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18. *On the Travel-Times of S-Waves, Derived from the Explosion Seismic Observations.*

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1. Introduction

The first large scale observation of tremors caused by a blast of a big amount of explosives was carried out on October 25, 1950, in north-eastern Japan, to study the structure of the earth's crust[1]. This blast took place near Isibuti, in order to get a large amount of rocks for construction of a rock-fill dam. Since then, for engineering purposes, many blasts have been carried out in Tōhoku and Kwantō areas. The Research Group for Explosion Seismology†, the present authors being members, observed eleven sets of tremors caused by these explosions. R. G. E. S. observed also two other large blasts, which were intended exclusively for our research purposes. Blasts are tabulated in Table 1. The results of observations were reported in each case[2].

The main object of R. G. E. S. is to study the structure of the earth's crust. Therefore, although the seismograms contain a lot of other interesting information, R. G. E. S. used mainly the arrival-times of the initial motions, as they are most reliable. Thus R. G. E. S. did

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† abbreviated to R. G. E. S. in this paper.
1) R. G. E. S., *Bull. Earthq. Res. Inst.*, **29** (1951), 97.
2) R. G. E. S., *Bull. Earthq. Res. Inst.*, **30** (1952), 279.
R. G. E. S., *Bull. Earthq. Res. Inst.*, **31** (1953), 281.
R. G. E. S., *Bull. Earthq. Res. Inst.*, **32** (1954), 79.
R. G. E. S., *Bull. Earthq. Res. Inst.*, **33** (1955), 699.
R. G. E. S., *Pub. Bureau Central Séism. Int., Serié A, Trav. Sci.*, **19** (1956).
R. G. E. S., *Bull. Earthq. Res. Inst.*, **36** (1958), 329.
T. USAMI, T. MIKUMO, E. SHIMA, I. TAMAKI, S. ASANO, T. ASADA and T. MATUZAWA, *Bull. Earthq. Res. Inst.*, **36** (1958), 349.
R. G. E. S., *Bull. Earthq. Res. Inst.*, **37** (1959), 89.
T. MATUZAWA., *Bull. Earthq. Res. Inst.*, **37** (1959), 123.

Table 1. Table of Explosions.

Name of Explosion		Origin Time, J. S. T.
Isibuti	I *	Oct. 25, 1950, $12^h 06^m 07.^s97$
〃	II	Dec. 27, 1951, 12 05 59.8
〃	III	July 25, 1952, 12 04 59.42
Kamaisi	I **	Dec. 7, 1952, 03 34 59.91
〃	II	Sept. 13, 1953, 03 04 57.07
Dōsen		May 1, 1954, 01 35 00.28
Sin'yama		May 1, 1954, 03 35 00.51
Daidō		May 3, 1954, 01 35 00.17
Takinosawa		May 3, 1954, 03 35 00.51
Nozori	I ***	Nov. 14, 1954, 01 05 00.87
〃	II	Aug. 15, 1955, 01 05 00.29
Hokota	I ****	Dec. 5, 1956, 01 05 00.21
〃	II	Aug. 26, 1957, 01 05 00.00

* abbreviated to I-I.
** abbreviated to K-I.
*** abbreviated to N-I.
**** abbreviated to H-I.

not pay much attention to the arrival-times of other late phases for interpreting the earth's crust, and the data were left unpublished, except in some of the papers.

In this paper we study the arrival-times of late phases, especially about the *S*-phases, which were recorded in the above mentioned thirteen observations.

2. Used data

Number of available seismograms obtained from thirteen observations were 196 in total. First, the supposed arrival-times of *S*-waves were read quite independently by each author, and the values were adopted only when the agreement was found satisfactorily. On some records, we could read only the arrival-times of the initial motions, but not of the late phases because of the scale-out owing to the high sensitivity of the instruments. After all, we could read 120 seismograms.

Adopted values are tabulated in Table 2 and 3. For convenience' sake, the read values were classified into five classes—a_1, a_2, b, c and d. These classes indicate the accuracy of reading, and the limits of errors are listed respectively at the end of Table 2. For the case of four observations, which were carried out near the Kamaisi Mine, we used the classes p, q, r, s and t. Because these blasts were rather on

Table 2.

Name of Explosion	Station	Δ km	S sec	Class	$S-O$ sec
I - I	Isibuti	1.8	8.52	a_1	0.55
			8.61	a_2	0.64
			9.27	a_1	1.30
〃	Sendai	98.24	37.2	d	29.2
I - II	Isibuti	1.69			0.34
〃	Orose	1.08	0.77	a_1	0.97
〃	Hondera	15.29	5.08	c	5.28
〃	Wakayanagi	14.62	5.14	b	5.34
〃	Dobasi	12.09	4.76	a_1	4.96
〃	Atago	8.65	3.12	a_1	3.32
〃	Kawatabi	41.92	14.1	c	14.3
〃	Katurazawa	21.10	6.8	b	7.0
〃	Kamaisi	87.54	26.42	a_2	26.62
〃	Kurikoma	22.52	7.12	b	7.32
			7.6	c	7.8
I - III	Hondera	15.3	4.78	d	5.36
〃	Mamurogawa	58.7	17.77	c	18.35
〃	Innai	46.0	14.42	a_2	15.00
			14.9	a_1	15.48
〃	Kawatabi	41.9	11.57	c	12.15
			13.33	c	13.91
〃	Nenosiroisi	87.8	26.46	a_2	27.04
〃	Yuzawa	33.8	10.61	a_1	11.19
〃	Motegi	290.7	80.72	d	81.30
			82.61	b	83.19
			83.39	a_2	83.97
K - I	Setamai	20.4	6.32	c	6.41
〃	Kesenuma	45.5	13.18	b	13.27
			13.54	b	13.63
〃	Mizusawa	51.4		c	16.6
〃	Onagawa	97.3	28.69	c	28.78
			29.65	b	29.74
〃	Kaneyama	173.7	49.47	a_2	49.56
			49.98	a_2	50.07
〃	Kawamata	202.3	58.85	d	58.94
			59.75	d	59.84
			60.13	d	60.22

(to be continued)

Table 2. (continued)

Name of Explosion	Station	Δ km	S sec	Class	$S-O$ sec
K-I	Nogisawa	261.1	71.39	d	71.48
			72.34	d	72.43
〃	Ide	36.9	11.00	a_2	11.09
〃	Yuzawa	103.3	30.46	b	30.55
			29.00	c	29.09
〃	Mamurogawa	130.5	39.68	d	39.77
K-II	Nakasone	11.2	0.63	a_1	3.56
〃	Sakari	23.92	4.48	b	7.41
〃	Kesennuma	45.04	10.78	a_2	13.71
〃	Sizugawa	72.25	17.20	b	20.13
〃	Onagawa	97.32	25.24	b	28.17
			27.59	b	30.52
〃	Mukaiyama	137.38	37.47	a_1	40.40
〃	Funaoka	159.6	44.55	d	47.48
			46.20	d	49.13
〃	Kaneyama	173.7	47.38	b	50.30
〃	Kawamata	202.46	54.11	a_2	57.04
〃	Nogisawa	261.04	67.31	c	70.24
N-I	Sawatariguti	18.22	7.10	c	6.23
〃	Takayama	30.19	11.39	a_2	10.52
〃	Ōgo	56.43	19.67	c	18.80
〃	Asikaga	88.86	27.96	c	27.09
〃	Totigi	103.34	31.46	c	30.59
〃	Tukuba	142.99	41.93	a_1	41.06
N-II	Sima	17.21	5.68	a_2	5.39
〃	Nakanozyō	24.05	7.64	c	7.35
〃	Ikaho	35.29	12.05	b	11.76
〃	Ōmama	65.75	19.86	a_2	19.57
〃	Kiryū	73.29	22.92	d	22.63
〃	Ōya	107.37	31.97	b	31.68
〃	Kakioka	149.56	42.42	b	42.13
			43.61	b	43.32
H-I	Tomoegawa	7.24	4.52	a_1	4.31
〃	Tamari	20.26	8.23	a_1	8.02

(to be continued)

Table 2. (continued)

Name of Explosion	Station	Δ km	S scc	Class	$S-O$ sec
H-I	Tukuba	41.26	13.72	a_1	13.51
〃	Yūki	63.73	22.56	a_1	22.35
〃	Asikaga	97.10	28.87	d	28.66
			32.36	d	32.15
〃	Ōgo	129.64	40.56	b	40.35
			44.83	b	44.62
〃	Sibukawa	146.06	44.24	a_2	44.03
			44.68	a_2	44.47
			48.95	b	48.74
〃	Agatuma	163.63	48.43	a_1	48.22
			53.6	b	53.4
〃	Hanasiki	180.91	51.18	a_2	50.97
			53.02	a_2	52.81
〃	Matusiro	215.94	61.00	a_2	60.79
H-II	Ōya	11.50	4.85	a_1	4.85
〃	Mito A	21.82	8.83	a_2	8.83
〃	Mito B	24.84	9.13	b	9.13
〃	Hitati	55.16	15.89	a_2	15.89
			17.83	a_1	17.83
〃	Daigo	73.03	23.95	b	23.95
〃	Tanakura	98.94	30.51	c	30.51
			31.05	c	31.05
〃	Tamagawa	119.47	35.25	b	35.25
〃	Tamura	131.79	40.16	a_2	40.16
〃	Siroiwa	150.33	43.10	a_2	43.10
			44.30	a_2	44.30
〃	Kawamata	171.72	48.49	a_2	48.49
〃	Isida	181.05	52.92	a_2	52.92
〃	Kaneyama	196.25	56.06	b	56.06
			57.77	b	57.77
〃	Watari	211.06	59.0	d	59.0
〃	Miyatoko	252.37	70.5	d	70.5

S: Arrival time of S-wave;
O: Origin Time;
Class: Accuracy of reading;

	sec sec
a_1	$0.0 < t \leq 0.1$
a_2	$0.1 < t \leq 0.3$
b	$0.3 < t \leq 0.6$
c	$0.6 < t \leq 1.0$
d	$1.0 < t$

Table 3.

