16. *On the Forerunners of Earthquake-motions.*

(The Second Paper.)

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I. INTRODUCTION.

One of us[1] and others have shown that seismograms of certain earthquakes recorded at Hongô (Tôkyô) or Kamakura indicate a typical forerunning part which may be attributed to a certain kind of local geological structure characteristic to the Kwantô District.

In the course of further study of that case, the present authors' attention was directed to existence of other set of forerunning waves with somewhat more general character. In this paper, these phases of waves will mainly be treated.

II. OBSERVED FACTS WITH REGARD TO THE FORERUNNING PART OF EARTHQUAKE-MOTIONS.

For explaining the existence of certain phases other than those such as P*, $\bar{P}$, etc., it will be convenient to show examples of seismograms which reveal such phases clearly. In the following, some examples will be shown.

No. 1. Earthquake of Jan. 18, 1927. This earthquake occurred far off the coast of Kinkwazan, and the position of its epicentre is estimated as $\lambda=142°14'$ and $\varphi=38°40'$. The time of commencement observed at Hongô, Tôkyô, was 6h 59m 88s. (l.m.t. $\lambda=135°$E). The epicentral distance from Hongô was 388 km. A set of seismograms recorded at Hongô will be reproduced in Pl. XII, Fig. 1. Phase P* and $\bar{P}$ are clearly identified on the seismograms at the exact position expected. From the fact that phase $\bar{P}$ appeared clearly, it will be inferred that the waves were generated in the uppermost layer. Closer examination will reveal a phase marked P_2' somewhat well defined and further P_2 though less defined. The $P-P_2'$ duration is about 3.1 sec. and the $P-P_2$ is 1.5 sec. in this case. The phase denoted by P_2 seems to correspond to the phase denoted by "2" in the former

1) T. MATUZAWA, K. HASEGAWA and S. HAENO, *Bull. Earthq. Res. Inst.*, 4 (1928), 85–106.

paper.[1] Seismograms recorded at Kiyosumi-yama, Yuigahama and Misaki were also available and the P_2' phase was identified as shown in Table I.

TABLE I.

	Tôkyô	Kiyosumi	Yuigahama	Misaki
Epicentral dist. in km.	388	424	434	448
Duration from commencement to phases concerned	$P-P_2=1{\cdot}5$ $P-P_2'=3{\cdot}1$	3·6	3·5	3·8

No. 2. Earthquake of June 1, 1928. This earthquake occurred far off the coast of Miyako and the position of its epicentre is estimated as $\lambda=143°.3$ and $\varphi=39°.8$. The time of commencement observed at Hongô was 22h 13m 31s or so (l.m.t. $\lambda=135°$E.) The epicentral distance from Hongô was 553 km. A seismogram recorded at Hongô is reproduced in Pl. XIII, Fig. 2. Phase P^* and $\overline{P}$ are also clearly identified. Thus, in this case also, the waves might have been generated in the uppermost layer. Further, phase P_2' is seen as before. The P_2 phase cannot be defined in this case, perhaps owing to the smallness of the motion and the lack of quick movements. This point will be taken up later in the section of discussion. Some other seismographs in our institute recorded other incidence of a phase 5.7 seconds after the commencement of phase P. In Fig. 2 it is difficult to identify this phase. But it is inevitable that a phase recorded by a seismograph is sometimes obscure in other records, because each seismograph has its own resolving power for incident waves similarly as spectrographs in spectroscopy.

From seismograms available we have obtained some values as shown in the following table.

TABLE II.

	Tôgane	Hongô	Titibu	Kiyosumi	Misaki	Yuigahama
Epicentral distance	542	553	563	588	612	601
Duration from comm.	5·0	3·2; 5·7 $P-S^*=72{\cdot}5$	2·8	6·3	3·3 5·9	4·4

1) T. MATUZAWA, et. al., *loc. cit.*, 241.

No. 3. Earthquake of Aug. 27, 1928. The epicentre of this earthquake is estimated as $\lambda=141°07'$ and $\varphi=36°34'$ in the Pacific. The depth of its origin is inferred to be situated in the uppermost layer by studying its seismograms within our reach and its time-distance curve. From reported time of commencement and duration of preliminary tremor the time distance curve has been constructed as shown in Fig. 3. The fact that most stations took the S* phase for the commencement of the principal portion

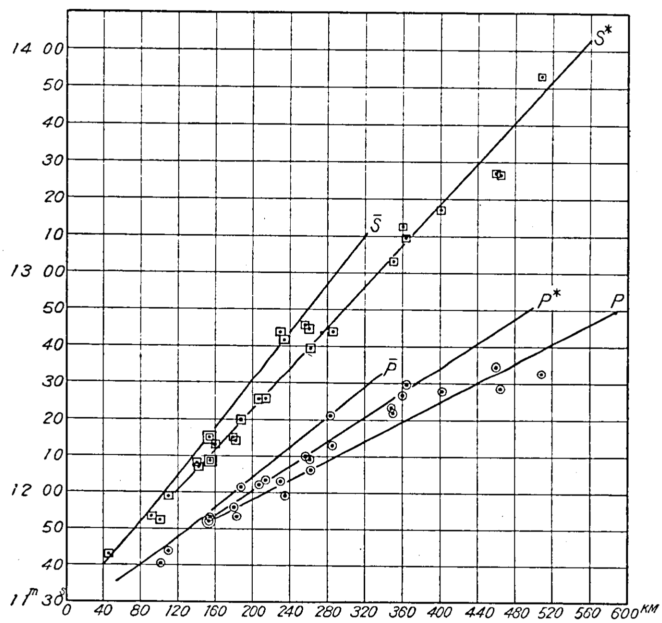

Fig. 3. Time-distance curve of earthquake on Aug. 27, 1928. ($\lambda=141°07'$, $\varphi=36°34'$.) ◎, ▣; determined by us.

and at certain stations the $\overline{\mathrm{S}}$ phase was interpreted as such may tell that the depth of its origin was in the uppermost layer as discussed in the former paper by one of us.[2]

One of seismograms obtained at Hongô is reproduced in Pl. XIII, Fig. 4. In the figure phase S* and $\overline{\mathrm{S}}$ are clearly identified. In the forerunning portion two distinct incidences marked as P_2' and P_2 can be seen. In this case it is somewhat difficult to interpret each incidence exactly. As the epicentral distance from Hongô is 155 km. or so, it is not easy to say with exact certainty, though inevitable from the present state of accuracy of

2) T. MATUZAWA, *Bull. Earthq. Res. Inst,* **6** (1929), 177–204.

observation, whether the very commencement is the P or P* phase, for at such an epicentral distance the first incidence may be phase P or P* according to circumstances. In this case, if the first incidence is P*, then the phase marked P_2' may be the $\overline{P}$ phase. Nevertheless the phase marked P_2 may be the same as that discussed before. It is worth noticing that the epicentre of this earthquake was in the region excluded in the former paper[1] (Fig. 7) from places producing earthquakes showing phase "2" distinctly. This point will be taken up later in discussion.

