Observation of some Recent Earthquakes and their Time-distance Curves.

(Part II).

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Nukigaki (abstract in Japanese.)

(1) Distortion no Nami ni oitemo Dilatation no Nami no Baai to dôyô ni S, S* oyobi $\overline{\mathrm{S}}$ no mitôri no Nami ga zissai ni kwansoku sareru kotowo tasikameta.

(2) Onoono Nami no araware-yasui Zyôken wo osihakari Zisin no Karada ni kanziru Kuiki no Mondai nimo hureta.

(3) Sore ni kwankeisite Syoki-Bidô-Keizoku-Zikan to Singen-Kyori tono 1-zi Siki no Keisû no iroiro na Atae no Imi wo gironsita.

I. INRODUCTION.

In part I, the author investigated the mode of propagation of seismic waves of dilatational character, and showed that even in such an island area as Japan three phases of movements, P, P* and $\overline{\mathrm{P}}$ can be observed if conditions are favourable.

As a natural consequence of this, a similar investigation with regard to the propagation of seismic waves of distortional character becomes necessary. It forms the main subject of this paper.

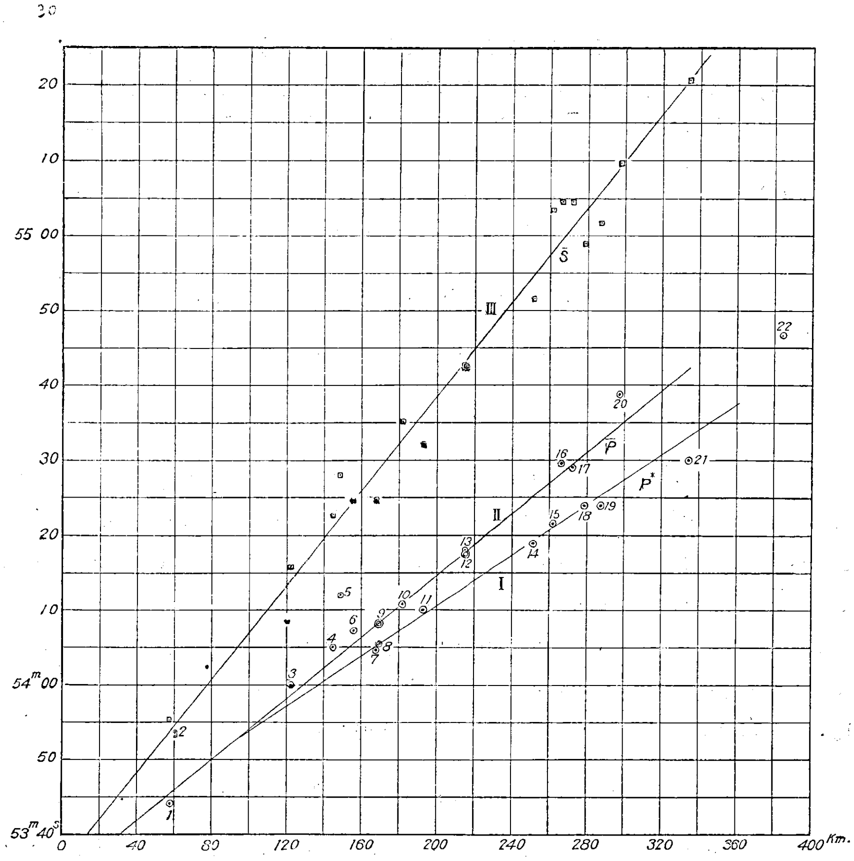
II. REVIEW OF SOME RECENT EARTHQUAKES.

As the distortional movements are superposed on the dilatational movements, determination of incidence of each phase is in general less accurate than that of the P phase. By selecting favourable cases and by means of suitable interpretation, however, the author has been able to determine a set of time-distance curves corresponding to each phase, which turned out fairly useful for practical purpose.

The Etigo earthquake of Oct. 27, 1927.

This example is the same as that investigated in part I, and utilising the same data in Table I, part I, a set of time-distance curves is constructed as shown in Fig. I.

Time-Distance Curve of Etigo Earthquake
of Oct. 27, 1927.



(Refer to Fig. 3 in Part 1.)

Fig. 1.

The points belonging to curve III were plotted in such a manner that the reported duration of the preliminary tremor is represented as the time measured from the corresponding point on curve I or II, according as the reported time of commencement belong either to curve I, or to curve II. Curve III is characterised by $\frac{\partial \Delta}{\partial T}=3.16$ km/sec. The observed value at Hongô (shown by double square in Fig. 1) is quite in accord with that curve. If this value of velocity is interpreted as that of the $\overline{S}$ phase, it seems somewhat too small compared with the current value 3.3 km/sec. On the other hand, Dr. N. Nasu(1) investigated the proportional constants of the linear equation between the hypocentral distance and the duration of the preliminary tremor ($y=kt$) in the case of after-shocks of the great Tango earthquake of March 7, 1927, hypocentres of which were mainly distributed within a depth of some fifteen kilometres, and obtained the value 8.4 km/sec. It will very naturally be inferred that this value corresponds to that due to the $\overline{P}$ and the $\overline{S}$ waves in the uppermost layer. Adopting 5.0 km/sec. as the velocity of propagation of the $\overline{P}$ waves which was obtained in part I, that of the $\overline{S}$ phase can be calculated as 3.13 km/sec., which is well in accord, within the limit of errors, with the value obtained above. Thus, curve III may very naturally be interpreted as that of the $\overline{S}$ movement.

In this case, the S^* movement seems to have been difficult to identify, due perhaps to a similar reason as discussed in part I. Indeed, closer examination of the seismogram recorded at Titibu (Pl. II. Fig. 2 in part I) will show the existence of the S^* and S phases. Other examples of identification of the S^* phase will be shown later.

The Earthquake of Feb. 4, 1926.

This earthquake occurred far off the coast of Erimo-saki, Hokkaidô, and was feebly felt by our unaided senses even at Tôkyô, some 670 km. distant from the seismic origin. It has been the subject of close study by Dr. S. I. Kunitomi(2) but as my views differ from his in certain respects, the subject is dealt with in the following paragraphs.

In this case, the distribution of the duration of preliminary tremor exhibited a peculiar manner as was shown in Fig. 3 of Mr. Kunitomi's paper,

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(1) N. Nasu, Proc. Imp. Acad. 4 (1928) No. 7, 379.

(2) S. I. Kunitomi, Journ. Meteor. Soc. Jap. [ii] 4 (1926) No. 9.

thus furnishing a favourable example for investigating the propagation of the distortional movements. The present author assumed $\varphi=41° 22' $N and $\lambda = 142° 25'$ E as the geographic coordinates of its epicentre, which seem to be in favourable accord with observed values of time of commencement and duration of the preliminary tremor. Relevant data were taken from "Kisyô Yôran" and Mr. Kunitomi's paper,(1) and tabulated in Table I.

TABLE I.

Earthquake, Feb. 4, 1926. (Assumed origin; $\varphi=41° 22'$N, $\lambda=142° 25'$E.)

No.	Station	Latitude Longitude	Δkm.	Time of Commencement	Duration of Preliminary Tremor	Remarks
1	Hakodate	41° 47′N 140° 43′E	146	$15^{h}\ 44^{m}\ 34^{s}.5$	$12^{s}.5$	
2	Muroran	42 20 140 57	159	39.0	14.0	$14^{s}.3$ by Kunitomi.
3	Miyako	39 38 141 59	200	46.0	18.0	
4	Sapporo	43 4 141 21	209	35.4	13.8	23.5 ,, ,,
5	Morioka	39 42 141 10	215	47.2		29.7 ,, ,,
6	Kusiro	42 59 144 24	239	30.0	28.0	29.7 ,, ,,
7	Akita	39 41 140 6	271	50.0	34.0	32.4 ,, ,,
8	Mizusawa	39 8 141 8	271	52.0	26.0	
9	Asahigawa	43 47 142 23	270.2	42.0	43.4	
10	Isinomaki	38 26 141 19	337	54.0	47.0	48.6 ,, ,,
11	Nemuro	43 20 145 35	337	45 07.1	35.4	36.5 ,, ,,
12	Haboro	44 23 141 42	341	44 58.1	57.3	
13	Yamagata	38 15 140 21	387	35.0	40.4	55.0 ,, ,,
14	Niigata	37 55 139 3	482	45 18.5	60.5	65.2 ,, ,,
15	Onahama	36 56 140 54	509	25.0	75.2	67.5 ,, ,,
16	Utunomiya	36 34 139 53	576	27.7	75.2	
17	Mito	36 23 140 28	579	28.0	76.9	74.9 ,, ,,
18	Takada	37 6 138 15	593	30.6	59.7	
19	Tukuba	36 13 140 06	605	10.9	58.0	

(to be continued.)

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(1) l.c. p. 179.