Name of Explosion	Station	Δ km	S sec	Class	$S-O$ sec
Dōsen	Ōhasi	5.615	2.07	q	1.79
〃	Ōmatu	2.437	1.55	p	1.27
〃	Noda	4.920	1.87	q	1.59
〃	Kosano	6.618	2.52	p	2.24
〃	Nakatuma	8.513	3.04	p	2.76
			3.19	p	2.91
〃	Takinosawa	12.895	4.2	s	3.92
〃	Uresi	10.943	3.81	t	3.53
〃	Tōni	11.414	4.33	s	4.05
			4.00	s	3.72
〃	Okirai	14.509	4.52	s	4.24
			4.74	p	4.46
〃	Hikoroiti	15.108	5.03	p	4.75
〃	Tōno	20.962	6.91	p	6.63
〃	Matusiro	3.177	1.33	t	1.06
Sin'yama	Ōhasi	3.500	1.60	t	1.09
〃	Matukura	10.235	3.75	t	3.24
〃	Noda	11.822	4.78	p	4.27
〃	Kosano	13.247	4.49	p	3.98
		13.097	4.80	p	4.29
〃	Nakatuma	14.590	5.18	q	4.67
			4.93	r	4.42
〃	Takinosawa	19.355	6.46	q	5.95
〃	Uresi	17.565	6.00	t	5.49
〃	Okirai	22.590	7.25	s	6.74
〃	Hikoroiti	18.971	6.08	r	5.57
〃	Asigase	4.447	1.98	t	1.47
〃	Tōno	13.294	4.76	p	4.25
Daidō	Ōmatu	4.943	1.90	q	1.73
〃	Dōsen	6.898	2.50	p	2.33
〃	Noda	11.458	3.87	q	3.70
〃	Kosano	13.111	4.51	t	4.34
〃	Takinosawa	19.498	6.38	q	6.21
〃	Uresi	17.729	5.84	r	5.57
〃	Okirai	17.857	5.60	p	5.43

(to be continued)

Table 3. (continued)

Name of Explosion	Station	Δ ōm	S sec	Class	$S-O$ sec
Daidō	Hikoroiti	13.244	4.14	p	3.97
〃	Asigase	3.026	1.20	q	1.03
〃	Tōno	14.638	4.79	p	4.62
Takinosawa	Ōhasi	16.729	5.65	p	5.14
			5.86	p	5.35
〃	Ōmatu	14.698	5.30	q	4.79
〃	Dōsen	12.730	4.67	t	4.16
			5.03	t	4.52
〃	Noda	8.154	3.28	q	2.77
〃	Kosano	6.381	2.26	r	1.75
			2.67	s	2.16
〃	Nakatuma	4.887	2.18	q	1.74
			2.32	q	1.81
〃	Uresi	1.999	1.39	p	0.88
〃	Tōni	6.737	2.75	q	2.24
〃	Okirai	18.679	6.28	s	5.77
〃	Hikoroiti	25.801	8.40	p	7.89
〃	Tōno	32.718	10.51	p	10.00

S: Arrival time of S-wave,
O: Origin Time;
Class: Accuracy of reading;

	sec	sec
p	$0.00 < t \leq 0.02$	
q	$0.02 < t \leq 0.06$	
r	$0.06 < t \leq 0.10$	
s	$0.10 < t \leq 0.20$	
t	$0.20 < t$	

a small scale and the distance from the origin to the farthest observation-point was 32.7 km, the paper-speed of seismograms was regulated faster and the accuracy of read values was better than the other cases. The limits of errors in the above stated cases are listed at the end of Table 3. The examples of these classes are shown in Figs. 6–15.

3. Travel-times

Fig. 1 shows the travel-time graph of the S-waves from the four explosions, which were blasted near the Kamaisi Mine. The ordinate

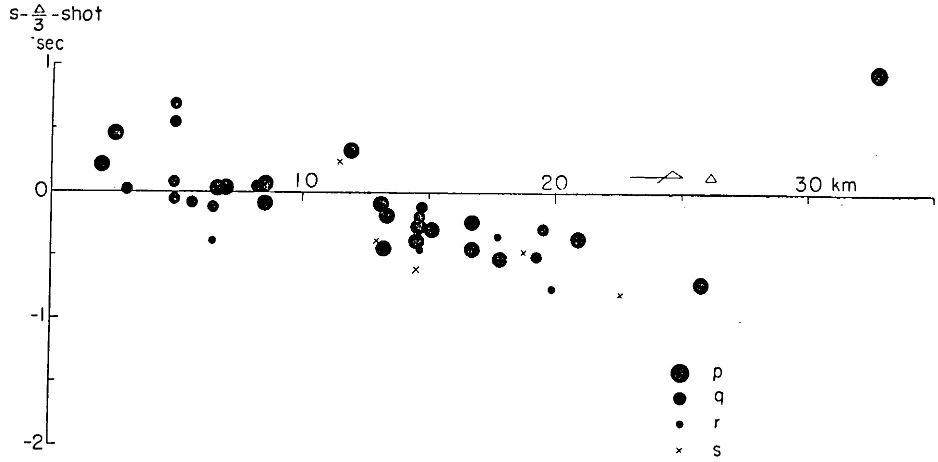

Fig. 1.

of this graph is $S-O-\frac{\Delta}{3}$(sec). We determined, by the method of least squares, the velocities of S-waves from this graph as follows:

$$t=(0.03\pm0.02)+\frac{\Delta}{(3.04\pm0.01)} \quad \text{sec} \qquad (1)$$

derived from 9 data for $\Delta<10$ km.

$$t=(0.26\pm0.06)+\frac{\Delta}{(3.36\pm0.04)} \quad \text{sec} \qquad (2)$$

derived from 16 data for $\Delta>10$ km.

In these calculations, we used the values of the classes p and q. Fig. 2 is the ordinary travel-time graph, showing the two velocities mentioned above. From equations (1) and (2), using the intercept time, we could calculate easily the depth of one of the velocity-discontinuities existing in the upper part of the earth's crust. We got 0.67 km as a value of the depth, assuming a structure of horizontal parallel layers. And the value is not so inconsistent with the one which was calculated from the data of P-waves.

Fig. 3 shows the travel-time graph of the S-waves from the blasts in Kwantō and Tōhoku areas. Observed values, concerning the Tōhoku area, are shown in this graph by the solid circles. We can see easily that the intercept time for Kwantō area is larger than that for Tōhoku area. So we determined the velocities of S-waves in each area and

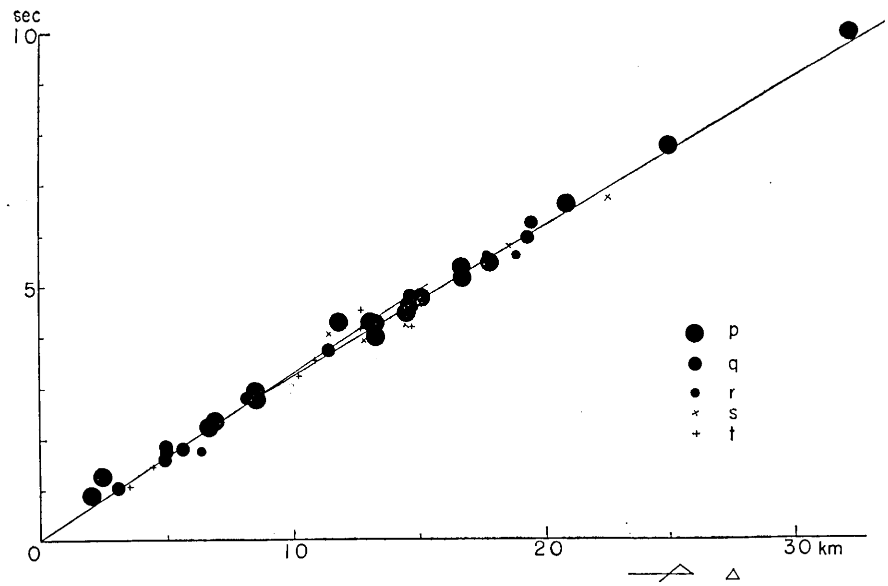
sec
10
5
0
10
20
30 km
p
q
r
s
t
Δ

Fig. 2.

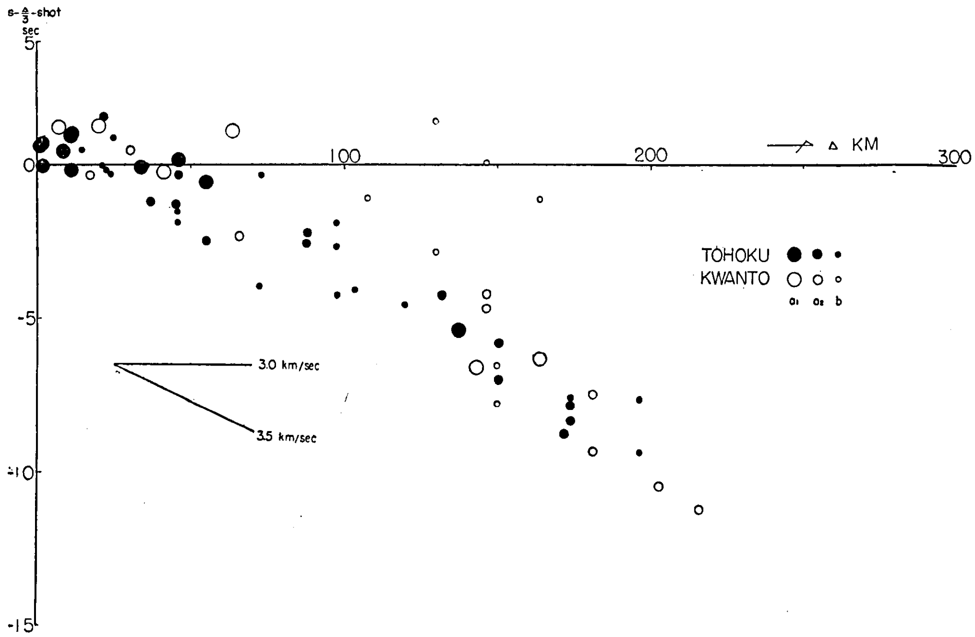
s-Δ/3-shot
sec
5
0
-5
-10
-15
100
200
300
Δ KM
TOHOKU
KWANTO
a₁ a₂ b
3.0 km/sec
3.5 km/sec

Fig. 3.

stated them as follows:

$$t=(0.07\pm0.03)+\frac{\Delta}{(3.06\pm0.03)} \quad \text{sec} \qquad (3)$$

derived from 20 data for $\Delta<100$ km (including the travel-times of late phases).

$$t=(1.66\pm0.29)+\frac{\Delta}{(3.57\pm0.02)} \quad \text{sec} \qquad (4)$$

derived from 24 data for $\Delta>30$ km.

$$t=(2.63\pm0.50)+\frac{\Delta}{(3.63\pm0.05)} \quad \text{sec} \qquad (5)$$

derived from 13 data for $\Delta>30$ km.

