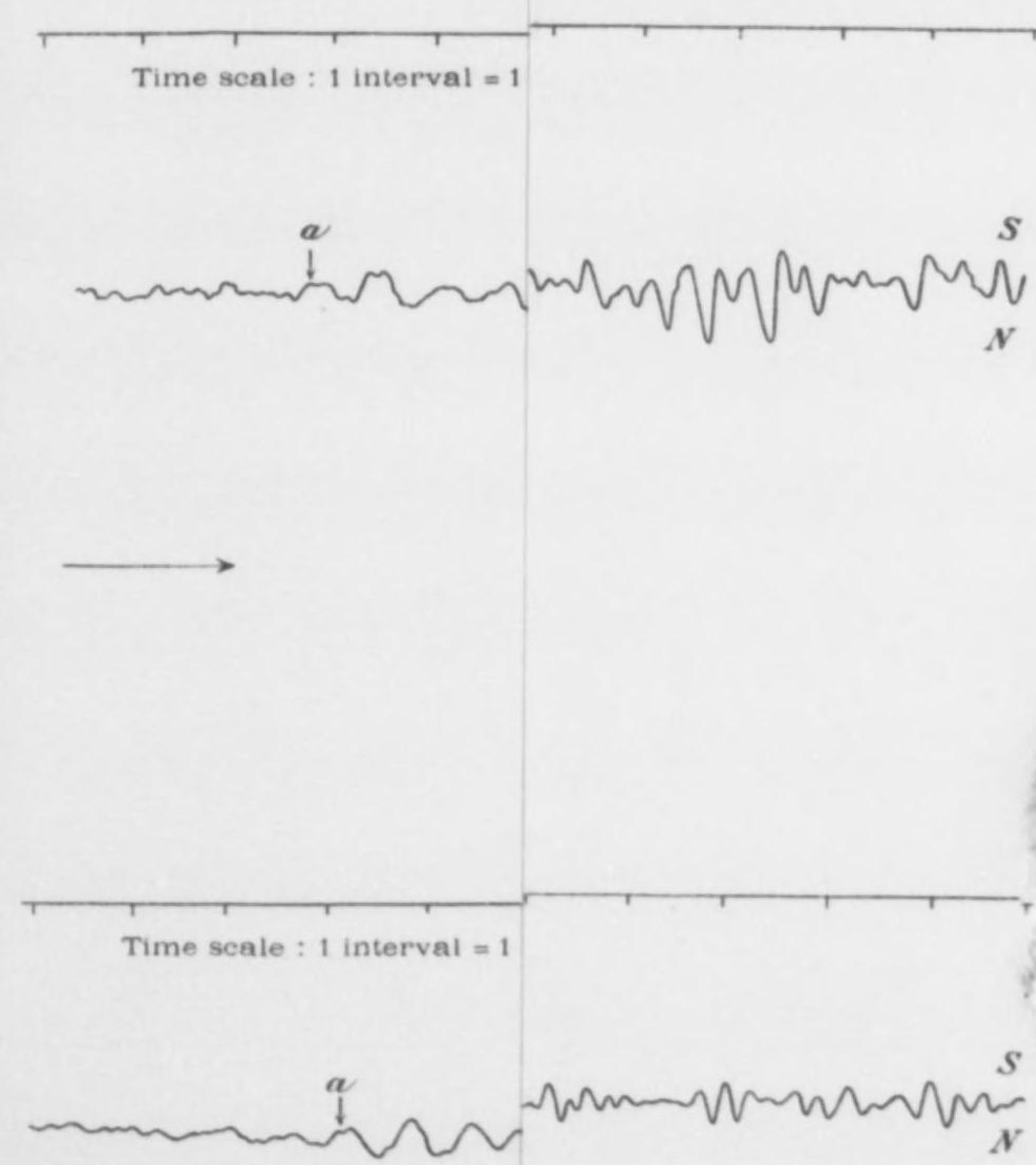
which have not yet been visited by a very violent shock. The two cities of Messina and Reggio-Calabria, which formerly had not been shaken by a great telluric convulsion originating from a centre close by, had evidently their turn on the present occasion, and for that very reason may be supposed as being free from the danger of a future seismic catastrophe. Even in the case of a great earthquake occurring along the seismic zone, the intensity of motion at these two cities would, on account of the distance from the centre, not be so very strong, and a certain precaution taken in the construction of houses would be sufficient to prevent the loss of life and property.

Tokyo. July 20, 1909.

List of Plates.

Pl. VI.

Prin approximately
Magnif mograms.



Seismographical Observations in Tokyo.

Principal Portion of the NS Component.
Magnification = 20. Pendulum Period = 48.5 sec.

The letters a, b, c, d, e, f, g, indicate some of the approximately corresponding vibrations in the two seismograms.

Fig. 1. Messina-Reggio Earthquake of Dec. 28, 1908.

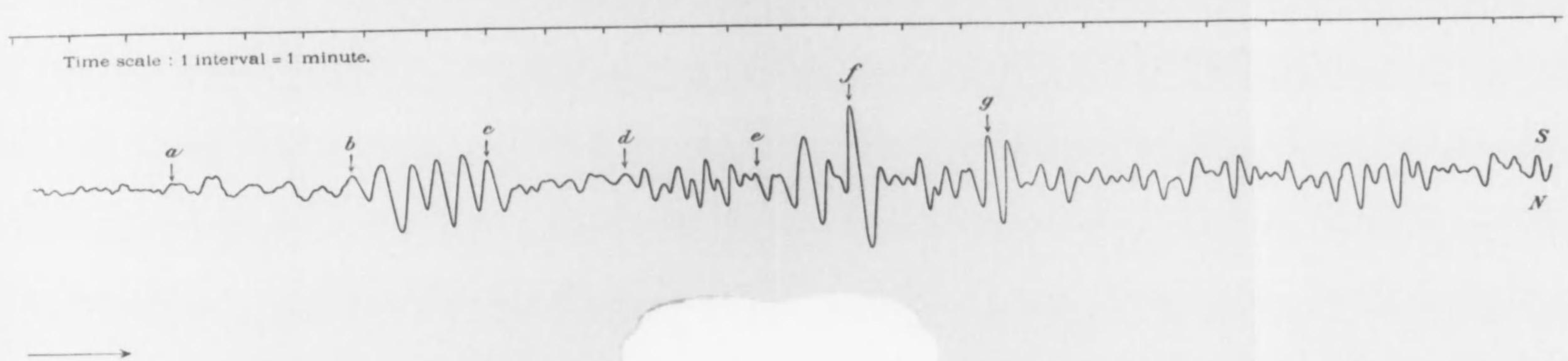


Fig. 2. Mont … ke of Sept. 8, 1905.

Fig. 3. Messina-Reggio Earthquake of Dec. 28, 1908.

Map showing the boundary of the area of great seismic damage and the direction of the maximum motion at the different places.

Arrow (⟶) indicates the direction of maximum seismic movement. The oval is the boundary of the area, within which the intensity of motion was equal to, or greater than an acceleration of 2,000 mm per sec. per sec.