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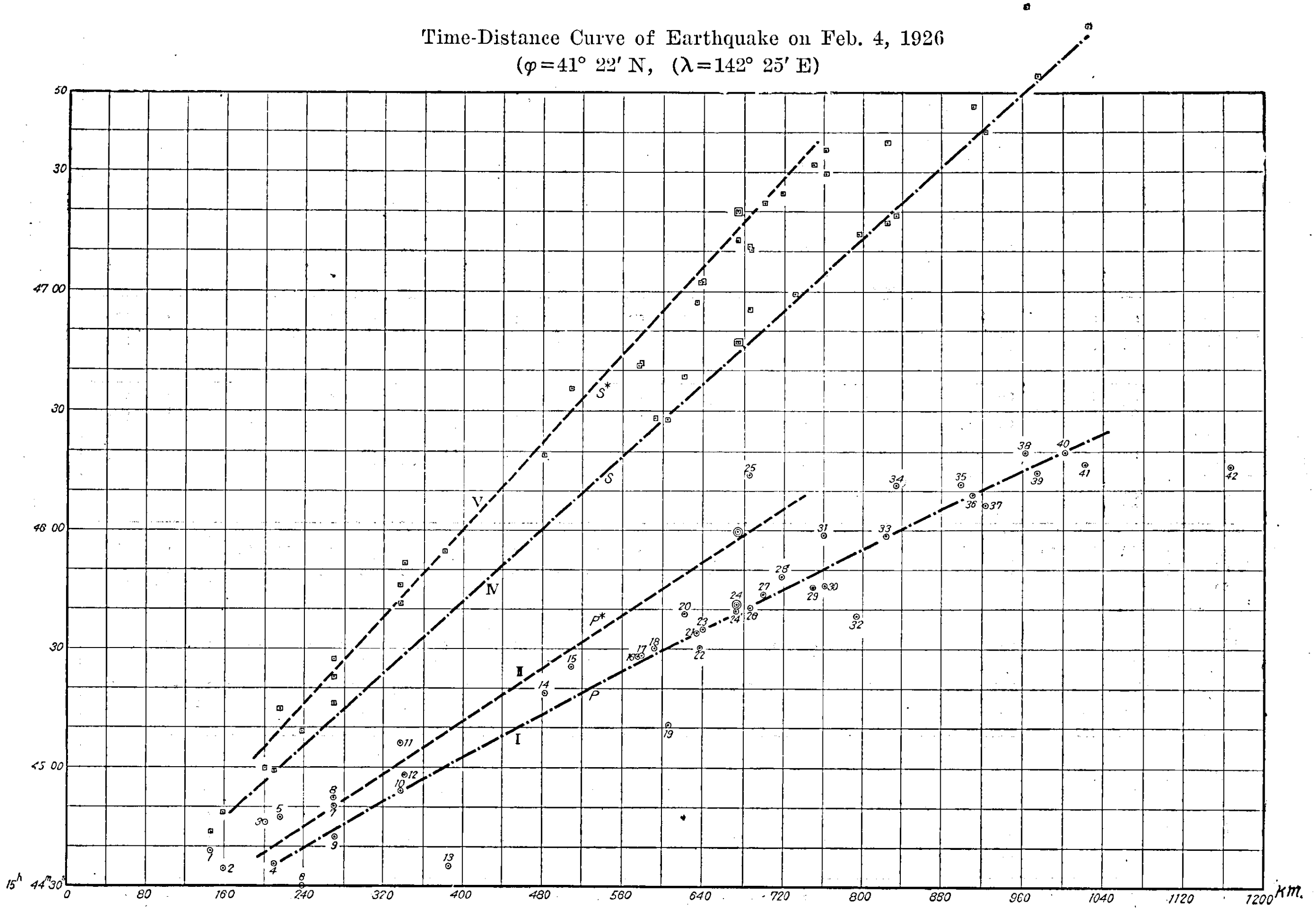
No.	Station	Latitude Longitude	Δ km.	Time of Commencement	Duration of Preliminary Tremor	Remarks
20	Maebasi	36 24 139 4	622	15 45 38.5	76.7	
21	Kumagai	36 9 139 23	635	33.8	83.8	
22	Nagano	36 40 138 12	637	30.0	99.0	89.0 by Kunitomi.
23	Tyôsi	35 44 140 51	640	34.7	97.5	88.4 „ „
24	Hongô	35 43 139 46	675	41.0	68.3 101.3	P-S by the present P-S* author.
24′	Tôkyô					94.0 by Kunitomi.
25	Husiki	36 47 137 3	687	46 13.4	42.3	91.0 „ „ Reported T.C. may be that of the P wave. 91.0 may be P-S.*
26	Matumoto	36 14 137 59	687	45 40.0	64.0	90.0 by Kunitomi.
27	Yokohama	35 27 139 39	700	43.3	100.0	
28	Kôhu	35 38 138 34	719	48.0		100.1 „ „
29	Mera	34 55 139 50	750	45.1	105.5	103.8 „ „
30	Iida	35 31 137 50	761	45.6	99.6	
31	Numazu	35 6 138 51	761	58.4	97.7	105.5 „ „
32	Hukui	36 3 136 16	795	38.0	80.0	
33	Gihu	35 24 136 46	824	58.7	79.8	99.6 by Kunitomi. 79.8 may be P-S duration.
34	Nagoya	35 10 136 58	835	46 11.0	80.0	
35	Tu	34 44 136 31	900	45 11.5	63.3	T.C. may be 46^m instead of 45^s.
36	Kyôto	35 01 135 44	914	46 8.9	98.4	
37	Toyooka	35 32 134 49	924	6.1	90.3	
38	Oosaka	34 39 135 26	963	19.2	117.3	
39	Kôbe	34 41 135 11	975	14.4	98.7	
40	Sakai	35 33 133 14	1002.5	29.3		
41	Sumoto	34 21 134 53	1021	16.3	105.4	
42	Kure	34 14 132 33	1165	15.8	117.6	

Using these values a time-distance diagram is constructed as shown in Fig. 2.

Time-Distance Curve of Earthquake on Feb. 4, 1926
(φ=41° 22′ N, (λ=142° 25′ E)



(Numbers are to be referred to Table I.)

Fig. 2.

The P and the P* curves are drawn so that they are reconcilable to those obtained in part I. Points corresponding to distortional movements are plotted so that the reported duration of the preliminary tremor is represented as the time reckoned from the corresponding point on the P or P* curves, according to whichever of their branches the observed time of commencement may seem to belong. As can be seen from the figure, the distributed points belonging to the distortional movements can be separated into two branches of curves (IV and V), in an especially clear manner for remote stations, and which are characterised by $\frac{\partial \varDelta}{\partial T}=4.40$ km/sec. and 3.62 km/sec. respectively. Thus the curves IV and V can be interpreted as belonging to the S movement and the S* respectively. It seems that at certain stations the commencement of the S phase was measured as being that of the principal phase, while at others that of the S* phase was so interpreted. In support of this conjecture a study of seismograms obtained at Hongô will be sufficient. (Pl. X. Fig. 3 and Pl. XI. Fig. 4). We find indeed that four phases, P, P*, S and S*, can be identified at just the same positions (within, of course, the limit of unmistakable identification) as expected from the curves in Fig. 2. In Fig. 2, values observed at Hongô are plotted by double circles and double squares. It must be remarked that quick movements are for the most part superposed on the S movements, as clearly seen in Fig. 4. This point will be taken up later.

At all events, the irregular appearance of the distribution of the iso-P-S line seems to be only apparent and due to difficulty in the identification of each phase. As far as the effect of the superficial strata alone of the earth's crust is concerned, it is quite naturally conjectured from the knowledge of trajectory of waves that the greater the epicentral distance the more clearly can the S phase be observed.

The Earthquake of July 13, 1927.

This earthquake occurred far off the coast of Kusiro, Hokkaidô, and was feebly felt without instrumental aid at Tôkyô about 900 km. distant from the epicentre. The geographic coordinates of its epicentre, $\varphi=42°$ 36′ N and $\lambda=145°$ 35′ E, accord favourably with the observed data. The data taken from "Kisyô Yôran" (except Hongô) are tabulated below. (Table II.)

TABLE II.

Earthquake of July 13, 1927. ($\varphi = 42°\ 36' \mathrm{N}$, $\lambda = 145°\ 35' \mathrm{E}$.)

No.	Station	Latitude Longitude	$\varDelta$ km.	Time of Commencement			Duration of Preliminary Tremor	Remark
				h	m	s	s	
1	Nemuro	43° 20′N 145° 35′E	81.5	6	9	15.9	3.2	T.C. is too late by one minute.
2	Kusiro	42 59 144 24	102		8	21.9		
3	Obihiro	42 55 143 12	196			33.0		
4	Asahigawa	43 47 142 23	290.5			49.0	25.0	
5	Muroran	42 20 140 57	378		9	5.0	47.0	
6	Hakodate	41 47 140 43	409			9.3	46.5	
7	Miyako	39 38 141 59	446			6.0	52.0	
8	Aomori	40 50 140 45	446			6.0	51.0	
9	Morioka	39 42 141 10	490			19.7	57.5	
10	Oodomari	49 39 142 46	501			53.0	45.0	T.C. is somewhat inconsistent.
11	Mizusawa	39 8 141 8	535			26.0	65.0	
12	Akita	39 41 140 6	559			24.0	66.9	
13	Isinomaki	38 26 141 19	586			29.0	65.7	
14	Yamagata	38 15 140 21	653			39.6	77.1	
15	Hukusima	37 45 140 24	694		10	8.0	78.0	?
16	Aizu	37 34 140 7	727			32.0	87.4	?
17	Onahama	35 56 140 54	744		9	31.0	78.2	?
18	Sikka	39 14 143 7	761		10	15.0		?
19	Niigata	37 55 139 3	769		9	59.0	73.2	
20	Mito	36 23 140 28	817			57.0	87.0	
21	Utunomiya	36 34 139 53	827			44.3	95.6	?
22	Kakioka	36 14 140 11	844		10	1.6	95.2	
23	Tukuba	36 13 140 6	850			2.5	30.0	

(to be continued.)

(Continued.)

No.	Station	Latitude Longitude	Δ km.	Time of Commencement		Duration of Preliminary Tremor	Remark
24	Tyôsi	35 44 140 51	862	10	9.5	95.3	
25	Takada	37 6 138 15	873		8.6	93.3	
26	Maebasi	36 24 139 4	886		8.8	94.6	
27	Kumagai	36 9 139 23	892		8.0	91.8	
28	Hongô	35 43 139 46	912		12.0	98.9	
29	Nagano	36 40 138 12	912		15.7	97.0	
30	Tôkyô	35 41 139 46	917		12.0	100.5	
31	Yokohama	35 27 139 39	948		30.0	92.0	?
32	Matumoto	36 14 137 59	960		4.0	161.0	?
33	Kôhu	35 38 138 34	981		25.0		
34	Mera	34 55 139 50	986		19.6	106.3	
35	Takayama	36 9 137 15	1011	9	43.5	107.4	?
36	Numazu	35 6 138 51	1018	10	26.6	100.7	
37	Hukui	36 3 136 16	1180	11	26.0		T.C. is too late by one minute.
38	Gihu	35 24 136 46	1091	10	34.6	116.9	
39	Nagoya	35 10 136 58	1110	11	5.9	109.6	
40	Ibukiyama	35 25 136 24	1122	10	34.8	64.3	
41	Hikone	35 16 136 15	1143		34.8	118.8	
42	Tu	34 44 136 31	1172		43.0	121.0	
43	Kyôto	35 1 135 44	1197		42.7		
44	Toyooka	35 32 134 49	1212		44.0		
45	Oosaka	34 39 135 26	1243		52.7	124.2	
46	Kôbe	34 41 135 11	1258		55.2	150.4	
47	Wakayama	34 14 135 9	1299		57.0		
48	Sumoto	34 21 134 53	1301		55.9	268.1	
49	Sakai	35 33 133 14	1320	9	57.1		T.C. is too early by one minute.
50	Hamada	34 54 132 4	1448	11	16.6	149.7	

(to be continued.)

(Continued.)

No.	Station	Latitude Longitude	Δ km.	Time of Commencement	Duration of Preliminary Tremor	Remark
51	Kôti	33 33 133 32	1452	6 11 13.2	159.2	
52	Ooita	33 14 131 37	1600	30.0	182.5	
	Hukuoka	33 35 130 25	1656	37.7	182.2	
	Kumamoto	32 49 130 42	1695	12 54.0		T.C. is too late by one minutes.
	Miyazaki	31 55 131 26	1720	11 59.0	185.4	
	Titizima	27 5 142 11	1750	54.4		
	Kagosima	31 34 130 33	1803	58.3		T.C. is too early by one minute.
	Nagasaki	32 44 129 52	1758	14 49.0	137.0	T.C. is too late by three minute.

Using these values a time-distance diagram is constructed in a similar manner as described in the foregoing case. (Pl. XII. XIII. Fig. 5).

