東京帝國大學

地震研究所彙報

第　五　號

Observation of some of recent Earthquakes and their Time-Distance Curves. (Part 1)

By

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Aramasi no Kotogara (Abstract in Japanese.)

(1) Etigo no Zisin (1927 nen 10 gt 27 nt) wo Tôkyô de kwansokusita Kekkwa ni yoruto Singen-Kyori ni taisite Syokibidô no Keizoku-Zikan ga itumo yori medatte sukunakatta.

(2) Ue no Kotogara wo akirakani suru Tame ni Zisin-ha no Tôtyaku-Zikan to Kyori tono Kwankei wo sirabeta.

(3) Hyômen de Tihen wo tomonau yôna ookii Zisin no Baai niwa Nippon demo P, P^*, $\overline{P}$ ni ataru Nami no aru Kotoga wakatta.

(4) Etigo no Zisin dewa P Nami wa mattaku miusinawareta rasii.

(5) Ippanni ono-ono no Sô (phase) wa Singen no Iti ya sono Okorikata ni kwankeisite aru Basyo dewa taihen mitomegatai.

(6) $\overline{P}$ Nami no Hayasa wa 5.0 km/sec., P^* wa 6.1 km/sec., gurai, Hyômen no Sô no Atusa wa 20 km. gurai ni naru.

(7) Oozisin no Baai niwa $\overline{P}$ Nami wa Hyômen ni taihen tikai Tokoro kara okoru yôni mieru. P Nami wa musiro Betu na Tokoro, sarani hukai Tokoro kara hiki-okosareru to kangaerareru. Sosite P Nami ni taisitewa "Epicentre" naru hitotu no Ten wo sadameru koto wa aru Tôkei-teki no Heikin yori hoka no Imi ga nai to omowareru.

(8) Oozisin no *Energy* no takuwaerareru Basyo wo P oyobi $\overline{P}$ wo okosu hutatu no Basyo ni wakete kangaeruto Zisin-hassei no Zikanteki-Bunpu no Riron no aru Konnan-na Ten ga sukosiku torinozokareru yôni omowareru.

I. Introduction.

On Oct. 27, 1927 a strong earthquake took place in Etigo Province, the geographic coordinates of which were $\varphi=37° \ 27'N$ and $\lambda=138° \ 46'E$. The author was appointed by the Director of this institute, Professor K. Suyehiro, to study this earthquake, and some phenomena directly accompanied with it are explained in another paper.(1) By way of instrumental study of this earthquake, the author came to a fact that the ratio of the epicentral distance to the duration of the preliminary tremor at Tôkyô was 8.6 and much greater than the ordinary value 7.44. For elucidation of this fact, it was necessary to study time-distance relation of the propagation of seismic waves, and instrumental records.

In addition to that, the time-distance curve within a small epicental distance, say less than 2000 km., in general is not yet very clear, although that of greater distance has been precisely studied by many authorities. The precise study of it is very important for investigation of the earth's crust.

Principal aim of this paper consists in promotion of precision of numerical values already obtained by senior authorities, so that nothing original may be found.

II. Investigation of the Etigo Earthquake,(2) Oct. 27, 1927.

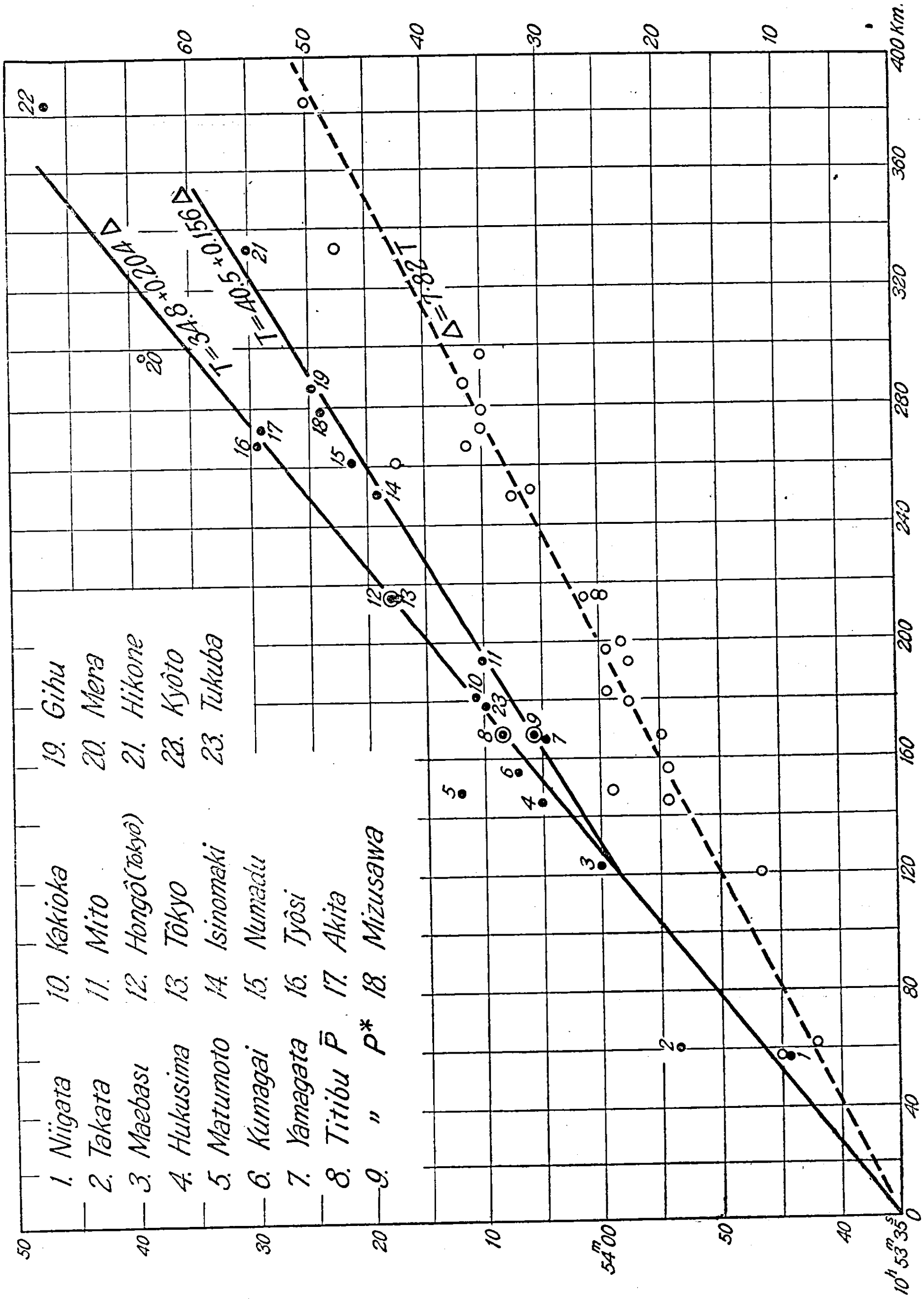
This earthquake was very local, so that its epicentre was determined precisely. Thus the principal merit of this case in studying the propagation of seismic waves consists in the accurate determination of epicentral distances. A pair of seismograms obtained at Hongô (Tôkyô) is as shown in Pl. I. Fig. 1. The time of commencement of the phase marked "1" was $10^h \ 54^m \ 17.^s5$ (L. M. T of $\lambda=135°E$) and is very consistent to that reported by the Central Meteorological Observatory. The duration of the preliminary tremor (1–3) is 25 sec and that by the Central Meteorological Observatory is 24.7 sec., which is also very consistent. Slow motions between "mark 2" and "3" may perhaps be a manifestation of pulsatory motions then prevailing, for such waves could not be identified at other stations such as Titibu (Pl. II. Fig. 2), Kamakura, Misaki, Kiyosumi-yama, etc.

In the next place, the time-distance relation of seismic waves is plotted in Fig. 3.

(1) T. Matuzawa, this Bull. **5** (1928), 29.

(2) During the preparation of this paper, the author came across a paper by Dr. S. I. Kunitomi on the same earthquake (Journ. Meteor. Soc. Japan. [ii] **6** (1928) 59-85), and yet my paper contains somewhat different views.

Time-distance curve of Etigo Earthquake, Oct. 27, 1927.



Dot: Time of commencement. Circle: Duration of preliminary tremor.

Origin of time for empirical formula, 10^h53^m (L.M.T. of $\lambda=135°$ E)

Fig. 3.

The data were adopted from the report of the Central Meteorological Observatory and tabulated below. (Table I.)

TABLE I.

Etigo Earthquake, Oct. 27, 1927. ($\varphi=37°\ 27'$, $\lambda=138°\ 46'$)

No.	Station	Latitude		Longitude		T. of Comm. L.M.T of $\lambda=135°E$	P. T. sec.	Δ km.
1	Niigata	37°	55′	139°	03′	10h 53m 44.2s	9.8	57.5
2	Takata	37	06	138	15	53.7	7.2	60.2
3	Maebasi	36	24	139	04	54 00.0	27.0	122.4
4	Hukusima	37	45	140	24	05.0	19.4	144.7
5	Matumoto	36	14	137	59	12.0	24.0	148.4
6	Kumagai	36	09	139	24	07.1	19.1	155.8
7	Yamagata	38	15	140	21	04.6	19.6	167.0
8	Titibu (P^*)	35	59	139	05	05.6		168.4
9	,, ($\overline{P}$)	,,		,,		08.0		
10	Kakioka	36	14	140	11	10.6	24.3	181.8
11	Mito	36	23	140	28	10.0	22.7	193.0
12	Hongô (Tôkyô)	35	43	139	46	17.5	25.0	215.
13	Tôkyô	35	41	139	46	17.9	24.7	215.
14	Isinomaki	38	26	141	19	19.0	32.3	250.4
15	Numazu	35	06	138	51	21.5	42.6	261.6
16	Tyôsi	35	44	140	51	29.7	36.3	267.1
17	Akita	39	41	140	06	29.0	35.1	272.7
18	Mizusawa	39	08	141	08	24.0	35.0	278.3
19	Gihu	35	24	136	46	24.9	36.5	287.5
20	Mera	34	55	139	50	38.9	34.9	296.8
21	Hikone	35	16	136	15	30.0	47.5	334.0
22	Kyôto	35	01	135	44	46.6	50.2	384.0
23	Tukuba	36	13	140	06	10.0	22.5	178.1

Remark: The time of commencement at Titibu was assumed on the curve (Fig. 3.)

As apparent from the figure, two branches of straight lines can clearly be seen one of which is characterised by $d\Delta/dT=4.99$ km/sec. and the other by $d\Delta/dT=6.4$ km/sec. The values observed at Tôkyô belong to the upper branch. From the distribution of stations belonging to each branch, no directional effect can be found. Moreover, it is remarkable that stations belonging to the upper branch are mainly those in the Kwantô plain. Thus a supposition is at hand that the forerunning part belonging to the lower branch was masked by the pulsatory motion of the earth's crust then having been prevailing and missed from observation, or rather could not be identified. Indeed, at Titibu the two phases were clearly observed. (Pl. II. Fig. 2).

The next point to be considered is that to which phase of waves each branch of curves belongs. This point can easily be explained by assuming a mechanism similar to that of Mohorovičić. Then the velocity in the upper layer becomes 4.99 km/sec. and that in the lower layer is 6.4 km/sec. The former value seems too small compared with the current value 5.56 km/sec. of $\bar{P}$ waves by European authorities, but is very near to that obtained by G. Krumbach.(1)

The latter value 6.4 km/sec. is near to the European value of P^* waves,(2) 6.2 km/sec. Thus assuming tentatively as such, the depth of the first discontinuity can be calculated. The time difference of $\bar{P}$ and P^*, τ, is given by

$$\tau=\frac{\sqrt{\Delta^2+f_1^2}}{v_1}-(2d_1-f_2)\frac{\cos i}{v_1}-\frac{\Delta}{v_2},$$

where d_1 is the depth of the first discontinuity,

v_1 ,, ,, velocity of $\bar{P}$ waves,

v_2 ,, ,, ,, ,, P^* ,, ,

f_1 ,, ,, depth of the origin of $\bar{P}$ waves,

f_2(3) ,, ,, ,, ,, ,, ,, ,, P^* ,, ,

Δ ,, ,, epicentral distance

and i is defined such that $\sin i=v_1/v_2$.

The distance for which $\tau=0$ is $\Delta=118$ km. Therefore,

$$d_1=18.2+f_2/2+f_1^2/125 \text{ in km.}$$

The depth of the seismic origin is not very clear but is doubtlessly not deep. Perhaps d_1 may plausibly be 20 km. or so.

III. Review of Some of Recent Great Earthquakes.

The values experienced in the foregoing example are much different from current values. And moreover, no literature with regard to the existence of the P^* phase in Japan can be found. Besides these, if each branch of curves in the above example is interpreted as above, another question arises that why the phase P was not present in that case. It may remain doubtfull that the phase interpreted here as P^* might correspond to the P phase, but this is not the case as discussed later. The reason why the P phase was missed is supposed as follows:

(1) G. Krumbach, über die Fortpflanzungsgeschwindigkeit der direkten Longitudinalwellen bei künstliche Beben, Zeits. f. Geophys. **2** (1926) 30-33.

(2) See B. Gutenberg, Der Aufbau der Erdkruste; Zeits. f. Geophys. **3** (1927) Hft. 7.

(3) The reason why distinguishing f_1 and f_2 will be discussed later.

that is, that earthquake was a very local shock and its energy was not sufficient to transmit P waves as detected by ordinary instruments. In addition to this, the pulsatory motion then having been prevailing disturbed much some of instrumental records and identification of the phase was much unfavourable.