Result of study of available seismograms at other stations is summarised as follows.

TABLE III.

	Tôgane	Tôkyô	Titibu	Yuigahama	Misaki
Δ km.	133	155	194	199	207
$P-P_2$		1·6		1·5	
$P-P_2'$	2·4	2·7	2·5	6·3	2·3 ; 4·5
$P-S^*$		16·1			
$P-\overline{S}$		22·5			

No. 4. Earthquake of Aug. 6, 1927. From available seismograms recorded at certain stations, we obtained seismometric values as follows:

Time of commencement at Hongô; 6h 13m 38s.

Epicentre; $\lambda=141°25'$, $\varphi=37°32'$.

TABLE IV.

Station	Δ km.	$P-P_2'$	$P-P^*$	$P-\overline{P}$	P–S	$P-S^*$	$P-\overline{S}$
Hongô	250	2·8	5·3	13·5	26·0	32·0	43·0
Titibu	268	4·3	6·4	13·4	28·5	36·5	48·–
Kiyosumi	286	4·0	7·2		29·8	42·6	
Yuigahama	297	4·0	7·9	15·4	28·6	40·0	59·–

In this case also, phases marked with * or – were clearly observed. Therefore, the origin of the disturbance may have been in the uppermost layer at least in the sense as discussed in the former paper by one of us.[3] The P_2' phase was also clearly identified.

1) T. MATUZAWA, et. al., *loc. cit.*, 241.

3) T. MATUZAWA, *Bull. Earthq. Res. Inst.*, 5 (1928), 1–29.

No. 5. Earthquake of Aug. 19, 1927. This was an earthquake with considerable intensity and studied by Dr. K. Wadati[4] as a "deep sea earthquake." The data of time of commencement and those of the P—S duration reported from some stations were somewhat inconsistent to determine an exact position of its epicentre. Here it will be tentatively assumed as $\lambda=141°03'$ and $\varphi=34°13'$, according to "Kisyô Yôran." Then with respect to the forerunning phase, we obtained the following values.

TABLE V.

	Koyosumi	Yuigahama	Tôkyô	Titibu
Δ km.	144	199	216	272
P–P₂′	2·1	3·3	2·9	3·0
P–P₃′	4·8			

No. 6. Earthquake of May 27, 1928. The time of commencement observed at Hongô was 18h 51m 36.9s. From reported data and our own seismometric data, the epicentre was to be taken as $\lambda=142°30'$, $\varphi=40°00'$. Hence the position is close to that of earthquake on June 1, 1928, (No. 2.) Characteristics of this earthquake were nearly the same as that in many respects. Seismometric data obtained by us are as follows.

TABLE VI.

Station	Tôgane	Tôkyô	Titibu	Kiyosumi	Yuigahama	Misaki
Δ km.	530	534	576	576	580	596
$P-P_2'$	3·9	2·9	3·1	3·6	3·6	3·5
$P-P_3'$		5·1	5·3			5·6
$P-P^*$	11·6	13·0	12·6	13·7		
$P-\bar{P}$		25·1				
P–S	48·5	54·–	47·0	28·5		
$P-P^*$	68·6	70·7	70·0	80·2		

No. 7. Earthquake of May 19, 1928. This earthquake occurred off the Pacific coast of the Kasima Province and its epicentre was estimated as $\lambda=141°01'$ and $\varphi=36°30'$. This position is not far distant from the

4) K. WADATI, *Journ. Meteor. Soc. Japan,* [ii] **6** (1928), No. 1.

epicentre of the earthquake of Aug. 27, 1928 already shown as No. 3. The time of commencement observed at Hongô was 18h 32m 32.6s.

Seismometric values with respect to forerunning phases are shown as follows.

TABLE VII.

Station	Tôgane	Tôkyô	Yuigahama	Kiyosumi	Titibu	Misaki
Δ km.	123	142	188	168	182	196
$P-P_2$	1·4	1·5				
$P-P_2'$		2·3	3·9	2·4	2·0	2·6

In this case also as in the case shown in No. 3 the phase defined as P_2 was clearly observed at Tôgane and Tôkyô.

No. 8. The great Tango earthquake on March 7, 1927. A seismometric study of this earthquake by one of the present authors was already published.[3] As widely known this was a very large earthquake so that very sensitive instruments were not available. Especially in the EW component at Hongô (most stations in the Kwantô District were under a similar condition) the movement of the earth crust was so large that certain phases of wave trains were masked by the instrumental vibration and analysis of them was difficult. And yet as the NS component was not so large as the EW, certain characteristics were revealed. Thus seismometric data concerning the forerunning phase determined by us are as follows.

TABLE VIII.

Station	Yuigahama	Misaki	Tôkyô	Kiyosumi
Δ km.	405	415	427	470
$P-P_2'$	4·2	3·6	5·0	3·8

According to Dr. S. I. Kunitomi's investigation,[5] he observed a typical incidence few seconds after the commencement of motion at certain

3) T. MATUZAWA, *loc. cit.*, 244.
5) S. I. KUNITOMI, *Journ. Meteor. Soc. Japan,* [ii] **5** (1927), No. 8.

stations as shown in the following table denoted by P—iP after his notation.

TABLE IX.

Station	Δ km	P–iP	Station	Δ km	P–iP
Toyooka	24·6	1·9	Nagoya	176	2·7
Kanazawa	175·7	2·2	Husiki	223	3·1
Kyôto	92·5	2·2	Tadotu	193	2·3
Sumoto	148	2·3	Kôti	267	4·7
Kôbe	106	1·9	Tokusima	179	2·5
Hukui	125·7	1·5	Hamada	280	2·8
Hikone	116	2·7	Hirosima	231	2·4
Gihu	157·2	2·5	Nagano	306	2·3
Yagi	140·5	2·2	Matuyama	285	2·8
Sakai	163	2·4	Sionomisaki	255	3·0
Takayama	209	2·5	Kumagai	399	4·7
Wakayama	160	2·9	Hamamatu	267	4·9
Okayama	149	2·5	Tôkyô	431	5·2

From our view point, this P—iP difference seems to be the same as our $P-P_2'$ (refer to Fig. 9.)

No. 9. Earthquake of Dec. 31, 1927. In the cases above shown, the origin of earthquakes was inferred to be in the uppermost layer, that is, very shallow. On the other hand, for elucidation of mechanism of occurrence of such phases, it is necessary to study earthquakes of different epicentral distances as well as of different depth.

The P—S duration reported from meteorological stations is shown in the table. (Table X.) The epicentre distance is calculated taking the epicentre as $\lambda=139°35'$, $\varphi=36°07'$ which was determined by us using the method proposed by Dr. R. Takahasi.[6] The time of commencement at Hongô was 14h 51m 06.9s. on Dec. 31, 1927.