The S curve is of course characterised by $\frac{\partial \Delta}{\partial T}=4.4$ km/sec. In this case it is remarkable that the distribution of points representing the observed values can be grouped into somewhat well defined P and S curves only. This may be due to the fact that the origin of this earthquake was perhaps too deepseated to produce the P*, $\overline{\mathrm{P}}$, S* and $\overline{\mathrm{S}}$ phases. This may therefore be a suitable example for observation of the S phase even at near stations.

Seismograms obtained at Hongô, Tôkyô, will be shown in Pl. XIV. Fig. 6. It may be seen that slow motions predominate from the commencement, superposed by quick motions. In this case also, in the S phase (not in S* or $\overline{\mathrm{S}}$), quick movements predominate. This is generally observed in the case of earthquakes occurring off the Pacific coast of Hokkaidô as well as in the case of deepseated earthquakes. Thus a governing factor common to both cases is that the length of the trajectory of waves in the superficial layer is not long and the angle of incidence at the boundary of stratification not great. Dissipation of quick vibrations in the superficial layer, geologically much disturbed, will far exceed that in the lower layers. A smaller part of energy moreover will be refracted into the upper layer if the angle of incidence is greater. Perhaps in the cases cited above, quick vibrations generated at a seismic origin will be observed without much loss through dissipation even at a considerable distance.(1) The present author's opinion on the apparent abnormal distribution of locality where seismic shocks are felt by our unaided senses is in line with Dr. K. Wadati's view(2) that this phenomenon depends mainly on the geological structure of the region.(3)

The Great Tango Earthquake of March 7, 1927.

In the above three examples, existence of the $\dot{S}$, S^* and $\overline{S}$ movements is confirmed while approximate positions of time-distance curves corresponding to them have been determined.

This earthquake was investigated in part I, but the investigation with regard to the distortional movements was reserved for a future occasion. Using the same data, a time-distance diagram is constructed as shown in Fig. 7.

Here attention will be confined to the distortional movements only. As is apparent from the figure, the upper boundary of the distributed points is coincident with a line characterised by $\frac{\partial \Delta}{\partial T}=3.16$ km/sec. Small values of difference of time between $\overline{S}$ and $\overline{P}$ at $\Delta=0$ (though not very exact) showed that the origin of fracture was no deeper than twenty kilometres or so, which is quite in accord with results obtained from other points of view. A line drawn through the approximate mean position of the densely distributed points is characterised by $\frac{\partial \Delta}{\partial T}=3.62$ km/sec. Thus it can be surmised that at most stations the commencement of the S^* phase was interpreted as being that of the principal portion. In fact, in seismograms

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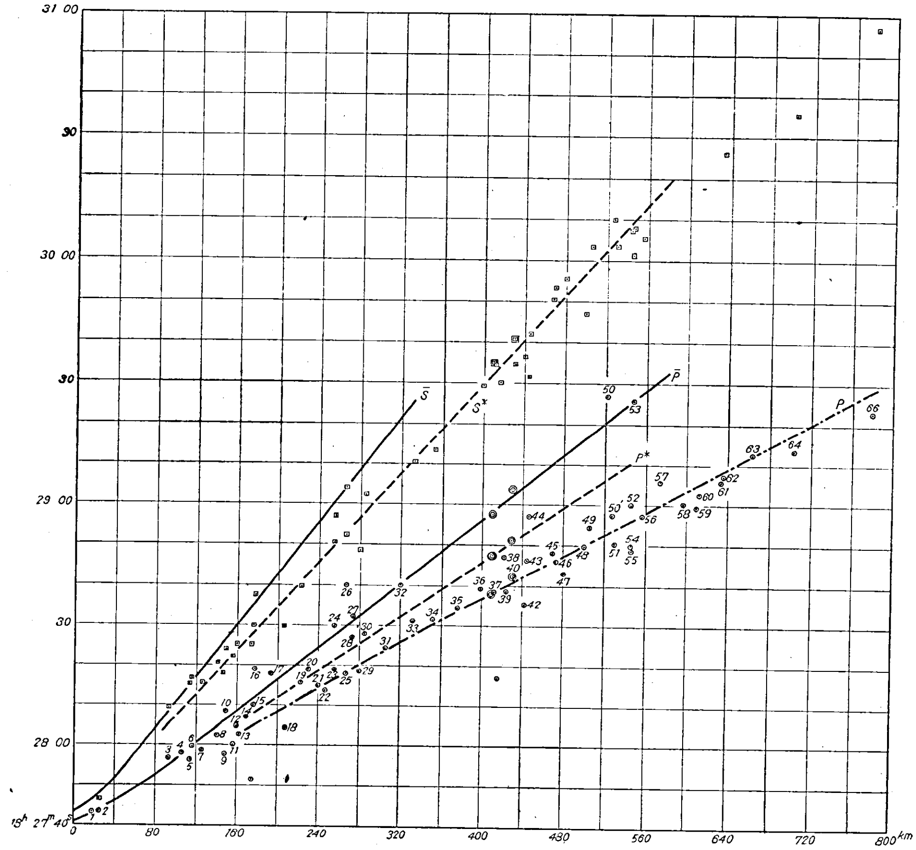
(1) Mr. T. Isikawa's explanation of this observed fact is that certain kinds of secondary oscillations near an observing station are excited by the incidence of seismic waves (Journ. Meteor. Soc. Japan [ii] **6** (1928) No. 3), although the existence of many exceptional cases somewhat impairs this theory. Dr. S. I. Kunitomi's explanation (Journ. Meteor. Soc. Japan [ii] **6** (1928) No. 4) is that local earthquakes are excited by the incidence of seismic waves, a theory which may require closer statistical study.

(2) K. Wadati, Journ. Meteor. Soc. Japan [ii] **5** (1927) 137.

(3) After all, this may not differ essentially from Mr. T. Isikawa's opinion, but if I understand him correctly, his idea seems to imply that, whatever the incident waves may be, a certain kind of secondary undulations is excited. In short, the essential difference in the two opinions hinges on which factor the stress is laid, whether on the resonator, or on the exciter.

Time-Distance Curve of Tango Earthquake on March 7, 1927.



(Refer to Pl. V. Fig. 6 in Part I.)

Fig. 7.

obtained at Hongô (Pl. III, Fig. 4 in part I) and at Kamakura (Pl. IV, Fig. 5 in part I), commencement of the S* phase could be very clearly distinguished. Identification of other phases in the distortional waves may be difficult without referring to the time-distance curves.

The same remark may be applied to the case of the Tazima earthquake, May 23, 1925 (Pl. VI, Fig. 7 in part I) and the Tango earthquake, April 1, 1927 (Pl. VII, Fig. 9 in part I).

In these two cases also it is remarkable that the S* phase could be identified without any difficulty.

This fact may perhaps be due to the small depth of the seismic origin. Another point to be noted is that quick vibrations, like those in the case of the Hokkaidô earthquakes, were not superposed. It may be that strong motion seismographs fail to record small, quick vibrations, but even in Pl. VII, Fig. 9 in part I, which was recorded by Prof. Imamura's tromometer,(1) which is very sensitive to quick motions, such motions are not shown. Even in the two other cases above mentioned, inspection of the seismograms obtained by more sensitive instruments, failed to show such motions. In these cases, the origins whence came the quick vibrations accompanied with local crustal fracture were in all probability too shallow to transmit them to a remote distance. Movements of wider portions of crust to produce the P movements, as discussed in part I, would not produce very quick motions.

The Earthquake of Aug. 3, 1926.

This earthquake occurred off the coast of Haneda (Tôkyô Bay) and was strongly felt at Tôkyô. Its seismometrical aspects were studied and the results published by Professor Imamura and Mr. Ch. Yasuda(2) and also by K. Sagisaka(3) and H. Satô, so that only the mode of propagation of disturbance will be described and discussed here. The position of its epicentre was determined as $\varphi=35° 33' $N and $\lambda=139° 48'$ E. Data concerning this earthquake taken from "Kisyô Yoran" (except those obtained at Hongô) are tabulated in Table III.

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(1) A. Imamura, Bull. Eqk. Res. Inst. **1** (1926) 7–25.

(2) A. Imamura and Ch. Yasuda, Bull. Eqk. Res. Inst. **3** (1927) 115.

(3) K. Sagisaka and H. Satô, Journ. Meteor. Soc. Japan [ii] **4** (1926) No. 12.

TABLE III.

Earthquake of Aug. 3, 1926. ($\varphi=25°\ 33'$ N, $\lambda=139°\ 48'$ E)

No.	Station	Latitude (N)	Longitude (E)	Δ km.	Time of Commencement	Dur. of P. T.
					h m s	s
1	Hongô			16.1	18 26 22.0	7.6
2	Tôkyô			〃	23.9	5.7
3	Yokohama			17.7	21.5	5.0
4	Yokosuka			32.2	22.0	
5	Mera	34° 55′	139° 50′	67.7	26.6	
6	Kumagai			76.8	30.4	11.1
7	Kakioka	36 14	140 11	83.8	28.3	11.5
8	Tyôsi			95.8	31.9	12.5
9	Numazu			100.5	31.0	12.0
10	Kôhu			112.7	26.0	18.0
11	Mito			112.7	31.0	10.0
12	Maebasi			116.0	30.8	21.4
13	Matumoto	36 14	137 59	179.5	40.0	18.0
14	Iida	35 31	137 50	180	41.3	21.8
15	Onahama	36 56	140 54	185	37.0	17.3
16	Nagano	36 40	138 12	190.5	41.7	25.4
17	Hamamatu	34 43	137 43	212	52.0	25.0
18	Takada	37 6	138 15	222	46.8	28.5
18′	Aidu	37 34	140 7	228	52.0	25.1
19	Takayama	36 9	137 15	237	50.8	32.2
20	Nagoya	35 10	136 58	259	51.0	34.0
21	Niigata	37 55	139 3	274	50.5	43.8
22	Gihu	35 24	136 46	274	53.3	29.4
23	Husiki	36 47	137 3	281	56.3	41.9
24	Yamagata	38 15	140 21	303	51.9	37.0
25	Hikone	35 16	136 15	324	27 7.3	37.5

(to be continued.)