If such consideration is not wrong, investigation of earthquakes of vast scale will reveal some evidence concerning the above stated inferences.

In doing so, earthquakes to be chosen must be those of distinct epicentre, because an error of epicentral distances even within a few tens of kilometers, which value is often probable in some cases, will produce a serious mistake with regard to the classification of waves.

Review of the Great Tango Earthquake, March 7, 1927.

Full reports concerning this earthquake instrumentally observed have been already published by such authorities as Dr. S. I. Kunitomi(1) and Professor A. Imamura.(2) Hence in this paper precise description will be omitted.

Indeed, instrumental records at Hongo (Tôkyô) (Pl. III. Fig. 4)(3) and at Kamakura (Pl. IV. Fig. 5)(4) will show very clearly three steps as marked P, P^* and $\bar{P}$. The time of commencement of the P phase can be determined by much sensitive instruments such as shown in Fig. 1 of Prof. Imamura's paper. The commencement of P was $18^h 28^m 43^s$ (L. M. T of $\lambda=135°$) on March 7, 1927 and the duration $P-P^*$ was $10.^s3$ and that of $P-\bar{P}$ was $22.^s5$ ($\Delta=427$ km). The time of commencement at Kamakura was not certain because the time keeping was not sufficient. The duration of each phase, however, could be determined very well such that $P-P^*$ was $9.^s2$ and $P-\bar{P}$, $19.^s2$ ($\Delta=410$ km).

Thus, existence of three phases in the preliminary tremor is almost beyond doubt, but for interpretation of these phases their time-distance relations must be carefully examined, for such a characteristic appearance may also be produced by step-wise occurrence of earthquake. In Pl. V. Fig. 6, reported values of time of commencement are plotted taking the epicentral distance as the abscissa. The values of time of commencement were adopted from Dr. S. I. Kunitomi's paper,(5) and tabulated below with some modifications of epicentral distances taking the epicentre as $\varphi=35° 38'N$, $\lambda=135° 03'E$.

(1) S. I. Kunitomi, Journ. Meteor. Soc. Japan [ii] 5 (1927) 8.
(2) A. Imamura, This Bull. 4 (1928) 179-202.
(3), (4). These figures are the same as those of Prof. Imamura's paper (ibid. Fig. 3 and Fig. 4), but with slight modifications of notations.
(5) l. c.

TABLE II.

Tango Earthquake, March 7, 1927. ($\varphi=35°\ 38'N,\ \lambda=135°\ 03'E.$)

No.	Station	Latitude		Longitude		T. of Comm. L.M.T of $\lambda=135°E$			$P\overline{P}$	P. T sec.	Epicentral Dis. km.
						h	m	s			
1	Miyazu	35°	32′	135°	12	18	27	43.5			17.5
2	Toyooka	,,		134	49			43.8		3.0	24.6
3	Kyôto	35°	01	135	44			56.9		10.6	92.5
4	Kôbe	34	41	135	11			58.1			106.
5	Oosaka	34	39	135	26			56.8		16.5	114.
6	Hikone	35°	16′	136°	15′		28	00.0		17.6	116.
7	Hukui	36°	03	136	16′		27	59.0		16.8	125.7
8	Yagi	34	31	135	48		28	02.6		16.2	140.5
9	Sumoto	34	21	134	53		27	58.0		17.9	148.
10	Okayama	34	40	133	54		28	08.7		18.0	149.
11	Gihu	35	24	136	46			00.7		20.3	157.2
12	Wakayama	34	14	135	09			05.		20.1	160.
13	Sakai	35	33	133	14			03.0		12.7	163.
14	Tu	34	44	136	31			07.2			170.
15	Nagoya	35	10	136	58			10.0		25.0	176.
16	Tokusima	34	04	134	33			19.		23.1	179.
17	Tadotu	34	17	133	46			18.0			193.
18	Takayama	36	09	137	15			04.9		20.1	209.
19	Husiki	36	47	137	03			15.9		24.0	223.
20	Hirosima	34	23	132	27			19.2			231.
21	Sisakazima	34	06	133	11			15.0			239.
22	Niihama	33	58	133	16			14.0		—	246.
23	Iida	35	31	137	50			19.2		29.8	255.
24	Siomisaki	33	27	135	46			30.		30.0	255.
25	Kôti	33	33	133	32			18.1		34.2	267.
26	Hamamatu	34	43	137	43			40.		35.	267.
27	Kure	34	14	132	33			32.0		—	273.
28	Matumoto	36	14	137	59			27.0			274.
29	Hamada	34	54	132	04			19.	3.9	28.9	280.
30	Matuyama	33	50	132	45			28.	4.3	36.3	285.
31	Nagano	36	40	138	12			24.7	6.2	—	306.
32	Kôhu	35	38	138	34			40.		—	320.
33	Takada	37	06	138	15			31.2	6.8	36.8	332.
34	Numazu	35	06	138	51			31.8	6.8	43.2	352.
35	Maebasi	36	24	139	04			34.6		—	376.

to be continued.

(Continued.)

No.	Station	Latitude	Longitude	T. of Comm. L.M.T of λ=135°E	$P\overline{P}$	P. T.	Epicentral Dist.
				h m s			
36	Kumagai	36 09	139 23	28 39.3	8.2	52.3	399.
37	Ooita	33 14	131 37	38.7		56.0	411.
38	Yokohama	35 27	139 39	47.2			421.
39	Yokosuka	35 17	139 40	39.			423.
40	Hongô (Tôkyô)	35 43	139 46	43.0			427.
41	Tôkyô	35 41	139 46	42.2	9.9	53.7	431.
42	Niigata	37 55	139 03	35.5	15.6	54.0	441.
43	Mera	34 55	139 50	46.6		49.0	444.
44	Utunomiya	36 34	139 53	57.9			446.
45	Tukuba	36 13	140 06	48.4		65.0	469.
46	Kakioka	36 14	140 11	46.	14.4	67.2	472.
47	Hukuoka	33 35	130 25	43.2		68.8	480.
48	Mito	36 23	140 28	50.		57.0	500.
49	Kumamoto	32 49	130 42	54.6		73.	505.
50	Hatizyô	33 06	139 50	29 27.			521.
50	Miyazaki	31 55	131 26	28 57.9		77.1	527.
51	Tyôsi	35 44	140 51	50.6		70.3	530.
52	Unzen	32 44	130 15	29 00.0		71.8	545.
53	Onahama	36 56	140 54	26.0			548.
54	Izuhara	34 12	129 17	28 50.0		72.0	546.
55	Husan	35 06	129 01	49.		66.0	546.
56	Yamagata	38 15	140 21	57.5		68.4	556.
57	Nagasaki	32 44	129 52	29 06.0			573.
58	Sendai	38 16	140 54	00.3			596.
59	Saga	33 12	130 18	28 59.6			609.
60	Kagosima	31 34	130 33	29 02.8			612.
61	Akita	39 41	140 06	06.0		78.5	633.
62	Isinomaki	38 26	141 19	07.8			636.
63	Mizusawa	39 08	141 08	12.8			662.
64	Morioka	39 42	141 10	13.8		78.0	703.
65	Miyako	39 38	141 59	51.			754.
66	Zinsen	37 29	126 37	23.1		89.0	780.
67	Hakodate	41 47	140 43	35.2			840.
68	Muroran	42 20	140 57	30 29.			901.
69	Nase	28 23	129 30	29 25.0			957.
70	Sapporo	43 04	141 21	29 46.5			986.

to be continued.

(Continued.)

No.	Station	Latitude		Longitude		T. of Comm. L.M.T of $\lambda=135°E$	$P\bar{P}$	P. T	Epicentral Dist.
						h m s			
71	Obihiro	42	55	143	12	59.			1073.
72	Asahigawa	43	47	142	22	30 05.			1099.
73	Kusiro	42	59	144	24	07.			1132.
74	Titizima	27	05	142	10	23.6			1162.
75	Dairen	38	54	121	38	12.			1238.
76	Nemuro	43	20	145	35	30 29.5			1240.
77	Ootomari	46	39	142	46	43.			1414.

Remark: Seismometrical elements were adopted (except Hongô) from Dr. S. Kunitomi's paper (Journ. Meteor. Soc. Japan [ii] **5** (1927) no. 8). The reported time of commencement at Onahama and Nemuro seems too earlier by one minute perhaps by accidental mistake of calculation of time marks. Therefore, in the table values with the correction are adopted.

In Fig. 6, the dot represents the reported time of commencement, the circle is plotted such that to represent the value of $P\bar{P}$ of Dr. Kunitomi's paper measured from the corresponding point on the P curve. Values obtained at Hongô and at Kamakura (represented by the concentric circle) were carefully measured by the present author. As to be seen from the figure, the distribution of the time of commencement can be classified into three groups in this case also. The upper curve (straight line) is characterised by $d\Delta/dT=5.0$ km/sec. and the middle is by $d\Delta/dT=5.9$ km/sec. The former value is quite consistent with that experienced in the case of the Etigo Earthquake. The latter value is somewhat smaller than the value in that case. The value 6.4 km/sec. may, however, be perhaps somewhat too large. In Fig. 3, if the point marked "21" is omitted, a smaller value will be obtained. At any rate, it is almost beyond doubt that the curve characterised by 6.4 km/sec. in the case of the Etigo earthquake will correspond to the middle branch of curves in this case. Besides these, the lowest curve which seems to belong to P waves has been obtained as expected. Thus the supposition that the P waves of the Etigo earthquake were missed from observation turns out highly probable. It is also almost doubtless that P, P^* and $\bar{P}$ phases are observed in Japan also as in the continent. The phase reported by Mr. Kunitomi as $\bar{P}$ waves seems to correspond to that of P^* waves. It may seem queer that at certain stations the P phase or both P and P^* phases are missed from observation in such a great earthquake. Many factors can, however, be considered for explaining such a fact, for examples, sensitivity of instrument, mechanism of occurrence of earthquake, disturbance of earth's crust other than seismic waves at those stations etc. Among these factors, the author is inclined to believe that the mechanism at the seismic origin may play an essential rôle as once discussed by the author.(1) Thus we must be very circumspect in discussing any thing concerning directional properties of propagation of seismic waves.

From these two earthquakes, the velocity of propagation of dilatational waves in the uppermost layer in Japan is very probably 5.0 km/sec. and that of the next layer is 6.1 km/sec. or so. Taking these values, the depth of the discontinuity will be re-examined. In this case the distance $\varDelta$ at which the P^* and $\overline{P}$ arrive simultaneously is 62 km. Therefore

$$d_1 = 9.8 + f_2/2 + 0.00705\, f_1^2 \text{ in km.}$$

In this case also values of f_1 and f_2 are not exactly known. If $f_2 = 15$ km.(2) and $f_1 = 10$ km. tentatively (these values are very probable), then $d_1 = 18.0$ km. Thus the depth of the first discontinuity will be taken as some 20 km in a round number.

The curve P will be discussed later.

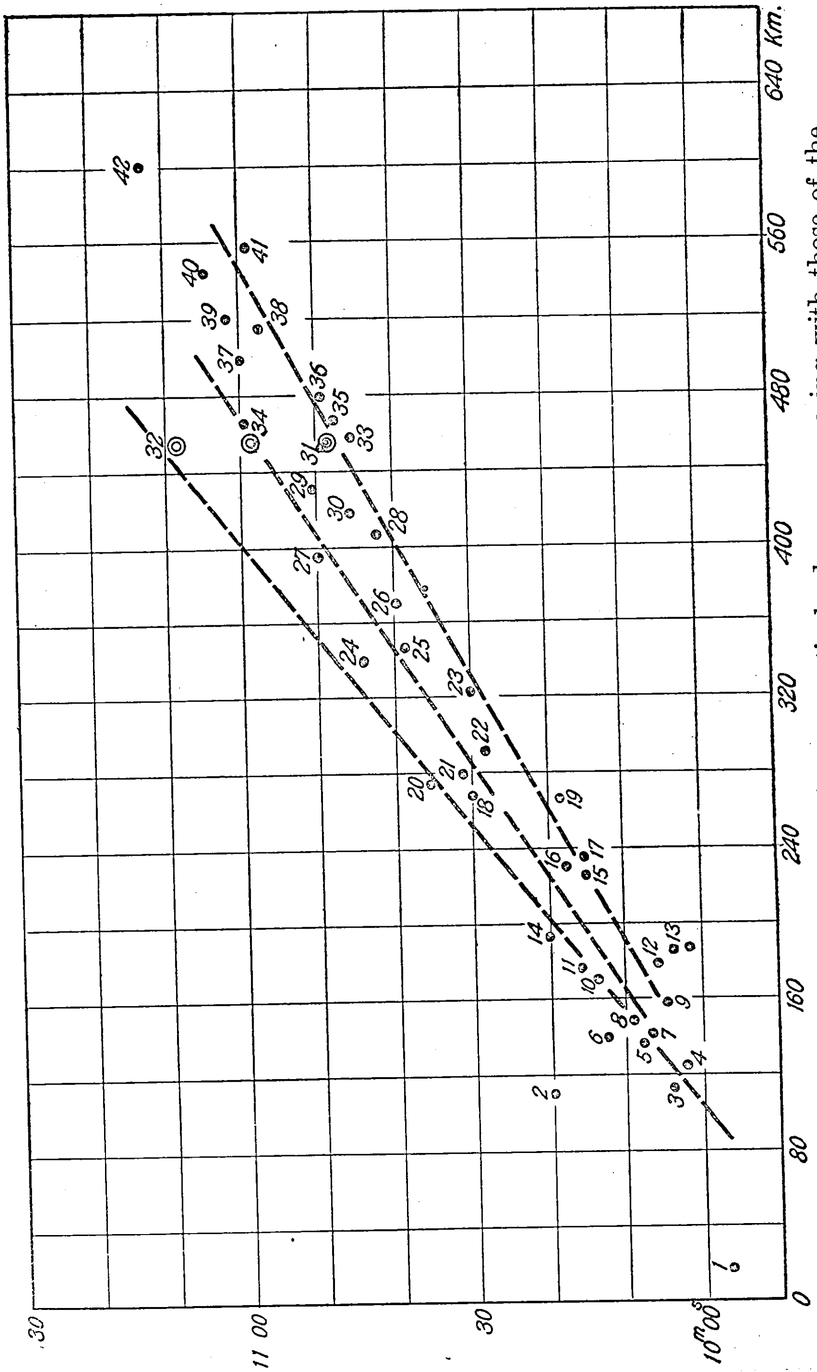
Review of the Great Tazima Earthquake, May 23, 1925.