6) R. TAKAHASI, *Bull. Earthq. Res. Inst.*, **6** (1929), 231–244.

TABLE X.

Station	Δ km.	P–S	Station	Δ km.	P–S	Station	Δ km.	P–S
Mito	87	16·4 s	Takayama	209	25·5 s	Sendai	264	30·3 s
Kumagai	17	14·5	Takada	159	23·1	Isinomaki	300	34·0
Maebasi	56	16·0	Tu	318	29·4	Miyako	443	44·0
Tukuba	48	16·0	Utunomiya	56	14·0			
Yokohama	70	18·8	Kôhu	104	15·0	Titibu	46	14·9
Kakioka	55	16·3	Husiki	240	25·9	Hongô	49	16·2
Niigata	208	28·0	Nagoya	263	21·9	Tukuba	50	16·2
Nagano	140	19·7	Onahama	150	20·9	Yuigahama	89	16·8
Mera	129	18·5	Hukui	303	35·2	Misaki	107	17·2
Tyôsi	120	23·4	Gihu	266	25·2	Kiyosumi	119	18·3
Numadu	130	17·4	Hikone	315	30·0			

(The last 6 cases were determined by us.)

A diagram showing the relation between the epicentral distance and the P—S duration is constructed as shown in Fig. 5. From the figure it may be seen that the P—S duration at the epicentre is expected to be 14

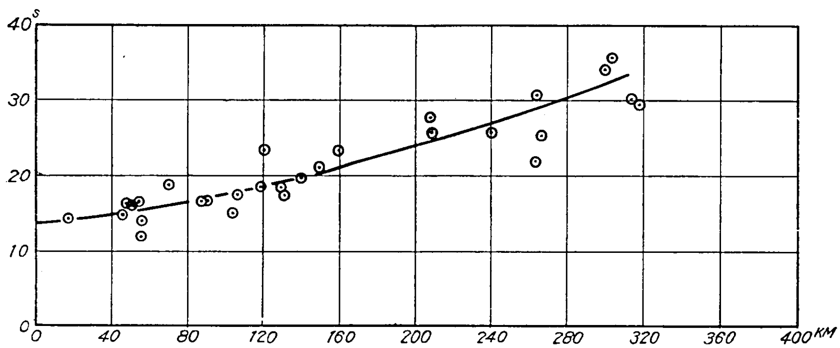

Fig. 5. The P–S duration of the earthquake of Dec. 31, 1927.

seconds or so. Thus, taking into account the stratified structure of the superficial portion of the earth crust and assuming those values obtained in our former paper, the depth of the origin in estimated at 140 km. in round numbers. A set of seismograms obtained at Hongô is shown in Pl. XIV, Fig. 6. As apparent from the figure, in this case also we can define some step-wise incidences of waves marked such as "P_2" "P_2'" and "P_3'". From seismograms within our reach recorded at other stations, we measured several values as shown below.

TABLE XI.

Station	Δ km.	P–P_2	P–P_2'	P–P_3'	P–S
Titibu	46	1·4	2·1		14·9
Hongô	49	1·2	2·4	5·6	16·2
Tukuba	50	1·0			16·2
Yuigahama	89	1·6	2·5	5·0	16·8
Misaki	107			7·5	17·2
Kiyosumi	119	1·6	2·2		18·3

No. 10. Earthquake of March 29, 1928.[7] This earthquake occurred at a certain place in the Pacific close to the Huzi volcanic zone. Unfortunately, however, the epicentre was too far from the main island of Japan, where observatories are mainly distributed, to determine the exact position. For the sake of reference, reported values of the time of commencement and the duration of the preliminary tremor observed at meteorological stations will be shown.

TABLE XII.

Station	Δ 1	Δ 2	Time of comm. h	Time of comm. m	Time of comm. s	Dur. of P.T. m	Dur. of P.T. s
Sakai	605	798				1	11·6
Miyadu	488	701	14	07	22·8		03·6
Tukuba	488	688			33·0		
Matumoto	466	685					58·–
Yagi	376	587			1·0	1	10·8
Hatizyô	173	344			2·–		50·–
Sionomisaki	288	480			4·2		49·4
Gihu	402	625			8·1		52·5
Numazu	347	561			12·7	1	01·2
Mera	347	544			13·3		58·5
Wakayama	372	570			14·0	1	00·–
Muroto	410	573			14·5		57·2
Uwazima	546	688			14·8	1	06·3

(to be continued.)

7) This earthquake was investigated by Dr. K. Wadati as an extremely deep-seated one. *Jour. Meteor. Soc. Japan,* [ii] **6** (1928), No. 5.

TABLE XII. (continued.)

Station	Δ		Time of Comm.			Dur. of P.T.	
	1	2	h	m	s	m	s
Nagoya	368	590	14	07	15·8		51·6
Kyôto	427	629			16·1		57·7
Sumoto	402	600			16·1		56·4
Kôbe	415	616			16·7		57·3
Oosaka	394	600			17·3		58·8
Ibukiyama	432	650			17·3		54·0
Yokohama	393	597			17·9		56·1
Tôkyô	423	625			18·3		59·8
Hongô	425	627			19·8		57·7
Hikone	410	629			19·7		57·6
Tadotu	483	660			21·-	1	03·-
Kumagai	377	671			21·4	1	01·4
Kôti	466	629			21·6		58·9
Utunomiya	504	710			23·9	1	06·8
Tyôsi	466	650			24·3	1	01·5
Kakioka	491	688			24·6	1	01·6
Mito	512	708			26·-	1	05·0
Toyooka	495	710			26·5	1	03·7
Maebasi	472	683			271		59·6
Husiki	542	766			28·2	1	09·2
Nagano	516	735			28·7	1	04·7
Oiwake	478	697			28·8		54·0
Okayama	500	688			30·0	1	03·0
Hirosima	592	765			33·2	1	11·5
Takayama	474	694			33·8		50·2
Hukui	487	710			34·8	1	02·6
Takada	559	778			36·0	1	06·1
Hamada	643	816			36·2	1	08·9
Matuyama	542	703			36·3	1	07·1
Miyazaki	632	727			36·4	1	09·7
Ooita	623	756			38·2	1	06·8
Aidu	623	829			42·-	1	13·6
Hukusima	775	858			42·-	1	16·8

(to be continued.)

TABLE XII. (continued.)

Station	Δ		Time of Comm.			Dur. of P.T.	
	1	2	h	m	s	m	s
Onahama	585	780	14	07	45·3	1	08·2
Unzendake	738	853			46·6	1	20·8
Isinomaki	747	943			49·7	1	21·6
Nagasaki	776	887			50·0	1	22·7
Hukuoka	742	875			50·4	1	07·5
Miyako	890	1088		08	00·0	1	27·–
Midusawa	814	1018			00·0	1	27·–
Husan	904	1060			1·–	1	38·–
Simonoseki	705	850			3·–	1	16·–
Akita	892	1062			3·8	1	32·7
Iduhara	850	986			4·2	1	33·–
etc.							