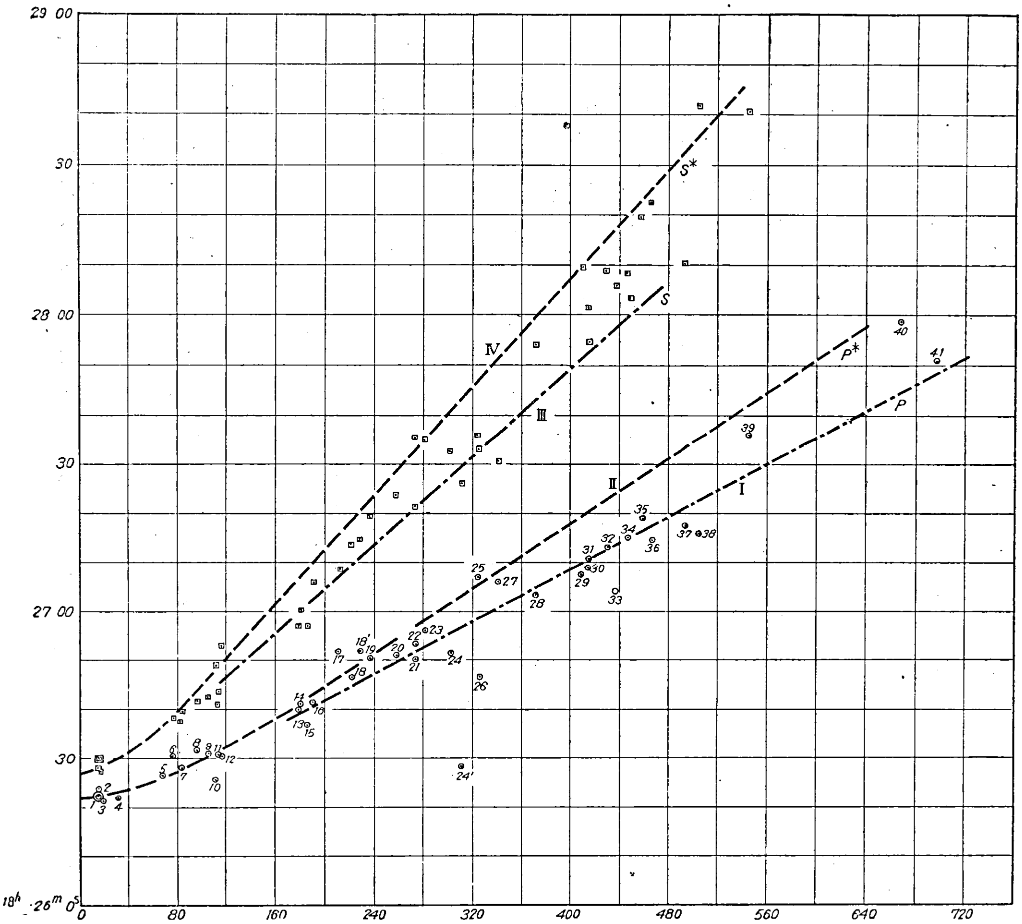
(Continued.)

No.	Station	Latitude (N)	Longitude (E)	$\varDelta$ km.	Time of Commencement	Dur. of P. T.
26	Hukui	36 3	136 16	326	18 26 46.9	34.5
27	Isinomaki	38 26	141 19	341	27 6.2	29.5
28	Kyôto	35 1	135 44	372	3.5	49.5
29	Oosaka	34 39	135 26	409	7.9	60.2
30	Miyazu	35 32	135 12	415	9.3	50.9
31	Mizusawa	39 8	141 8	416	11.0	44.0
32	Kôbe	34 41	135 11	430	13.0	56.6
33	Siomisaki	33 27	135 46	437	4.2	52.5
34	Wakayama	34 14	135 9	446	15.0	54.0
35	Akita	39 41	140 6	459	19.0	74.0
36	Sumoto	34 21	134 53	467	14.8	65.6
37	Miyako	39 38	141 59	494	18.0	50.0
38	Tokusima	34 4	134 33	507	16.0	80.0
39	Okayama	34 40	133 54	546	36.0	70.0
40	Matuyama	33 50	132 45	671	59.0	99.1
41	Hakodate	41 47	140 43	697	51.0	99.0

From these data a time-distance diagram has been constructed as shown in Fig. 8.

The P and P* curves are so drawn that they will be in accord with those obtained in part I. With regard to the distortional movements, points are almost confined between the S and S* curves, though $\frac{\partial \varDelta}{\partial T}=4{,}49$ for the S and 3.73 for the S* phase. Therefore, they are somewhat greater than former values. This may perhaps be due to the circumstance that the stations were clustered more or less near the epicentre while the origin of the earthquake was somewhat deep. This can be understood from the fact that at most stations the P or P* and the S or S* phases were observed and not the $\overline{\mathrm{P}}$ or the $\overline{\mathrm{S}}$ phase. The time-difference between the commencement of the S* and that of the P* at $\varDelta=0$ can be estimated as 5.2 sec. or so. If

Time-Distance Curve Earthquake on Aug. 3, 1926
(φ=35° 33′ N, λ=139° 48′ E)



(Numbers are to be referred to Table III.)

Fig. 8.

the thickness of the uppermost stratum is taken as 20 km, the depth of the origin is estimated as 45 km. or thereabouts, which would harmonise with the fact that the P, P*, S and S* phases were observed to the exclusion of the $\overline{P}$ and $\overline{S}$ phases.

The Earthquake of June 5, 1926.

One more example of a south-western earthquake will be added, since it is necessary to verify if there is a difference of propagation or not between the south-western and the north-eastern earthquakes.

Earthquakes of sufficient energy for this purpose have been rare in the South-western Japan, and yet this instance will show that the velocity of propagation is not essentially different in the two cases. The author assumes the position of its epicentre as $\varphi = 30° 36'$N and $\lambda = 130° 40'$E, for by taking this position the distribution of intensity and results of instrumental observation are in fair agreement. The stations are distributed over a narrow band forming the Japanese Islands, and in this case the origin was situated nearly at its end. Therefore, errors of position of epicentre do not seriously affect the slope of the time-distance curves, which becomes a measure of the velocity of propagation. Data were taken from "Kisyô Yôran" and are tabulated in Table IV.

TABLE IV.

Earthquake of June 5, 1926. ($\varphi = 30° 36'$ N, $\lambda = 130° 40'$ E)

No.	Station	Latitude (N)		Longitude (E)		Δ km.	Time of Com.			Dur. of P. T.	Remark
							h	m	s	s	
1	Kagosima	31°	34′	130°	33′	107.7	18	10	5.9	18.0	
2	Miyazaki	31	55	131	26	164.7			11.4	22.0	
3	Nagasaki	32	44	129	52	248			11.0	25.0	
4	Kumamoto	32	49	130	42	250			16.4	25.4	
5	Saga	33	12	130	18	292		11	0	29.5	
6	Ooita	33	14	131	37	305		10	21.5	31.	
7	Hukuoka	33	35	130	25	333			18.7	30.0	
8	Simonoseki	33	57	130	56	374			16.0	34.0	
9	Matuyama	33	50	132	45	394			7.9	31.6	
10	Kôti	33	33	133	32	424			36.5	40.0	
11	Hamada	34	54	132	4	496		11	2.0	26.0	$\overline{P}$—S?
12	Tadotu	34	17	133	46	501		10	19.0	46.0	
13	Tokusima	34	4	134	33	530			59.0	53.0	
14	Sumoto	34	21	134	53	576			56.1	56.8	

(to be continued.)

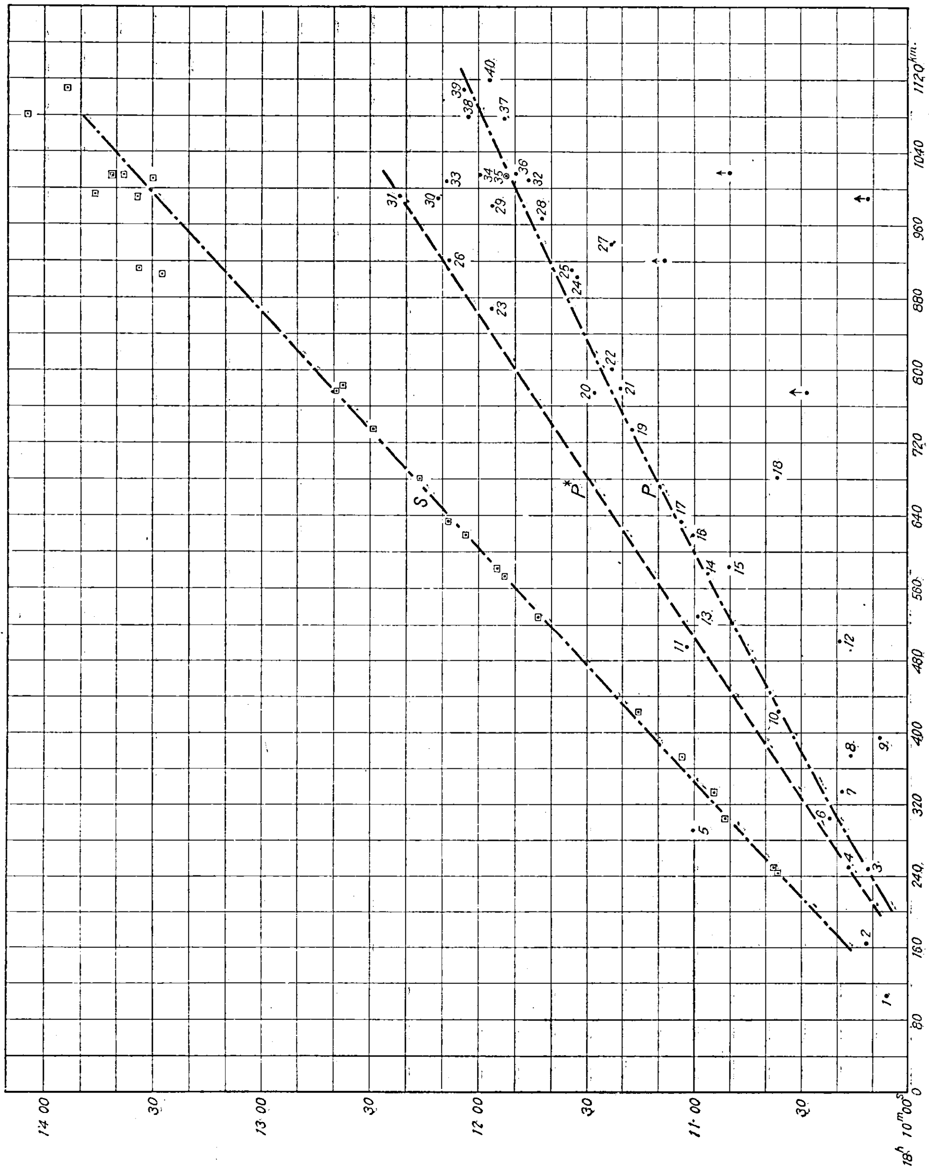
(Continued.)