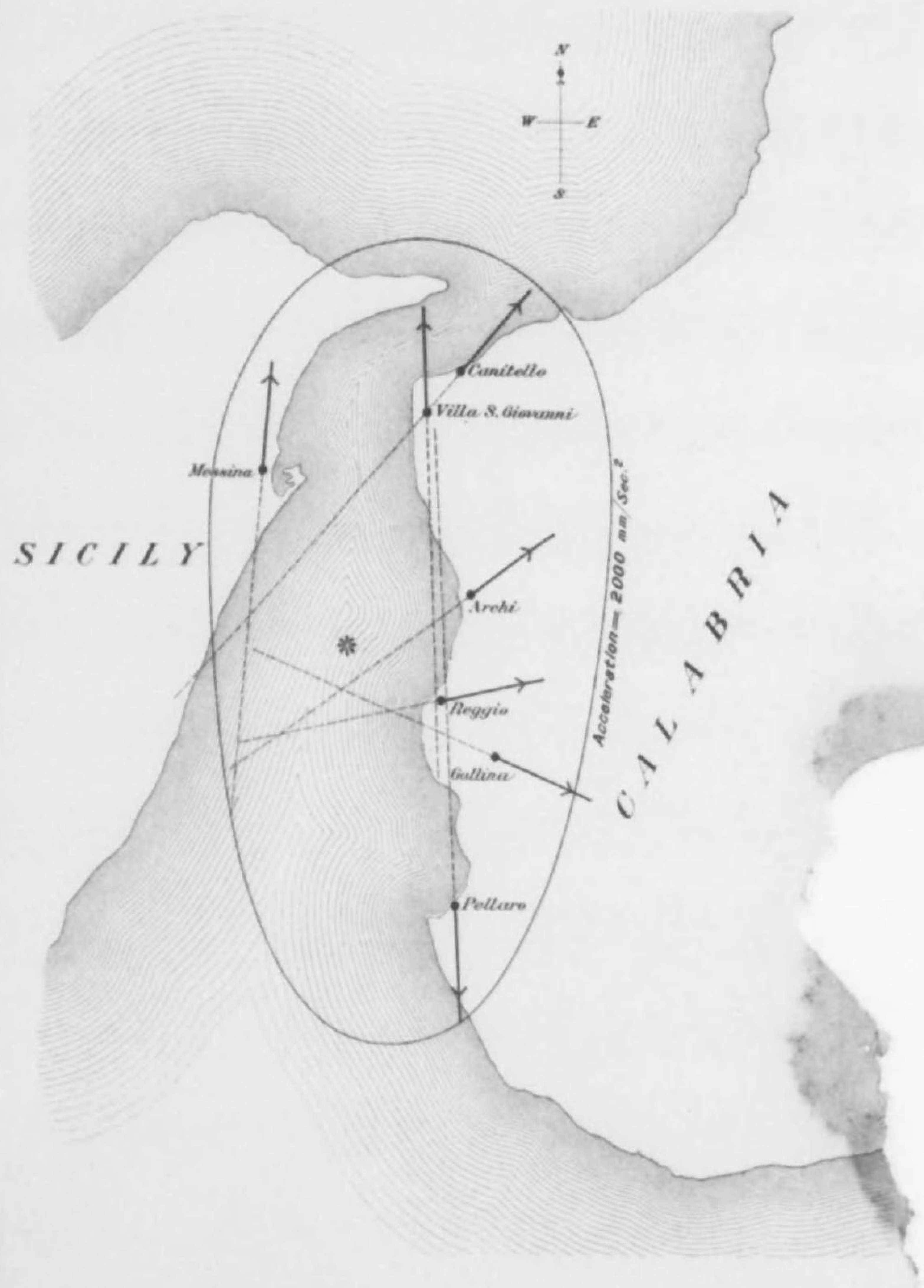
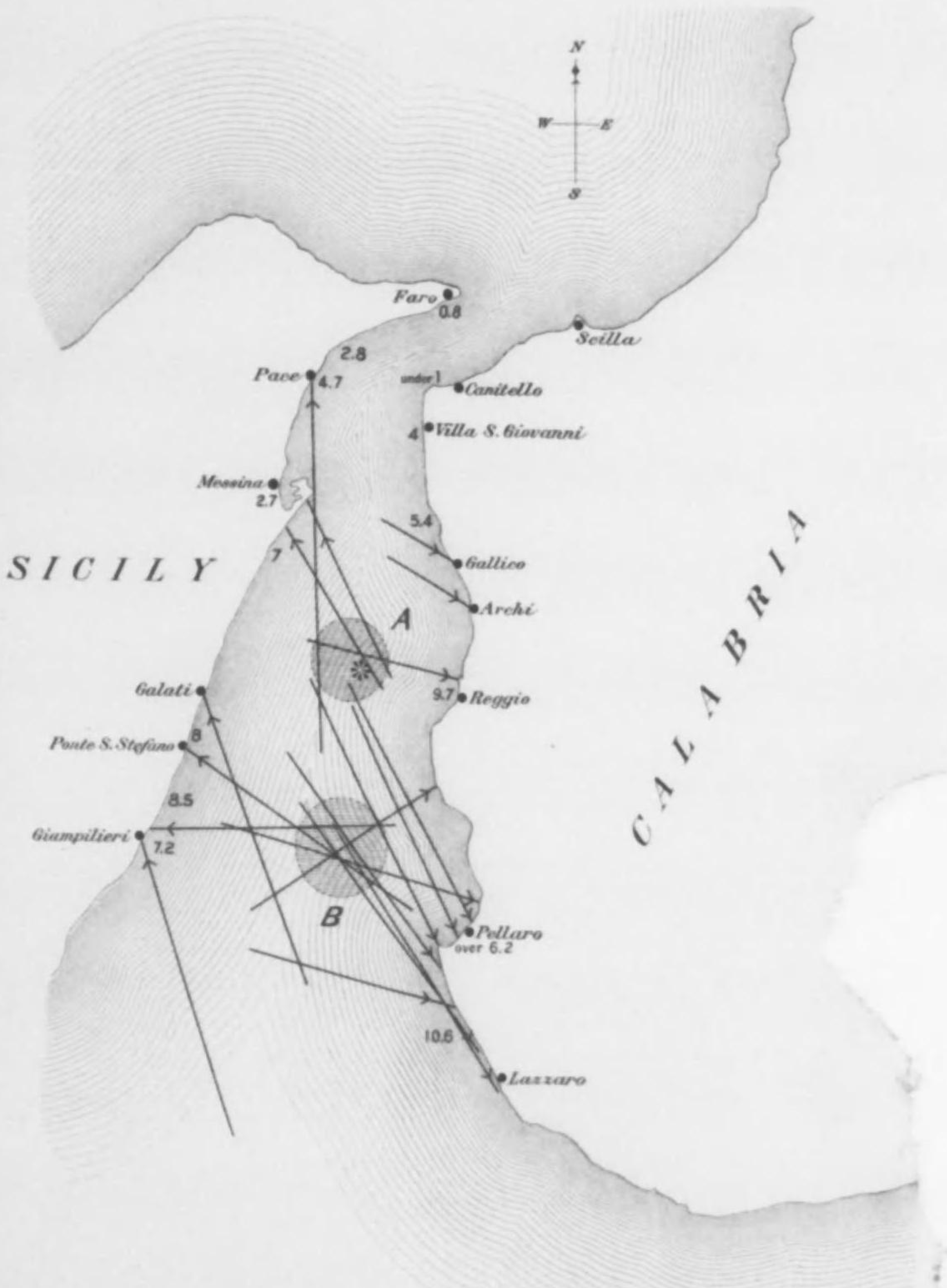


Fig. 4. Messina-Reggio Earthquake of Dec. 28, 1908.

Map showing the direction and height of the ***Tsunami*** (maremoto) at different places on the coast of the Messina Strait.

Arrow (⟶) indicates the direction, and the numeral the height (in metres), of the ***tsunami***. (B) is the approximate position of the principal centre, and (A) that of the secondary centre, of the ***tsunami***.



Pl. IX.

Fig. 5. Map showing the Mutual Relations of the Great Destructive Earthquakes in Central and Southern Italy.

The shaded area, No. 13, is the violent motion district of the Messina-Reggio Earthquake; the other areas, Nos. 1 to 12, are the similar districts for the previous 12 great earthquakes.

Fig. 6. Messina-Reggio Earthquake of Dec. 28, 1908.

A wrecked house on Via Porta Imperiale, Messina. The clock on the corner post indicates the time of earthquake occurrence, $5^h\ 20^m$ (morning).

Fig. 7. Messina-Reggio Earthquake of Dec. 28, 1908.

Messina. A house on the eastern side of the Piazza Cavallotti, showing the complete destruction of its front part due principally to the imperfect construction of the roof and the bad quality of the building material.