This earthquake occurred also in the land and its epicentre could be determined well. The seismograms recorded at Hongô are shown in Pl. VI. Fig. 7. On the case of this earthquake Dr. K. Wadati(3) drew attention for the first time in Japan the existence of the P and $\overline{P}$ waves. In this case also the three phases P, P^* and $\overline{P}$ can be identified in Fig. 7, especially clear in the vertical component. The time of commencement at Hongô was $11^h\, 10^m\, 49^s$ (L. M. T of $\lambda = 135°E$) on May 23, 1925. The duration $P-P^*$ was 10 sec and that of $P-\overline{P}$ was 20 sec. $P-(S^*) = 59.0$, $P-(\overline{S})$ or $P-(L) = 75.5$. Again the time-distance relation of propagation of seismic waves will be examined using mainly the reported values of the time of commencement at certain stations. The data are tabulated in Table III.

The values are plotted in Fig. 8.

The broken lines representing the time-distance curve are so drawn that the uppermost line coincides with that of the Tango earthquake (Fig. 6) and

(1) T. Matuzawa, Japanese Journ. Astr. Geophy. **4** (1926) no. 1.
(2) Dr. N. Nasu read a paper at the colloquium of this Institute that the depth of after-shocks of this earthquake was mainly distributed within this value.
(3) K. Wadati, Journ. Meter. Soc. Japan [ii] **3** (1925) 201-211.



Time-distance curves (broken lines) are tentatively drawn comparing with those of the Great Tango earthquake.

Fig. 8.

TABLE III.

Tazima Earthquake, May 23, 1925. ($\varphi=35°\ 38'.5$, $\lambda=134°\ 50'$)

No.	Station	Latitude		Longitude		T. of Comm. L.M.T of $\lambda=135°E$			Δ
						h	m	s	
1	Toyooka					11	9	57.0	
2	Turuga	35	38	136	03		10	20.0	110
3	Kôbe	34	41	135	11			04.4	112
4	Oosaka	34	39	135	26			01.8	124
5	Hikone	35	16	136	15			08.2	137
6	Hukui	36	03	136	16			12.0	138
7	Okayama	34	40	133	54			07.4	140
8	Sumoto	34	21	134	53			09.2	149
9	Yagi	34	31	135	48			05.0	158
10	Wakayama	34	14	135	09			14.0	169
11	Gihu	35	24	136	46			16.7	177
12	Tokusima	34	04	134	33			06.0	178
13	Tadotu	34	17	133	46			04.0	185
14	Kure	34	14	132	33			20.6	194
15	Takayama	36	09	137	15			15.6	225
16	Sisakazima	34	06	133	11			18.0	231
17	Husiki	36	47	137	03			15.8	235
18	Hirosima	34	23	132	27			30.4	265
19	Siomisaki	33	27	135	46			18.6	266
20	Iida	35	31	137	50			35.9	273
21	Matuyama	33	50	132	45			31.0	279
22	Matumoto	36	14	137	59			28.0	291
23	Nagano	36	40	132	12			30.0	322
24	Kôhu	35	38	138	34			44.0	338
25	Takada	37	06	138	15			38.2	346
26	Numazu	35	06	138	51			39.1	371
27	Maebasi	36	24	139	04			50.2	393
28	Simonoseki	33	57	130	56			42.0	405
29	Yokohama	35	27	139	39			50.5	430
30	Kumagai	36	09	139	23			45.8	416
31	Niigata	37	55	139	03			49.3	453
32	Hongô (Tôkyô)	35	43	139	46			49.0	455
33	Tôkyô	35	41	139	46			45.5	455
34	Hukuoka	33	35	130	25			59.7	464
35	Utunomiya	36	34	139	53			47.8	466

to be continued.

(Continued.)

No.	Station	Latitude		Longitude		T. of Comm. L.M.T of $\lambda=135°E$		Δ
						h m	s	
36	Mito	36	23	140	28	10	57.0	514
37	Miyazaki	31	55	131	26	11	02.1	520
38	Tyôsi	35	44	140	51		04.8	543
39	Nagasaki	32	44	129	52	10	59.0	556
40	Kagosima	31	34	130	33	11	13.0	601
41	Tukuba	36	13	140	06		49.6	479
42	Saga	33	12	130	18	11	00.0	497

Remark: The reported value of time of commencement at Tokusima seems to be too small by one minute, perhaps being due to a mistake of calculation of time marks.

other lines are drawn in just the same position relative to the uppermost one as in Fig. 6. In this case, points representing time of commencement scatter somewhat irregular, and yet are included well between the P and the $\bar{P}$ curve. This fact can easily be explained by considering that the energy of producing the P wave was not sufficient to be observed everywhere. Indeed, the observed values at Hongô are quite reconcilable in this case also. Moreover, the P and the $\bar{P}$ curve are clearly defined by drawing the boundary of the domain of the distributed points. This will also furnish an evidence of the above stated idea. It may be remarked that the P wave seems to be rather well defined at a remote stations beyond 400 km. compared with the nearer stations ($280<\Delta<400$ km.) in this case. Closer examination of distribution of stations will show that most stations with later commencement are situated almost in the $E-W$ direction relative to the epicentre, as stated by Dr. S. I. Kunitomi.(1) A contrary proposition that stations distributed in the $E-W$ direction show later commencement than that represented by the lowest curve (Fig. 8) without exception is not the case. For example, Nagano (23), Simonoseki (28), Niigata (31) Tôkyô (32, 33) etc. This point will be discussed later. Here it will only be remarked that the P phase was quite small compared with the principal part observed at Hongô (See Fig. 7) which is situated almost in the East direction.

Tango earthquake on April 1, 1927.

This is one of after-shocks of the Great Tango earthquake on March 7.

(1) S. Kunitomi, Journ. Meteor. Soc. Japan [ii] 3 (1925) no. 7.

According to Dr. N. Nasu, its epicentre was determined as $\varphi=35°\ 28'N$ and $\lambda=135°\ 07'$ by seismic triangulation. Instrumental records at Hongô are shown in Pl. VII. Fig. 9. The time of commencement at Hongô was $6^h\ 9^m\ 37^s.3$ (L. M. T $\lambda=135°E$). Careful study of the records will also reveal the existence of three phase P, P^* and $\bar{P}$. The duration of $P-P^*$ was $6^s.75$ and $P-\bar{P}$ was $18^s.1$. $P-(S)=42^s$, $P-(S^*)=54^s$, and $P-(\bar{S})=73^s$. It is remarkable that magnitude of the preliminary phase of this earthquake observed at Hongô was quite small compared with the principal part.

In the next place, the time-distance relation of propagation of seismic waves will be examined as before. The values of time of commencement were adopted from "Kisyô-Yôran" published by the Central Meteorological Observatory, and tabulated below.

TABLE IV.

Tangô Earthquake, April 1, 1927. ($\varphi=35°\ 28'$, $\lambda=135°\ 07'$)

No.	Station	Latitude		Longitude		T. of Comm. L.M.T of $\lambda=135°E$			P. T sec.	Δ km.
						h	m	s		
1	Miyaz	35	32	135	12	6	08	29.3		10.6
2	Toyooka	,,		134	49			42.6	3.8	40.2
3	Kyôto	35	01	135	44			49.9	9.8	75.2
4	Kôbe	34°	41	135	11			52.0	13.0	87.1
5	Oosaka	34	39	135	26			51.3	15.5	95.1
6	Hikone	35	16	136	15			57.6	13.2	105.4
7	Yagi	34	31	135	48		09	00.0		122.5
8	Hukui	36	03	136	16		08	52.5	13.0	123.
9	Sumoto	34	21	134	53			57.2	17.4	126.
10	Wakayama	34	14	135	09			59.0	22.5	136.9
11	Okayâma	34	40	133	54		09	00.0	17.1	140.5
12	Gihu	35	24	136	46		08	54.7	18.6	148.0
13	Tu	34	44	136	31		09	10.7	20.0	151.1
14	Tokusima	34	04	134	33		08	54.0	23.0	164.
15	Sakai	35	33	133	14		09	20.7	22.8	168.3
16	Nagoya	35	10	136	58			6.8	22.3	170.1
17	Tadotu	34	17	133	46			28.0	19.0	175·7
18	Kanazawa	36	32	136	39			21.0	23.0	181.2
19	Takayama	36	09	137	15			9.0	25.9	205.3
20	Husiki	36	47	137	03			10.9	35.6	225.6
21	Siomisaki	33	27	135	46			2.0	35.0	231.5
22	Iida	35	31	137	50			13.7	32.6	244.1

to be continued.

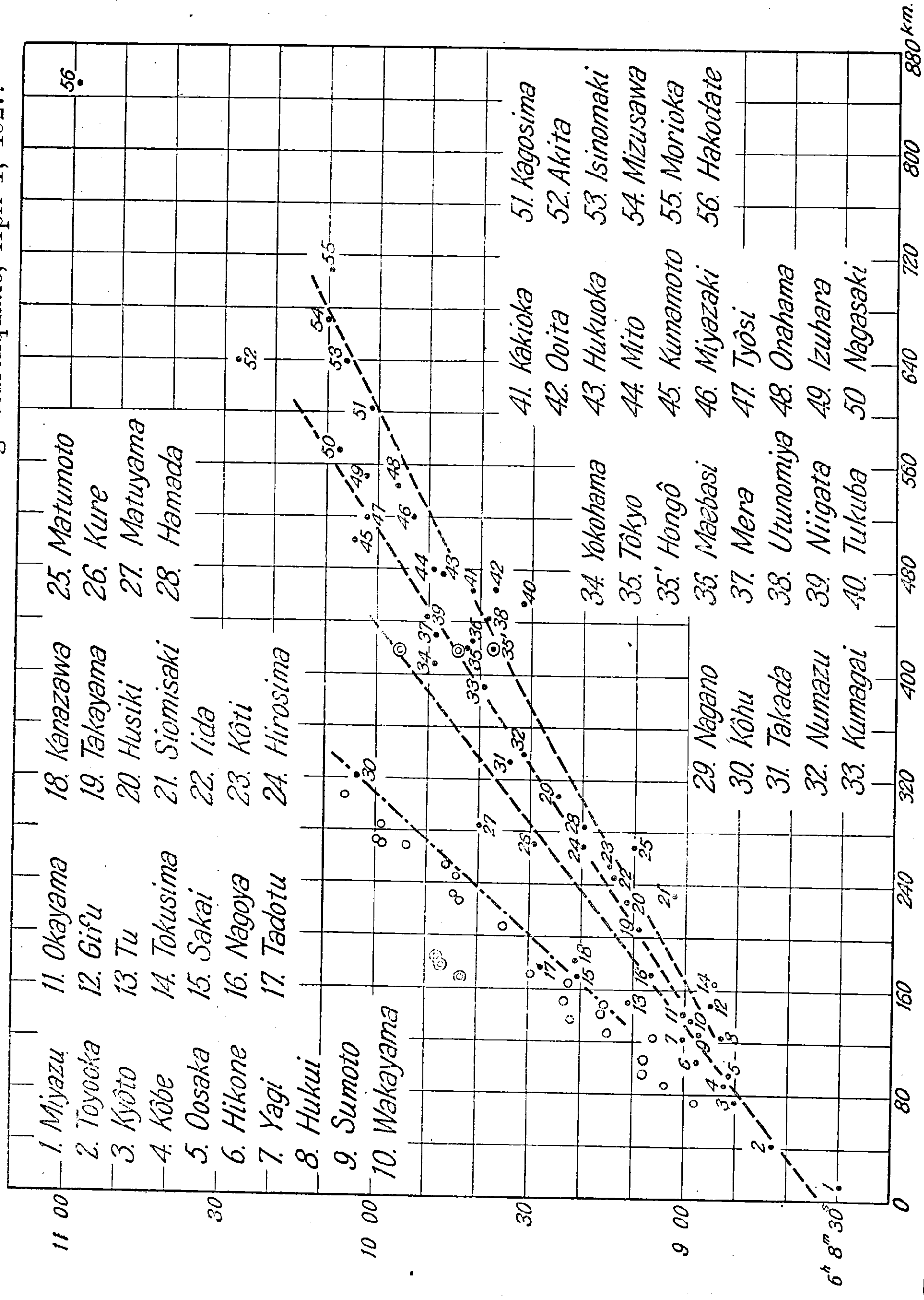
(Continued.)