(3) and (4) are equations of travel-time for Tōhoku area. (5) is an equation for Kwantō area. From equations (3) and (4), the depth of the discontinuity was calculated as 4.72 km. Fig. 4a and 4b are ordinary travel-time graphs.

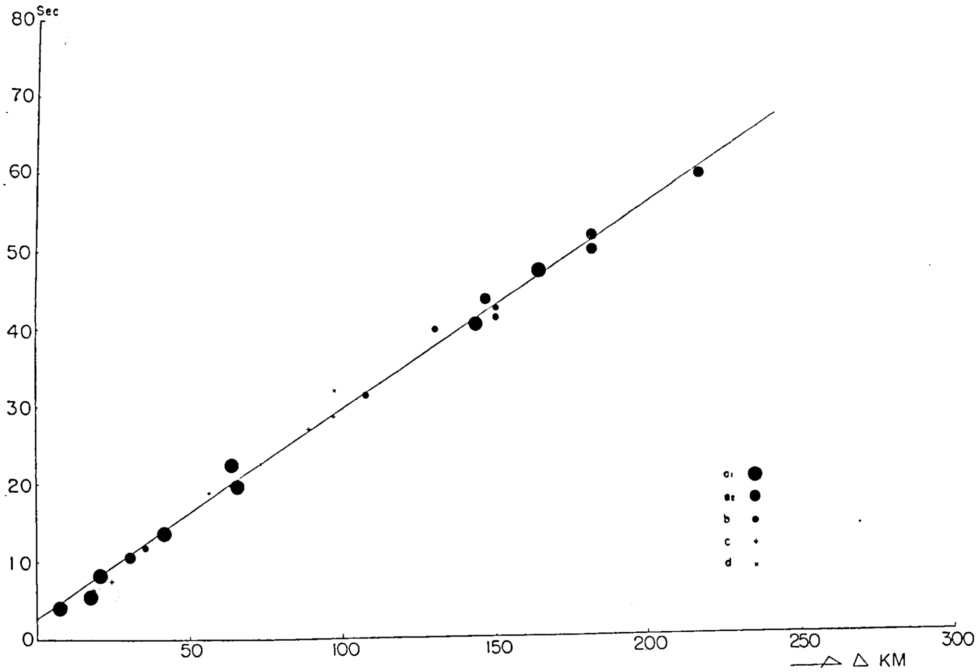

Fig. 4a. Kwantō.

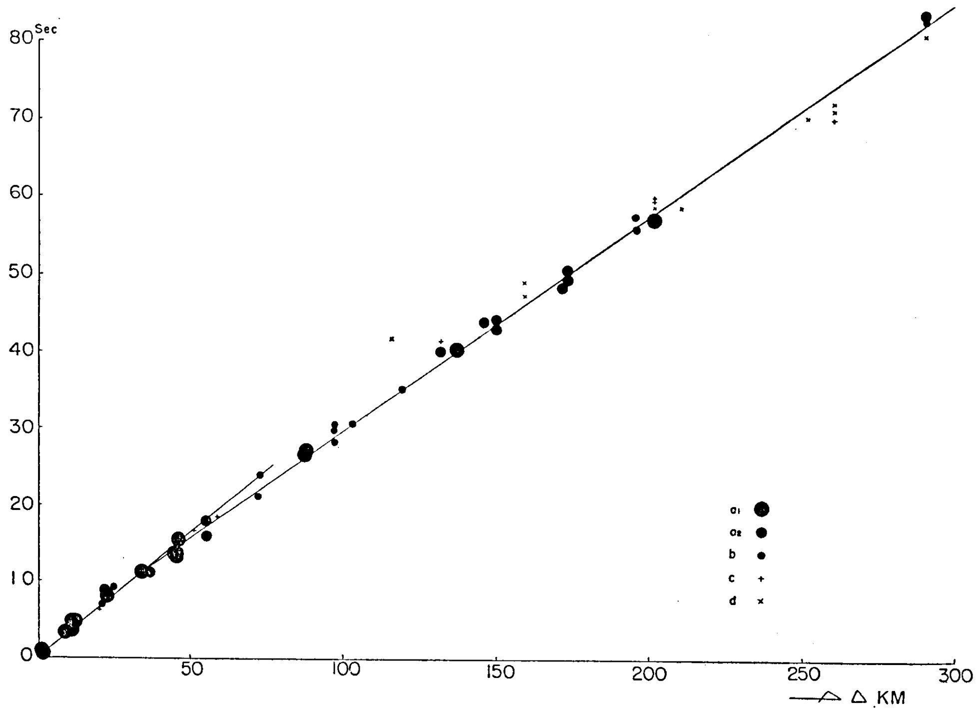

Fig. 4b. Tōhoku

4. Discussion

As stated above, we determined the velocities 3.04 km/sec and 3.36 km/sec near the Kamaisi Mine, 3.06 km/sec and 3.57 km/sec in Tōhoku area, and 3.63 km/sec in Kwantō area. But it is very difficult to verify whether these phase velocities are those of *S*-waves or of some kinds of surface-waves. In fact the phase velocity of *Lg*-waves, first suggested by Press and Ewing[3], is 3.51 km/sec. Utsu[4] found also this phase in seismograms, and the velocity as 3.4~3.6 km/sec. But in the short epicentral distances, such as our observations, it is impossible to separate *S*-phases from *Lg*-phases, even if both phases existed on the seismograms.

The fact that *S*-waves are not produced from a point source, such as explosive's blasts, in an infinite medium, was proved theoretically by

3) F. PRESS and M. EWING, *Bull. Seism. Soc. Amer.*, **42** (1952), 219.
4) T. UTSU, *Quart. Journ. Seism.*, **23** (1958), (in Japanese).

many authorities. But if the charges were blasted near the boundary of a semi-infinite medium, then the conditions would be changed. For example, S-waves must be generated by the reflection of P-waves at the surface. Hence, in a medium such as the earth's crust, in which there are many discontinuities, S-waves must be generated in the neighbourhood of the origin. Recently Usami[5] studied theoretically the generation of elastic waves from some ellipsoidal sources. His results indicate that the push and pull regions of the initial motions may exist around the source, and S-waves are also generated. Shima[6] found experimentally, from the observations of small explosions near the surface, the existence of push and pull regions, and assured himself that these phase were not due to sound waves. Also in the case of a big explosion, for example Hokota II Explosion, we could find these push and pull regions clearly. When push and pull regions are produced around the source, then S-waves must be generated from the origin. So we could say that, even by blasts, S-waves might be generated.

One of the writers constructed the loci of orbital motions of a point of the ground from his observed data in the above explosions. Fig. 5

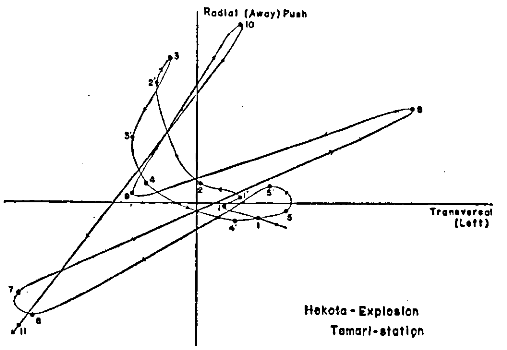

Fig. 5a.

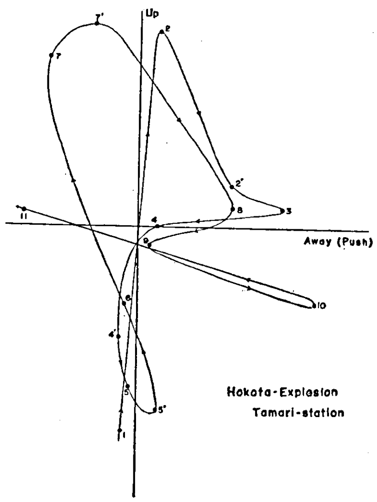

Fig. 5b.

5) U. USAMI, *Geophys. Mag.*, **29** (1958), 11.
6) E. SHIMA., *Monthly Meeting of the Earthq. Res. Inst.*, (SePt. 1954).

is an example of the loci. From these loci he found that the phases, which were identified by us as S-waves, did not behave as surface waves, but as S-type waves.

Now, let us compare our results with the S-wave velocities derived from observations of natural earthquakes. If there exists sufficient agreement between them, it may be said that the observed phases are these of S-waves. Professor Matuzawa[7] studied travel-times of shallow-earthquakes, and obtained the velocities of S-waves as 3.0 km/sec, 4.0 km/sec and 4.5 km/sec, and the depths of discontinuities from the surface of the earth as 20 km and 50 km respectively. According to Kishimoto's[8] results, the velocities of S-waves were derived as 3.1 km/sec, 3.4 km/sec, 4.0 km/sec and 4.7 km/sec, corresponding to the depths of discontinuity surfaces of 6 km, 20 km and 30 km respectively. On the other hand, Koshikawa[9] studied the travel-times of eight natural earthquakes, occurred in Kwantō area, and determined the velocities of S-waves as 3.1 km/sec, 3.3 km/sec and 3.6 km/sec. We can see from these results that although the agreement of these results with ours is not always good, the values in this paper are often found in these studies. The reasons why one to one correspondence between them is not found seem to be as follows:

(1) The accuracy of our results is much higher than those of natural earthquakes.

(2) The misidentification of the S-phase.

(3) The difference of the underground structure of the regions studied, and so on.

