29. *On Aftershocks Accompanied the Imaichi Earthquake, December 26, 1949.*

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Following the occurrence of the Imaichi Earthquake, December 26, 1949, the members of the institute hurried to the Imaichi district and set up a network of seismological stations temporarily to study the aftershocks. The observation was continued for about half a month and closed on January 8, as has been reported in the previous paper. After these stations were closed, the present authors attempted to continue the observation in a reduced scale for some long interval of time, because, in an observatory temporarily set up in the Keimei mines, Ochiai village, the observation of extension and inclination of the earth's crust had just commenced at that time,[1] and besides, the activity of aftershocks was not so diminished yet. New seismological stations were set up at three points, Imaichi, Nikkō and Ochiai and the observations commenced on Jan. 10, 1950. Among them, for the station of Nikkō the older

Table I. List of seismographs installed at the stations and the period of observation.

Station	Constants of seismographs			The period of observation	
	Component	Naturl period	Magnification	from	to
		sec.			
Imaichi *)	E-W **)	6	30	Jan. 10,	
	N-S	0.1	120	1950	——
Nikkō	E-W	6	30	Jan. 10,	Mar. 20,
	N-S	0.1	120	1950	1950
Ochiai	E-W	1	230	ibid.	
	N-S	0.1	120		
	N-S	1	230		
	U-D	0.1	220		

*) The station is about 2 km apart from the old station of Imaichi.
**) This has been exchanged for an acceleration seismograph, afterwards.

1) T. HAGIWARA and T. RIKITAKE, *Bull. Earthq. Res. Inst.*, 28 (1950), 435.

station was appropriated but the other two were newly constructed. Two months after the stations of Nikkō and Ochiai were closed on Mar. 20, while, the station of Imaichi, alone, was kept intact and is still operating. The position and the instruments of each station are respectively shown in Fig. 1 and Table I.

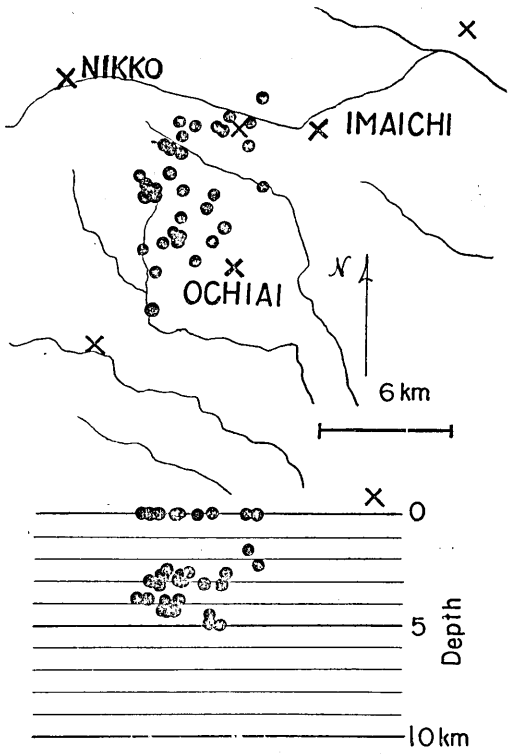

Fig. 1. Distribution of foci of aftershocks. (●)

To see the change in seismic activity, the daily number of occurrence of aftershocks counted at Imaichi and Ochiai were described, as shown in Fig. 2, with respect to the tremors having the maximum amplitude larger than 2 mm on the acceleration seismogram and the $P-S$ time less than 3 seconds. Though the number of earthquakes recorded at Ochiai is always much greater than that of Imaichi, some kind of parallelism between the two curves is clearly seen in the figure, both declining day by day.

Some examples of records of each station are shown in Fig. 7. The frequency distribution of $P-S$ times of the aftershocks observed in the above mentioned interval are shown in Fig. 3. In general, $P-S$ times are small in each station, and even in Nikkō which is considered to be far away from the seismic active center, we find no $P-S$ times exceeding 2 seconds.