No.	Station	Latitude		Longitude		T. of Comm. L.M.T of $\lambda=135°E$		P. T	Δ
						h m	s		
23	Kôti	33	33	133	32	09	14.6	33.2	253.3
24	Hirosima	34	23	132	27		19.9	39.0	268.1
25	Matumoto	36	14	137	59		10.0	39.0	268.1
26	Kure	34	14	132	33		29.3	52.4	270.0
27	Matuyama	33	50	132	45		39.8	41.7	283.
28	Hamada	34	54	132	04		19.7	37.3	283.0
29	Nagano	36	40	138	12		24.9	40.2	307.0
30	Kôhu	35	38	138	34	10	4.0	14.0	323.6
31	Takada	37	06	138	15	09	34.2	38.8	333.0
32	Numazu	35	06	138	51		31.5	48.3	340.2
33	Kumagai	36	09	139	23		39.6	56.4	390.2
34	Yokohama	35	27	139	39		48.7	40.3	408.6
35	Tôkyô	35	41	139	46		42.8	54.6	420.
35′	Hongô (Tôkyô)	35	43	135	46	9	37.3		419.
36	Maebasi	36	24	139	04		41.2	38.9	426.
37	Mera	34	55	139	50		48.5	50.4	429.
38	Utunomiya	36	34	139	53		38.1	55.0	444.
39	Niigata	37	55	139	03		50.1	56.5	444.
40	Tukuba	36	13	140	06		31.3	51.8	453.7
41	Kakioka	36	14	140	11		41.5	1^m 11.5	462.
42	Ooita	33	14	131	37		37.0	56.0	465.
43	Hukuoka	33	35	130	25		47.2	1^m 03.8	477.
44	Mito	36	23	140	28		49.0	1^m 00.0	479.
45	Kumamoto	32	49	130	42	10	4.3	1^m 16.6	501.
46	Miyazaki	31	55	131	26	09	53.0	1^m 16.0	519.
47	Tyôsi	35	44	140	51	10	2.1		518.
48	Onahama	36	56	140	54	09	55.6	1^m 11.1	544.
49	Izuhara	34	12	129	17	10	2.3	1^m 00.0	551.
50	Nagasaki	32	44	129	52		7.7	1^m 19.4	569.
51	Kagosima	31	34	130	33		1.9	1^m 32.9	603.
52	Akita	39	41	140	06		27.3	1^m 25.2	640.
53	Isinomaki	38	26	141	19		6.4	1^m 41.9	639.
54	Mizusawa	39	08	141	08		10.0	1^m 12.0	669.6
55	Morioka	39	42	141	10		9.2	1^m 30.7	708.
56	Hakodate	41	47	140	43		58.8	1^m 27.3	850.

Remark: The reported values at Kôhu and Onahama may be too small by one minute.

These values are plotted in Fig. 10.

Time-distance curve of one of after-shocks of the Great Tango Earthquake, April 1, 1927.



Time curves (broken lines) are tentatively drawn comparing with those of the Great Tango Earthquake. Circles denote the time of commencement of the principal phase.

Fig. 10.

Broken lines are drawn in a similar manner as in the case of the Tazima Earthquake. Essential characters to be remarked are almost the same as in that case. In this case, however, the distributed points can be grouped in three sets of curves somewhat better compared with the case of the Tango earthquake, March 7, 1927. At stations situated between 280 km. and 400 km., it seems that the P phase was missed out of observation and the P^* phase was observed as the commencement. The stations included within this range are distributed almost in the east-west direction relative to the origin of the earthquake. Thus, a consideration is at hand that in such directions the dilatational waves presented themselves quite small in magnitude and the P phase was missed from observation. This point can be inferred from the record at Hongô (Pl. VII. Fig. 9). Indeed, the phase between P and P^* is quite liable to be missed. The value of the time of commencement observed at the Central Meteorological Observatory differed from that at Hongô by just the same amount as $P-P^*$ difference.

Another point to be remarked is the phase characterised by the one dot chain line in the figure (Fig. 10). The distribution of stations is too systematic to be rejected as due to observational errors. The direction of the stations from the epicentre is almost in $E-W$ except Tadotu (marked 17). If the commencement of (S^*) at Hongô is plotted, it will just fall on the line. Moreover this chain line borders approximately the lower limit of points representing the commencement of the principal phase (denoted by circles in Fig. 10). Thus the author is inclined to explain that at such stations all the dilatational part was gone out of observation. Indeed, from Pl. VII. Fig. 9, it will be seen that the magnitude of the preliminary part is quite small compared with that of the principal part. The reported values of duration of preliminary tremor (denoted by concentric circle in Fig. 10) may be some other phase such as $S-L$ or the like.

Even in Fig. 9, after several tens of seconds from (S) larger motions can be seen.

IV. Review of the Great Kwantô Earthquake, Sept. 1, 1923.

This earthquake has been investigated from many points of view and even now its investigation is being carried on from several sides by many authorities. Accordingly, instrumental studies have also been published by many authorities, for examples, T. Hirano,[1] K. Suda,[2] A. Imamura,[3] S. T. Nakamura,[4] K. Siratori[5] S. I. Kunitomi[6] et. al.

This earthquake was of a considerable scale and had considerable energy for transmitting seismic waves. Moreover, the epicentral region was apparent, so that the time-distance curve within a considerable distance, say 3000 km., could be determined with a small probable error as shown in Pl. VIII. Fig. 11. The value of time of commencement is adopted from Professor Imamura's report,[7] and tabulated below.

TABLE V.

Kwantô Earthquake, Sept. 1, 1923. ($\varphi = 35° 16'$, $\lambda = 139° 20'$)

No.	Station	Latitude		Longitude		T. of Comm. L.M.T of $\lambda = 135°E$			Δ km.
1	Numazu	35°	06′	138°	51′	11h	58m	39s	47.8
2	Tôkyô (Hongô)	35	41	139	46			44	60.8
3	Kumagai	36	09	139	23			51	98.1
4	Tukuba	36	13	140	06			53	126.5
5	Tyôsi	35	44	140	51			57	147.8
6	Matumoto	36	14	137	59		59m	04	163.
7	Mito	36	23	140	28		58	56	163.
8	Nagano	36	40	138	12			56	187.
9	Takayama	36	09	137	15		59	03	214.5
10	Takada	37	06	138	15			10	226.
11	Gihu	35	24	136	46			02	235.
12	Tu	34	44	136	31			11	263.
13	Hikone	35	16	136	15			14	283.
14	Niigata	37	55	139	03			14	298.
15	Kyôto	35	01	135	44			33	329.
16	Yagi	34	31	135	48			21	331.
17	Yamagata	38	15	140	21			39	344.
18	Sendai	38	16	140	54			21	361.
19	Oosaka	34	39	135	26			24	362.
20	Kôbe	34	41	135	11			26	383.
21	Isinomaki	38	26	141	19			30	392.

to be continued.

(1) T. Hirano, Journ. Meteor. Soc. Japan (in Japanese) [ii] **2** (1924) 116-121.
(2) K. Suda, Memoirs Imp. Marine Obs. Kôbe, **1** (1924) 137-239.
(3) A. Imamura, Rep. Imp. Earthq. Invest. Comm. **100** A (1925) 21-65.
(4) S. T. Nakamura, ibid, 67-140.
(5) K. Siratori, Jap. Journ. Astro. Geophy. **2** (1925) 173-192.
(6) S. I. Kunitomi, Journ. Meteor. Soc. Japan [ii] **3** (1925) 281-293.
(7) A. Imamura, Rep. Imp. Earthq. Invest. Comm. **100** A (1925) 31, 32.

(Continued)

No.	Station	Latitude		Longitude		T. of Comm. L.M.T of $\lambda=135°E$ h	m	s	Δ
22	Mizusawa	39	8	141	8			40	459.
23	Tadotu	34	17	133	46			42	519.5
24	Okayama	34	40	133	54			55	501.
25	Matuyama	33	50	132	45			58	623.
26	Hamada	34	54	132	04	12	00	06	662.
27	Hakodate	41	47	140	43			13	734.
28	Ooita	33	14	131	37			24	742.
29	Simonoseki	33	57	130	56			22	780.
30	Hukuoka	33	35	130	25			22	837.5
31	Kagosima	31	34	130	33			36	910.
32	Nagasaki	32	44	129	52			30	915.
33	Kusiro	42	59	144	24			33	960.
34	Oodomari	46	59	142	46		01	20	1334.
35	Naha	26	13	127	41			19	1494.
36	Dairen	38°	54	121	38		01	48	1615.
37	Shanghai	31	11.5	121	25.8		02	15	1719.
38	Taihoku	25	02	121	31		01	49	2045.
39	Hongkong	22	18.2	114	10.5		04	00	2822.
40	Manila	14	34.7	120	58.6		04	11	2930.

Remark: Time of commencement is adopted from Professor A. Imamura's Paper (Rep. Imp. Earthq. Invest. Commit. (in Japanese) **100** A (1925) 31). The time of commencement at Taihoku was too earlier by one minute, perhaps being due to mistake ef calculation of minute-marks.

The author tentatively assumed the epicentre of this earthquake as $\varphi=35°\ 16'$ and $\lambda=139°\ 20'$ which is somewhat different from that determined by Professor Imamura and rather near to that determined by Professor S. T. Nakamura.(1) This assumed epicentre is not inconsistent even with the seismogram at Hongô, if the duration of the preliminary tremor is taken as $9.^s8$ which can be clearly seen from the record.(2)

From Fig. 11 it is almost beyond doubt that in this case also the phase exactly corresponding to $\bar{P}$ existed. If the epicentre determined by Professor Imamura is adopted, $d^2T/d\Delta^2$ for the $\bar{P}$ phase has considerable positive value within 120 km. or so, so that the depth of the origin generating $\bar{P}$ waves must be 40 km. or more which would not give rise to the $\bar{P}$ waves as apparent from

(1) S. T. Nakamura, l. c. p. 18.

(2) See Fig. 1 of Prof. Imamura's report, l. c. p. 18.

the mechanism of occurrence of that phase. This is another reason why the author assumed the above stated origin. With regard to the P^* waves, discussion will be found later.

It is remarkable that the P curve is situated far below the $\bar{P}$ curve and seems not to intersect with each other. This point will also be discussed in the next section.

V. Concluding Remarks.

From the foregoing examples, it is almost doubtless that three phases P, P^* and $\bar{P}$ are observed in Japan too, at least in cases shown above. In the following, some remarks will be given with respect to each phase and other allied problems.

The $\bar{P}$ phase.

In all the five cases above shown, a time-distance curve characterised by $d\Delta/dT=5.0$ km/sec. has been observed clearly. This fact implies that the origin of this phase of waves is situated in a shallow place less than some twenty kilometres deep, that is to say that the depth of origin must be shallower than that of the first discontinuity. In addition to this, closer study of its time-distance curve will show that it is practically a straight line even in the region very near to the epicentre. Usually, curves are drawn so that $d^2T/d\Delta^2>0$ near the epicentre. In present cases, however, such is not the case within the limit of observational errors. H. Jeffreys stated in his paper,(1) "....I have called attention, ..., to the possibility that the compressional movement originally sent out from the focus may be inappreciable and that the observed movement arises only by reflection of S_g(2) movement at the outer surface. If this is true the apparent depth of the focus found from the compressional waves is zero...." Whether or no his case corresponds to these cases is not certain for I have not yet come across to his full paper. And yet, these cases seem formally correspond to his one. Indeed, such a case may be probable in a special mechanism of occurrence of earthquakes. In general, however, such a consideration is beyond author's comprehension. Moreover the author does not know how such a consideration reconciles with the P or other phase.

Returning to the original problem, these earthquakes were all severe ones

(1) H. Jeffreys, Gerlands Beitr. z. Geophys. **17** (1927) 424–425.

(2) S_g stands for current notation $\bar{S}$.

with remarkable terrestrial disturbances such as fault etc. It may be quite natural that elastic vibrations will be excited with the formation of such disturbances.To what depth such disturbances extend is not certain generally. Their extension, however, may very probably be confined within several kilometers deep in ordinary cases. Indeed, Dr. N. Nasu[1] has found that origins of after-shocks of the great Tango earthquake, March 7, 1927 are almost confined within some fifteen kilometers, thus furnishing a supposition that the origin of the waves directly accompanied with a fracture would also be at a certain point within such a depth.

If the $\bar{P}$ waves is interpreted as a wave of such an origin, the observed fact may very naturally be understood. This view is very akin to that of certain authors mainly of geological school, who implicitly suppose that formation of faults is nothing but an earthquake phenomenon.

The P phase.

From Figs. 6, 8, 10 and 11, it will be seen that a dot representing the P phase seems to appear for the first time at an epicentral distance 120 km. or so. A more remarkable fact is, however, that the appearance of the P phase is much earlier than $\bar{P}$ ordinarily expected. This point is especially clear in the case of the Kwantô earthquake (Pl. VIII. Fig. 11). Even if the P curve were prolonged, it would not intersect with the $\bar{P}$ curve. In ordinary text-figures explaining them, the time of the first appearance of the P phase is so situated that it is later than that of the $\bar{P}$ phase corresponding to that distance. The present experience seems to be irreconcilable to it. Therefore, it is necessary to examine this point carefully.

Assuming that all P, P^* and $\bar{P}$ waves are emitted from a point source and their respective velocity of propagation is constant in each layer, their time-distance relations will be given as follows:[2]

for $\bar{P}$, $$\tau_1=\frac{\sqrt{\Delta^2+f_1^2}}{v_1},$$

,, P^*, $$\tau_2=(2d_1-f_2)\frac{\cos i_1}{v_1}+\frac{\Delta}{v_2}, \quad \Delta>(2d_1-f_2)\tan i_1,$$

and

for P, $$\tau_3=(2d_1-f_3)\frac{\cos i}{v_1}+2d_2\frac{\cos i_2}{v_2}+\frac{\Delta}{v_3},$$

(1) N. Nasu l. c. p. 10.