The epicentral distance in column "1" was calculated from an epicentre taken as $\lambda=138°22'$E, $\varphi=32°00'$N and that in "2" from that taken as $\lambda=138°58'$E, $\varphi=30°05'$N. In this case the reported data are somewhat inconsistent mutually. Both epicentres taken above render the fluctuation of reported values from the mean smaller than other assumptions. If the epicentre is taken as "1" the depth of origin of this earthquake must be very deep (above a few hundreds of kilometres) as Mr. K. Wadati[7] stated. On the other hand, if the second position is taken, it is not so extraordinary as the case "1". And yet its origin will be far deep-seated than ordinary inland earthquakes. Seismograms obtained at Hongô are shown in Pl. XV–XVI, Fig. 7 and Fig. 8. If this earthquake was of a shallow origin, certain phases such as P^*, $\overline{P}$, S^* or $\overline{S}$ would be observed. Nevertheless, the preliminary portion is far simple, as apparent from the figures, compared with ordinary cases. And yet, phase P_2' is quite clearly identified in Fig. 7. In this figure the commencement of phase P is somewhat vague, but in Fig. 8 it will clearly be defined, especially in the vertical component. From seismograms at some other stations within our reach the following values were obtained.

7) K. WADATI, *loc. cit.*, 249.

TABLE XIII.

Station		Tôkyô	Titibu	Yuigahama	Misaki	Kiyosumi	Tôgane
Δ	1	425	446	378	369	378	433
	2	627	648	581	570	572	618
$P-P_2'$		3·7	4·3	3·0	4·5	4·1	4·9
$P-P_3'$		8·9					8·2
P–S		57·7	59·5	55·1	54·6	56	57·6

No. 11. Earthquake of Nov. 11, 1927. The epicentre of this earthquake was estimated as $\lambda=138°00'$E, $\varphi=36°03'$N from the time of commencement and the duration of the preliminary tremor reported from meteorological stations. The data adopted from "Kisyô Yôran" are shown below.

TABLE XIV.

Station	Δ	Time of Comm.			Dur. of P.T.
		h	m	s	s
Onahama	278	4	48	11·4	36·5
Tu	202			52·1	33·8
Maebasi	104			49·3	31·6
Iida	62			52·2	32·0
Nagano	70			53·2	23·8
Takada	118			54·0	25·1
Gihu	133			54·9	26·1
Nagoya	144			55·2	24·7
Kumagai	126			55·5	26·3
Husiki	119			56·8	22·7
Tukuba	190			57·3	32·0
Numadu	131			58·9	27·9
Matumoto	22			59·–	18·0
Kakioka	196			59·5	32·6
Hikone	181		49	01·2	27·5
Yagi	264			01·5	
Kôhu	70			02·–	30·–
Miyadu	260			02·7	

(to be continued.)

TABLE XIV. (continued.)

Station	Δ	Time of comm.			Dur. of P.T.
		h	m	s	s
Tôkyô	166	4	49	02·9	29·7
Kanazawa	134			04·–	25·–
Mito	225			04·–	28·7
Toyooka	292			05·0	
Kôbe	297			06·6	
Kyôto	233			07·1	34·5
Mera	202			07·9	28·2
Wakayama	328			08·0	
Oosaka	275			08·4	35·4
Tyôsi	256			09·3	34·5
Niigata	229			10·0	17·0
Oiwake	59				24·0
Sumoto	340			11·6	39·8
Sendai	353			14·2	
Sionomisaki	350			18·0	43·2
Isinomaki	395			18·8	42·0
Tokusima	385			20·5	43·2
Mizusawa	441			21·–	47·–
Okayama	400			23·0	38·0
Akita	448			23·6	48·5
Morioka	494			26·9	53·5
Kôti	490			27·2	52·0
Ibukiyama	160			31·2	
Miyazaki	766			54·6	86·3
Ooita	667			56·0	
Sapporo	832		50	04·5	80·6
etc.					

From these data it may be seen that the origin of this earthquake was very deep-seated. Owing to the limited accuracy of the data the position is not determined very exactly, but the depth of the origin seems to be about 200 km. in round numbers.

In this case also, certain forerunning phases were observed as shown below.

TABLE XV.

Station	Δ km.	P–P₂	P–P₂′
Titibu	100	1·2	2·6
Tôkyô	166		2·0
Yuigahama	164	1·3	3·4

No. 12. Earthquake of Dec. 10, 1927. The epicentre was determined as $\lambda = 138°56'E$, $\varphi = 38°00'N$ from the data shown below, which was adopted from "Kisyô Yôran."

TABLE XVI.

Station	Δ km.	Time of comm.			Dur. of P.T.
		h	m	s	s
Aidu	122				27·6
Tukuba	230				28·0
Niigata	22	11	44	47·5	19·0
Hukusima	147			51·–	20·6
Takada	114			51·6	21·1
Utunomiya	186			52·7	24·7
Sendai	180			54·8	23·3
Yamagata	136			55·9	19·1
Maebasi	180			56·1	24·4
Takayama	250			56·4	32·0
Nagano	160			56·9	22·2
Kumagai	213			57·8	25·5
Kakioka	232			58·0	25·2
Oiwake	188			58·0	31·5
Hamamatu	380			58·0	
Akita	218			59·4	25·8
Midusawa	235		45	00·–	26·–
Mito	231			00·–	25·2
Onahama	217			00·9	23·8
Isinomaki	220			02·6	24·5
Morioka	275			03·8	30·3
Tôkyô	273			05·2	31·1
Tyôsi	312			06·3	28·9

(to be continued.)

TABLE XVI. (continued.)

Station	Δ km.	Time of comm.			Dur. of P.T.	
		h	m	s		s
Yokohama	294	11	45	06·7		31·5
Numadu	325			09·1		37·5
Matumoto	212					28·0
Kôhu	266			10·5		
Miyako	323			12·0		33·0
Gihu	344			13·1		45·5
Hikone	383			20·8		44·1
Ibukiyama	361			20·8		40·8
Nagoya	362			21·8		46·0
Hakodate	447			22·0		
Kyôto	434			25·0		54·5
Toyooka	450			26·3		52·4
Husiki	210					31·8
Obihiro	658			40·0		59·0
					m	
Sionomisaki	575			40·6	1	04·8
Sapporo	600			41·6		
Kusiro	720		46	00·0	1	02·7
Mera	350		45	11·5		36·0

From these data, the depth of the origin is estimated as about 100 km. in round numbers. Results of our own observations are as follows.

TABLE XVII.