No.	Station	Latitude (N)	Longitude (E)	Δkm.	Time of Com.	Dur. of P. T.	Remark
15	Wakayama	34 14	135 9	583	18 10 50.1	57.5	
16	Kôbe	34 41	135 11	620	11 0	61.2	
17	Oosaka	34 39	135 26	633	3.5	64.0	
18	Kyôto	35 1	135 44	681	10 36.4	66.0	T.C. may be incorrect.
19	Hikone	35 16	136 15	735	11 16.8	71.7	
20	Nagoya	35 10	136 58	776	10 28.0	77.0	T.C. may be too early by one minute.
21	Gihu	35 24	136 46	781	11 20.2	74.7	
22	Hamamatu	34 43	137 43	802	23.0	55.0	?
23	Takayama	36 9	137 15	869	56.1		
24	Husiki	36 47	137 3	904	32.5	109.6	
25	Numazu	35 6	138 51	912	34.4	115.0	
26	Matumoto	36 14	137 59	922	8.0		
27	Zinsen	37 29	126 37	940	23.0	52.0	?
28	Nagano	36 40	138 12	968	42.6	14.9	?
29	Mera	34 55	139 50	981	56.9		
30	Kôhu	35 38	138 34	990	10 11.0	84.0	T.C. may be too early by 2 min.
31	Yokohama	35 27	139 39	993	12 21.9	85.0	T.C. is somewhat too late.
32	Takada	37 6	138 15	1011	11 46.6	14.0	?
33	Maebasi	36 24	139 4	1009	12 9.2	81.6	T.C. is too late.
34	Tôkyô	35 41	139 46	1016	11 59.7	106.7	
35	Hongô				52.4	110.3	By the present **author**.
36	Kumagai	36 9	139 23	1018	10 49.9	102.7	T.C. is too early by one minute.
37	Utunomiya	36 34	139 53	1079	11 52.6		
38	Kakioka	36 14	140 11	1080	12 2.9	126.0	
39	Mito	36 23	140 28	1110	4.0	112.0	
40	Niigata	37 55	139 3	1120	11 56.3	166.9	

By plotting these values and in the same way as done in the preceding cases time-distance relations are obtained as shown in Fig. 9.

Time-Distance Curve of Earthquake of June 5, 1926.

(φ=30° 36′ N, λ=130° 40′ E)



(Numbers are to be referred to Table IV.)

Fig. 9.

From the figure it may be seen that the time-distance curves obtained previously can be applied fairly well to this case also. Seismograms obtained at Hongô will be added in Pl. XV. Fig. 10. Identification of the commencement of the P phase is somewhat difficult, owing to pulsatory motions then going on although it can be measured without serious errors. In this case quick motions are not so conspicuous as in the case of earthquakes originating off the Pacific coast of Hokkaidô.

III. APPLICATION TO AN AMBIGUOUS CASE.

From about $17^h\ 56^m\ 43^s.5$ on Aug. 24, 1927 (L.M.T. of longitude 135°E) seismographs at Hongô, Tôkyô, began to record an earthquake with unusual features. (Fig. 11.)

As can be seen from the figure, commencement of phases belonging to the distortional movements can scarcely be identified, or, if so, only very vaguely, that is as concerns these particular seismograms. In this case, the period of motions underwent little fluctuation throughout the whole motion, while the magnitude of the amplitude of motion varied almost gradually,(1) so that to classify the motions was not easy. On the other hand, accurate determination of incidence of the distortional phase, especially in such an unusual case as this one ought not to be without value in studying the nature of the earth's crust. For this purpose, accurate determination of the seismic epicentre are extremely desirable. Through the courtesies on the part of the directors of several meteorological stations, and to whom the author records here his warmest thanks, it was possible to determine its epicentre as being $\varphi = 36°\ 26'$N and $\lambda = 142°\ 30'$E. Seismograms obtained at the Mizusawa International Latitude Station will be reproduced here for the sake of comparison. (Fig. 12).

According to these records, the commencement of the distortional phase is well defined, and yet in the NS component slow motions with $9^s.5$ period can be seen. In this component of motion, the commencement of the distortional phase is less defined.

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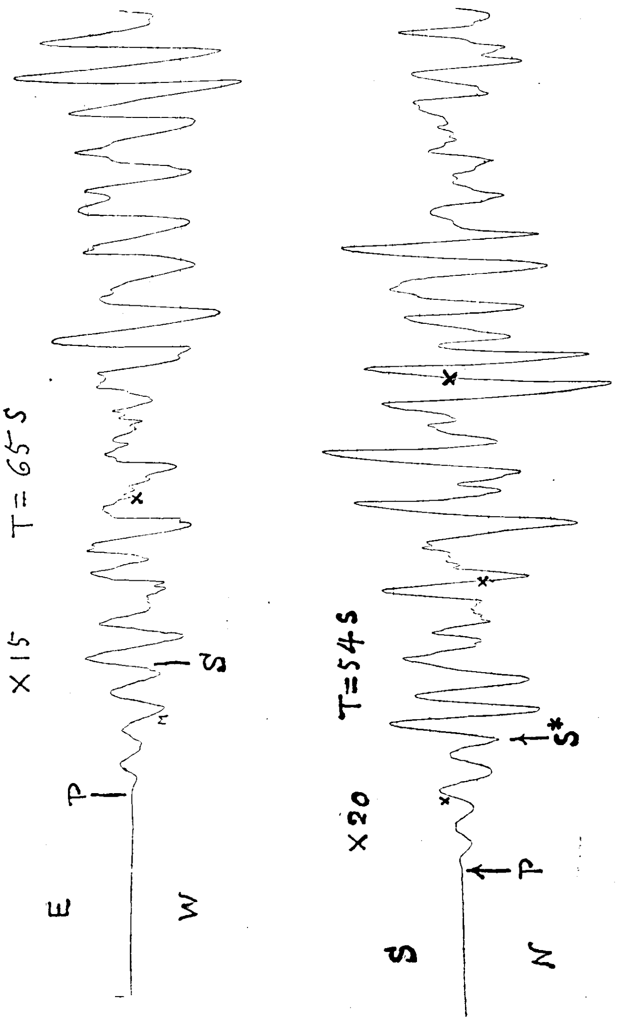
(1) These were not due to instrumental errors, since the proper period of the seismographs used was far greater than those of the incident movements.

Earthquake of Aug. 24, 1927.
(φ=36° 26′ N, λ=142° 30′ E)
(Observed at Hongô)



× Minute mark.
(For S in the EW comp. read S*.)

Fig. 11.

Earthquake of Aug. 24, 1927.
($\varphi = 36° 26' N$, $\lambda = 142° 30' E$)
(Observed at Mizusawa)

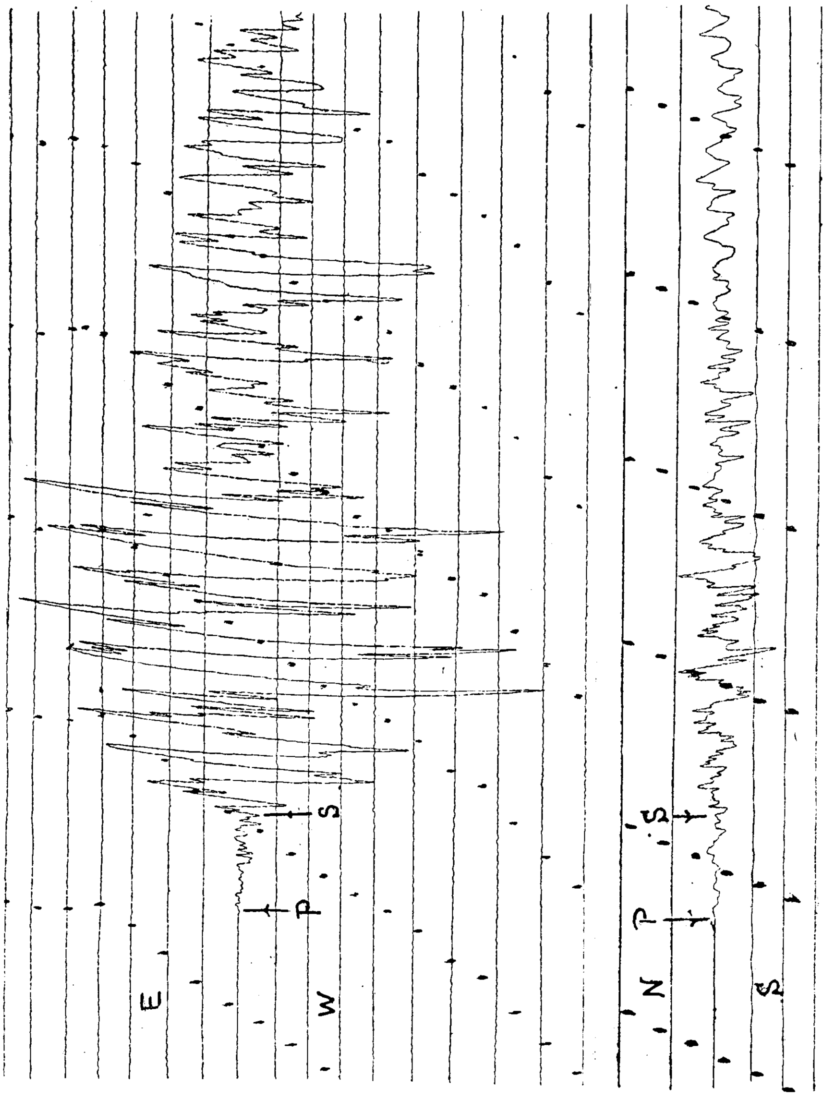


Fig. 12.

Returning to the case of Hongô, if the position of the epicentre is assumed as above, its epicentral distance will be about 250 km. For such a distance, the P-S and P-S* differences may be expected to be about 27 sec. and 37 sec. respectively. In Fig. 11 the S* can be found though not distinctly, at the expected position as a somewhat sudden increase of magnitude of motion. Thus the essential characteristic of this earthquake observed at Hongô is the long period of motions even in the dilatational movements. The epicentre was situated in the deep sea bed of the Pacific more than 3000 metres deep, and it will be included in th class of "Deep sea earthquakes" as proposed by Mr. K. Wadati.(1)

Comparison of seismograms at Hongô and at Mizusawa will show that the orientation of stations relative to the epicentre plays an important rôle in connection with the character of motions observed, which again will mainly be due to the mechanism associated with the particular earthquakes.(2)

IV. CONCLUDING REMARKS.

The foregoing examples leave no room for doubt as to the existence of three phases in the two movements, distortional as well as dilatational. The difference in their appearances, needless to say, depends on the depth of the seismic origin, and on the epicentral distance, and also on the mechanism of earthquake occurrence.

The presence of proofs that superficial crustal stratification may be expected even in such an unstable island area as Japan, goes a long way to show how persistent is the stratifying process, notwithstanding the remarkable geological disturbances the islands have been subjected to.

According to Wegener's hypothesis, the mode of stratification of land areas is not the same as what obtains in the bottom of the Pacific Ocean. A definite answer on this point is not deducible from the foregoing investigations of near earthquakes, for the reason that in every case investigated, the seismic wave traversed a considerable portion of terrestrial as well as suboceanic region. This point however willl be discussed in part IV.

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(1) K. Wadati, Jorn. Meteor. Soc. Jap. [ii] **6** (1928) No. 1.

(2) T. Matuzawa, Jap. Journ. Astr. Geophys., **4** (1926) No. 1.

We shalll now offer a few remarks on the coefficient of a linear equation connecting the epicentral distance, (not very large, say, less than 1000 km.), and the duration of the preliminary tremor. In the equation $y=kt$, the value of k was determined by F. Omori as $k=7.42$ (km/sec). This value of k has been usefull and convenient for determination of epicentres of earthquakes in Japan, especially for the case of earthquakes with epicentral distance of only a few hundreds of kilometres.