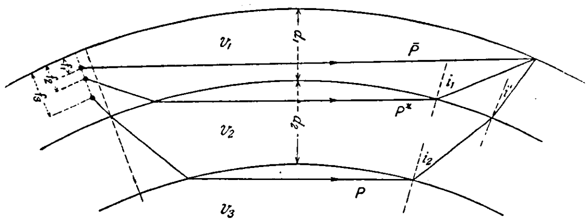
(2) Effect of curvature of the earth's surface can be neglected for near stations.

$$\varDelta > (2d_1 - f_3)\tan i' + 2d_2 \tan i_2,$$

where $\sin i_1 = \dfrac{v_1}{v_2}$, $\sin i' = \dfrac{v_1}{v_3}$ and $\sin i_2 = \dfrac{v_2}{v_3}$.

The meaning of notations will be understood by the next figure. (Fig. 12.)

Fig. 12.



The above shown expressions hold good when f_1, f_2 and f_3 are all less than d_1. If $d_1 + d_2 > f_3 > d_1$, then

$$\tau_3 = (d_1 + 2d_2 - f_3)\frac{\cos i_2}{v_2} + d_1\frac{\cos i'}{v_1} + \frac{\varDelta}{v_3},$$

$$\varDelta > (d_1 + 2d_2 - f_3)\tan i_2 + d_1 \tan i'.$$

When $d_1 + d_2 > f_1 > d_1$, the expression for τ_1 will be much complicated as was given in our former paper.(1) By the way it will easily be shown from expressions for τ's that $\partial^2\tau_1/\partial\varDelta^2$ may be positive for a shorter distance, however, $\partial^2\tau_2/\partial\varDelta^2$ or $\partial^2\tau_3/\partial\varDelta^2$ cannot be so, which fact is sometimes mistaken carelessly.

Returning to the present problem, it will be sufficient if attention will be payed for the distance $\varDelta_0 = (2d_1 - f_3)\tan i' + 2d_2 \tan i_2$ for the case $d_1 > f_3$, and $\varDelta_0 = (d_1 + 2d_2 - f_3)\tan i_2 + d_1 \tan i'$, for the case $d_1 + d_2 > f_3 > d_1$. In the following, τ's corresponding to that distance will be denoted by adding prefix, 0, such as ${}_0\tau_3$. For the P^* waves, $\varDelta_0 = (2d_1 - f_2)\tan i_1$ and ${}_0\tau_2 = (2d_1 - f_2)\dfrac{1}{v_1 \cos i_1}$.

Thus ${}_0\tau_1 - {}_0\tau_2 = (2d_1 - f_2)\dfrac{1}{v_1 \cos i_1}(\sin i_1 - 1) + \dfrac{f_1^2}{2v_1\varDelta_0}$. From assumption, as $f_1 < d_1$, the last term is small, so that ${}_0\tau_1 - {}_0\tau_2$ is negative. This is not inconsistent with the observed cases.

For the P waves

$${}_0\tau_3 = (2d_1 - f_3)\frac{1}{v_1 \cos i'} + \frac{2d_2}{v_2 \cos i_2},$$

and

$${}_0\tau_1 = (2d_1 - f_3)\frac{\tan i'}{v_1} + \frac{2d_2}{v_1}\tan i_2 + \frac{f_1^2}{2v_1\varDelta_0}, \text{ when } f_3 < d_1,$$

(1) T. Matuzawa, K. Hasegawa and S. Haeno, this Bull. 4 (1928) 96.

where $\Delta_0=(2d_1-f_3)\tan i'+2d_2\tan i_2$.

Thus

$$ {}_0\tau_1-{}_0\tau_3=\frac{2d_1-f_3}{v_1\cos i'}\left(\frac{v_1}{v_3}-1\right)+\frac{2d_2}{\cos i_2}\frac{v_2^2-v_1v_3}{v_1v_2v_3}+\frac{f_1^2}{2v_1\Delta_0}. $$

If $f_1<d_1$ and $d_1+d_2>f_3>d_1$,

then

$$ {}_0\tau_3=(d_1+2d_2-f_3)\frac{1}{v_2\cos i_2}+\frac{d}{v_1\cos i'}, $$

and

$$ {}_0\tau_1=(d_1+2d_2-f_3)\frac{\sin i_2}{v_1\cos i_2}+\frac{d_1\sin i'}{v_1\cos i'}+\frac{f_1^2}{2v_1\Delta_0}, $$

$$ \Delta_0=(d_1+2d_2-f_3)\tan i_3+d_1\tan i'. $$

Thus

$$ {}_0\tau_1-{}_0\tau_3=(d_1+2d_2-f_3)\frac{1}{\cos i_2}\left(\frac{v_2^2-v_1v_3}{v_1v_2v_3}\right)+\frac{d_1}{v_1\cos i'}\left(\frac{v_1}{v_3}-1\right)+\frac{f_1^2}{2v_1\Delta_0}. $$

The values of v_3 and d_2 are not exactly certain in the present case. Even if $v_3=6.5$ km/sec. is tentatively assumed as apparently to be seen from Fig. 6, and $d_2=30$ km. which value is supposed to be probable from some of other phenomena, ${}_0\tau_1-{}_0\tau_3$ is negative.

Thus the observed fact cannot be explained by only such a consideration. This point will be examined from somewhat different consideration.

Assuming that P wave is emitted from the seismic origin simultaneously with the $\bar{P}$ waves, from Fig. 6, ${}_0\tau_3=18.^s5$ and $\Delta_0=116$ km. are measured. Thus following simultaneous equations are obtained.

$$ \left.\begin{aligned} &(2d_1-f_3)\frac{1}{v_1\cos i'}+\frac{2d_2}{v_2\cos i_2}=18.5,\\ &(2d_1-f_3)\tan i'+2d_2\tan i_2=116. \end{aligned}\right\} $$

$d_1=20$ km., $v_1=5.0$ km/sec., $v_2=6.1$ km/sec. have been already determined. Taking into account of these values, values of v_3 and d_2 satisfying these equations cannot be found within the domain $f_3<20$ and $v_3>v_2$.

If $d_1+d_2>f_3>d_1$,

then

$$ \left.\begin{aligned} &(d_1+2d_2-f_3)\tan i_2+d_1\tan i'=116\\ &\frac{d_1+2d_2-f_3}{v_2\cos i_2}+\frac{d_1}{v_1\cos i'}=18.5. \end{aligned}\right\} $$

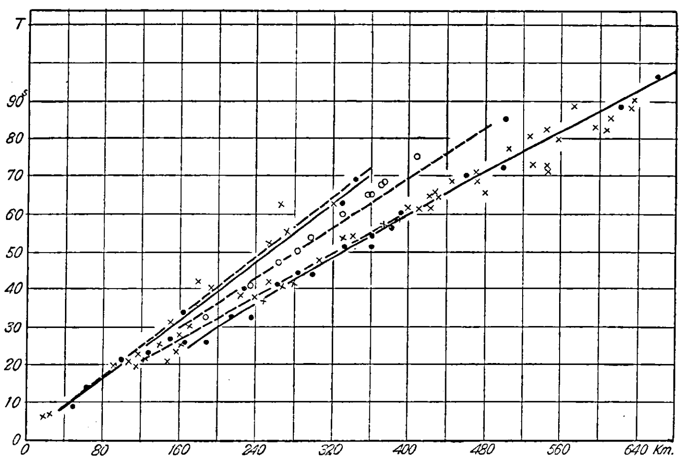
Taking the former values, an equation for dertermining v_3 can be obtained,

$$116\, v_3 - 689 \doteqdot -\frac{49}{\sqrt{1-\frac{v_1^2}{v_3^2}}}.$$

This equation has not such a solution as $v_3 > v_2$. Therefore, another way of explanation must be attempted.

In short, the observed fact seems to be very naturally explained by taking into account of a certain kind of effective dimension of the hypocentral region generating the P waves. If this is the case, *effective* epicentral distances of near stations must be smaller than those measured from an approximate middle point of epicentral region. This idea was already elucidated by Mr. T. Hirano[1] in his elegant paper on the velocity of propagation of the preliminary tremors of the great Kwantô earthquake and the area of the Seismic Origin (written in Japanese), though his method of treating the data was, I think, somewhat unsatisfactory. In fact the great Kwantô earthquake, Sept. 1, 1923 was of a much greater scale than that of the Tango earthquake or others. This fact seems to be seen by comparison of Fig. 6 with Fig. 11, or Fig. 13, though not very distinct owing to some uncertainty of observed data.

Comparison of two Great Earthquakes.
The Tango Earthquake and The Kwanto Earthquake.



Cross: Tango Earthquake
Dot: Kwantô Earthquake
Fig. 13.

Thus a consideration is at hand that a hypocentral *point* of an earthquake could not be determined by observing the P wave, but only a hypocentral

(1) l. c. p. 18.

region may be determined with accuracy of the order of magnitude of wave length of disturbances. This consideration may be very akin to that of the wave mechanics by Schrödinger in quantum theory. Thus the time-distance curve of the P phase in a definite meaning may be determined by observation of very intense and very local shocks. The Etigo earthquake Oct. 27, 1927 was unfortunately in too shallow depth to produce the P movement.

From above considerations, a supposition with regard to generation of P waves follows. In discussion of the $\bar{P}$ movement, it was supposed that the movement may be very probably emitted from a point (of course in a statistical sense but may be far definite compared with the case of P) very near to the surface. On the other hand, with respect to the P movement somewhat wider range must be considered as its origin. Thus the origin of each kind of waves must be taken as different, as was implicitly assumed in the foregoing discussions. This point must be more closely examined, from the point of view of occurrence of such great earthquakes as to produce superficial terrestrial disturbances. It is very probably considered that destruction of earth's crust such as to produce the $\bar{P}$ movement is a result of accumulation of potential energy not only in that part but also in a much wider part connected in a certain manner with the former part. The author is inclined to believe that the accumulation of energy producing the $\bar{P}$ movement takes place in the superficial layer mainly in the form of strain energy and that producing the P movement will do in the lower layer. The origin of energy may be gravitational or endogen dynamical. Some kind of endogen dynamical process may play an important rôle in converting the gravitational energy into the kinetic energy. Of course, strain energy caused by endogen dynamical process itself will also not be excluded.

Thus at a certain stage of accumulation of strain, by destruction of material at a certain point, release of accumulated strain will take place, generating the P and $\bar{P}$ waves almost simultaneously. In such a case, the accumulation of energy corresponding to the $\bar{P}$ movement may be more localised as a result of the mosaic structure of the superficial crust than that of the P in a deep region. The mechanism of emission of the movement which can be observed as P with sufficient magnitude at a remote station is perhaps a certain mode[1] of motion of somewhat *large* part as a whole of the upper layer directly trans-

(1) It may be bodily movement of the so-called crustal block or elastic vibration of a certain oscillator. It seems to me. however, that the latter may be more probable.

mitted to the lower layer or of the lower layer itself. The fact that the period of the P movement is long(1) (very often nearly equal to that of pulsatory motion) may be very naturally understood by such a mechanism.

The following factor must also be taken into account. The velocity of propagation of elastic waves when they are propagated releasing initial elastic strain is given in the elegant paper of K. Uller(2) as follows:

For the dilatational wave

$$v_p^2 = \frac{\left(\varepsilon_v + \frac{4}{3}\varepsilon_g\right)(\mathfrak{N}, \text{grad div } \mathfrak{S})}{\rho\,(1-\text{div } \mathfrak{S}_0)\,(\mathfrak{N}, \text{grad div }(\mathfrak{S}-\mathfrak{S}_0))} + \text{higher terms},$$

and for distortional waves

$$v_s^2 = \frac{\varepsilon_g\,[\mathfrak{N}, \text{rot rot } \mathfrak{S}]}{\rho\,(1-\text{div } \mathfrak{S}_0)\,[\mathfrak{N}, \text{rot rot}(\mathfrak{S}-\mathfrak{S}_0)]} + \text{higher terms},$$

where ε_v is the bulk modulus

ε_g ,, ,, rigidity ,,

ρ ,, ,, density

$\mathfrak{S}$,, ,, strain vector

$\mathfrak{S}_0$,, ,, initial strain vector

$\mathfrak{N}$ is the unit vector normal to wave front

( ) means the scalar product of vectors

and [ ] ,, ,, vector ,, ,, ,, .

Therefore in a region where $\mathfrak{S}_0 \neq 0$, that is, in the hypocentral region, waves may be propagated very quickly, thus apparently showing a finite dimension of source even if waves are originated from a point. Hence the P wave appears somewhat earlier than expected.

By specifying regions where the energy of such an earthquake as stated above is stored, the mode of time-distribution of earthquakes related to a main shock may naturally be understood.

After-shocks of small intensity may be understood as a kind of irreversible process of somewhat gradual release of residual strain through the region destructed severely. The result of Mr. N. Nasu(3) will furnish an evidence of this

(1) Dissipation of quick motion only cannot explain the fact. Indeed very deep earthquakes show superposition of quick vibrations from the commencement even observed at a remote station.

(2) K. Uller, Gerlands Beitr. z. Geophys. **15** (1926) Hft. 2.

(3) N. Nasu, l. c. p. 18.

theory. The reason why the process of release takes place intermittently can easily be understood as the process is irreversible. Thus in such a region, a theory of after-shocks such as that of F. Omori(1) or of S. Kusakabe(2) will be applied. S. Kusakabe's idea that the number of after-shocks in a unit time may be proportional to the rate of recovery of elastic after-effect may naturally be understood by supposing such a mechanism.