Now let us see Table 4, in which the representative velocities of P-waves and S-waves in some regions of the world, obtained from seismic observations of blasts, are tabulated. Values of S_2 show good agreement with each other. So does S_1 which was also found in Western Transvaal. It seems that the corresponding layers in these areas are seismically similar. Suffixes of S were put by the authors for convenience' sake of comparison, and other suffixes were used in each original paper.

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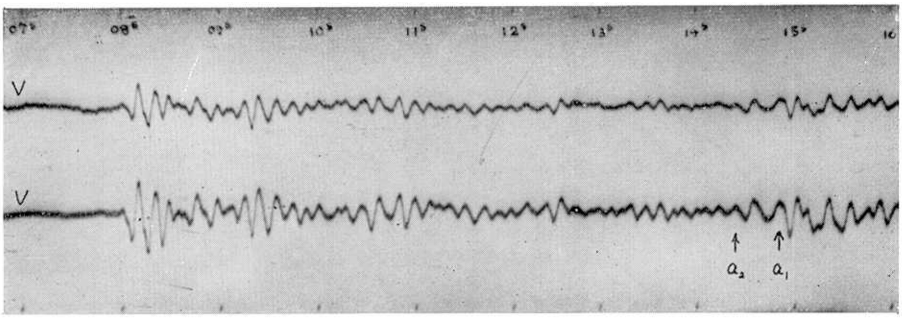
7) T. MATUZAWA, *Bull. Earthq. Res. Inst.*, **5** (1928) 1.
T. MATUZAWA, *Bull. Earthq. Res. Inst.*, **6** (1929), 177, 205, 213.

8) Y. KISHIMOTO, *Mem. Coll. Sci. Kyoto Univ., Ser. A*, **27** (1955), 243.

9) Y. KOSHIKAWA, *Bull. Utsunomiya Univ.*, **6** (1956) 31.

(1)



(2)

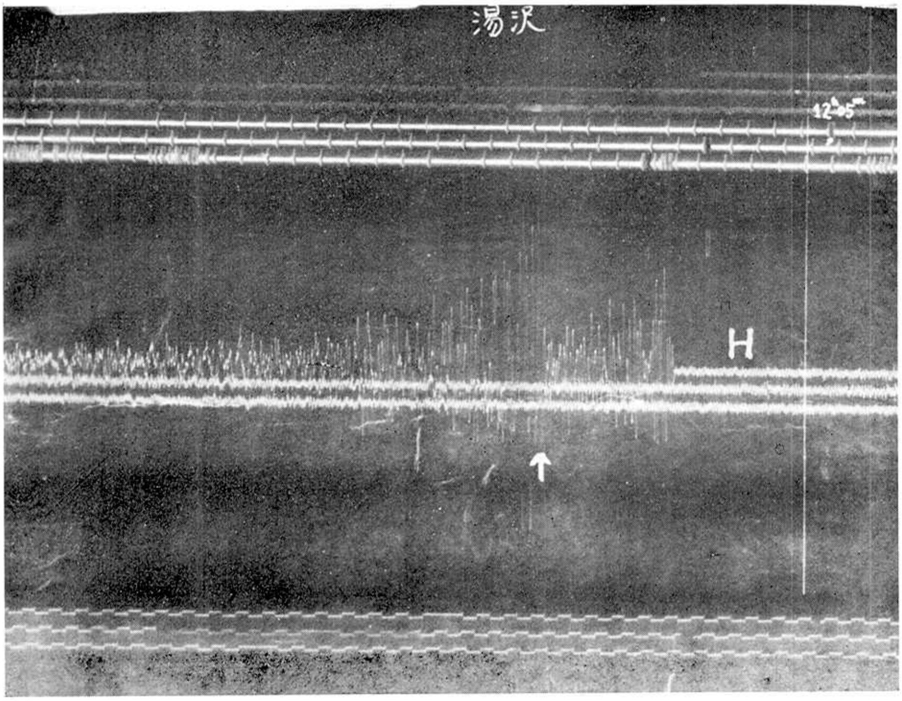
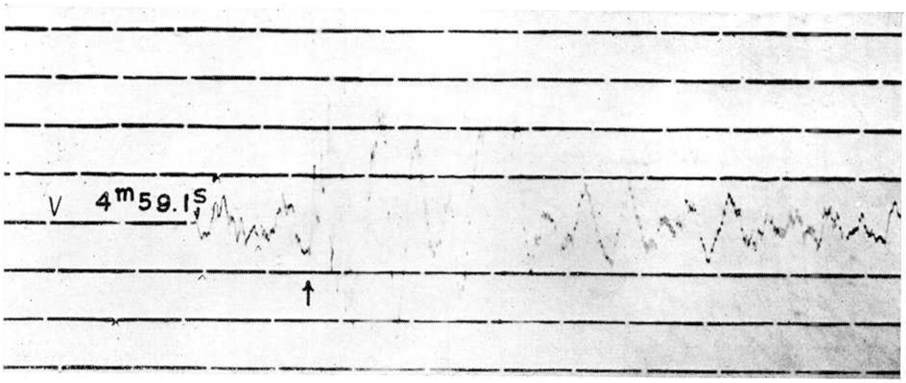
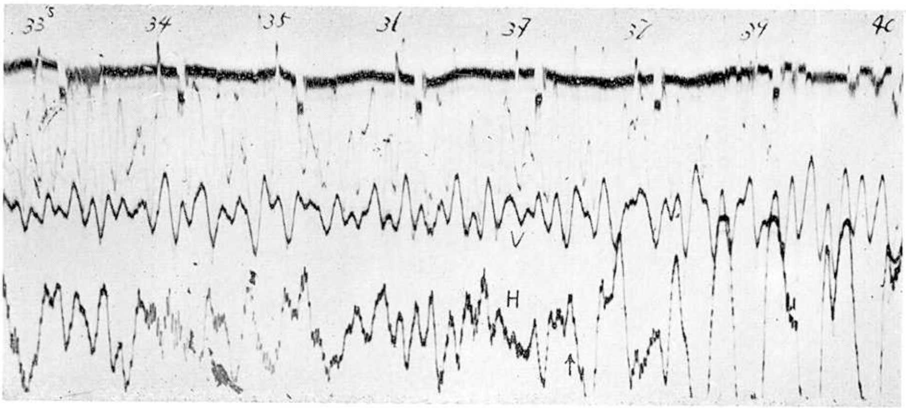


Fig. 6. Examples of records with class a_1.
(1) Seismogram at Innai in I–III (Δ=46.0 km).
(2) Seismogram at Yuzawa in I–III (Δ=33.8 km).

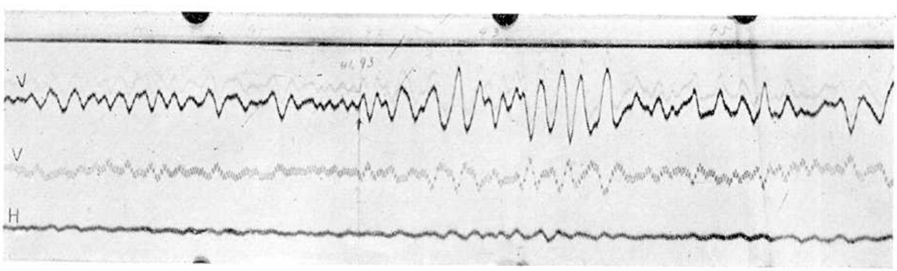
(3)



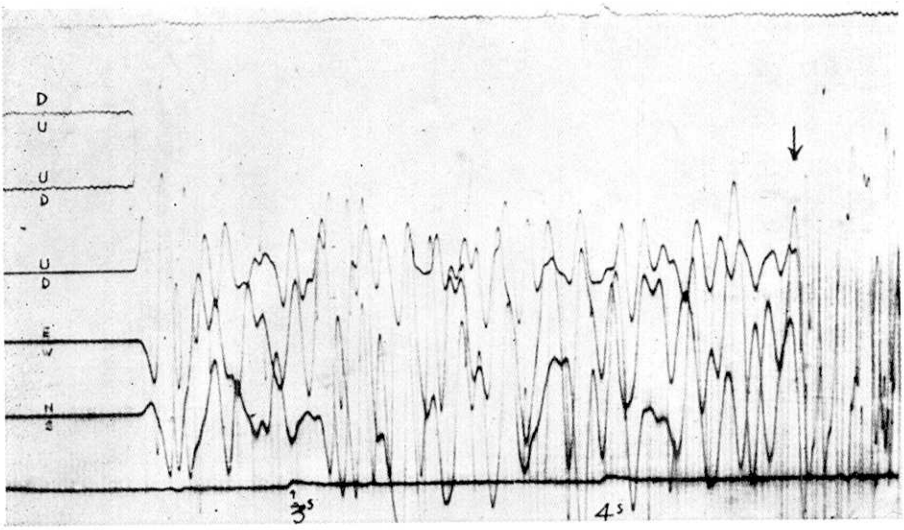
(4)

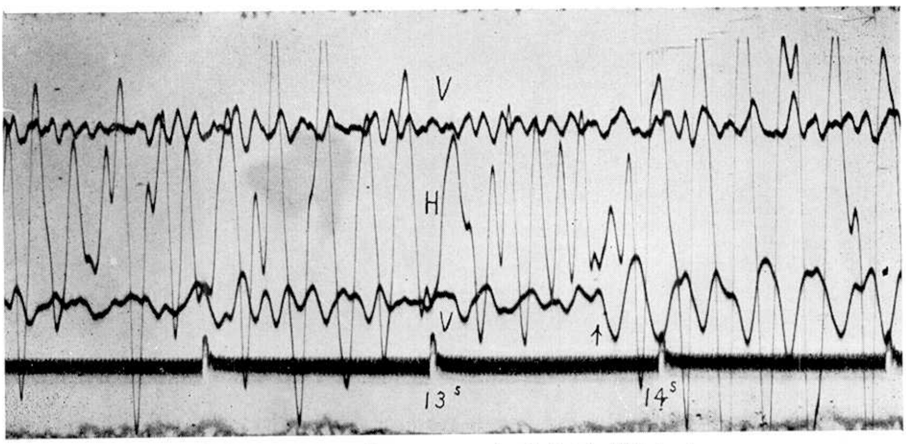


(5)



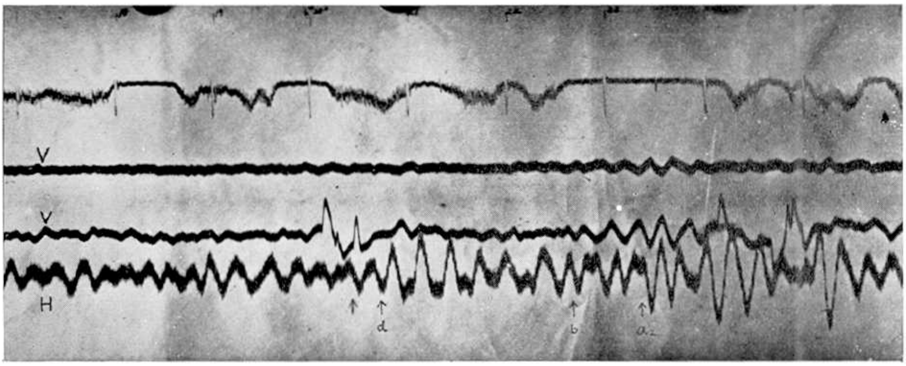
(3) Seismogram at Nakasone in K-II (Δ=11.2 km).
(4) Seismogram at Mukaiyama in K-II (Δ=137.4 km).
(5) Seismogram at Tukuba in N-I (Δ=143.0 km).