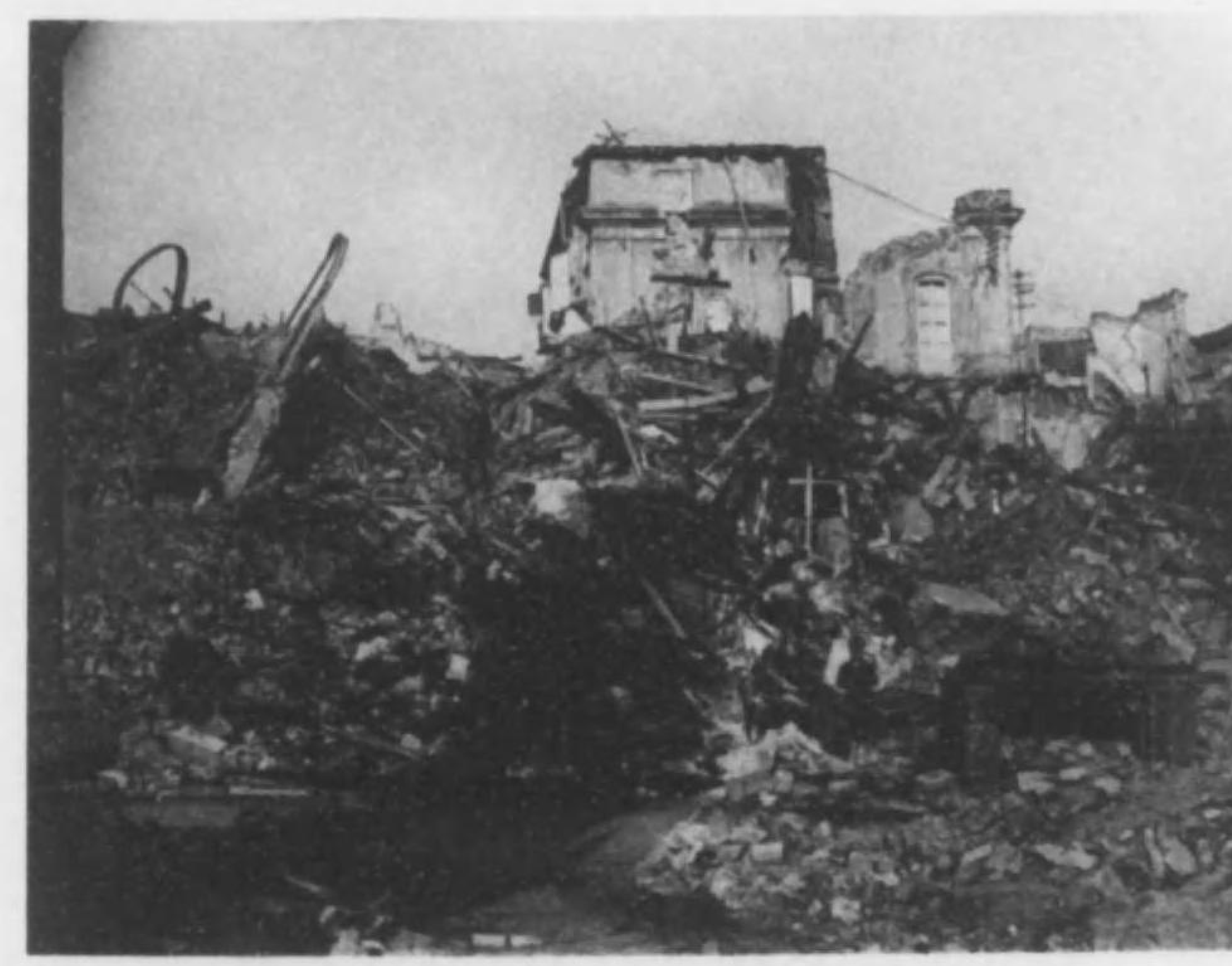


Fig. 8. Messina-Reggio Earthquake of Dec. 28, 1908.

Messina. Via Cavour, at its crossing with Via Idria, showing the enormity of the mass of the *debris*, which completely blocks the street to an average height of about 5 metres.

Pl. XII.

Fig. 9. Messina-Reggio Earthquake of Dec. 28, 1908.

Effect of the *tsunami* (maremoto), showing a large concrete block (2.6 × 2.5 × 1.2 metres) of ... of the port of Reggio carried away about 20 metres from its original position.

Note on the Propagation Velocity of the Formosa Earthquakes of 1906 and 1908.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Plates XIII, XIV, and XV.

CONTENTS.

1. ***Introduction.*** The present paper is a note on the rate of propagation within the epicentral distance of about 3,000 km of the 1st. preliminary tremor of the four strong Formosa earthquakes in 1906 and 1908. The velocity calculation has been made according to the "direct" as well as to the "difference" method*; the seismic waves being supposed to be propagated along or parallel to the great circles of the earth. For the sake of comparison are also considered the Calabrian earthquake of Sept. 8, 1905, the Geiyo (Aki-Iyo) earthquake of 1905, and the Omi (Central Japan) earthquake of 1909.

* See the "Bulletin," Vol. I, No. 1.

The times of occurrence of the different Formosa and Japan earthquakes are given in the 1st Normal Japan Time, or the mean civil time of longitude 135° east of Greenwich. Following notations are used :—

v_1 = Velocity of propagation corresponding to the commencement of the earthquake motion.
T_0 = Time of earthquake occurrence at the origin (epicentre).
t_1 = " " " " at a given observing place.
x = Epicentral (arcual) distance.

The geographical positions of the different stations, whose observations have been utilized in the deduction of the propagation velocity of the Formosa and Japan earthquakes, are as follows :—

Station.	Latitude, N.	Longitude, E.
Mizusawa.	39° 08′ —″	141° 07′ —″
Tokyo (Seismological Institute)	35 42 29	139 45 53
Osaka.	34 42 —	135 31 —
Kobe.	34 41 —	135 11 —
Taichu.	24 09 —	120 42 —
Manila.	14 34 41	120 58 33

2. ***Formosa earthquakes of April 14, 1906.*** (See Figs. 1 and 2, Pl. XIII.) The present author has experienced the severe Kagi (Formosa) earthquake of April 14, 1906, in the city of Taichu at an epicentral distance of about 90 km, and determined with a fair accuracy the time of occurrence in the above-named place to be $8^h\ 52^m\ 22^s$ am. In the early morning of the same day, there was another shock nearly equal in extension, whose

time of occurrence observed at the meteorological observatory of Taichu was, with proper corrections, $4^h\ 18^m\ 20^s$ am. These two earthquakes, which may be regarded as belonging to the series of seismic manifestations following the great destructive shock of March 17th in the same year, originated about 10 miles to the south of the centre of the latter, probably in the vicinity of the town of Tenshiko, at about $\varphi=23°\ 25'$ N, $\lambda=120°\ 30'$ E.

The following table gives, for the different stations, the epicentral distance,* the time of occurrence and the velocity v_1 calculated by the "direct method."

FORMOSA EARTHQUAKES OF APRIL 14, 1906.

Origin...... $\varphi = 23° 25'$ N, $\lambda = 120° 30'$ E.
1st Earthquake...... $T_0 = 4^h\ 18^m\ 00^s$ am.
2nd " ...... $T_0 = 8\ 52\ 00$ am.

Station.	Epicentral Distance.	Time of Occurrence. (1st Normal Japan Time).		v_1 (Direct method).	
		1st Eqke.	2nd Eqke.	1st Eqke.	2nd Eqke.
Taichu.	90 km.	$4^h18^m20^s$ am.	$8^h52^m22^s$ am.	— km/sec.	— km/sec.
Manila.	983	19 56	53 52	8.48	8.78
Kobe.	1889	21 50	56 08 }	8.28	7.60
Osaka.	1922	21 51	56 14 }		
Tokyo.	2300	22 20	56 46	8.84	8.04
Mizusawa.	2611	22 58	57 12	8.77	8.37
		Mean	....	**8.59**	**8.20**

* In the "Bulletin," Vol. I, No. 2, the epicentral distance of Tokyo has by an unfortunate mistake been taken to be 1710 km. instead of 2300 km. The result given there was accordingly entirely wrong.

The mean values of the velocity v_1 calculated according to the "direct method" are for the two earthquakes respectively 8.59 and 8.20 km per sec., with the average of 8.39 km per sec.; the limits of the epicentral distance being about 1000 km (Manila) and about 2600 km (Mizusawa).

3. *Kagi (Formosa) earthquake of march 17, 1906.* (See Fig. 3.) The origin of this destructive earthquake was a zone extending in a WSW and ENE direction having its centre in the vicinity of the town of Baishiko, at $\varphi=23°\ 35'$ N, $\lambda=120°\ 32'$ E.* The approximate time (T_0) of occurrence at the origin may be estimated from a comparison with the earthquakes of April 14 in the same year (§ 2). Thus, it will be observed that the epicentral distance of Manila in the cases of the earthquakes of April 14, was practically equal to that in the case of the earthquake of March 17. Now, assuming a transit velocity of the preliminary tremor to be 5 km per sec. for the epicentral distance of 90 km between Taichu and the earthquake origin, the times of occurrence of the two earthquakes at the origin itself were probably as follows :—

(1) $8^h\ 52^m\ 04^s$ am. (2) $4^h\ 18^m\ 02^s$ am.

The differences between these and the times of occurrence at Manila, the station nearest to the origin, are :—

(1) $1^m\ 48^s$
(2) 1 54 } ....*mean*, $1^m\ 51^s$

Applying this result to the case of the earthquake of March 17 the approximate time of occurrence at the origin may be estimated from the Manila observation to be about $7^h\ 42^m\ 49^s$ am.