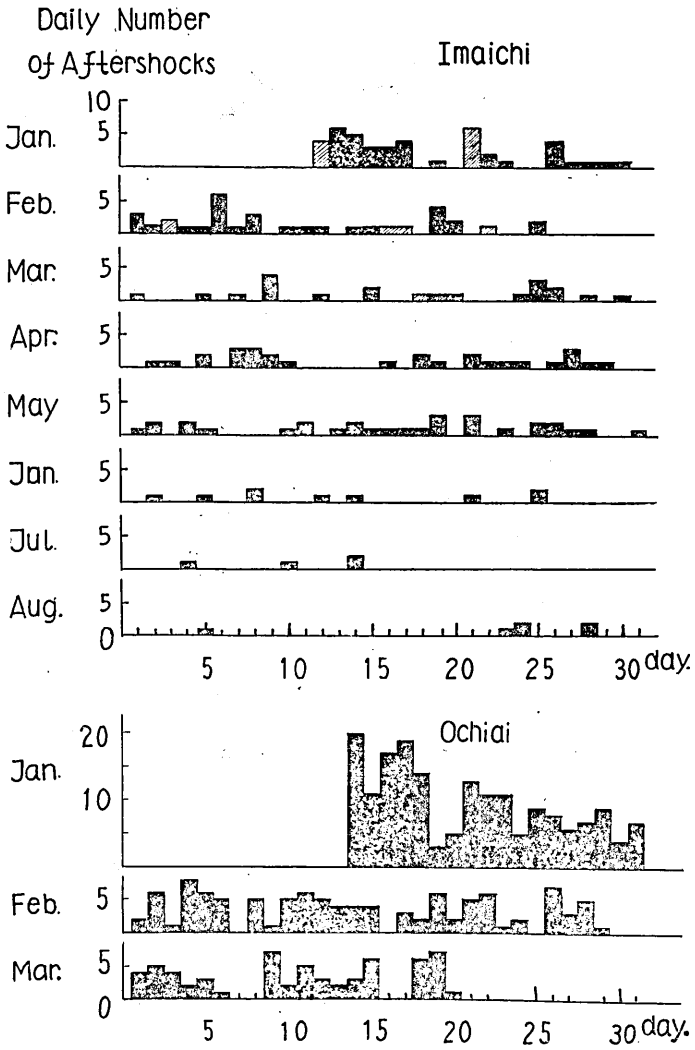

Fig. 2.

When the P—S times of an aftershock are determined at three stations, we can determine its hypocenter. In this case, we need to know the value of k the constant of the so-called Ōmori's formula $D=kt$, where D is the hypocentral distance, t the P—S times, k a constant. To serve this purpose, we can use the result of the preceding seismic net-work, in which k was determined to be 7,1. During the observation period, 33 aftershocks were available for the procedure and their hypocenters thus determined are shown in Table

II and Fig. 1 together with their commencement-times and P—S times. Comparing the epicentral distribution of this period with that of the preceding period, it is quite noticeable that there is no epicenter in the region to the south of the station of Ochiai. This fact, however, may be attributed to the presence of no station to the south. As a matter of fact, we can find a similar tendency in the epicentral distribution of the first period if we neglect the data obtained at the southern stations, Kanuma and Nishi-ōashi. The general tendency in the hypocentral distributions, therefore, may be considered to be approximately the same in both periods, except that the aftershocks originating in deeper position, say 10 km or so beneath the surface, were not found in the present period.

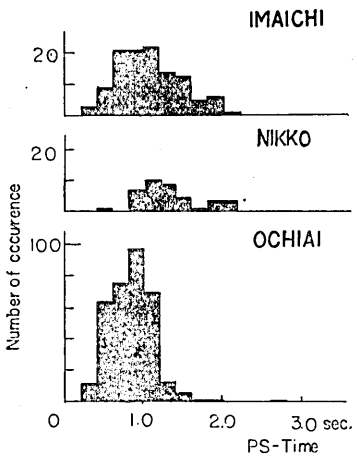

Fig. 3. Frequency distribution of P-S times.