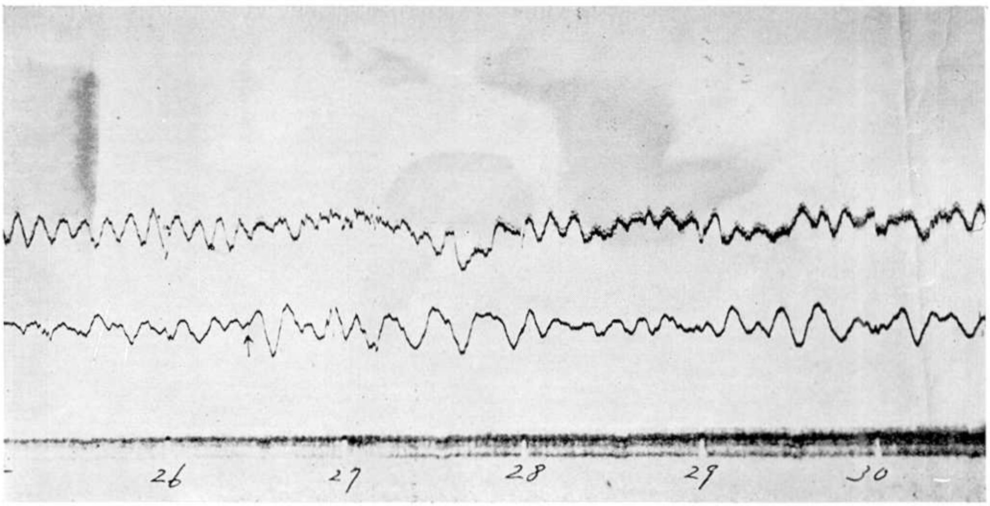
(6)


(7)


(6) Seismogram at Tomoegawa in H-I ($\varDelta$=7.24 km).
(7) Seismogram at Tukuba in H-I ($\varDelta$=41.3 km).

(1)





(2)

(3)

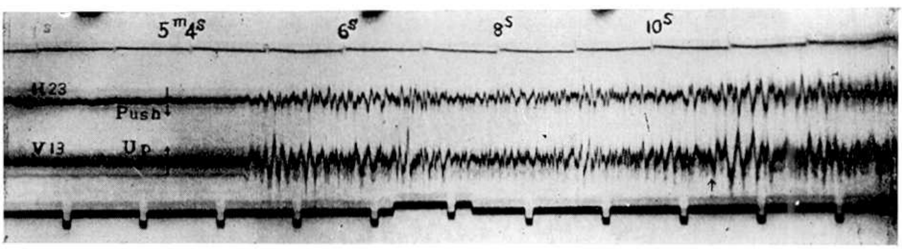


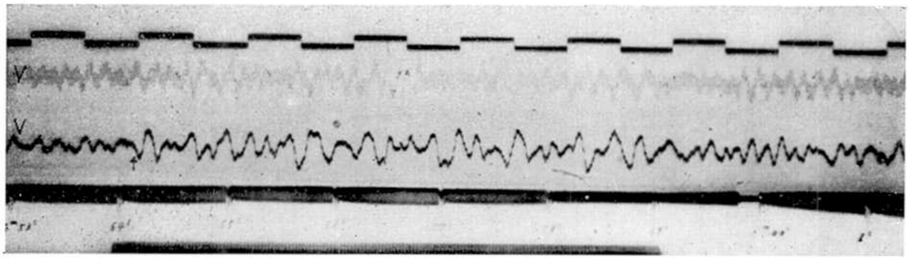
Fig. 7. Examples of records with class a_2.

(1) Seismogram at Motegi in I–III (Δ=290.7 km).

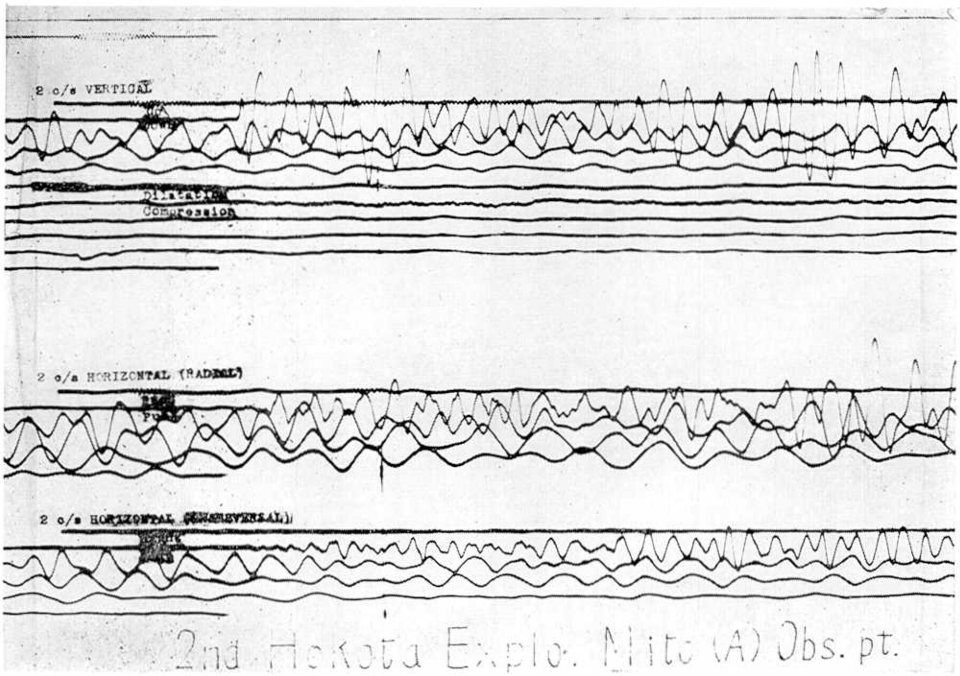
(2) Seismogram at Nenosiroisi in I–III (Δ=87.8 km).

(3) Seismogram at Kesenuma in K–II (Δ=45.04 km).

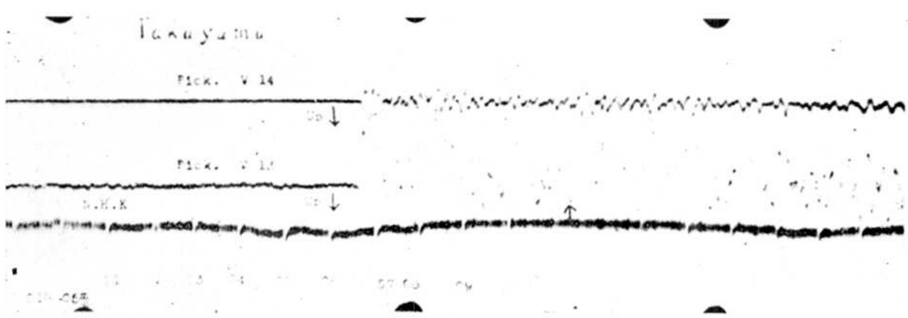
(4)



(5)



(6)



(4) Seismogram at Kawamata in K-II (Δ=202.5 km).
(5) Seismogram at Mito (A) in H-II (Δ=21.8 km).
(6) Seismogram at Takayama in N-I (Δ=30.2 km).