* An account of this earthquake is given in the "Bulletin," Vol. I, No. 2.

FORMOSA EARTHQUAKE OF MARCH 17, 1906.

Origin...... $\varphi=23°\ 35'$ N, $\lambda=120°\ 32'$ E.
Approximate $T_0=7^h\ 42^m\ 49^s$ am.

Station.	Epicentral Distance.	Time of Occurrence. (1st. N. J. T.)
Manila.	1000 km	$7^h\ 44^m\ 40^s$ am.
Kobe.	1877	46 25
Osaka.	1903	46 37
Tokyo.	2286	47 18

4. *Formosa earthquake of Jan. 11, 1908.* (See Fig. 4.) This earthquake shook strongly the south-eastern part of the island of Formosa, the origin being probably in the Taito longitudinal valley*. The time of occurrence at the epicentre, roughly estimated from that at Manila as in the preceding §, is found to be $0^h\ 35^m\ 10^s$ pm.

FORMOSA EARTHQUAKE OF JAN. 11, 1908.

Origin......$\varphi=23°\ 37'$ N, $\lambda=121°\ 15'$ N.
$T_0=0^h\ 35^m\ 10^s$ pm.

Station.	Epicentral Distance.	Duration of Preliminary Tremor.	Time of Occurrence. (1st N. J. T.)
Manila.	1000 km	$4^m\ 18^s$	$0^h\ 37^m\ 01^s$ pm.
Osaka.	1844	4 49	38 37
Tokyo.	2235	3 56	39 11
Mizusawa.	2544	—	39 45

* See the "Bulletin", Vol. II, No. 2.

5. *Geiyo (Aki-Iyo) earthquake of June 2, 1905.* The Geiyo earthquake of June 2, 1905, which shook strongly the two provinces of Aki and Iyo, originated in the Inland Sea, the position of the seismic centre being, according to Dr. A. Imamura, at $\varphi=34° \ 8'$ N, $\lambda=132° \ 24'$ E. From the observations at the different meteorological observatories in and near the meizoseismal district, the time of occurrence at the epicentre may be estimated to be *about* $2^h \ 39^m \ 30^s$ pm. The values of the velocity v_1 calculated according to the "direct method" are given below.

GEIYO (AKI-IYO) EARTHQUAKE OF JUNE 2, 1905.

Origin......$\varphi=34° \ 8'$ N, $\lambda=132° \ 24'$ E.

$T_0=2^h \ 39^m \ 30^s$ pm.

Station	Epicentral Distance.	Duration of Preliminary Tremor.	Time of Occurrence. (1st N. J. T.)	v_1 (Direct method.)
Kobe.	264 km	— sec.	$2^h \ 40^m \ 12^s$ pm.	6.29 km/sec.
Osaka.	292	25	40 21	5.73
Tokyo.	693	93	41 16	6.54
Mizusawa.	954	—	41 42	7.22
Manila.	2457	—	44 23	8.40

6. *Omi earthquake of Aug. 14, 1909.* The earthquake of Aug. 14, 1909, shook violently the north-eastern part of the province of Omi, causing the loss of 41 lives. The origin seems to have been situated among the mountains in the vicinity of the Torahime village, at about $\varphi=35° \ 30'$ N, $\lambda=136° \ 20'$ E. The time of occurrence at the epicentre was approximately about $3^h \ 30^m \ 40^s$ pm.

OMI EARTHQUAKE OF AUG. 14, 1909.

Origin......$\varphi=35° \ 30'$ N, $\lambda=136° \ 20'$ E.

Approximate $T_0=3^h \ 30^m \ 40^s$ pm.

Station.	Epicentral Distance.	Time of Occurrence. (1st N. J. T.)
Tokyo.	311 km	$3^h \ 31^m \ 38^s$ pm.*
Mizusawa.	584	32 15
Manila.	2783	36 17

(* According to the observation with Omori hor. pend. tromometer at the Central Meteorological Observatory.)

7. *Calabrian earthquake of Sept. 8, 1905.* Prof. G. B. Rizzo gives in his work "Sulla velocità di propagazione delle onde sismiche del terremoto della Calabria del giorno 8 Settembre, 1905," a very valuable and elaborate discussion of the propagation velocity of the Calabrian earthquake of 1905. The following table embodies part of the results obtained by Prof. Rizzo, and relates to the different stations whose epicentral distance was below 2500 km.

CALABRIAN EARTHQUAKE OF SEPT. 8, 1905.

Probable $T_0=2^h \ 43^m \ 11^s$, Central Europe Time.

[*According to Prof. G. B. Rizzo.*]

Station.	Epicentral Distance.	v_1 (direct-method)	t_1
Messina.	84 km	— km/sec.	$1^h \ 43^m \ 17^s$
Catania.	174	6.0	43 30
Caggiano.	200	3.5	44 09

Station.	Epicentral Distance.	v_1 (direct method)	t_1
Ischia.	274 km	7.6 km/sec.	$1^h\ 43^m\ 47^s$
Rocca di papa.	434	9.0	44 00
Mean.	354	8.3	43 54
Urbino.	616	11.3	44 07
Siena.	640	10.7	44 05
Athens.	673	9.2	44 04
Carloforte.	677	9.4	44 04
Florence.	682	8.1	44 34
Quarto-Castello.	688	8.8	44 29
Pola.	698	6.8	44 52
Fiume.	727	6.7	45 00
Belgrade.	757	5.7	45 25
Triest.	783	7.7	44 56
Venice.	798	12.1	44 16
Laibach.	798	12.1	44 19
Padua.	811	8.0	44 55
Temesvar.	879	8.1	45 00
Salò.	883	8.2	45 00
Pavia.	920	8.1	45 01
Turin.	981	8.2	45 12
Mean.	765	8.8	44 40
O'-Gyalla.	1020	9.4	45 00
Kremsmuenster.	1037	6.9	45 43
Vienna.	1048	8.3	45 18
München.	1098	7.3	45 43
Hohenheim.	1232	8.2	45 42
Strassburg.	1274	12.5	44 56
Cracow.	1287	9.3	45 05
Heidelberg.	1297	8.6	45 40

Station.	Epicentral Distance.	v_1 (direct method)	t_1
Plauen.	1336 km	8.5 km/sec.	$1^h\ 45^m\ 08^s$
Tortosa.	1347	8.0	46 00
Jena.	1393	8.3	46 02
Leipzig.	1421	8.2	46 05
Goettingen.	1492	7.8	46 22
Mean.	1253	8.6	45 36
Potsdam.	1526	8.0	46 22
Uccle.	1618	7.9	46 38
Hamburg.	1703	7.7	46 55
Shide.	1896	8.5	46 47
Kew.	1900	8.3	47 00
S. Fernando.	1979	7.9	47 04
Batum.	1998	8.5	47 11
Mean.	1803	8.1	46 51
Coimbra.	2104	8.6	47 03
Liverpool.	2178	9.1	47 02
Dorpat.	2306	8.4	47 51
Achalkalaki.	2336	8.1	47 58
Upsala.	2341	8.5	47 50
Edinburgh.	2376	8.2	48 00
Paisley.	2426	8.8	47 08
Tiflis.	2447	8.1	48 23
Moscow.	2464	8.0	48 19
Mean.	2331	8.4	47 44

The mean values of the velocity v_1 (direct method) obtained by properly grouping the 48 stations given in the above table, whose epicentral distance varied from 273 km (Ischia) to 2464 km (Moscow), are as follows :—

Group.	Number of Stations grouped together.	Mean Epicentral Distance.	v_1 (direct method).
(i)	2	354 km.	8.3 km/sec.
(ii)	17	765	8.8
(iii)	13	1253	8.6
(iv)	7	1803	8.1
(v)	9	2331	8.4

The values of the velocity v_1 for the groups ii and iii are greater than those for the other groups. We are, however, not warranted to conclude from this that the velocity was really maximum at the epicentral distances corresponding to the groups ii and iii, as these latter include a number of those time observations which were probably not perfectly correct, and which gave exceptionally high values of the velocity varying from 10 to 12.5 km per sec.