On the other hand, we have experienced some examples of successive occurrence of strong earthquakes of nearly equal intensity at nearly the same region.(3) One of the most remarkable examples may be that of the great Tazima earthquake, May 23, 1925 and the great Tango earthquake, March 7, 1927. Such process of occurrence is difficult to understand if the region of accumulation of a certain kind of potential energy is confined only in a superficial layer of crust where remarkable terrestrial disturbances take place. On the contrary, if storage of energy somewhat deeprooted is released by a local fracture of the superficial crust, such process of successive occurrence may result with high probability. Change of topography with a vast scale will also be a natural consequence. In the above reasoning, fracture in the lower layer, too, is not denied of course.

Indeed, in the Kwantô District, the distribution(4) of seismic hypocentre has been found mainly between twenty and fifty kilometres deep which is the prabable thickness of the second layer.

On the case of such a great earthquake as that of Kwantô and in such a geologically week region as Kwantô, it may very naturally be understood that fracture may proceed very quickly to a deeper region.

The P^* phase.

Existence of this phase was clearly seen on the occasions of the Etigo earthquake, Oct. 27, 1927, the great Tazima earthquake, May 23, 1925, the great Tango earthquake, March 7, 1927, and the Tango earthquake April 1, 1927. Even in the case of the Great Kwantô earthquake, Sept. 1, 1923, its existence is inferred though somewhat vaguely. In Fig. 13, the circle is plotted according to the data of Mr. S. Kunitomi,(5) reported as the $P-\bar{P}$ difference.

(1) F. Omori, Rep. Imp. Earthq. Invest. Comm. (in Japanese) **2** (1893) 103.
(2) S. Kusakabe, Publ. Imp. Earthq. Invest. Comm. **17** (1904) 1–48.
(3) For example, see F. Omori's paper. Rep. Imp. Earthq. Comm. **94** (1921) 16.
(4) T. Matuzawa, K. Hasegawa, S. Haeno, this Bull. **4** (1928) 101.
(5) S. Kunitomi, Journ. Meteor. Soc. Japan [ii] **3** (1925) 291.

From the present view point, they are rather interpreted as the $P-P^*$ difference.

The time-distance curve of the P^* movement is nearly straight, and the effect of dimension of source of energy can hardly be detected. From this reason, the place where that movement is emitted may not be far different from that of the $\bar{P}$ phase, or rather be regarded the same in usual cases,[1] and accordingly is started in the uppermost layer. Even if the origin of this phase is situated in the second layer, a phase can be detected corresponding to the P^* phase, although the mechanism becomes rather similar to that of the $\bar{P}$ phase.[2] In such a case the time of appearance of the P^* phase will be somewhat earlier than the former case, and $d^2T/d\Delta^2$ may be positive. In cases of earthquakes such that destruction of material takes place only at a very deeper place than the thickness of the first layer, the $\bar{P}$ phase characterised by $d\Delta/dT=5.0$ km/sec. will disappear. Thus it may very naturally be expected that the apparent velocity of propagation of $\bar{P}$ waves determined by taking mean values takes an intermediate value between 5.0 and 6.1 km/sec.

April, 1928.

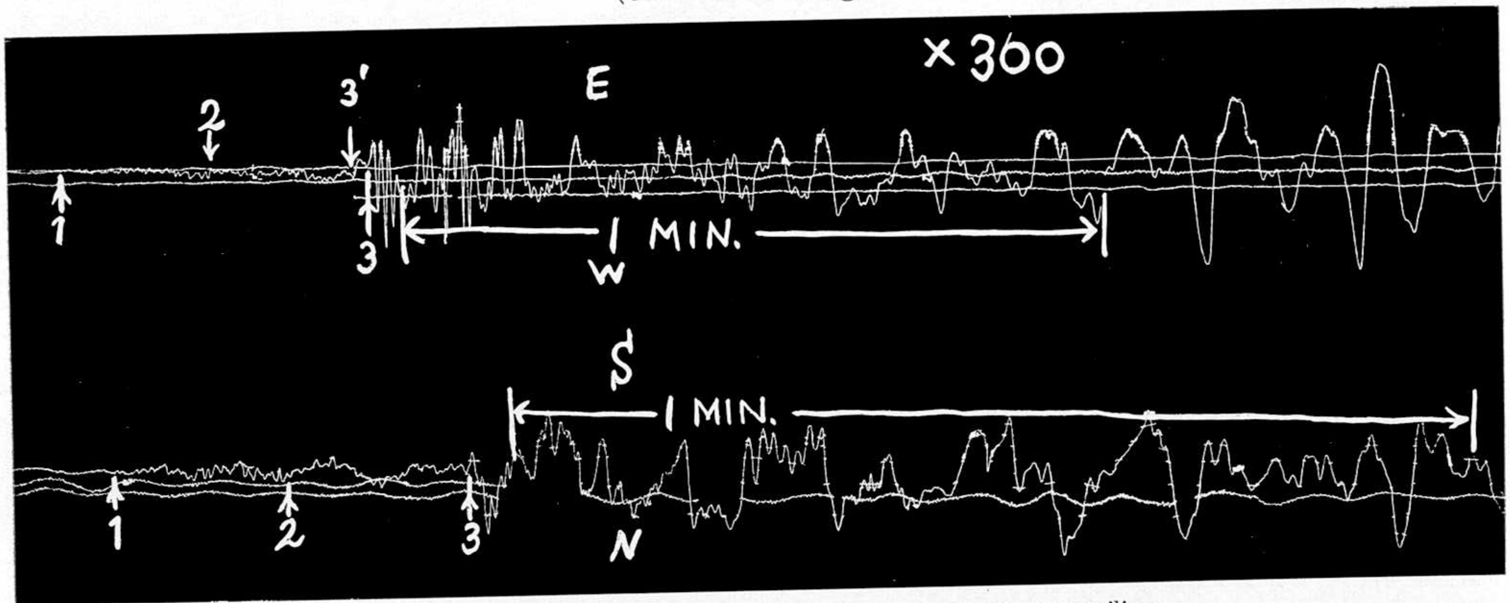
Seismological Institute, Imperial University, Tokyô.

(1) The case of the Etigo earthquake may be regarded as such.

(2) Examples of such a case will be shown in the next paper which will be published in the next volume of this bulletin.

Seismograms of the Etigo earthquake, Oct. 27, 1927.

(Observed at Hongô)



The slow motion between 2-3 may be the pulsatory motion then prevailing.

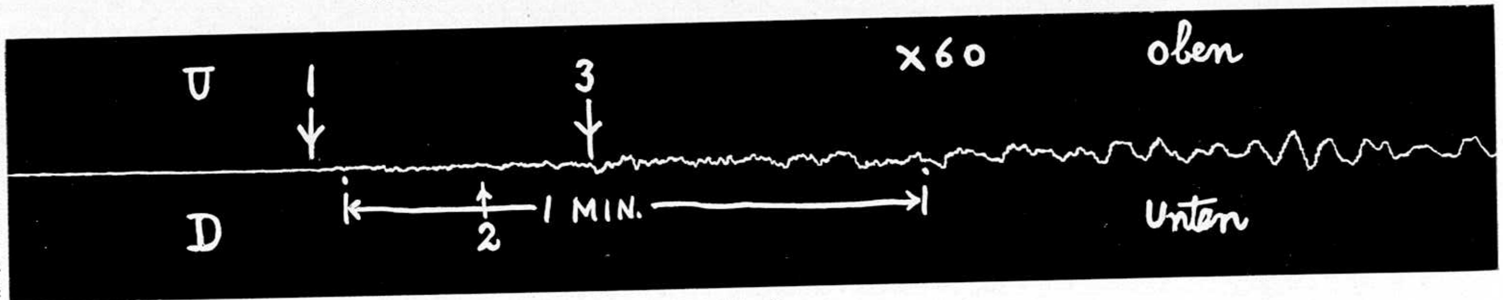


Fig. 1.

（震研彙報第五號、圖版、松澤）

Seismogram of the Etigo earthquake, Oct. 27, 1927.
(Observed at Titibu)

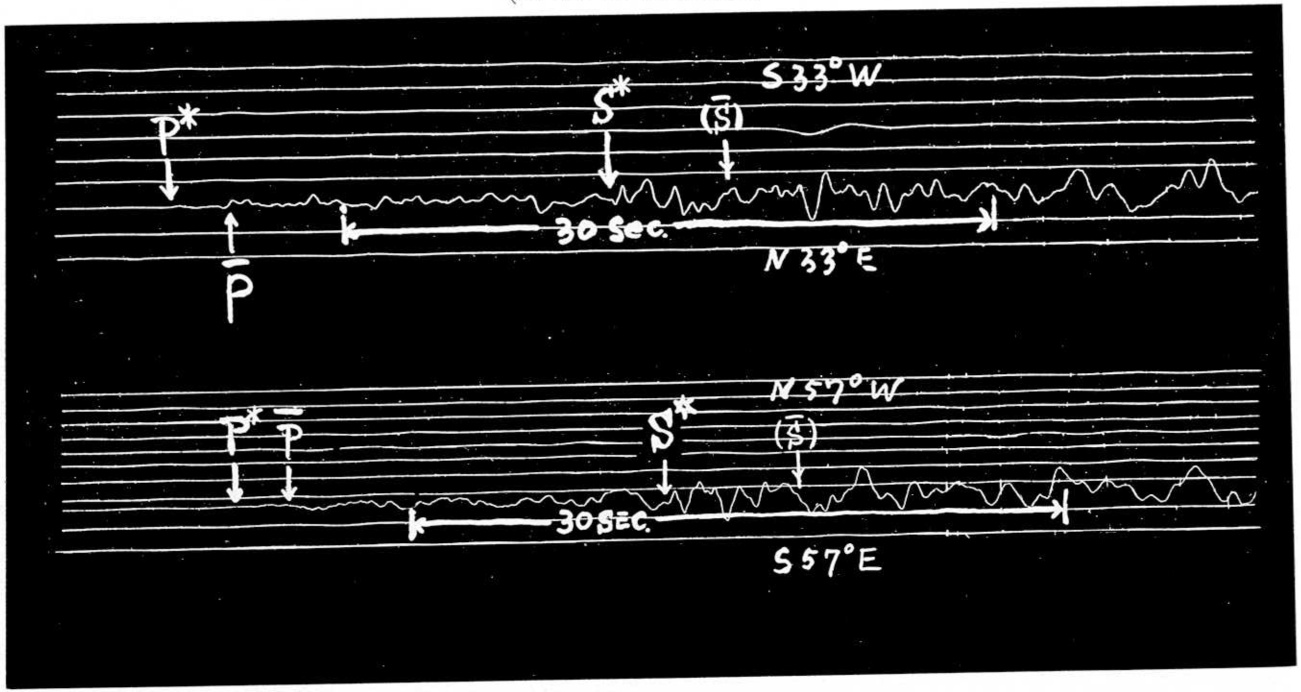
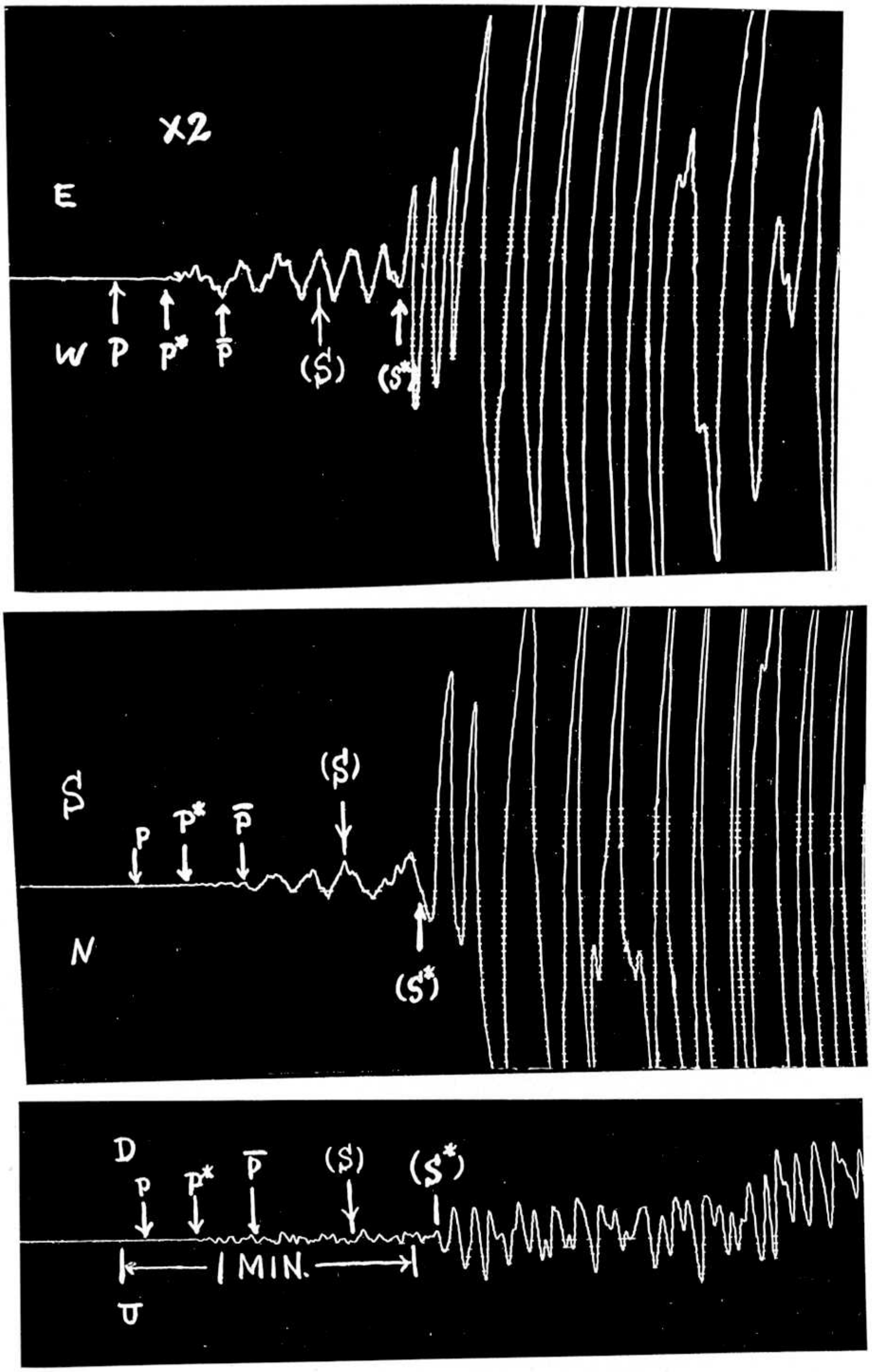