Station	Δ km.	P–P₂′	P–S	Remarks
		s	s	
Titibu	230	2·1	27·1	In the record at Kiyosumiyama time
Tôkyô (Hongô)	273	4·5	28·7	marks were not printed. Therefore
Yuigahama	300	4·3	31·2	the P–S duration 34s was deter-
Kiyosumiyama	342	5	34	mined by interpolation.

DISCUSSION.

From examples shown above, in the forerunning portion of earthquake motions some kinds of incidence of train of waves other than the P^* or $\overline{P}$ phase are defined with considerable certainty.

One evidence that these phases are not due to mistake of identification of the P* or $\overline{P}$ phase is that these phases are found even in the case of extremely deep-seated earthquakes, the origin of which is plausibly inferred to lie below the lower boundary of the second layer.

If this phenomenon is a real entity and not an apparent matter due to certain errors, it is desirable to make clear the mechanism of production of such phases. Generally speaking, the characteristic features of the seismigram will, on one part, be due to the mechanism of occurrence of an earthquake and, on the other part, to the mechanism of propagation of disturbances. For interpretation of seismograms, it is necessary at first

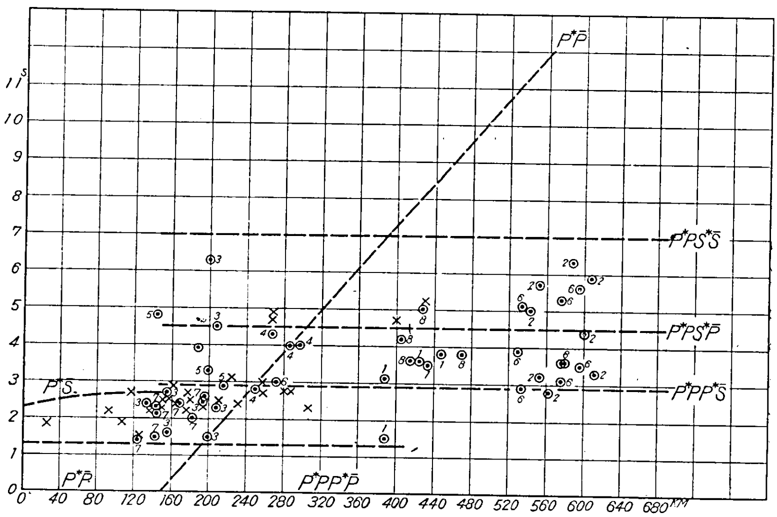

Fig. 9. Interval from the commencement to each phase.

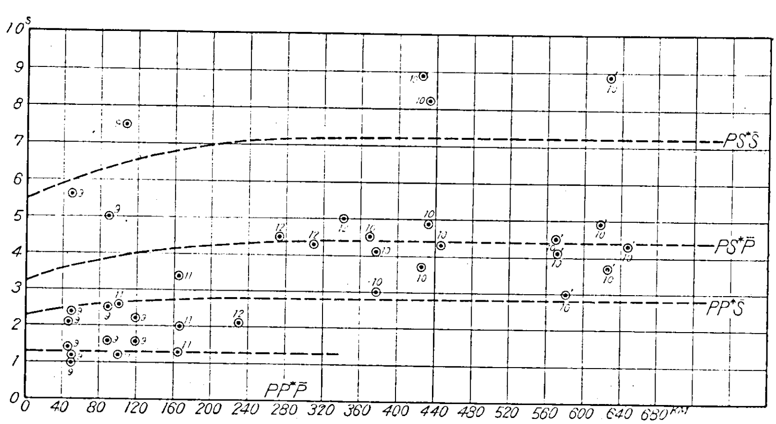

Fig. 10. Interval from the commencement to each phase.

to distinguish these two effects. Thus, in our cases we shall study this point at first.

The data concerning shallow-seated earthquakes (from No. 1 to No. 8 in the foregoing section) are plotted in Fig. 9 and those of deep-seated ones (from No. 9 to No. 12) in Fig. 10.

The fact that these phases occur in different cases in almost similar positions in seismograms may be a strong support to infer that these phases are due to the mechanism of propagation and not to that of generation of earthquakes.

Even if such a case is taken for granted, there may be several ways of elucidation. Some one may attribute this to a mosaic structure of earth's crust. A principal difficulty in this way of explanation is in the typical polarisation of waves, that is, in the observed waves the vertical component of movement at the commencement is generally far distinct compared with the horizontal. Thus a case of apparent earlier commencement of the vertical motion than the horizontal occurs very frequently owing to insufficient sensitivity of the horizontal component of a seismograph. This point was correctly discussed by Visser[8] and Berlage and their way of explanation was similar to that proposed in our former paper.[1]

Now we shall try to explain this phenomenon in a similar way discussed in that paper. The mode of the superficial stratification of the earth's crust will be assumed as determined by one of us,[2,3] and shown in the following table.

TABLE XVIII.

	Thickness	Vel. of dil. waves.	Vel. of dis. waves.
The first layer	20 km.	5·0 km/sec.	3·15 km/sec.
The second layer	30	6·2	3·7
Immediately below the lower boundary of the second layer	50 from the surface.	7·5	4·5

For the sake of simplicity, we will denote the dilatational wave in the first layer by $\overline{P}$, that in the second layer by P^* and that in the lower

8) S. W. VISSER and H. P. BERLAGE, JUN, *Beitr. z. Geophys.* **19** (1928), 147–152.
1) T. MATUZAWA, et. al., *loc. cit.*, 241.
2, 3) T. MATUZAWA, *loc. cit.*, 243–244.

medium simply by P. With regard to the distortional wave, similar notations such as S, S^* and $\bar{S}$ will be used.

At first we shall treat the case when the source of disturbance is in the first layer. As an examplel its depth will be taken 15 km. deep. Results of calculation are shown in Fig. 11.

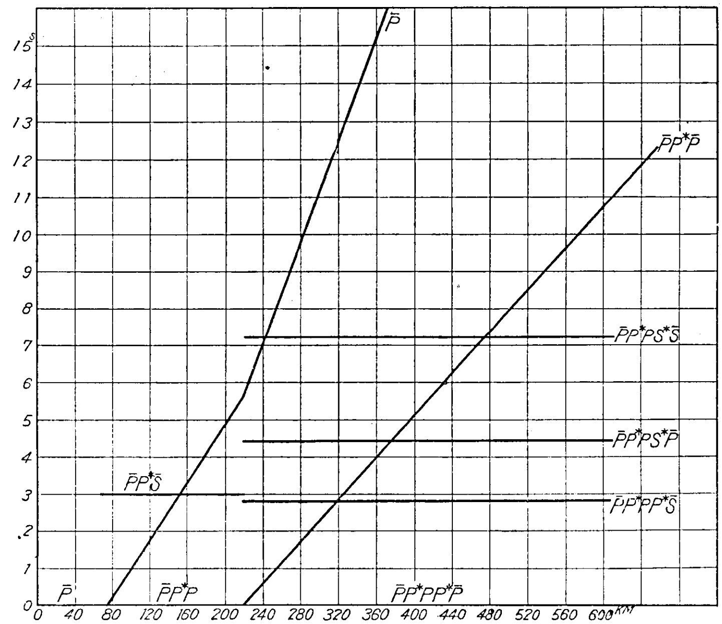

Fig. 11. Interval from the commencement to each phase.