It was not always possible to determine the direction of initial motion of the aftershocks observed, because the seismic motion sometimes commenced in a quite complicated mode. We can, however, recognize a certain tendency in the direction of initial motion at every station. For instance, the seismic motion seems to commence towards the origin (pull) at station Nikkō and Ochiai, but backwards (push) at Imaichi, in most cases (Fig. 4). Thus we may presume a mode of push-pull distribution of initial motion, under the assumption that every aftershock occur with the same mechanism.[2] As to the main shock, the mode of push-pull distribution is presumed to be such as is shown in Fig. 5, in which the data obtained at various observatories, belonging to the Central Meteorological Observatory, were plotted. We find a remarkable difference in the mode of push-pull distribution between the main shock and the aftershocks. However, more detailed discussion on the phenomenon will be postponed.

We consider, in the next step, frequencies of the time interval of occurrence of aftershocks. From the view-point of the theory of random walk, some investigators have tried to study the time interval of occurrence with regard to ordinary or volcanic earthquakes,[3] but not with regard to aftershocks

2) T. HAGIWARA, S. MURAUCHI and J. YAMADA, Special Report of the Earthq. Res. Inst., No. 5 (1947), 164.

3) F. KISHINOUYE and H. KAWASUMI, *Bull. Earthq. Res. Inst.*, 4 (1928), 75.
S. YAMAGUTI, *Bull. Earthq. Res. Inst.*, 11 (1933), 46; *ibid.*, 14 (1936), 399.
S. WATANABE, "*Riken-iho*," 15 (1936), 1083.

Table II. List of the aftershocks, whose hypocenters have been determined.

Commencement time			*P*—*S* time			Depth
d.	h	m.	Nikkō	Imaichi	Ochiai	
Jan.			sec.	sec.	sec.	km
10	6	00	1.4	0.5	0.9	0
	6	07	1.4	0.6	1.1	1.7
12	21	39	1.1	0.7	1.0	0
14	12	18	1.3	1.7	0.8	0
17	10	27	1.1	1.3	1.3	4.0
	16	49	1.2	1.1	0.8	0
21	17	34	1.6	1.5	1.0	4.5
	19	04	1.6	1.5	0.9	4.0
	23	05	0.9	1.0	1.2	0
22	15	04	1.6	1.6	1.0	4.3
23	0	01	1.5	1.1	0.7	3.1
	21	48	0.9	1.2	0.8	0
26	7	19	1.1	1.3	0.9	0
	21	50	1.3	0.9	1.2	3.2
28	19	32	1.2	1.5	1.2	3.8
Feb.						
2	17	12	1.4	1.3	0.9	2.9
5	15	21	1.8	1.3	0.9	4.9
6	5	12	1.1	1.1	1.1	2.7
7	0	15	1.6	1.6	0.8	0
	18	12	1.3	0.8	1.2	2.7
10	2	07	1.6	1.2	1.0	4.7
	5	35	1.1	1.2	1.0	2.5
11	5	23	1.9	1.9	1.0	3.0
16	22	55	1.6	1.5	1.0	4.5
19	2	38	1.2	0.3	1.1	0
25	19	24	1.7	0.7	0.7	2 2
Mar.						
9	3	14	1.1	1.0	1.2	2.6
	22	25	1.6	1.4	0.4	0
11	0	16	1.1	1.1	1.2	3.1
12	12	54	1.8	1.4	0.9	5.0
15	3	23	1.0	1.2	1.2	2.7
18	21	46	1.1	1.5	1.3	3.9
19	13	13	1.2	1.4	1.1	3.2

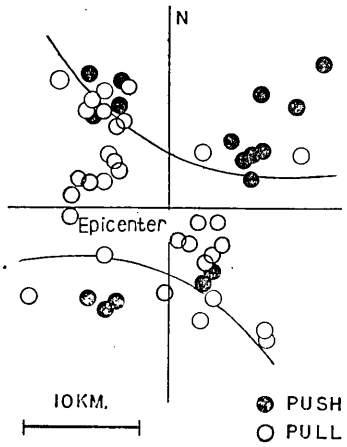

Fig. 4.