Fig. 2

(震研彙報第五號、圖版、松澤)

Tango Earthquake, March 7, 1927.
(Observed at Hongô)

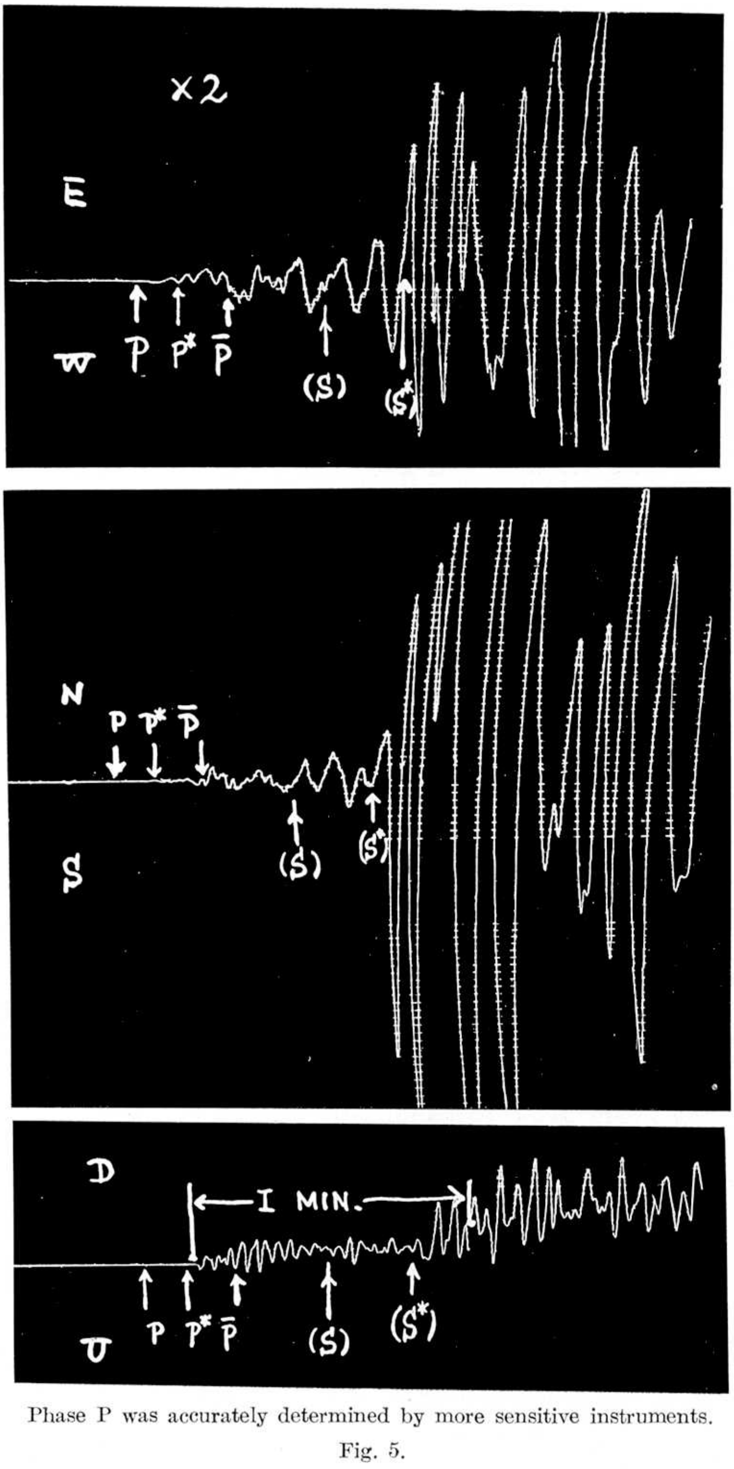


Phase P was determined by more sensitive instruments.

Fig. 4.

（震研彙報第五號、圖版、松澤）

Tango Earthquake, March 7, 1927.
(Observed at Kamakura)

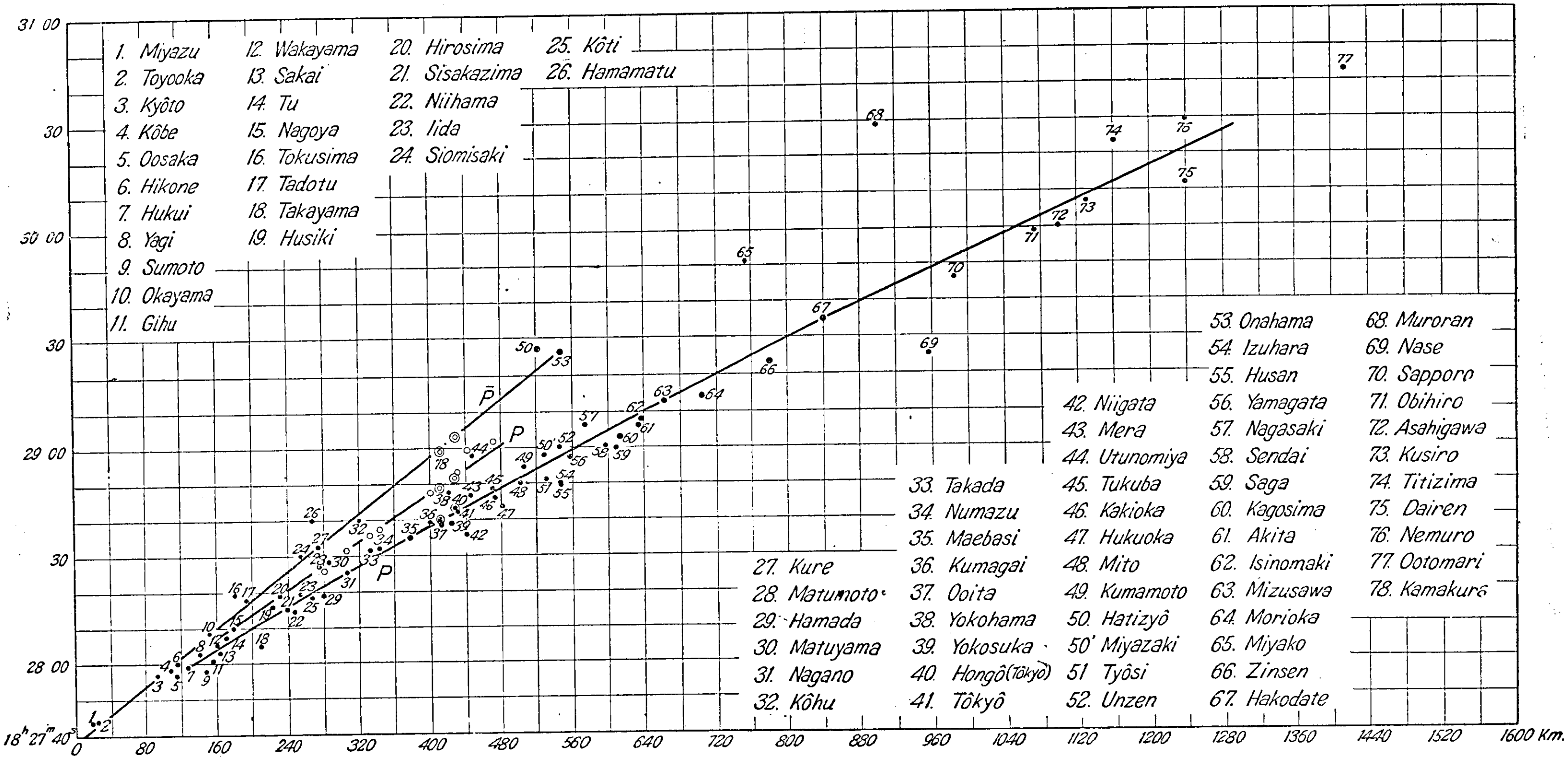


Phase P was accurately determined by more sensitive instruments.

Fig. 5.

（震研彙報第五號、圖版、松澤）

Time-distance curve of the Great Tango Earthquake, March 7, 1927.



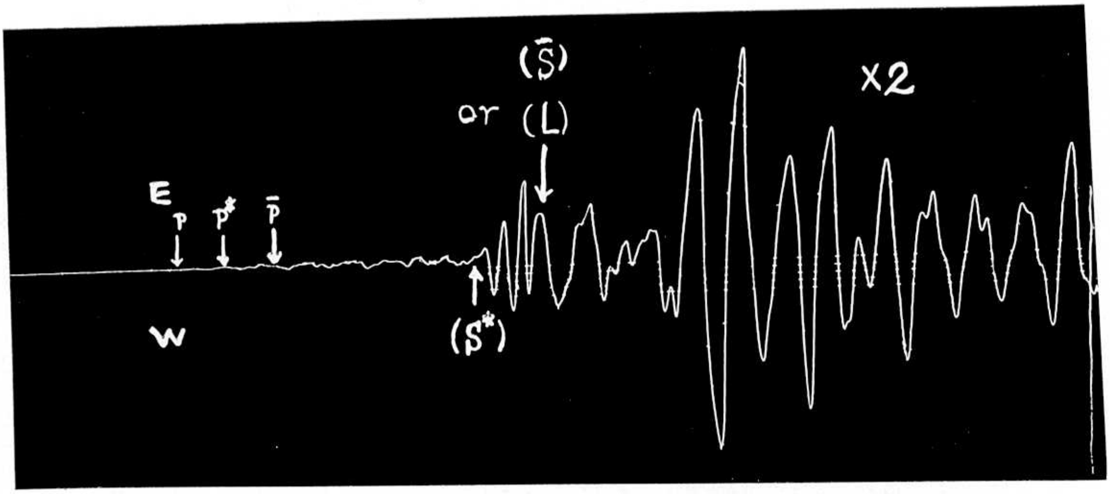
Curve $\overline{P}$: $T = -2.0 + 0.20\triangle$

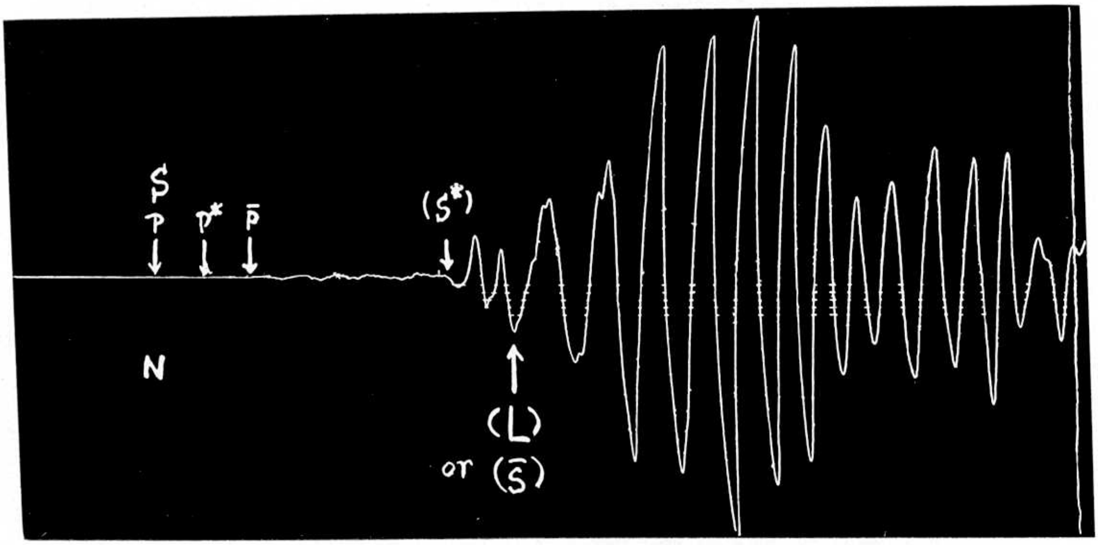
" P^*: $T = -0.075 + 0.169\triangle$

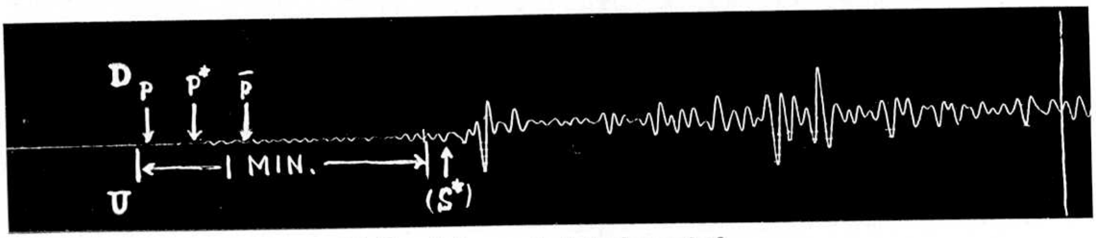
" P : $T = -0.43 + 0.1539\triangle - 2.08 \times 10^{-5}\triangle^2\ (120 < \triangle < 400)$; $-1.08 + 0.1522\triangle - 1.875 \times 10^{-5}\triangle^2\ (400 < \triangle < 600)$; $8.0 + 0.1275\triangle\ (600 < \triangle < 800)$.