8. *Velocity v_1 calculated by the "difference method."* The mean values of the velocity v_1 for the different earthquakes calculated according to the "difference method" by Least Squares are as follows :—

Earthquake.	Limits of epicentral distance (x).	Relation between epicentral distance x and the time interval $y(=t_1-T_0)$	v_1 (difference method).
2 Formosa Eqkes of April 14, 1906.	$90^{km}-2611^{km}$	$x^{km}-8.55\,y^{sec.}+62^{km}=0$	8.55 km/sec.
Formosa Eqke of March 17, 1906.	1000–2286	$x-8.08\,y-103=0$	8.08
Formosa Eqke of Jan. 11, 1908.	1000–2544	$x-9.45\,y+64=0$	9.45
Geiyo Eqke of June 2, 1905.	264–2457	$x-8.87\,y+175=0$	8.87
Omi Eqke of Aug. 14, 1909.	311–2783	$x-8.92\,y+224=0$	8.92
Calabrian Eqke of Sept. 8, 1905.	273–2331	$x-8.43\,y-12=0$	8.43

The results for the two Formosa earthquakes of April 14, 1906, and the Calabrian earthquake of Sept. 8, 1905, are based on the observations more numerous, and may be regarded as being more accurate, than those for the remaining earthquakes. Calculating the average value we find :—

$$v_1 \text{ (difference method)} = \mathbf{8.66} \text{ km/sec.}$$
$$\text{for} \ldots 90 \text{ km} < x < 2783 \text{ km.}$$

9. *Velocity v_1 calculated by the "direct method."* The following table gives the values of the velocity v_1 calculated by the "direct method" for the different earthquakes, in each of which the time (T_0) of occurrence at the origin is more or less accurately known.

Epicentral Distance.	v_1 (direct method)			Mean.	
	2 Formosa Eqkes of April 14, 1906.	Geiyo Eqke.	Calabrian Eqke. of 1905.	Epicentral Distance.	v_1
278 km	— km/sec.	6.01 km/sec.	— km/sec.	316 km	7.16 km/sec.
354	—	—	8.3		
693	—	6.54	—	729	7.67
765	—	—	8.8		
954	—	7.22	—	1063	8.15
983	8.63	—	—		
1253	—	—	8.6		
1803	—	—	8.1	1871	7.99
1899	7.92	—	—		
1922	7.95	—	—		
2300	8.44	—	—	2425	8.45
2331	—	—	8.4		
2457	—	8.40	—		
2611	8.57	—	—		

The mean value of the velocity v_1 thus varies, for the epicentral distances of about 300 to 2500 km, from 7.16 to 8.45 km per sec., giving the general average of **7.88** km per sec. This latter value is 0.78 km less than the average velocity v_1 calculated by the "difference method" (§ 8).

10. *Comparison of the rate of propagation of the Formosa earthquakes with that of the Calabrian earthquake of 1905.* The time interval $(t_1 - T_0)$ taken by the seismic waves of the four Formosa earthquakes in travelling the different epicentral distances (x) are given in the following table.

Epicentral Distance. \ Eqke.	April 14, 1906; 4.18 AM.	April 14, 1906; 8.52 AM.	March 17, 1906.	Jan. 11, 1908.	Mean.	
					Epicentral Distance.	Time Interval.
983 km	$1^m\ 56^s$	$1^m\ 52^s$	m s	m s	**983**km	**$1^m\ 52^s$**
1844	—	—	—	3 27		
1877	—	—	3 36	—		
1889	3 50	4 08	—	—	**1892**	**3 51**
1903	—	—	3 48	—		
1922	3 51	4 14	—	—		
2235	—	—	—	4 01		
2286	—	—	4 29	—	**2280**	**4 24**
2300	4 20	4 46	—	—		
2544	—	—	—	4 35	**2589**	**4 55**
2611	4 58	5 12	—	—		

For the Calabrian earthquake of 1905, the relation between the

epicentral distance (x) and the time interval $(t_1 - T_0)$ are as follows :—

Group of the stations (§ 7)	Epicentral distance $= x$.	Time interval $= t_1 - T_0$.
i	354 km	$0^m\ 43^s$
ii	765	1 29
iii	1253	2 25
iv	1803	3 40
v	2331	4 33

As is illustrated in Fig. 5 (Pl. XV), the relation between the epicentral distance x and the time interval $(t_1 - T_0)$ is almost identical for the Formosa earthquakes and for the Calabrian earthquake, implying the approximate equality of the rate of propagation in the cases under consideration. It is hereby to be noticed that with respect to the Calabrian earthquake, all of the stations, whose observations have been utilized in the calculation of the velocity (§ 7), are in Europe; the earthquake motion reaching, therefore, the different places by essentially continental paths. Again, the seismic waves originating in Formosa are propagated to the Main Island (Japan) and to Manila by paths, which lie under the shallow seas in the immediate vicinity of the south-eastern coast of Asia, and which my be regarded also as being of a continental nature. The approximate identity for the Formosan and Calabrian earthquakes of the relation between the epicentral distance x and the time interval $(t_1 - T_0)$ is probably due to the similarity of the nature of the paths of seismic propagation. As will be seen from Fig. 5, the distance and time relation for the Geiyo earthquake is, for the value of x from 1500 to 2500 km, close enough to that in the cases above considered.

Formosa Earthquakes. Relation between the Time of Occurrence and the Epicentral Distance.

Fig. 1. Earthquake of April 14, 1906; 4h 18m am.