In the figure, intervals of time from the first incidence of a certain phase to that of other kinds of phases are shown as ordinate and the abscissa represents the epicentral distance. For instance, at a place 120 km. from the epicentre the first incidence is that of waves tentatively denoted by $\bar{P}$ P^* $\bar{P}$ (a disturbance which is started in the first layer as dilatational waves, refracted into the second layer as dilatational and again into the first layer as dilatational waves.) After 1.7 sec. the $\bar{P}$ phase may set in and after 3 sec. from the commencement the $\bar{P}$ P^* $\bar{S}$ phase will arrive. Transformation of the dilatatinal wave into the distortional wave or *vice versa* will occur every time when waves are refracted or reflected at a boundary. Thus, there will take place a lot of varieties of waves. Indeed, such will be the case in the real earthquakes. Comparative simple appearance of seismograms due to deep-seated earthquakes is perhaps due to this cause. But here our attention will only be paid to the case of transformation of types at the later stage of propagation. Otherwise, the interval of phases will be affected very much according to the difference of depth of disturbance and of the epicentral distance. On the other hand, our each observed case has much mutual similarity and generality.

In the next place, the case when the source of disturbance is in the depth of 40 km. from the surface, that is, in the second layer, will be treated. The results are shown in Fig. 9 with broken lines. The line at 1.3 sec. is drawn in addition as a local character of the Kwantô district.[1] By this local effect certain phases must undergo some corrections, as far as they concern with observations in the Kwantô District, but the amount is about 0.3 sec. or so even at the greatest.

From the figure, the observed values seem to be somewhat well explained at least qualitatively, considering the practical difficulty of exact identification of incidence of waves. The observed values plotted in Fig. 9 concern with such earthquakes that show the $\overline{\mathrm{P}}$ phase. On the other hand, the curves have been drawn according to the calculation on an assumption that the origin of disturbance is in the middle layer. Therefore, it may seem erroneous to compare them. These earthquakes here shown, however, were all of considerable magnitude. Therefore, if the idea of generation of seismic waves discussed in a paper by one of us[3] is allowed, this way of comparison may be justified. Indeed, some of them may rather be compared with Fig. 11.

In the next place, we shall try the case of deep-seated earthquakes. For example, the depth of the source of disturbance will be assumed as 100 km. from the surface. Our cases depend mainly on the mode of stratification of the superficial earth's crust and less on the position of origin of disturbance. The curves showing the results of calculation are shown in Fig. 10. Comparison with the observed data will make clear that the general features of the observed phenomena are considerably well explained by the assumption.

If it is taken for granted that this observed phenomenon is due to the superficial stratification of the earth's crust, it may naturally be inferred that the practical difficulty of identification of incidence of certain phases is greatly due to the wave length. If the wave length is too large compared with the thickness of stratification it will be practically difficult to distinguish the transformed waves from another. When the epicentral dis-

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1) T. MATUZAWA, et. al., *loc. cit.*, 241.
3) T. MATUZAWA, *loc. cit.*, 244.

tance is large, it is generally observed that waves with long wave length survive from certain causes. Thus, in the case of distant earthquakes the identification of phases especially with short duration becomes difficult.

The distribution of earthquakes showing the characteristic forerunner with 1.3 sec. duration at certain stations in the Kwantô District was shown in Fig. 7 of our former paper, "On the forerunners of earthquake motions of certain earthquakes, this Bull. 4 (1928) 93." Its explanation then given must undergo now some modification. Indeed, as apparent from Fig. 9 and Fig. 10 even in the case of distant earthquakes (for example, earthquake No. 1) it was clearly observed. Therefore it is inferred that if the movement is sufficiently quick that phase will generally be observed despite of the position of its epicentre. Thus, the typical distribution of earthquakes explained in the former paper is considered to be due to the typical character of earthquakes habitual to each locality. (Of course it does not mean the step-wise occurrence of movements, but the character of waves.) Deep-seated earthquakes contain generally quick movements, and show clearly the typical forerunner.

The P_2' wave discussed in this paper seems to correspond to the P_x wave by Prof. V. Conrad[9] in the case of "Schwadorfer Beben."

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16. Disin-dô no Sakigake no Bubun ni Tuite.

1. Disin-dô no Hazimari no Bubun ni P^* ya $\overline{P}$ to tigatta Nami no Atumari ga kubetu dekiru Baai ga ooi.
2. Sorera no Nami no Seisitu wa mae no Ronbun "Aru Disin no Sindô no Sakigake no Bubun ni tuite, Ihô, Maki no 4 (1928), 85–106" ni nobeta Baai to yoku nite iru.
3. Kono Gensyô no okoru Setumei to sitewa Ue no Ronbun no Baai to dôyô na Kangae ni yori, tada Nami no tutawaru Hayasa ya Tikaku no Kôzô wa Tyosya no Hitori[2,3] (Matuzawa) ga mae ni motometa mono wo tukatte kanari na Teido ni setumei dekiru koto wo simesita.
4. Kono Gensyô ni tomonau ikutukano Tyûi mo nobetearu.