Fig. 6.

Tazima Earthquake, May 23, 1925.
(Observed at Hongô)







S,* S̄ and L were tentatively marked.

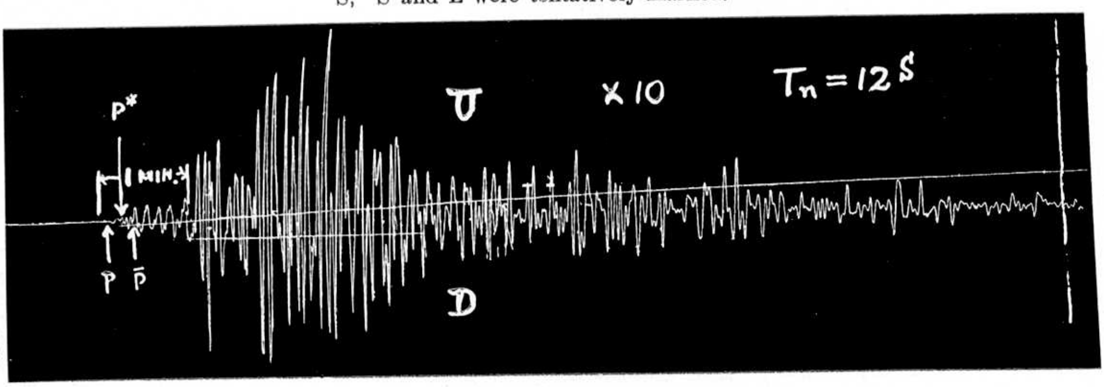
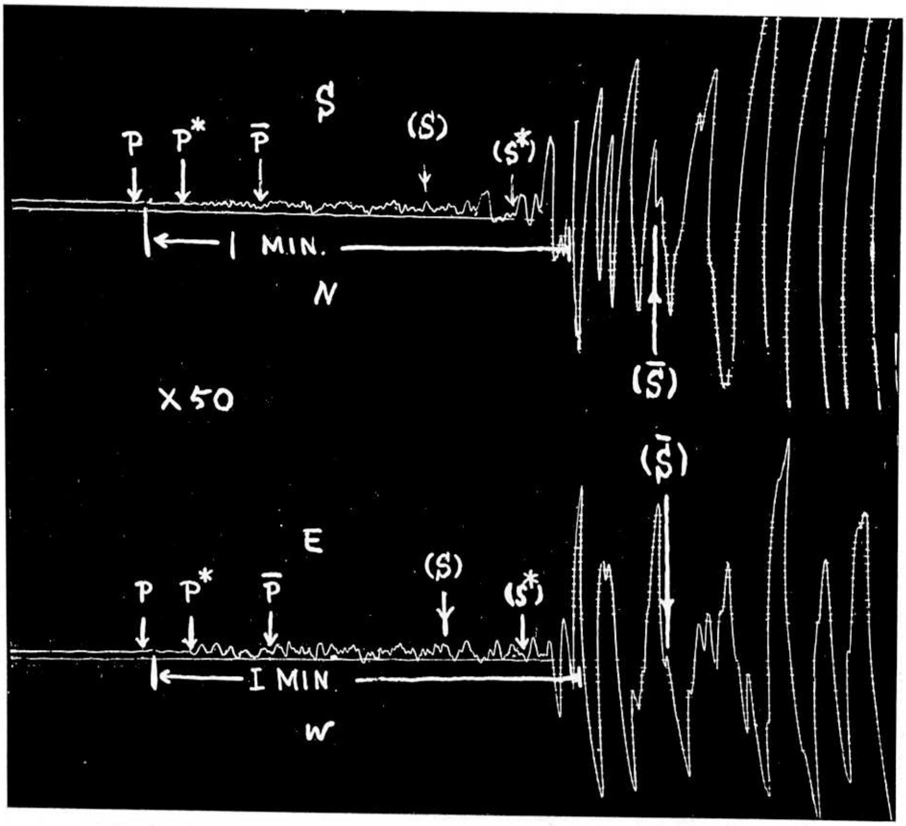


Fig. 7.

(震研彙報第五號、圖版、松澤)

Tango Earthquake, April 1, 1927.
(Observed at Hongô)

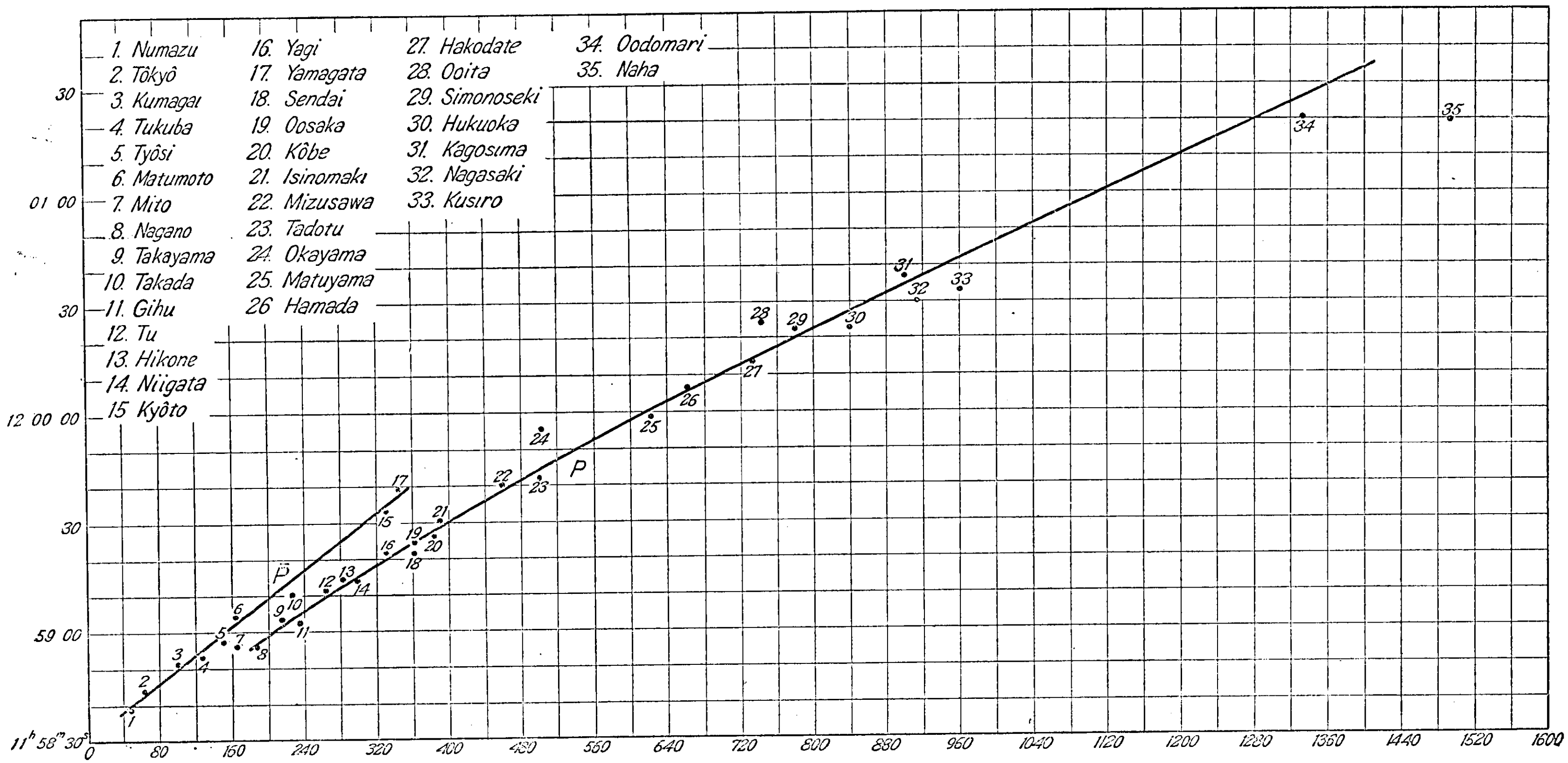


The S phase was tentatively classified, but is not certain accuraetly.

Fig. 9.

（震研彙報第五號、圖版、松澤）

Time-distance curve of the Great Kwantô Earthquake, Sept. 1, 1923.



(To be continued to the next sheet.)

Curve $\overline{P}$: $T=0.48+0.194\triangle$

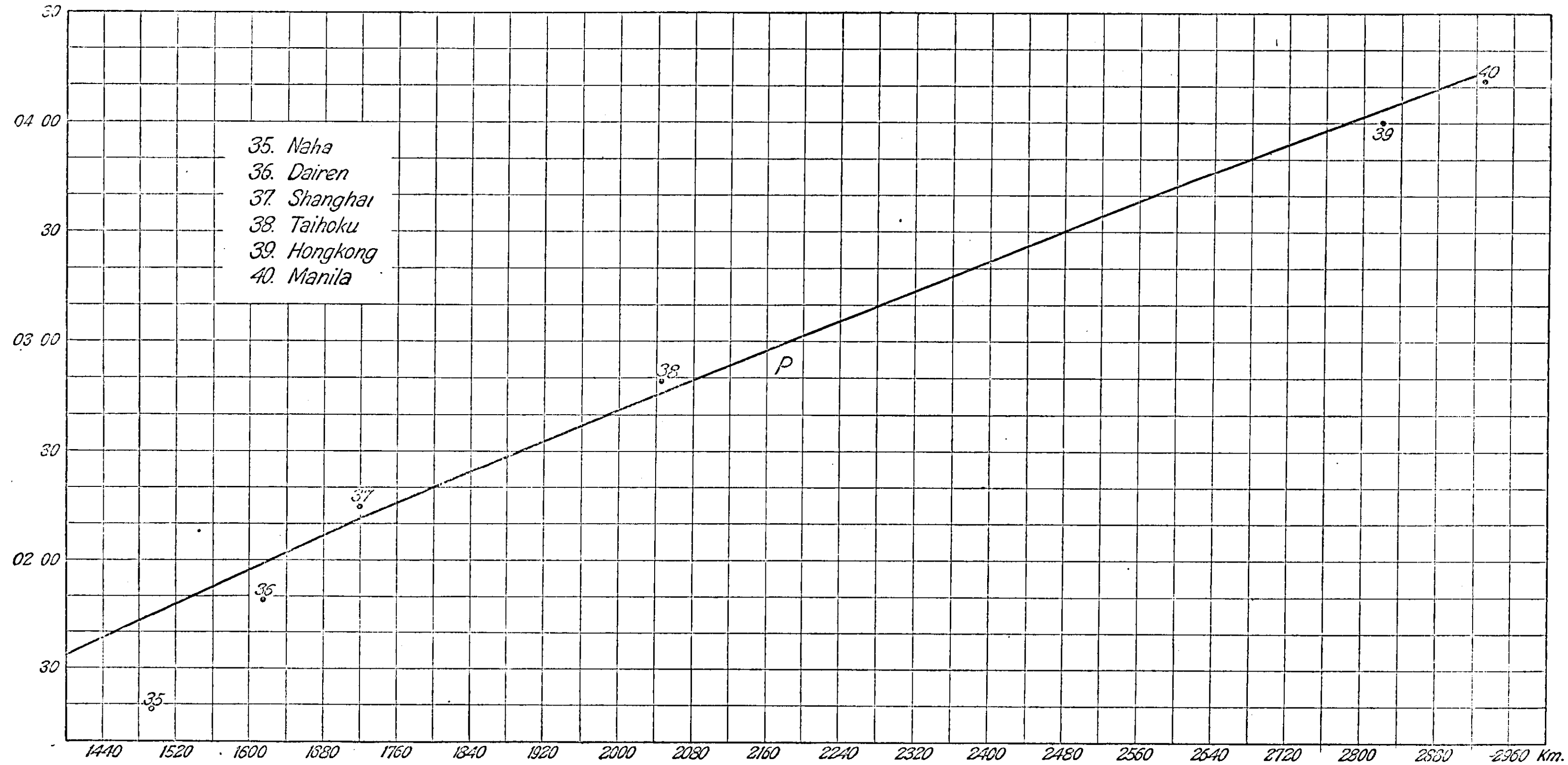
P: $T=-2.81+0.163\triangle-3.9\times10^{-6}\triangle^2-2.8\times10^{-8}\triangle^3$ $(200<\triangle<600)$

$T=12.538+0.1270\triangle-3.31\times10^{-6}\triangle^2$ $(600<\triangle<1400)$

} origin of time. $11^h58^m30^s$ (L. M. T. of $\lambda=135°$E)

Fig. 11.

Time-distance curve of the Great Kwantô Earthquake, Sept. 1, 1923.



Curve P: $T=1.000+0.143\triangle-9.01\times10^{-6}\triangle^2$ $(1400<\triangle<3000)$; origin of time. $11^h58^m30^s$ (L. M. T. of Long. 135°E) (continued)

Fig. 11.