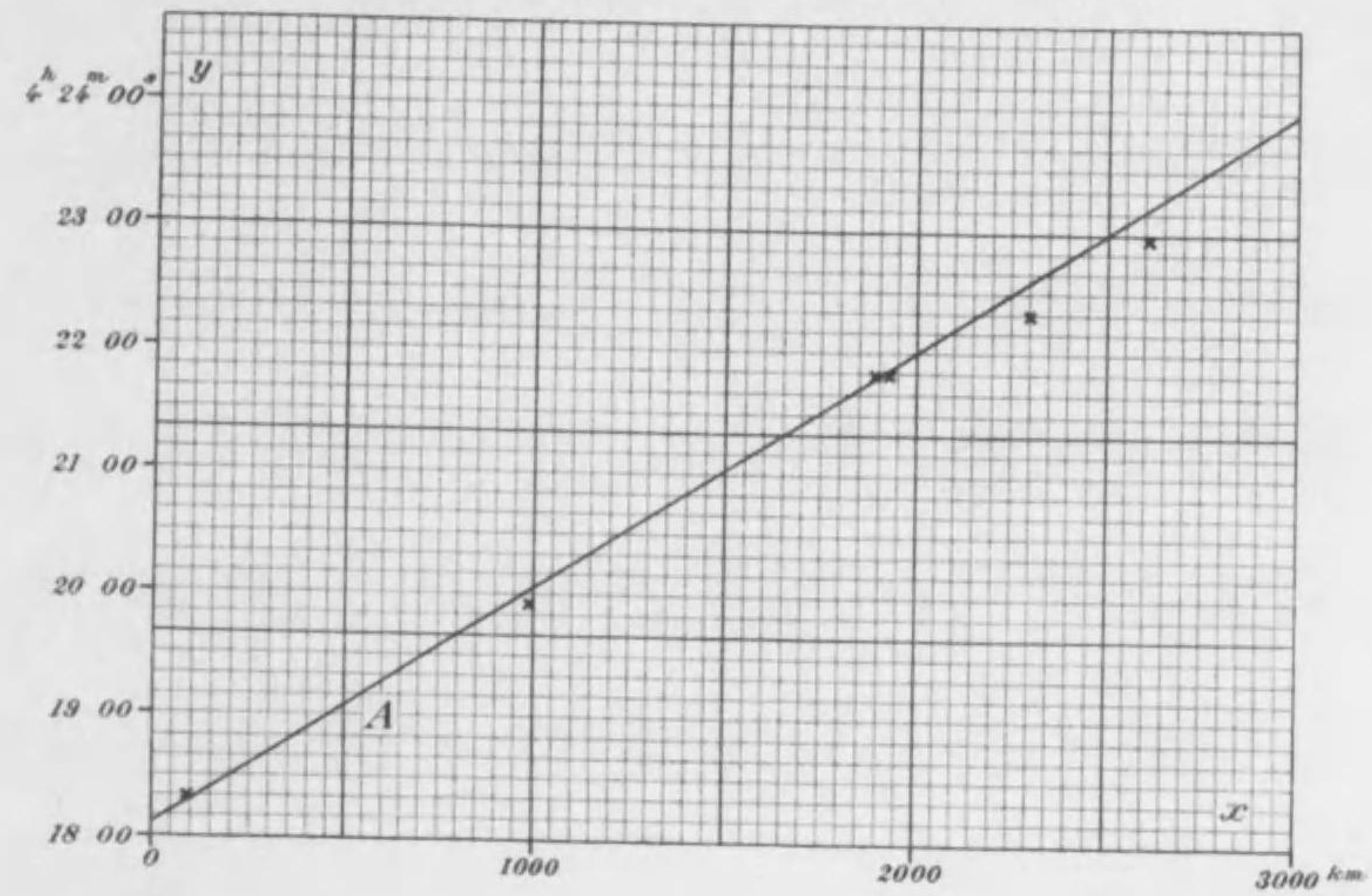
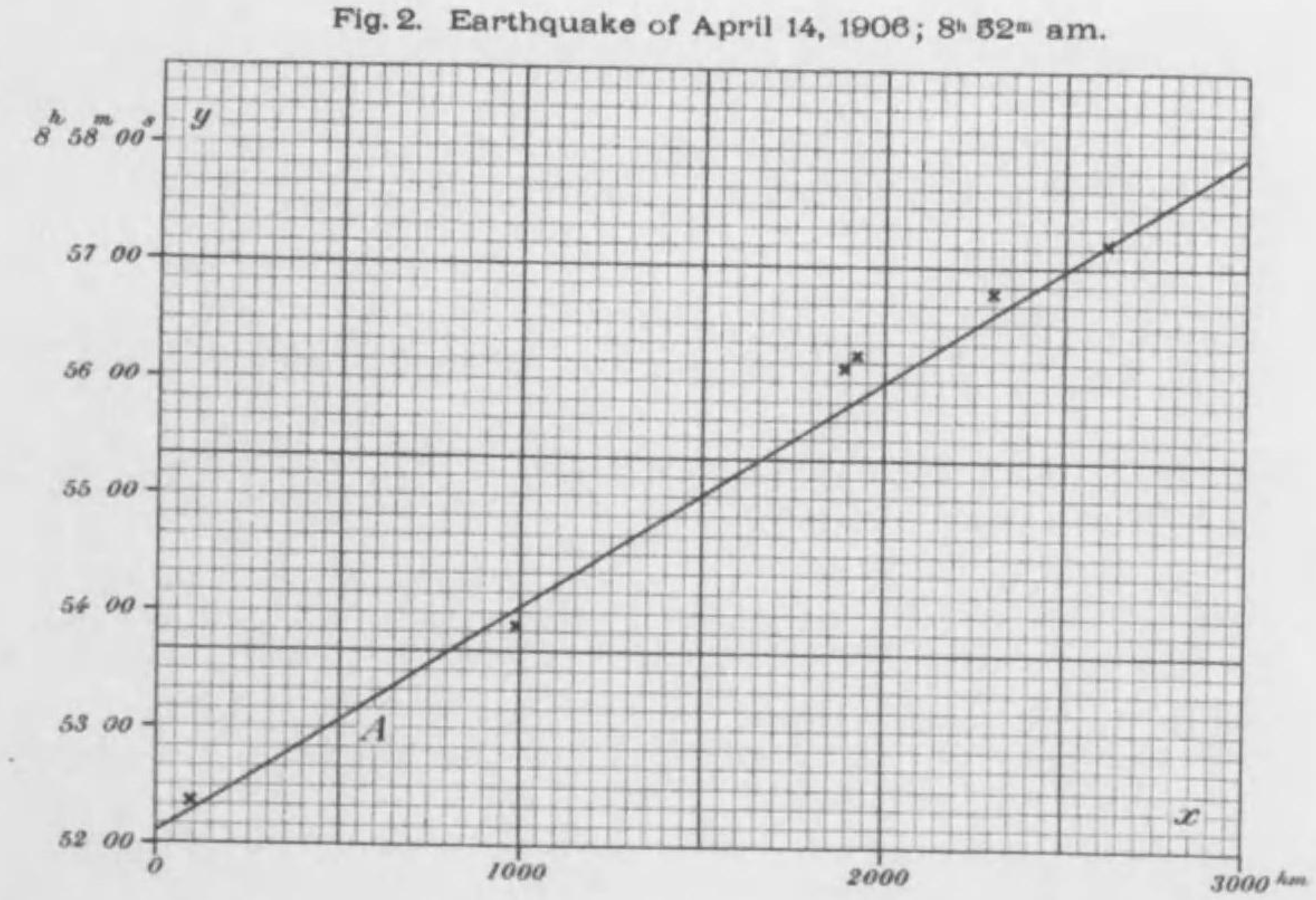


Fig. 2. Earthquake of April 14, 1906; 8h 52m am.



Formosa Earthquakes. Relation between the Time of Occurrence and the Epicentral Distance.

Fig. 3. Earthquake of March 17, 1906.

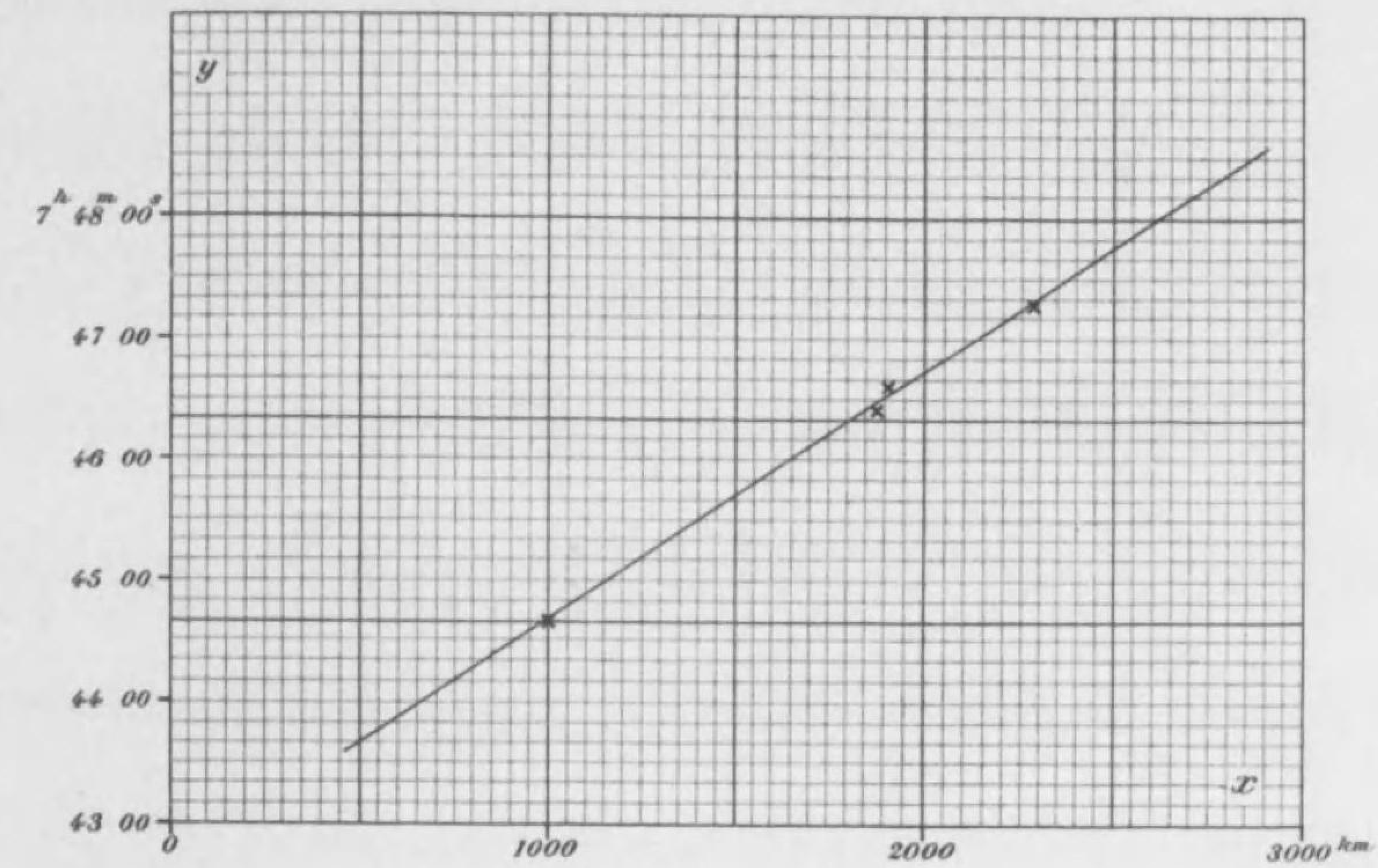


Fig. 4. Earthquake of Jan. 11, 1908.