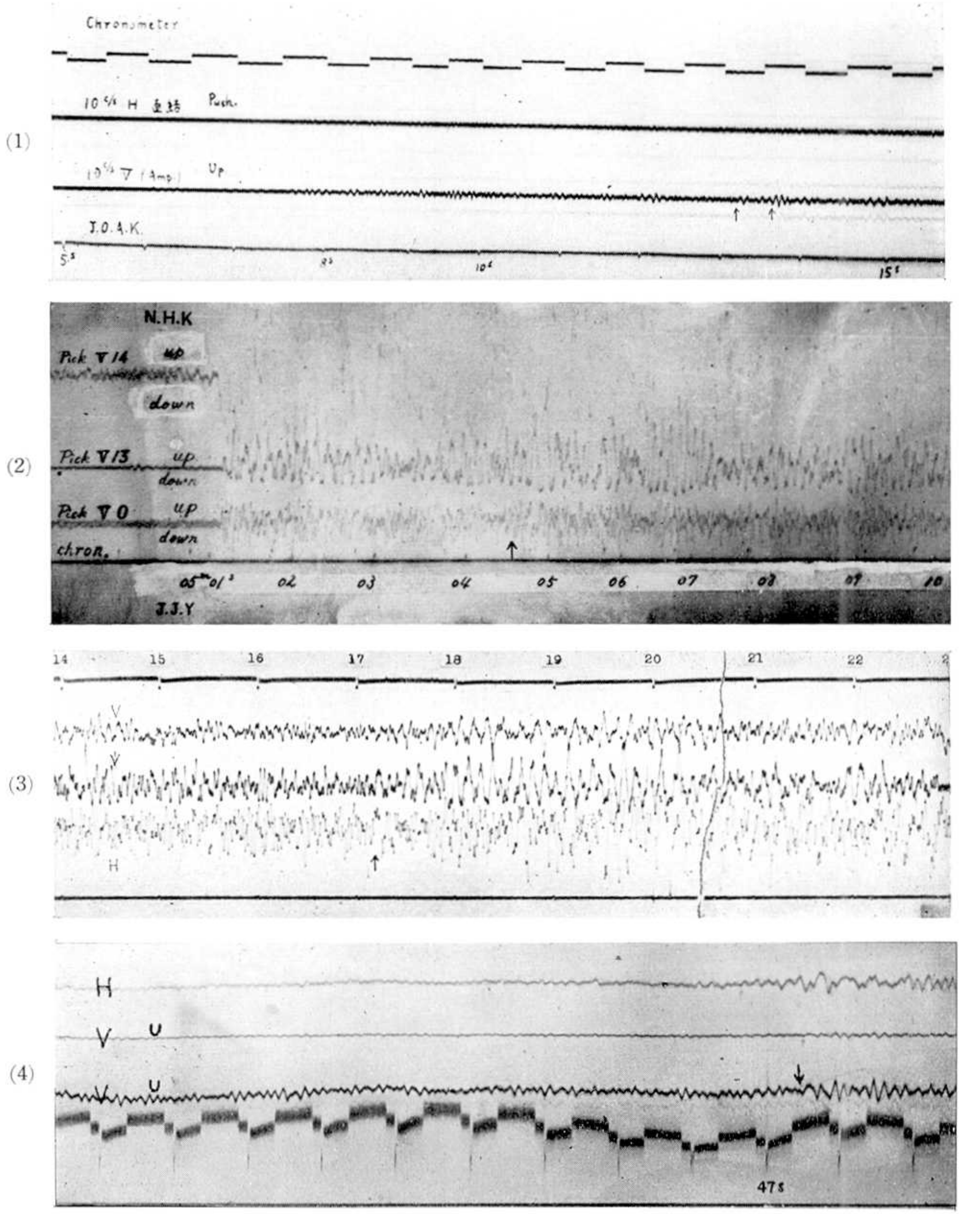


Fig. 8. Examples of records with class b.

(1) Seismogram at Kesennuma in K-I (Δ=45.5 km).
(2) Seismogram at Sakari in K-II (Δ=23.9 km).
(3) Seismogram at Sizugawa in K-II (Δ=72.3 km).
(4) Seismogram at Kaneyama in K-II (Δ=173.7 km).

(1)

(2)

(3)

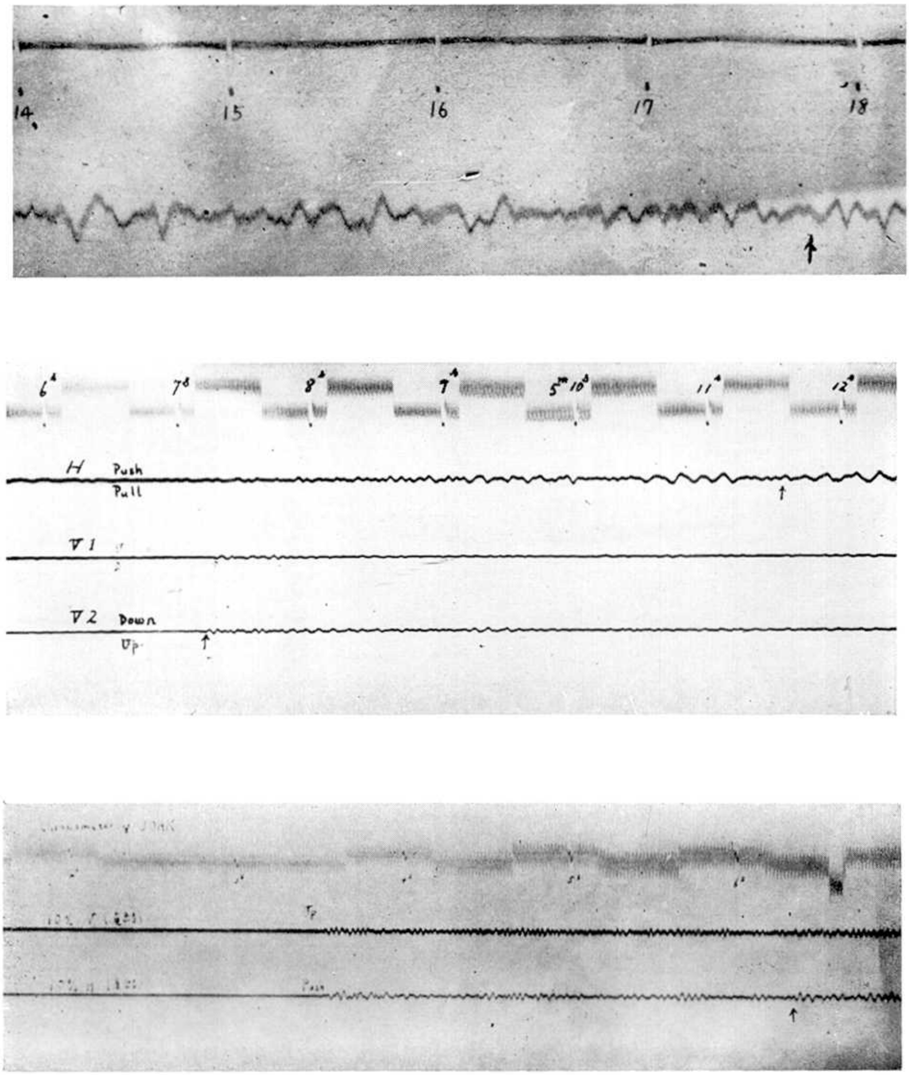


Fig. 9. Examples of records with class c.

(1) Seismogram at Mamurogawa in I-III (Δ=58.7 km).

(2) Seismogram at Kawatabi in I-III (Δ=41.9 km).

(3) Seismogram at Setamae in K-I (Δ=20.4 km).

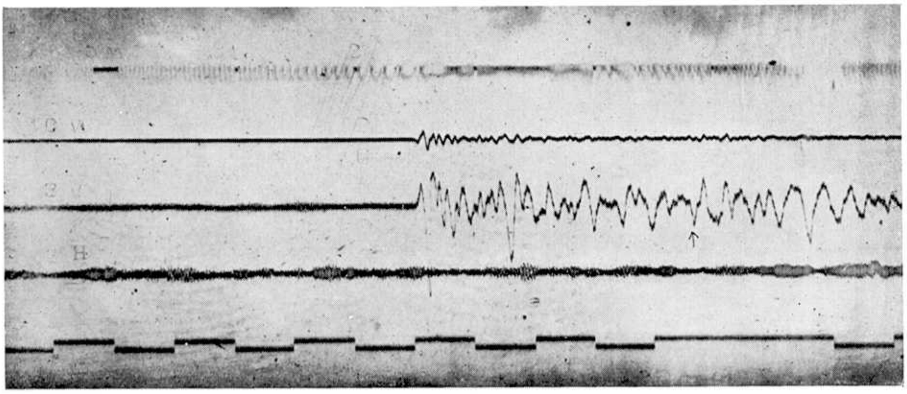
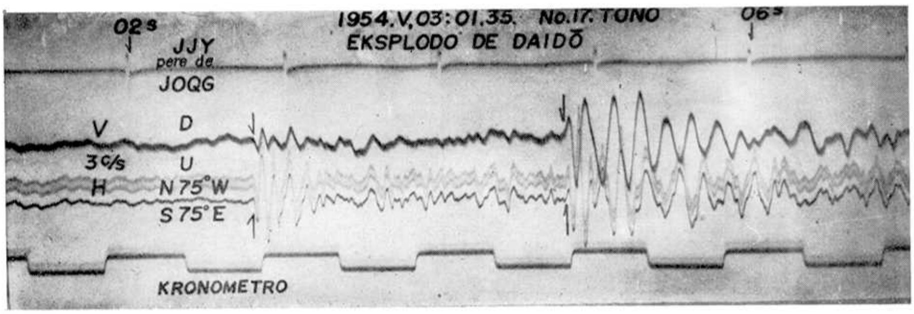


Fig. 10. Example of record with class d.
Seismogram at Hondera in I-III ($\Delta=15.3$ km).

(1)


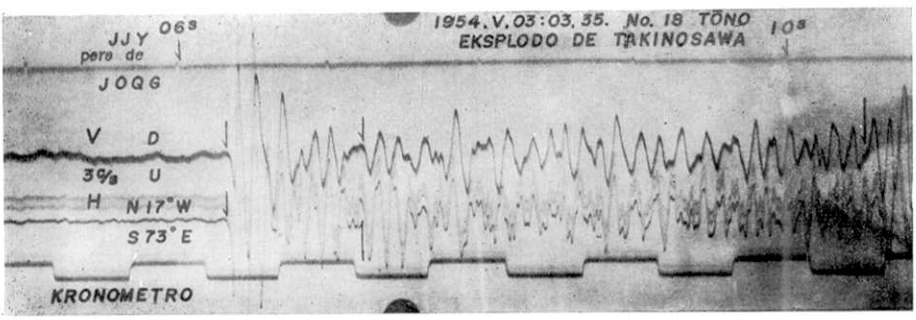
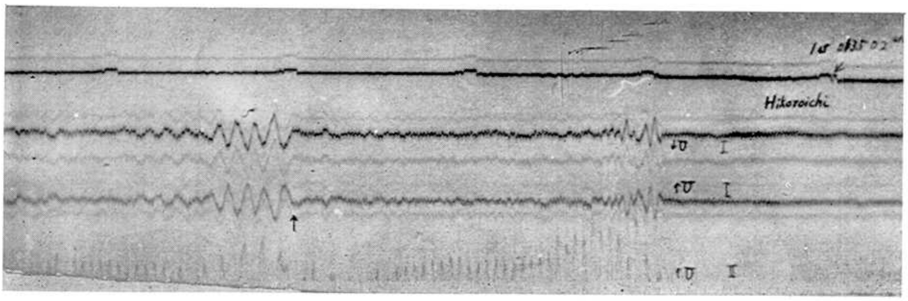
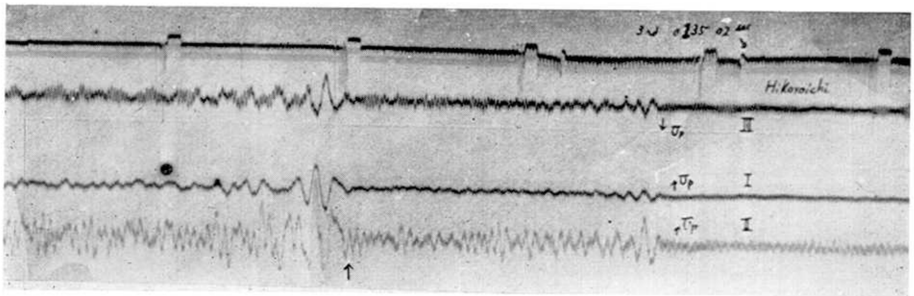
(2)


Fig. 11. Examples of records with class p.
(1) Seismogram at Tōno in Daidō Explosion ($\Delta=14.64$ km).
(2) Seismogram at Tōno in Takinosawa Explosion ($\Delta=32.72$ km).