Roughly speaking, the physical meaning of k is that $k=\frac{v_P v_S}{v_P-v_S}$ where v_P is the velocity of propagation of the first phase and v_S is that of the second phase. Now that three phases in each of the dilatational and the distortional phase are identified, this point needs to be examined thoroughly.

Velocity of propagation of each phase is well expressed by

$$v_P=7.5 \text{ km/sec.}^{(1)} \qquad v_P{}^*=6.1 \text{ km/sec.} \qquad v_{\overline{P}}=5.0 \text{ km/sec.}$$

$$v_S=4.5 \quad ,, \qquad v_S{}^*=3.7 \quad ,, \qquad v_{\overline{S}}=3.15 \quad ,,$$

In ordinary cases the first phase observed is the P. On the other hand, the second phase observed is frequently the S* in cases of ordinary inland earthquakes, an example of which is the Tango earthquake observed at Tôkyô. If such is the case, then the value of k will be 7.3 (km/sec) which is in accord with Omori's value.

In such cases as when the depth of origin of the earthquake is great, or when the epicentral distance is not small, the second phase observed will be the S. In such a case Omori's value cannot be applied, as was seen in the case of the earthquake of July 13, 1927, observed at Hongô, Tôkyô. The value of k will be expected to be 11.25(2) (km/sec.)

When an earthquake whose origin is not deep-seated is observed at a small distance, the first phase observed corresponds to the $\overline{\text{P}}$ and the second will be the S. In such a case k is calculated as 8.51 (km/sec.) which is not very different from experience.

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(1) This value will be discussed in part III.

(2) After this paper was written, the author came across a paper by Mr. M. Simizu (Journ. Meteor. Soc. Japan [ii] **6** (1928) 261–263) in which exactly the same value was given from direct determination of k, using earthquakes of moderate distance. His cases seem to have been very favourable for observation of the P and the S phase respectively.

In the above discussions, if the effects of each layer traversed by a trajectory of waves are taken into account, the problem will naturally be complicated. At any rate, a suitable interpretation of observed waves is of paramount importance in applying the linear equation.

July 4, 1928.

Supplement to Section II; Earthquake of July 7, 1928.

After the close of the preceding paper, data of the earthquake on July 7, 1928 became available. This was a strong earthquake which occurred in the approximate middle part of the Kii-Suidô, its geographic coordinates were $\varphi = 34° \, 00'$N and $\lambda = 134° \, 52'$E approximately. Localities where the shock was felt with our unaided senses were distributed somewhat wide. For example, at Kure about 200 km. distant from the epicentre it was felt slightly. Data were taken from "Kisyô Yôran" and tabulated below.

TABLE IV.

No.	Station	φ (N)	λ (E)	Δ (km.)	Time of Comm.	P. T.
					h m s	s
1	Tokusima	34° 4′	134° 33′	30.2	17 39 38.5	6.0
2	Wakayama	34 14	135 9	36.8	43.0	8.5
3	Kôbe	34 41	135 11	79.5	47.0	11.1
4	Siomisaki	33 27	135 46	96.3	44.4	11.6
5	Muroto	33 15	135 11	105.4	47.4	10.0
6	Tadotu	34 17	133 46	109.1	47.0	13.0
7	Yagi	34 31	135 48	109.1	48.8	12.6
8	Oosaka	34 39	135 26	109.9	44.6	15.2
9	Kôti	33 33	133 32	134.9	51.1	13.6
10	Kyôto	35 1	135 44	138.6	53.4	16.8
11	Toyooka	35 32	134 49	170.1	59.2	20.9
12	Tu	34 44	136 31	173.8	59.3	15.2

(to be continued.)

(Continued.)

No.	Station	φ (N)	λ (E)	Δ (km.)	Time of Comm.	P. T.
13	Matuyama	33 50	132 45	199.7	17 39 54.0	15.7 ?
14	Hikone	35 16	136 15	192.3	59.0	21.2
15	Hirosima	34 23	132 27	229.3	40 2.4	23.4
16	Nagoya	35 10	136 58	231.1	6.6	24.8 PS 27.6 PL
17	Gihu	35 24	136 46	234.8	7.9	25.0
18	Hukui	36 3	136 16	262.5	13.5	23.0
19	Hamada	34 54	132 4	275.5	9.6	25.5
20	Ooita	33 14	131 37	314.3	17.7	48.8
21	Takayama	36 9	137 15	323.5	15.4	14.7 ?
22	Matumoto	36 14	137 59	375.3	19.0	24.0 ?
23	Kôhu	35 38	138 34	384.6	26.8	37.9
24	Numazu	35 6	138 51	384.6	29.5	59.0
25	Miyazaki	31 55	131 26	395.6	24.5	37.3
26	Kumamoto	32 49	130 42	408.6	27.2	
27	Hukuoka	33 35	130 25	414.2	26.8	65.9
28	Oiwake	36 20	138 33	422.8	34.2	42.5
29	Nagano	36 40	138 12	425.3	39.3	51.3
30	Unzendake	32 44	130 15	451.1	31.6	20.8
31	Yokosuka	35 17	139 40	462.2	47.6	56.8
32	Yokohama	35 27	139 39	465.9	43.4	60.0
33	Maebasi	36 24	139 4	465.9	48.1	37.9
34	Nagasaki	32 44	129 52	484.4	35.6	
35	Tôkyô	35 41	139 46	484.4	47.0	65.0
36	Kagosima	31 34	130 33	484.4	48.9	
37	Kumagai	36 9	139 23	493.7	38.6	49.1
38	Sakai	35 33	133 14	229.2	{23.9 S?	{18.0 S* ?
39	Hongô	35 43	139 46	484.2	42.9	38.9 S 60.8 S*

Using these data the time-distance diagram has been constructed as shown in Fig. 13.

Earthquake on July 7, 1928.
($\varphi=34°\ 00'$ N, $\lambda=134°\ 52'$ E)

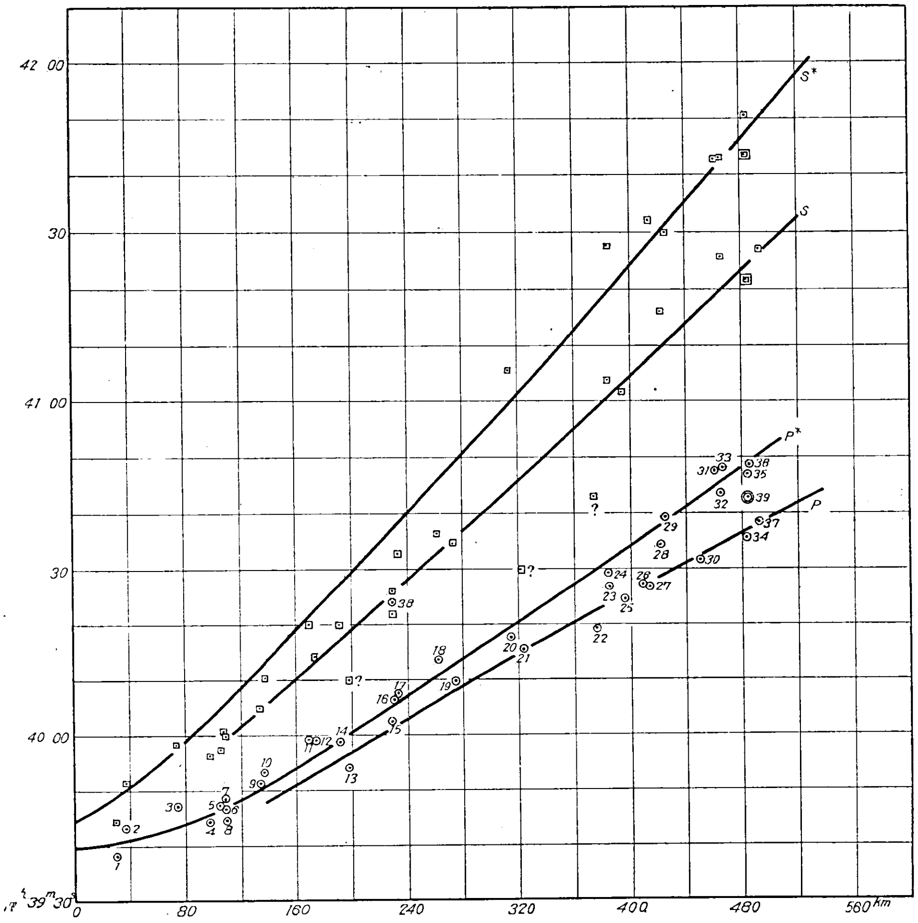


Fig. 13.

In the figure, the double circle and the double square were plotted using the data determined by the present author. With regard to the dilatational phase, the reported time of commencement was confined mainly between the P and the P* curves. Even at Hongô, the commencement of the P phase was very small in magnitude and moreover too disturbed by pulsatory motions to be determined accurately. Consequently a certain point between the P and the P* was judged as the commencement. The time of commencement reported by the Central Meteorological Station was quite in accord with that of the P*. The reported time of commencement of the principal portion is grouped fairly well into that belonging to the S and to the S*. At Hongô, the S and the S* were well defined, though the magnitude of the former was very small compared with that of the latter. The general appearance of the time-distance diagram in this case is quite similar to that of the earthquake on Aug. 3, 1926 off the coast of Haneda (see Fig. 8). Therefore, remarks similar to those stated in that case will be applied in this case. Thus, this will be a good example showing that the mode of propagation in the case of earthquakes in the western Japan is not essentially different from that in the case of earthquakes in the eastern Japan.

Sept. 28, 1928.

When this paper was in the press, Dr. H. Jeffreys kindly send me his paper "On two British Earthquakes" (Monthly Notice of R. A. S. Geophys. Suppl. 1 (1927) No. 9) in which three phases in the distortional waves were also clearly shown. Dr. V. Conrad, who has remarked the existence of the P* phase for the first time, was also kind enough to send me "Das Schwadorfer Beben vom 8 Obtober 1927" (Gerl. Beitr. z. Geophys. **20** (1928) Ht. 3/4) in which similar subjects were shown.

ERRATA TO PART I.

Page 5, line 21. For 18.2 read 20.6
" " 125 " 147×2.