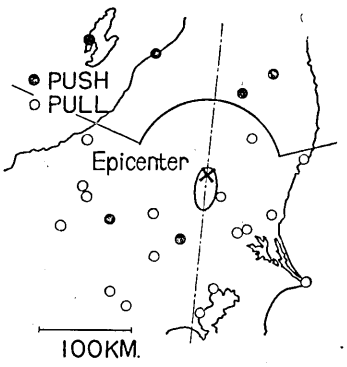

Fig. 5.

occurring in a limited region. The authors took as material the time intervals between two adjoining aftershocks observed at station Ochiai with an acceleration seismograph during the period from Jan. 14 to 23. In those days, about three weeks after the occurrence of the main shock, seismic activity was diminished to a certain extent and the activity could be approximately considered as stationary.

Aftershocks were observed 193 times, during the total observation time which amounts to 12044 minutes (about 8 days), and consequently the mean interval of occurrence Θ[4] was determined to be 62.4 minutes. According to the theory of statistics, the probability of the time interval of two adjoining aftershocks lying between the interval $t_n \sim t_{n+1}$ is given as follows:

$$\int_{t_n}^{t_{n+1}} \psi(t)\, dt = e^{-ct_n} - e^{-ct_{n+1}}, \quad \text{where } c = \frac{1}{\Theta},$$

provided every aftershock occurs completely at random.

Now, taking the time interval $t_n \sim t_{n+1}$ as 10 minutes and calculating the probability, we obtain Table III and Fig. 6, where the observed frequencies are also shown. It is noticeable in the figure that the observed line is similar to the calculated one for large values of t, but when t is less than 10 minutes the former is far higher than the latter. The reuslt seems to suggest that the present group of aftershocks occurs rather successively than entirely at random, though the quantity of the material is not large enough to ascertain the conclusion.

4) R. FÜRTH, Schwankungserscheinungen, S. 35.

Table III. Relation between time intervals and number of occurrence.

Time interval	Number of occurrene	
	Obs.	Calc.
min.		
0— 9	47	29
10—19	24	24
20—29	17	21
30—39	11	18
40—49	12	15
50—59	11	13
60—69	10	12
70—79	10	11
80—89	6	10
90—99	5	10
100—	39	30

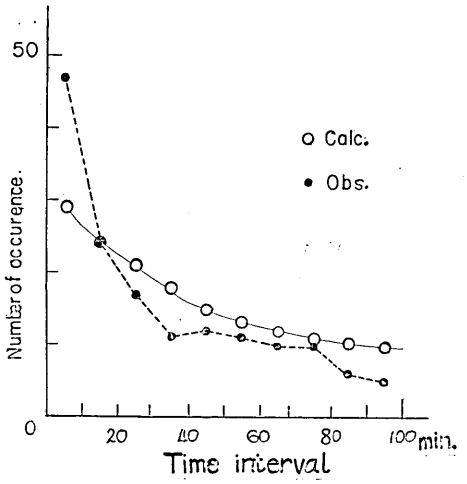

Fig. 6.

The tendency is, however, confirmed only for the present aftershocks, observed by a portable acceleration seismograph. It will be interest to examine whether the similar tendency is found or not in case of another great earthquake.

Summary and acknowledgement.

In the present paper the authors reported the result of the observation of aftershocks which accompanied the Imaichi Earthquake, during the period following the first observation carried out by the party of our Institute. It was found out that the distribution of hypocenters did not differ materially from that in the preceding period, and the general characteristics of aftershcoks during the two preriods were almost the same.

The character of the occurence of aftershocks was also examined from the view-point of the theory of random walk, and some successivity in their occurrence was concluded. According to the data obtained at the station of Imaichi, where the observation is still going on, seismic activity degenerated considerably since June, but a number of aftershocks were sometimes counted as before.

In conclusion, the authors' thanks are extended to J. Yamada and M. Watanabe for their as istance in operating the Ochiai station, and also to Mr. Y. Mori and Mr. T. Honda for their cooperation with the authors in constructing and maintaining the stations at Imaichi and Nikkō.