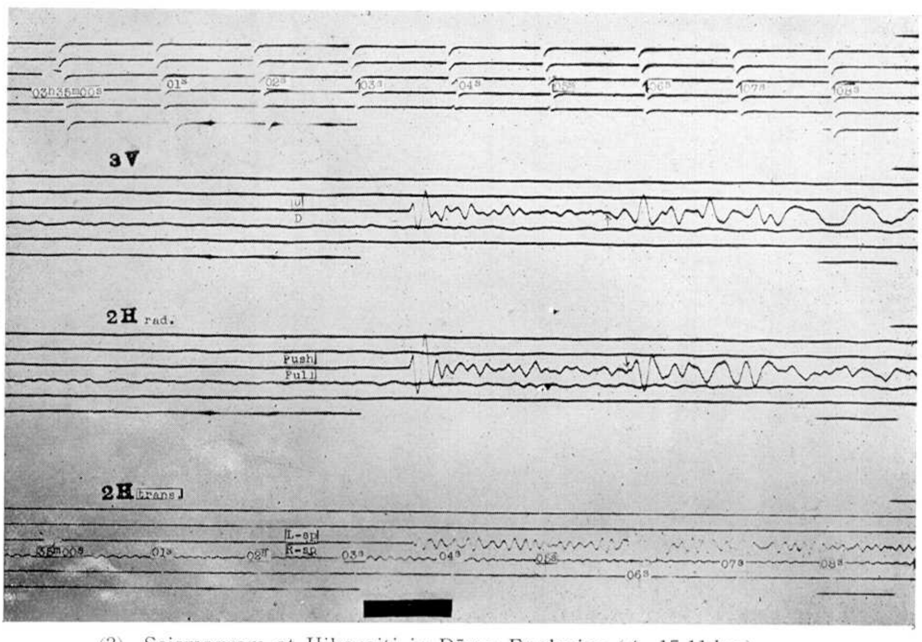
(3)



(4)

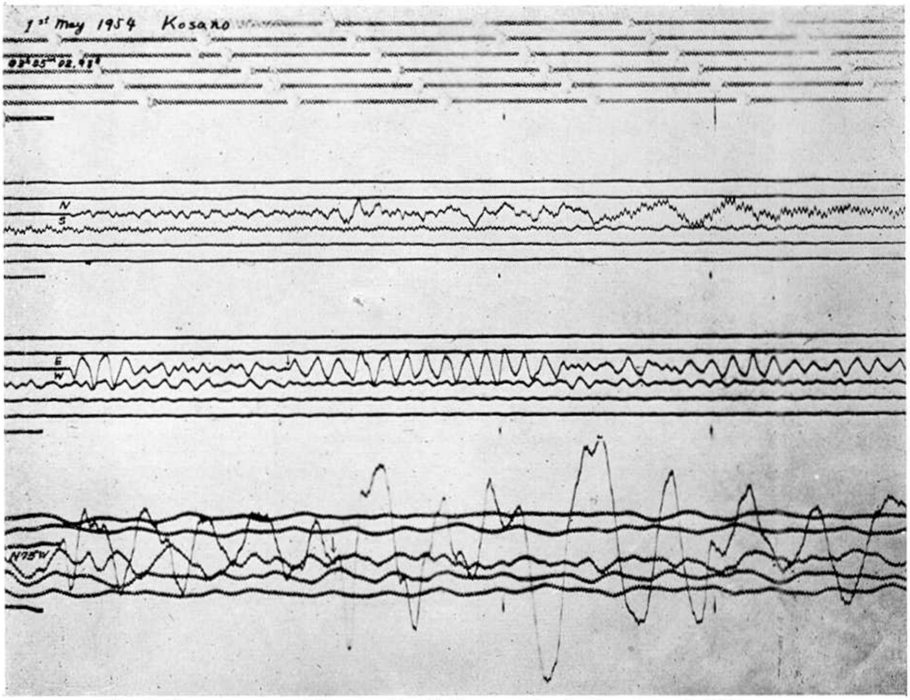


(5)



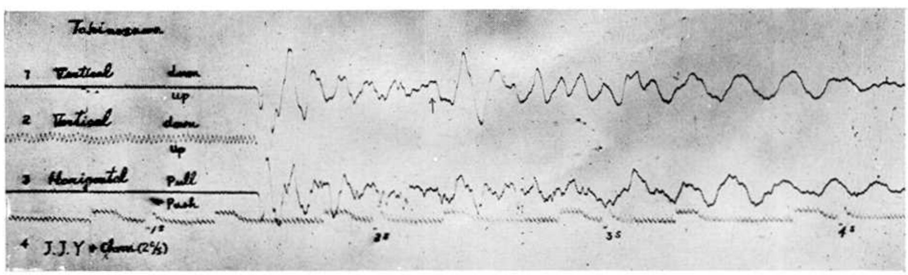
(3) Seismogram at Hikoroiti in Dōsen Explosion (Δ=15.11 km).
(4) Seismogram at Hikoroiti in Daidō Explosion (Δ=13.24 km).
(5) Seismogram at Ōhasi in Takinosawa Explosion (Δ=16.73 km).

(6)



(6) Seismogram at Kosano in Sin'yama Explosion (Δ=13.25 km).

(1)



(2)

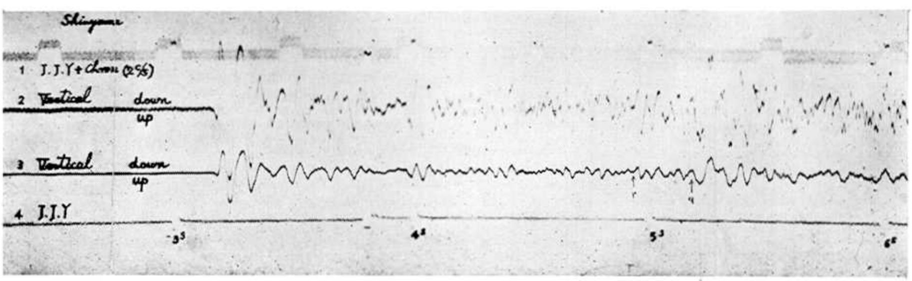
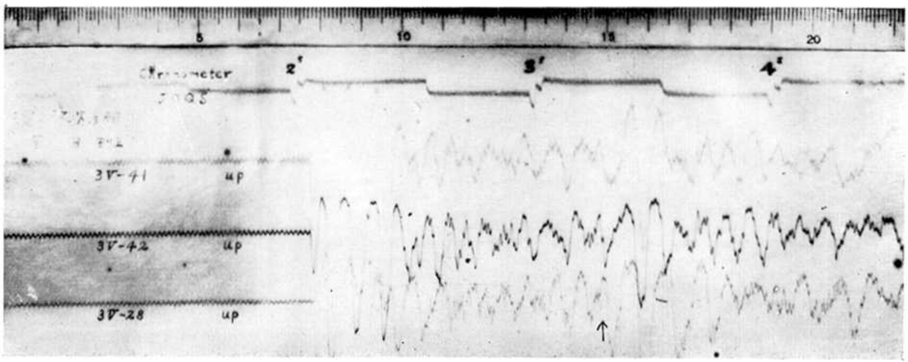


Fig. 12. Examples of records with class q.

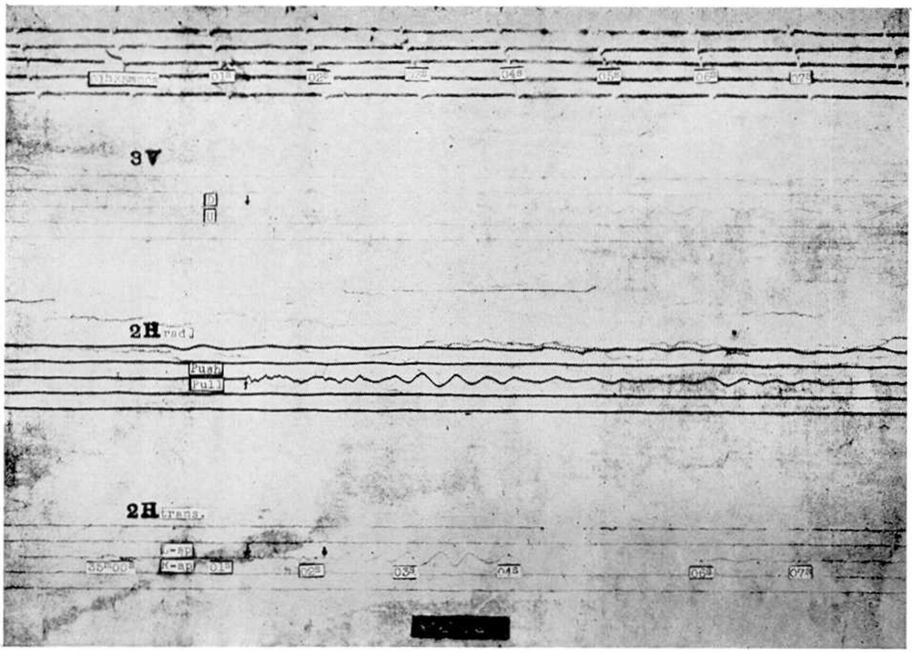
(1) Seismogram at Nakatuma in Takinosawa Explosion (Δ=4.89 km).