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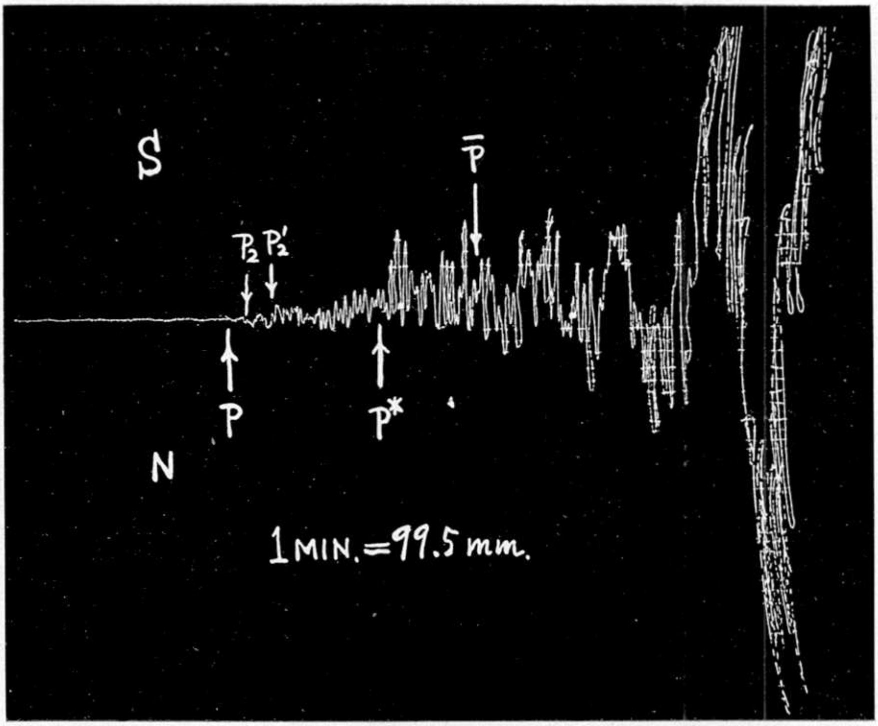
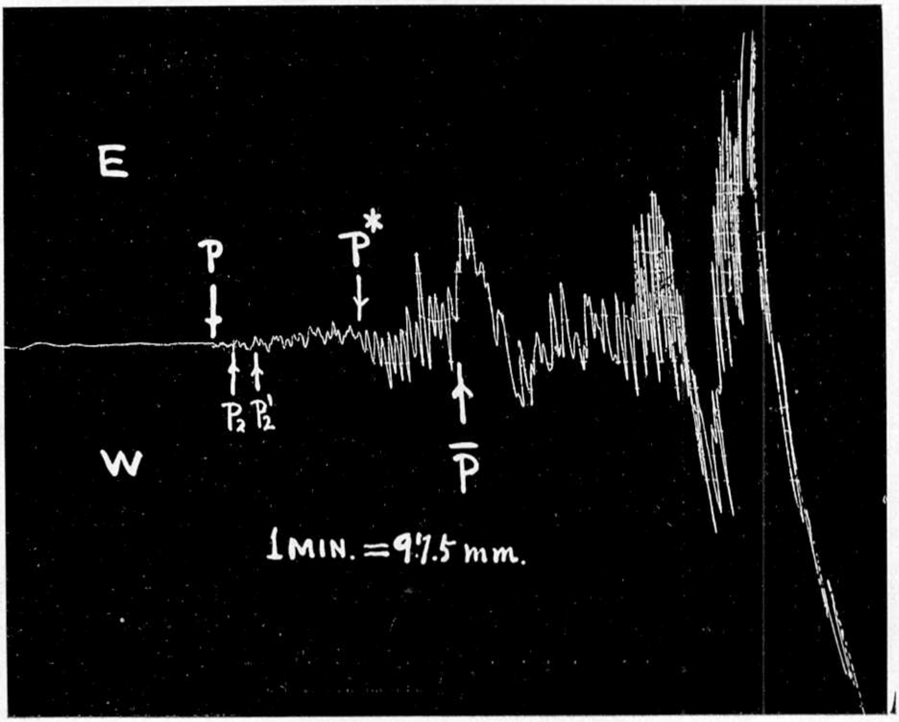
9) V. Conrad, *Beitr. z. Geophys.*, **20** (1928), 259.
2, 3) T. Matuzawa, *loc. cit.*, 243–244.





（震研彙報、第七號、圖版、松澤・山田・鈴木）

Fig. 1. Earthquake of Jan. 18, 1927.
$\lambda = 142°14'E$, $\varphi = 38°40'N$.
Magnification, 300.

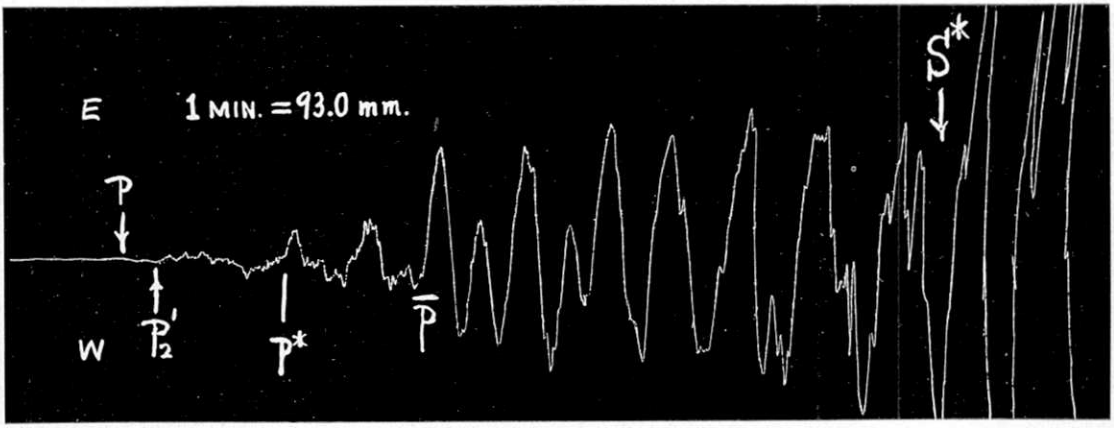


Fig. 2. Earthquake of June 1, 1928.
λ = 143°.3 φ = 39°.8. Recorded at Hongô.
Magnification, 300.

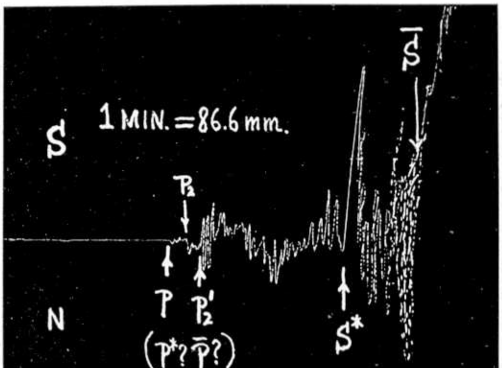
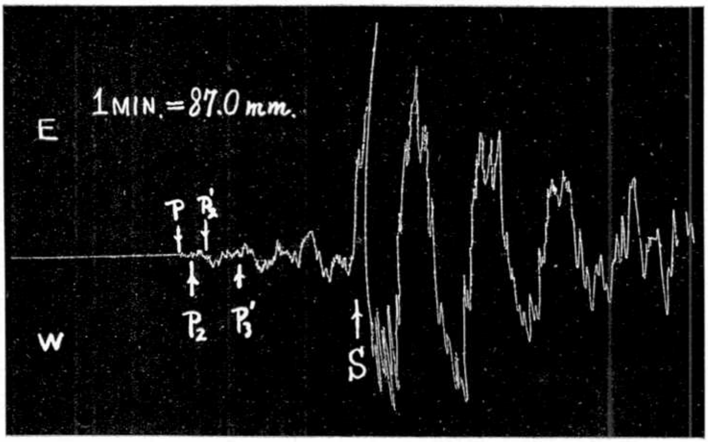


Fig. 4. Earthquake of Aug. 27, 1928.
λ = 141°07′, φ = 36°34′.
Recorded at Hongô.
Magnification, 300.