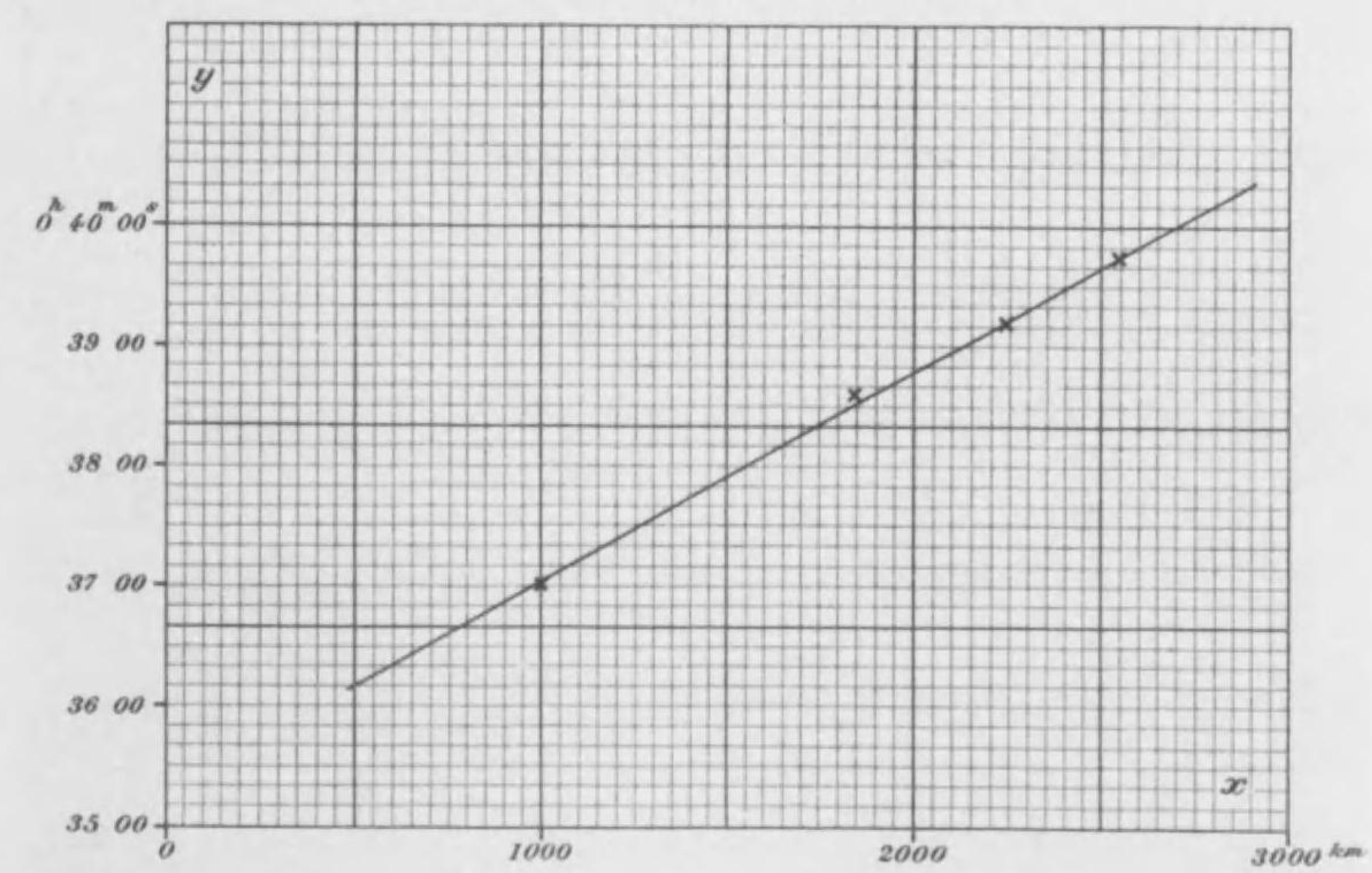
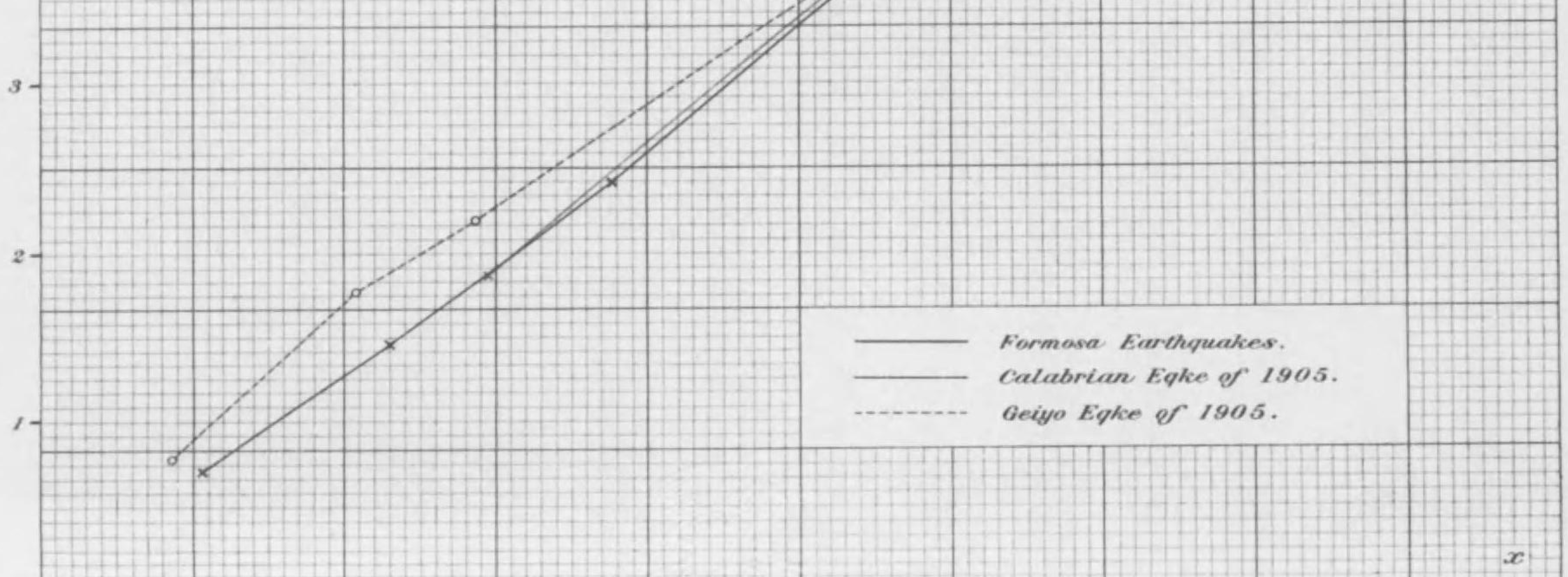


Fig. 3. Relation between the Time of Occurrence and the Epicentral Distance.



On the Dependence of the Transit Velocity of Seismic Waves on the Nature of Path.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. ***Introduction.*** Calculating by the "difference method," the transit velocity v_1 of the 1st preliminary tremor of the Guatemala earthquake of April 19, 1902, is found to be 16.02 km per sec., for the limits of the epicentral distance of $38^\circ.6$ (=4290 km) to $149^\circ.3$ (16590 km)*. On the other hand, the velocity v_1 (difference method) of the Indian (Kangra) earthquake of April 4, 1905, is found to be 11.36 km per sec., for the limits of the epicentral distance of $27^\circ\ 57'$ (=3110 km) to $121^\circ\ 16'$ (=13470 km)**. Finally, the velocity v_1 (difference method) of the San Francisco earthquake of April 18, 1906, is found to be about 13.97 km per sec., for the epicentral distance of $30^\circ\ 36'$ (=3400 km) to $108^\circ\ 21'$ (=12040 km)*. Thus it will be noticed that the transit velocity v_1 of the Guatemala earthquake was greater respectively 2.05 and 4.66 km per sec. than those of the San Francisco and Indian earthquakes. These differences in the values of the transit velocity of the three great earthquakes are not likely to be the result of accidental errors in the time determinations, or of inaccuracies in the location of the seismic centres; as each of the velocity calculations, which has been made according

* See the "Bulletin," Vol. I, No. 1.

** See the "Publications" No. 24, p. 155.

to the "difference method," is based on the observations at a large number of seismological stations. In the "difference method," there is no need of the knowledge of the time of earthquake occurrence at the epicentre, while the error relating to the position of the latter affects generally to a comparatively small degree the results of the calculation. I shall next examine the broad features of the paths, along which the waves of the earthquakes under consideration reached the different seismological stations.