(2) Seismogram at Nakatuma in Sin'yama Explosion (Δ=14.59 km).

(3)



(4)



(3) Seismogram at Noda in Takinosawa Explosion (Δ=8.15 km).

(4) Seismogram at Ōhasi in Dōsen Explosion (Δ=5.62 km).

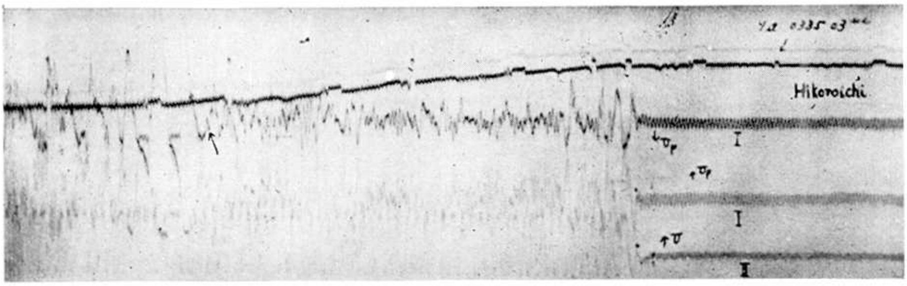


Fig. 13. An example of record with class r.
Seismogram at Hikoroiti in Sin'yama Explosion (Δ=18.97 km).

(1)

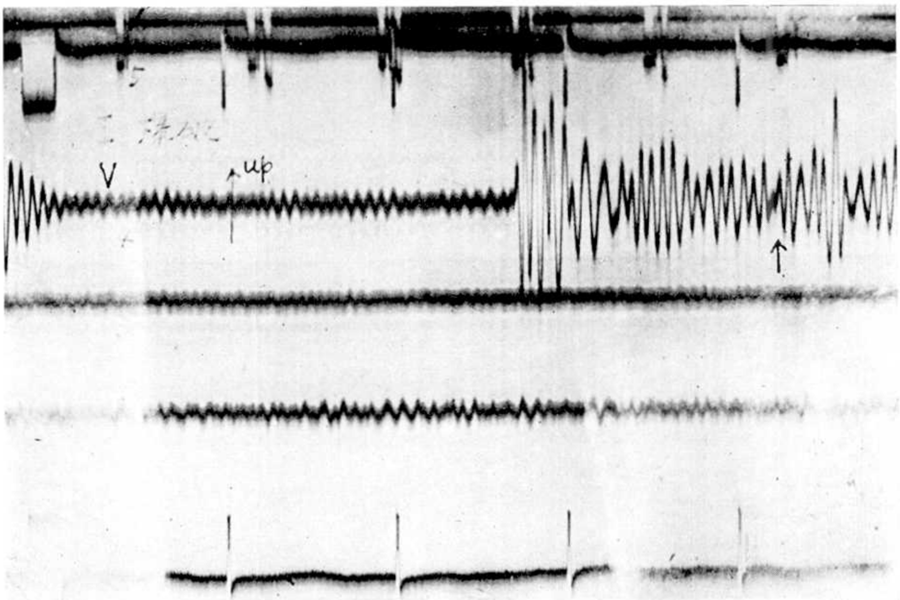
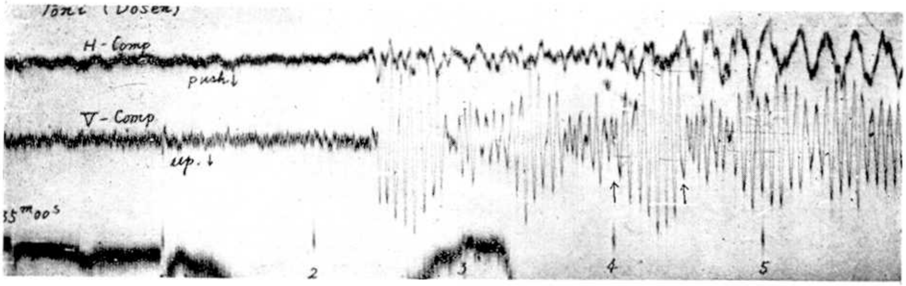


Fig. 14. Examples of records with class s.
(1) Seismogram at Takinosawa in Dōsen Explosion (Δ=12.90 km).

(2) 

(2) Seismogram at Tōni in Dōsen Explosion (Δ=11.41 km).

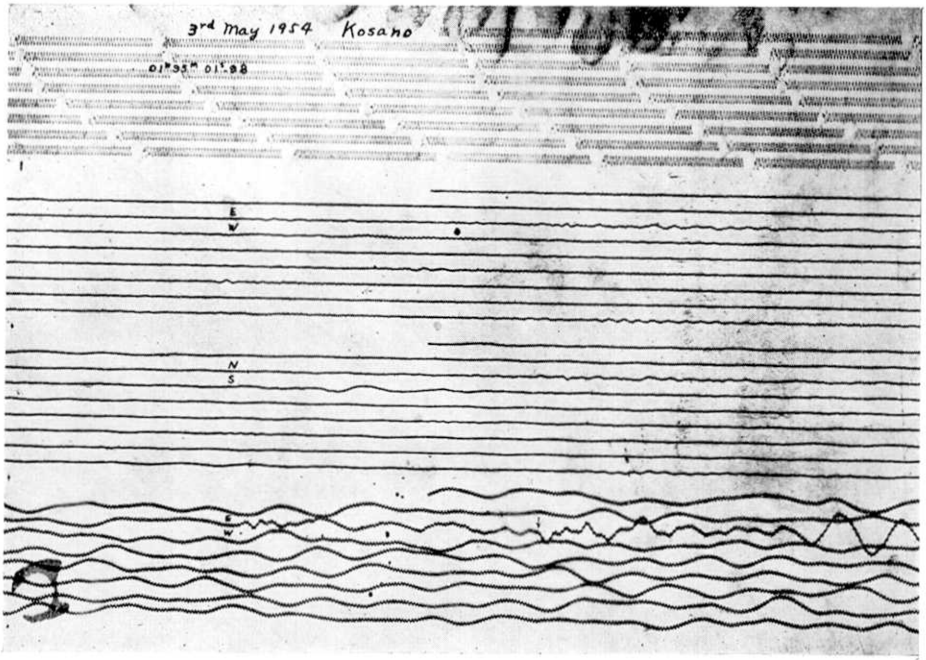


Fig. 15. An example of record with class t.
Seismogram at Kosano in Daidō Explosion (Δ=13.11 km).

Table 4.

		P_n	S_n	P_n/S_n	P_2	S_2	P_2/S_2	P_1	S_1	P_1/S_1
Western Transvaal[10]		8.27	4.83	1.72	6.09	3.68	1.66	5.65	3.37	1.68
Canadian Shield[11]		8.18	4.85	1.69	6.25	3.54	1.77	—	—	—
Western Australia[12]		8.21	4.75	1.73	6.03	3.55	1.70	—	—	—
Japan	Kwantô[13]	—	—	—	6.10	3.63	1.68	—	—	—
	Tôhoku	—	—	—	6.15	3.57	1.72	5.80	3.36	1.73

The values of V_P/V_S were also calculated, and tabulated in Table 4. The values of the Kwantō area are a little smaller. But in general their values are reasonable.

At the end of the discussion we must refer to the high sensitive seismometers used in most of our observations. These seismometers were designed by Den[14]. But they are designed to get a sharp break of initial motions, so the natural frequency of the seismometer is rather high, and characteristics are insufficient to get clear S-phases. Because, in general, periods of S-waves are rather longer than those of P-waves, so we had better reconstruct the seismometer and change the characteristics for the better study of the travel-times of S-waves.

5. Concluding remarks

From the observations of thirteen blasts in Tōhoku and Kwantō areas, we derived the velocities 3.04 km/sec and 3.36 km/sec near the Kamaisi Mine, 3.06 km/sec and 3.57 km/sec in Tōhoku area, and 3.63 km/sec in Kwantō area respectively. We take these velocities as those of S-waves.

The depths of the discontinuities from the surface calculated from these velocities are not so inconsistent with those of the depths calculated from P-waves, although these S velocities were those of mean values determined by the process explained in the text.

We could not get sufficient informations about S_n, because of the scanty data of the distant observations.

10) P. L. WILLMORE, A. L. HALES and P. G. GANE, *Bull. Seism. Soc. Amer.*, **42** (1952), 53.

11) J. H. HODGSON, *Publ. Dom. Obs. Ottawa*, **16** (1953), 113.

12) B. A. BOLT, H. A. DOYLE and D. J. SUTTON, *Gephys. Journ.*, **1** (1958), 135.

13) *loc. cit.*, 1), 2).

14) N. DEN, *Annual Meeting of the Seism. Soc. of Japan*, (Nov., 1954).

The values of V_P/V_S were calculated, and these values are reasonable in general.

In conclusion, authors express their hearty thanks to Professor T. Matuzawa and to all other members of the Research Group for Explosion Seismology who gave them facilities for using the valuable seismograms.

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18. 爆破地震動観測によつて得られた S 波の走時について

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東京大学地球物理学教室 田望
京都大学地球物理学教室 三雲健
地震研究所 嶋悦三
気象庁 宇佐美竜夫

爆破地震動研究グループにおいては，現在までに，自力発破2回を含め13回の観測を行つた．グループの観測の主眼は地下構造の推定にあり，このため解析には原則として初動の走時のみをとりあつかつていた．この論文では，Late Phase の中で特に S 波と思われるものをとりあげ，その速度を最小自乗法によつて求めた．式 (1), (2) は釜石鉱山附近で得られた値，(3), (4) は東北地方，(5) は関東地方における値である．なお S_n に相当するものについては遠方の観測がたりないために得られなかつた．これ等の式を用いて平行層の仮定のもとに，intercept time から不連続面の深さをきめると，釜石附近で 0.67 km，東北地方で 4.72 km を得るが，この値は P 波よりもとめたものとそう矛盾しない．

V_P/V_S の値は，関東が少々小さいが，東北地方の値は妥当な値であると思われる。(Table 4) なお世界各地の，爆破により求められた S 波の速度に似ているものがあるのは面白いことである．