29. 今市地震の餘震

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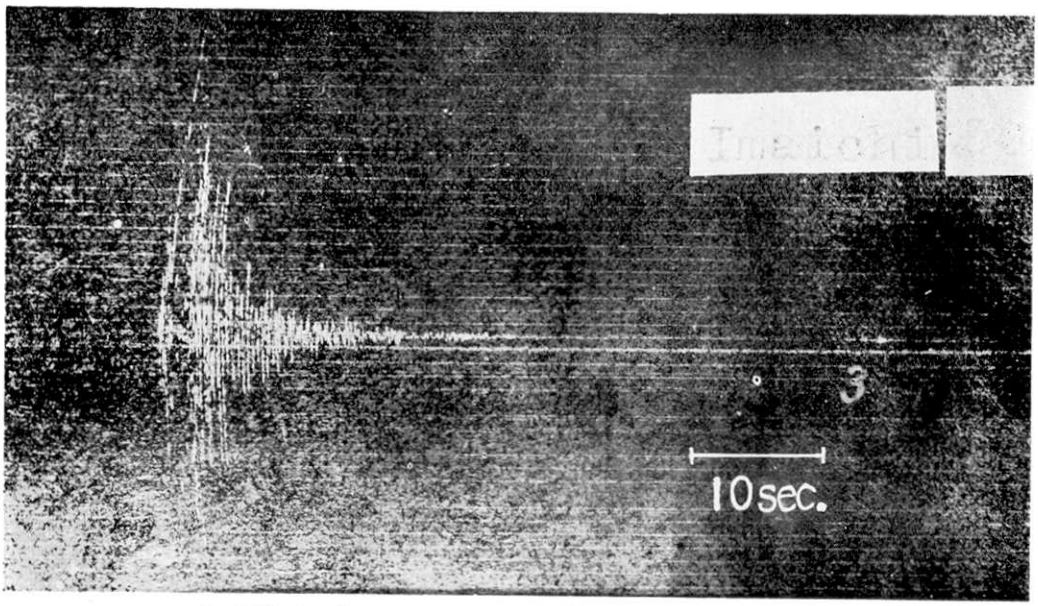
前記共同觀測の後をうけて，筆者等は今市，日光，落合の三觀測所を3月下旬まで維持したが，その結果によると，餘震は依然，共同觀測期間中と同一の地域内に發生している模様である．觀測所のうち，今市のそれは引續き現在まで觀測を行つており，餘震活動が次第に減衰してゆく狀況を見ることができる．

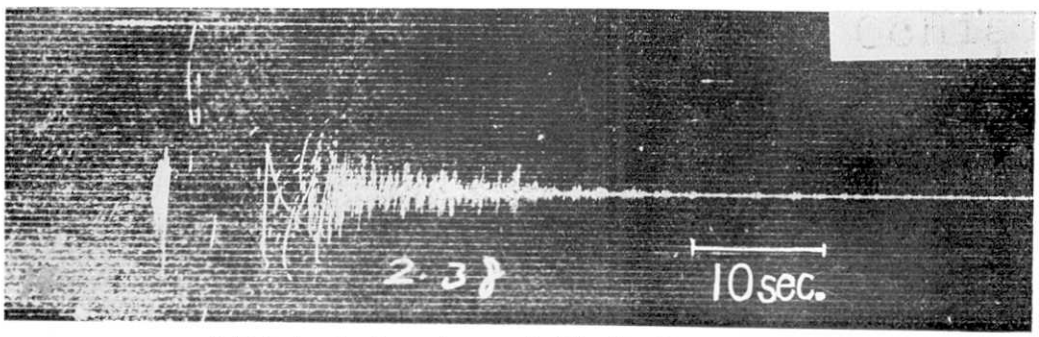
なお，報告中，落合で得られた資料につき，統計現象論的な立場から簡單な考察を行つて見たが，その結果では，餘震の發生の仕方に若干續發的な傾向が認められた．

Fig. 7. The earthquake of 2^h38^m, Feb. 19, 1950.



Imaichi, Acceleration seismograph (N—S). (1.7× the actual)

Nikkō, Acceleration seismograph (N—S). (1.7× the actual)



Ochiai, Acceleration seismograph (N—S). (1.7× the actual)