2. *Guatemala earthquake of April 19, 1902.* The majority of the great circles connecting the different seismological stations with the earthquake origin, whose position was, according to Mr. R. D. Oldham, at $\varphi=14°\frac{1}{2}$ N, $\lambda=91°\frac{1}{4}$ W, are sub-oceanic as follows :—

Station or District.	Path of the Seismic Waves.
(i) Great Britain, Spain.	Off the E. coast of Yukatan, then off the coast of the United States to the vicinity of Newfoundland, thence across the Atlantic to Great Britain or to Spain.
(ii) Belgium, Germany, Austria, South Russia.	Nearly in the same direction as (i).
(iii) Central and Southern Italy.	Across the Atlantic to Bay of Biscay, thence passing into the Gallic and Tyrrenean Seas.
(iv) Tokyo.	Along the coast of Mexico up to Southern California, then across the Pacific, passing close to the Aleutian Islands and along the Tuscarora Deep off the north-eastern coasts of Japanese islands.
(v) New Zealand.	Across the South Pacific.
(vi) Perth, W. A.	Across the South Pacific and then off the southern coast of Australia.
(vii) Batavia.	Across the Pacific.
(viii) Calcutta.	Across the Gulf of Mexico, the E. part of the United States, Central Canada, the Arctic, Siberia, and Tibet, passing almost exactly through the North Pole.
(ix) Kodaikanal, Bombay.	Similar to (viii).
(x) Irkutsk.	Through the United States, Canada, the Arctic, and Siberia.
(xi) Cape Town.	Across Columbia and Brazil, then across the South Atlantic.
(xii) Toronto.	Through Guatemala, Yukatan, Gulf of Mexico, and the E. part of the United States.
(xiii) Baltimore.	Similar to (xiii).
(xiv) Victoria, B. C.	Across Mexico and the W. part of the United States.
(xv) Cordova.	Partly under the Pacific, and partly through South America.

The paths of the seismic propagation to the 18 stations in Europe (Groups i, ii, and iii) were almost entirely sub-Atlantic, while those to the 5 stations of Tokyo, Wellington, Christchurch, Perth, W.A., and Batavia, (Groups iv, v, and vi), were almost entirely sub-Pacific. The three Indian stations of Calcutta, Kodaikanal, and Bombay, were very nearly in, or not much out of, the great circle passing through the origin and the North Pole. The paths to the 5 stations of Irkutsk, Cape Town, Tashkent, Tiflis, and Cordova, A.R., were partly sub-marine and partly through land; only those to the 3 stations of Toronto, Baltimore, and Victoria, B. C., being essentially continental.

3. *Indian (Kangra) earthquake of April 4, 1905.* The Indian (Kangra) earthquake of April 4, 1905, which originated among the sub-Himalayan chains in the Punjab, with the epicentre at about $\varphi = 31^\circ\ 49'$ N, $\lambda = 77^\circ\ 0'$ E, was observed at a great number of seismological stations*. The main features of the paths of the seismic waves to these latter are indicated in the following table.

Station or District.	Path of the Seismic Waves.
(i) Colaba (Bombay), Kodaikanal.	Across the Indian Peninsula.
(ii) Calcutta.	Along the convex, or outer, side of the Himalayas.
(iii) Tashkent.	Across the Hindu Kush and the plateau of Pamir.
(iv) Irkutsk.	Across the mountain ranges of the central part of Asia.
(v) Zikawei (Shanghai).	Across Tibet and China.
(vi) Japan.	Through the plateau of Tibet, and across North China and Corea.
(vii) Formosa, Manila.	Across the plateau of Tibet, and the mountainous districts of South China.
(viii) Caucasus.	Across Afghan and Trans-Caspian districts.
(ix) Beyrut.	Across Afghanistan and Persia.
(x) Great Britain, North Germany. Jurjew, Upsala.	Across the flat regions of Europe.
(xi) Austro-Hungary, North Italy, Serbia. Nicolajew.	Across the Caspian and along the northern border of the Black Sea.
(xii) Batavia.	Across India and the Bay of Bengal.

* For a full discussion of the seismographical observations of the Kangra earthquake the reader is referred to the "Publications," No. 24.

Station or District.	Path of the Seismic Waves.
(xiii) New Zealand.	Through India, along the coast of Burma and Annam, and across Borneo and Australia.
(xiv) Spain.	Across the Caspian and Black Seas, and along the northern border of the Mediterranean.
(xv) Azores.	Across Europe, from the Caspian to France.
(xvi) Porto Rico.	Across Europe and the Atlantic.
(xvii) Honolulu.	Across North China and through the Pacific.
(xviii) Samoa.	Across the south-eastern Asia and through the Pacific.
(xix) Rio de Janeiro.	Across Arabia, Africa, and the Atlantic.
(xx) Mauritius.	Across India and the Indian Ocean.
(xxi) Cape Town.	Across India, through the Arabian Sea and the Indian Ocean, and across the south-eastern Africa.
(xxii) Tacubaya.	Across Siberia, the Arctic, and North America.
(xxiii) Toronto, Victoria, B. C.; Washington, Cheltenham, and Baltimore.	Similar to (xxii).

The routes of the earthquake propagation to the different stations of the 11 groups, (i) to (xi), were each entirely continental; especially, those relating to the five groups (iii) to (vii) being laid across the plateau of Tibet or the great mountain ranges in the centre of Asia. The seismic paths to the stations of the 4 groups (xii) to (xv) were also for the greater part continental, while those for the remaining 8 groups were partly submarine and partly continental. The stations of the two groups (xxii) and (xxiii) were situated approximately on, or not very much out of, the great circle passing through the origin and the North Pole.

4. *San Francisco earthquake of April 18, 1906.* The paths of the seismic waves to the different stations were as follows.

Station or District.	Path of the Seismic Waves.
(i) Sitka (Alaska).	Off the Pacific coast.
(ii) Honolulu.	Entirely under the Pacific.
(iii) Japan, Formosa.	Do.
(iv) Batavia.	Do.
(v) New Zealand.	Do.
(vi) Spain, Great Britain, Germany, Italy, Austria.	Through Canada, then across the North Atlantic.
(vii) Victoria, B.C.	Along the Pacific coast.
(viii) Tacubaya, Toronto, Ottawa, Washington, Cheltenham, Baltimore.	Entirely continental.
(ix) Porto Rico.	Through the United States and the Caribbian Sea.
(x) Tiflis, Tashkent.	Nearly through the North Pole.
(xi) British India.	Along or off the Pacific coast of North America, then through Asia, from the north-eastern part of Siberia to India.

The seismic waves reached the stations of the first 5 groups by entirely sub-oceanic paths, and those of the 3 groups, vii, viii, and ix, by entirely or almost entirely continental paths. The great circles connecting the earthquake origin with the stations of the remaining 3 groups, vi, x, and xi, are partly sub-oceanic and partly continental.

5. *Remarks.* From § 2, it will be seen that the motion of the Guatemala earthquake reached the majority of the seismological stations by *trans-Atlantic* or by *trans-Pacific* routes. On the contrary, the paths of the seismic propagation of the Indian (Kangra) earthquake were, according to § 3, mainly *continental*, being laid, in many cases, across the plateau of Tibet or the great mountain ranges in the centre of Asia. On these differences in the character of the regions, through which the earthquake movements were propagated, may possibly depend the marked discrepancy between the transit velocities of the two earthquakes under consideration. In other words, the earth's crust is to be supposed, in its continental parts and especially in the centre of Asia, to be abnormally deficient in rigidity, giving the low transit velocity of 11.36 km per sec. for the Indian earthquake. The earth's crust under the Pacific and the Atlantic Oceans is, on the other hand, to be supposed to be abnormally great in rigidity, giving the high velocity of 16.02 km per sec. for the Guatemala earthquake. In the case of the San Francisco earthquake, some of the seismic paths were sub-Pacific, while the others were continental, or partly continental and partly sub-marine (§ 4). Consequently, the velocity of this earthquake was about 13.97 km per sec., being nearly equal to the mean of the two earthquakes before considered.

The idea respecting the seismic velocity put forth in the present note is simply a suggestion, which, if correct, requires further verifications.

Oct., 1909.

印刷所　三秀舍
東京市神田區美土代町二丁目一番地
印刷者　島連太郎
東京市神田區美土代町二丁目一番地
編纂兼發行者　震災豫防調査會
明治四十二年十二月三日發行
明治四十二年十二月一日印刷

終