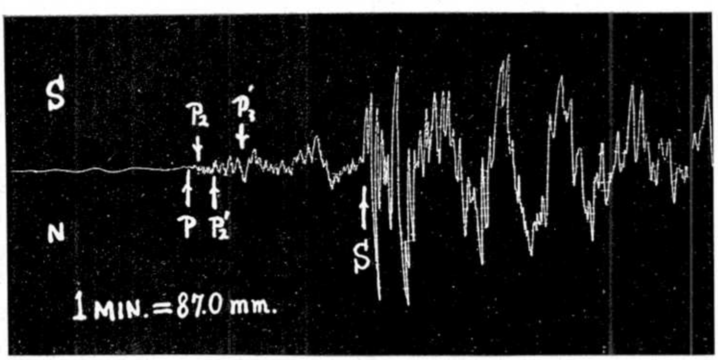


Fig. 6. Earthquake of Dec. 31, 1927.
Recorded at Hongô.

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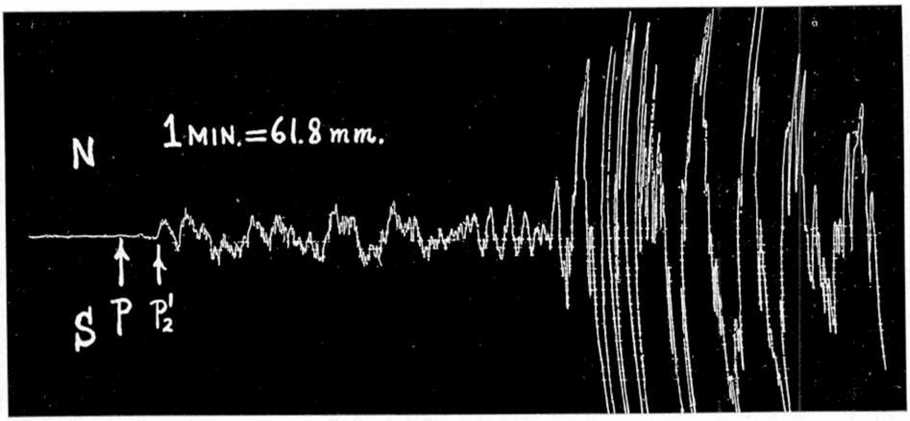

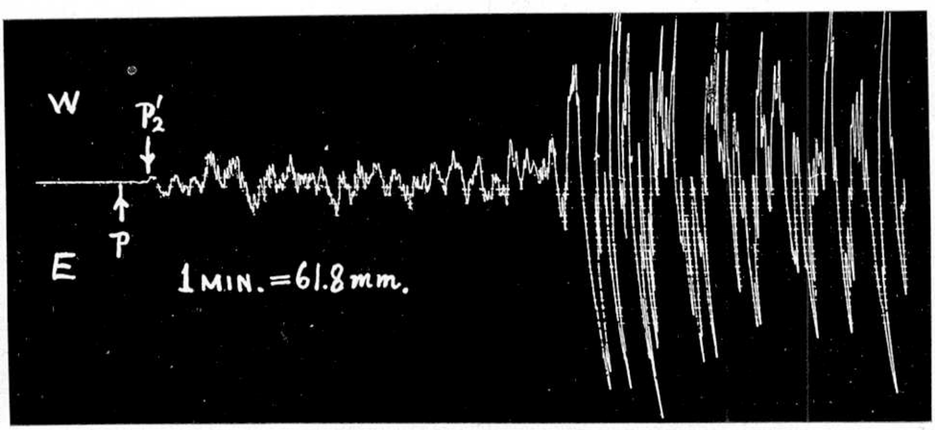

Fig. 7. Earthquake of March 29, 1928.
Recorded at Hongô.

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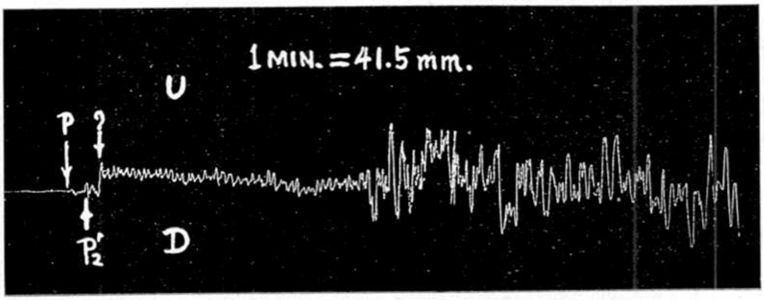

? will be instrumental.

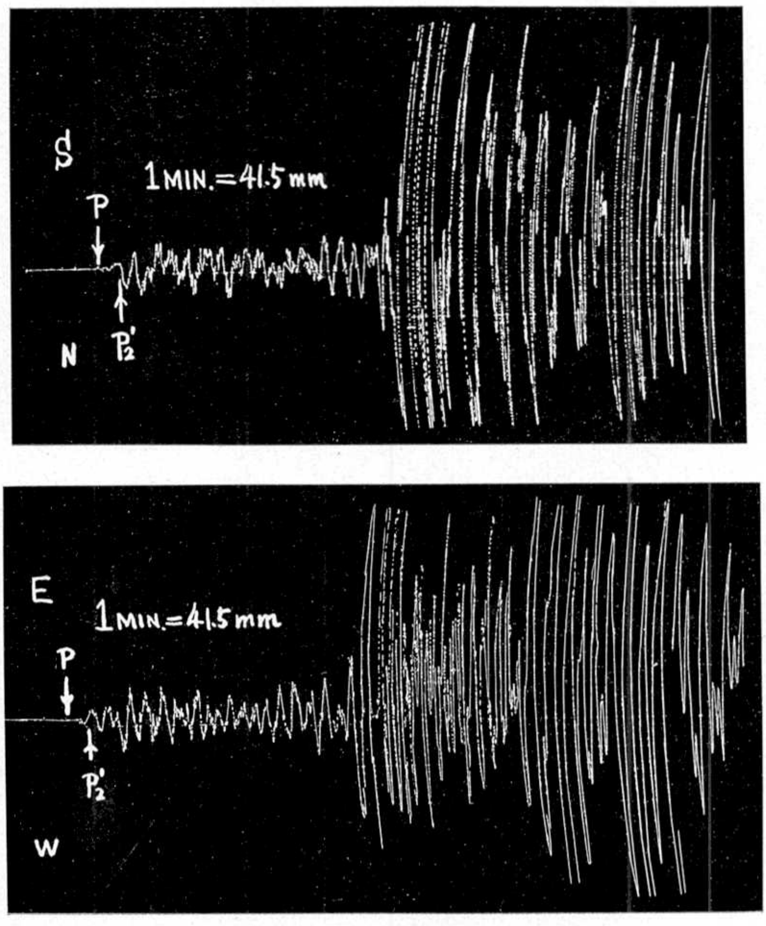

Fig. 8. Earthquake of March 29, 1928.
Recorded at Hongô.

（震研彙報、第七號、圖版、松澤、山田、鈴木）