Earthquake of Feb. 4, 1926.
($\lambda=41^\circ\ 22'$ N, $\varphi=142^\circ\ 25'$ E)

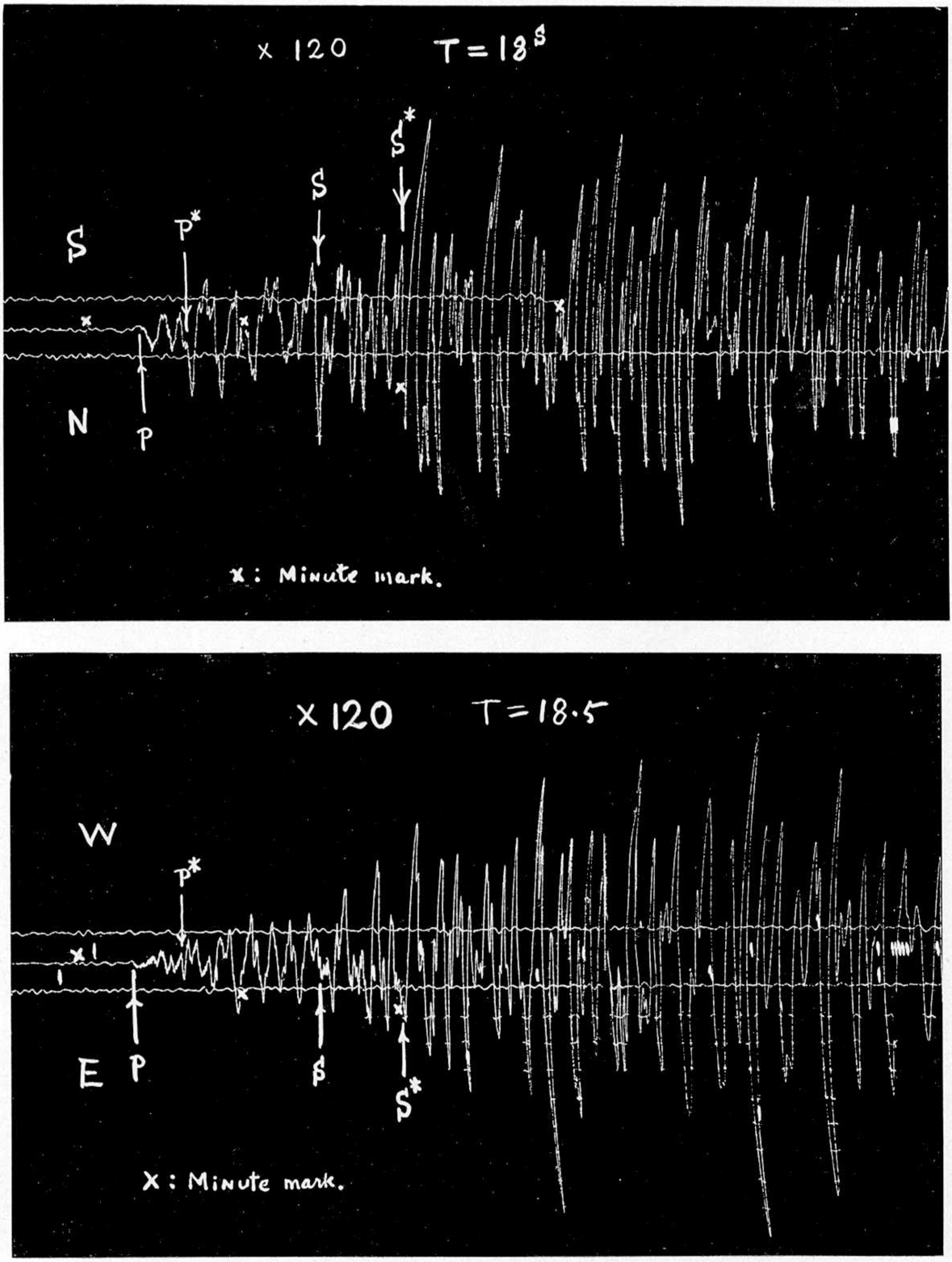


Fig. 3.

（震研彙報、第六號、圖版、松澤）

Earthquake of Feb. 4, 1926.
(φ=41° 22′ N, λ=142° 25′ E)

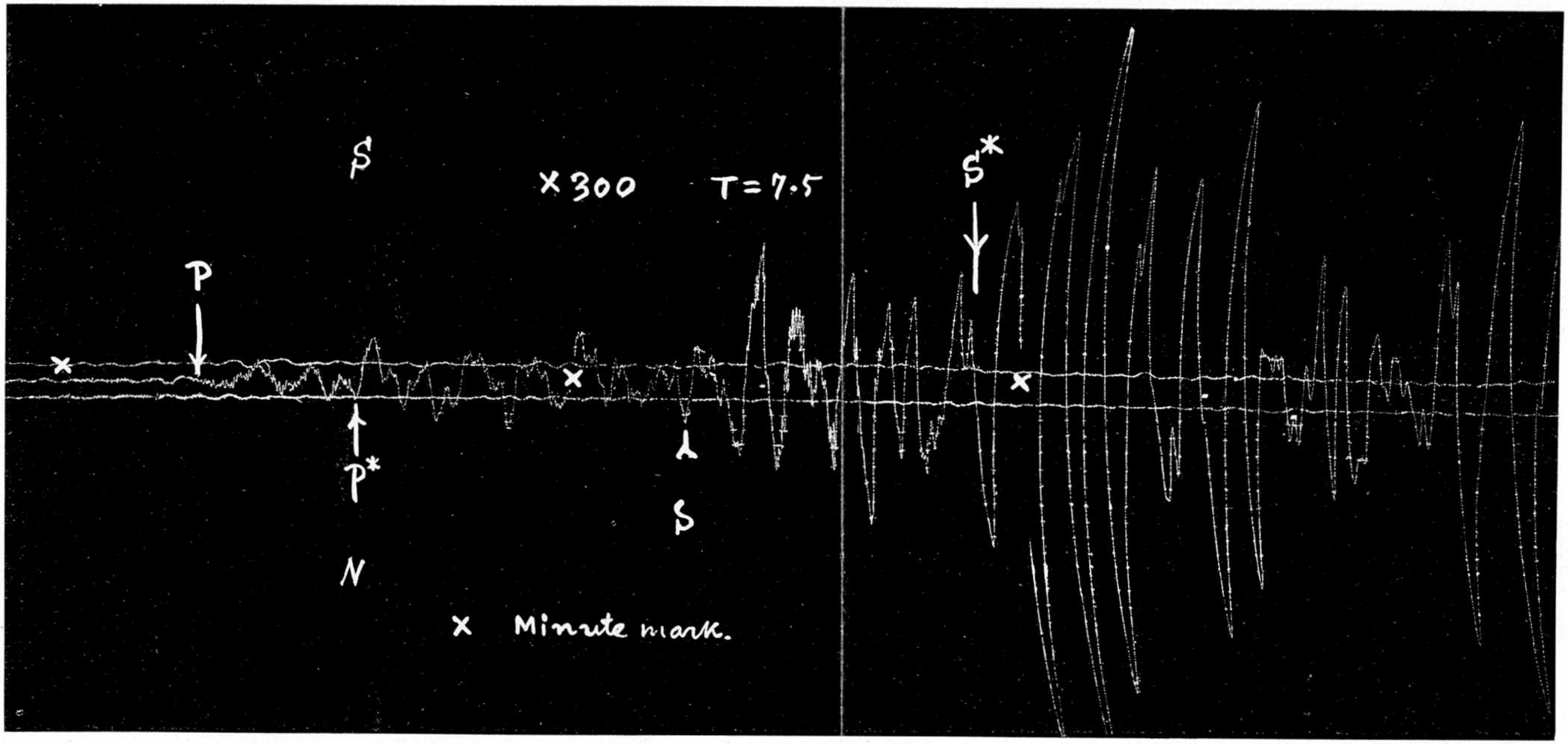
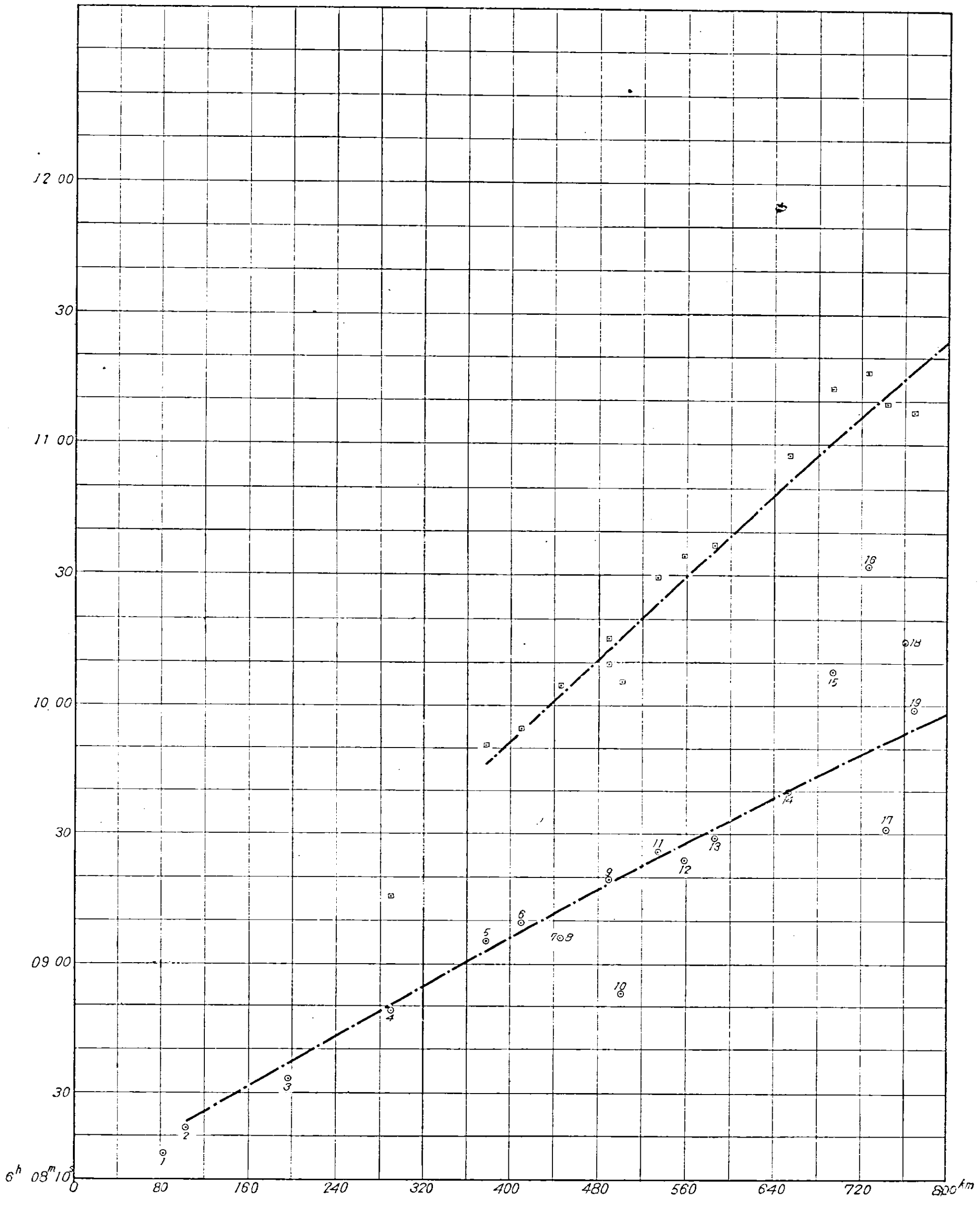


Fig. 4.

Time-Distance Curve of Earthquake on July 13, 1927
($\varphi = 42° 36' N$, $\lambda = 145° 35' E$)



(to be continued.)

(Numbers are to be referred to Table II.)

Fig. 5.

（震研彙報、六號、圖版、松澤）

(Continued.)

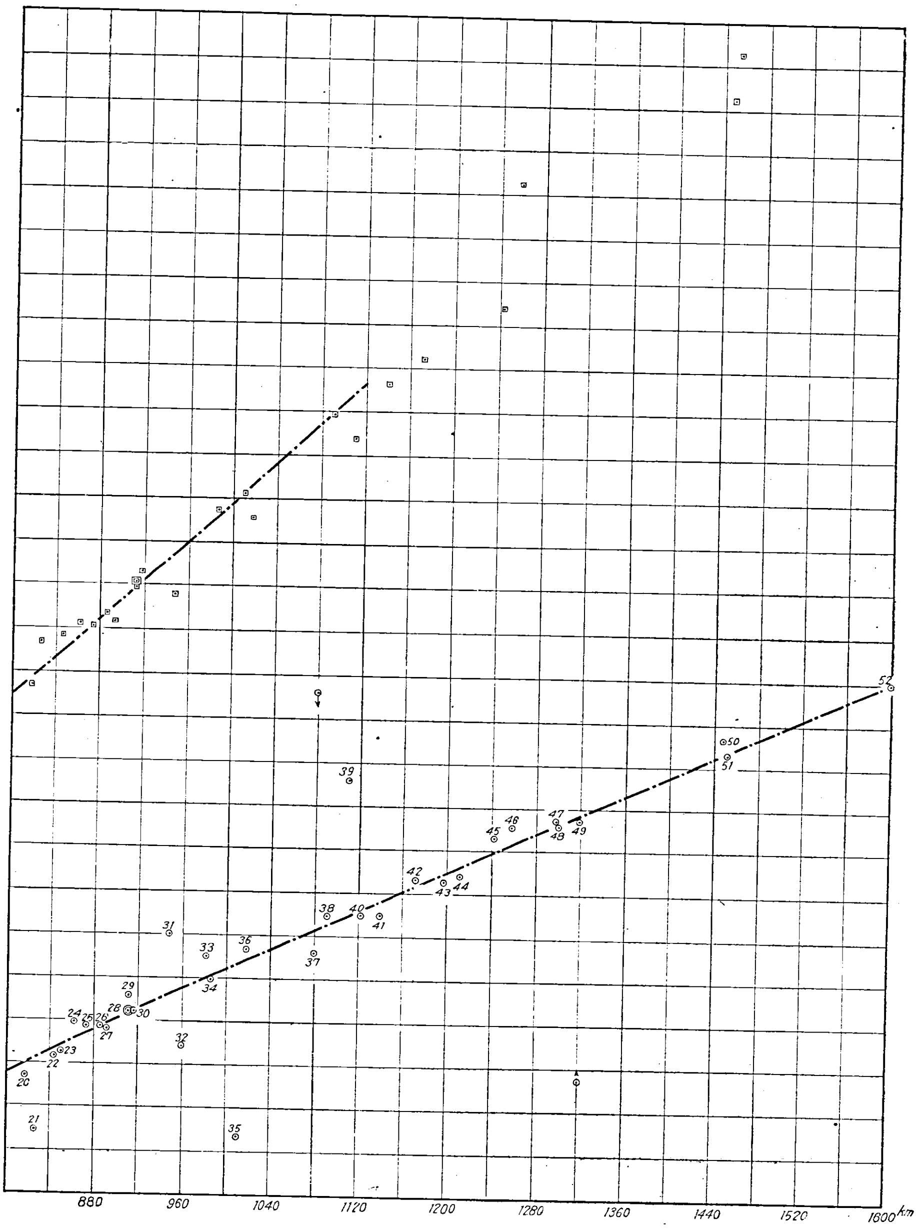


Fig. 5.

（震研彙報、第六號、圖版、松澤）

Earthquake of June 5, 1026.
($\varphi=42^\circ\ 36'$ N, $\lambda=145^\circ\ 35'$ E)

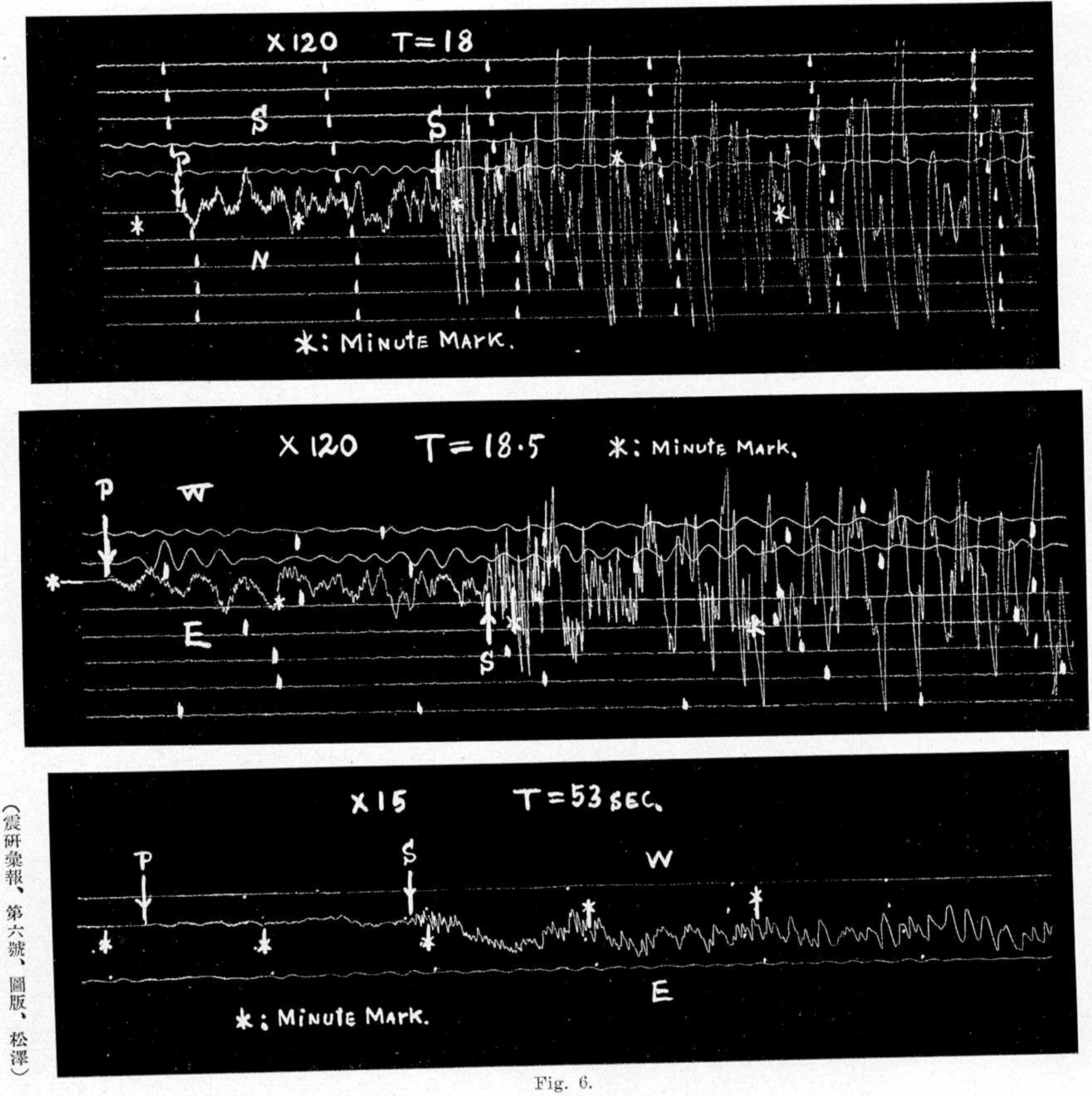


Fig. 6.

Earthquake of July 13, 1927.
($\varphi=30°\ 26'$ N, $\lambda=130°\ 40'$ E)

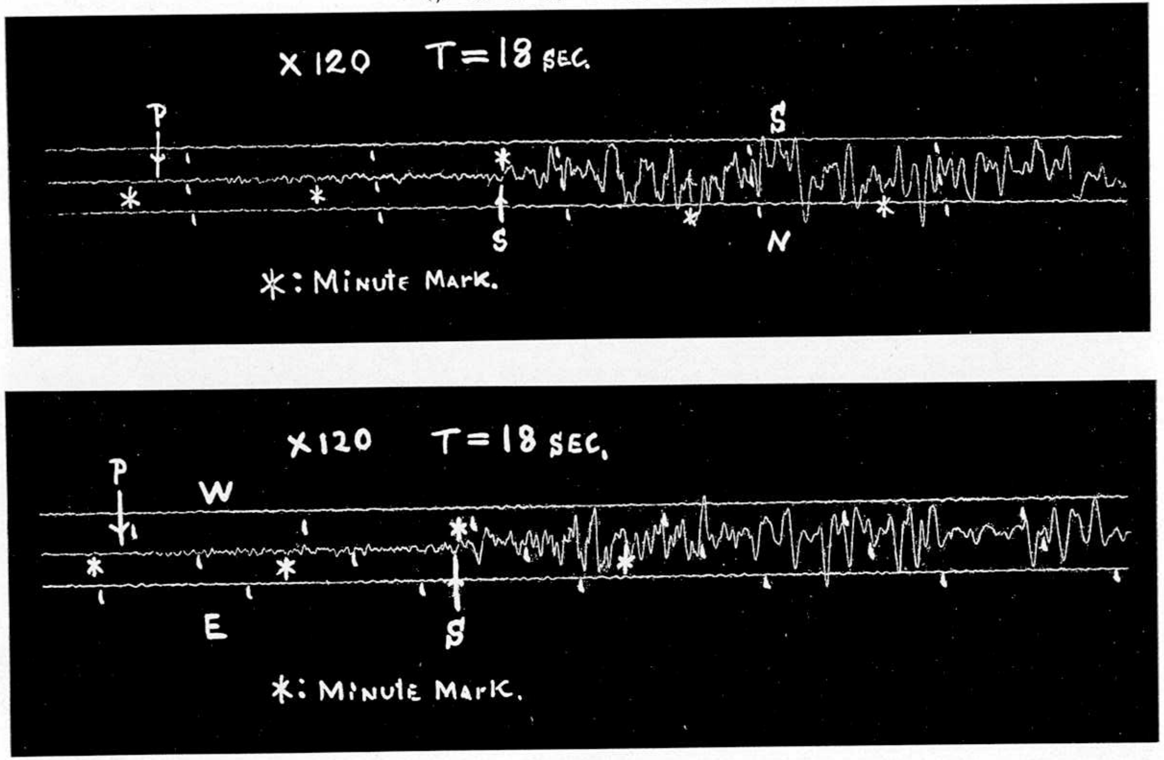


Fig. 10.

（震研彙報、第六號、圖版、松澤）