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Seismometric Observations of Matsushiro Swarm Earthquakes

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Abstract

This paper is the report of seismometric observations of Matsushiro swarm earthquakes made by Abuyama Seismological Observatory and Disaster Prevention Research Institute, independently or co-operatively.

Continuous observation at Shinko has been carried out to investigate the time variation of the seismic activity since the joint observation of ultramicro-earthquakes at the end of 1965. As the seismicity became active, continuous observation was started at Sanada, too, on June, 1966, with the main purpose of investigating the "Ishimoto-Iida's relation" and the time variation of seismic activity, but it was abandoned on September, 1966 because of overlapping the station with that of the Earthquake Research Institute. For studying the attenuation of seismic wave in short hypocentral distance and formulating the equation for calculating the magnitude of an earthquake, the Matsushiro swarm earthquakes are a very good source observations. On the basis of this idea, we picked out four observation points on the array line from Matsushiro to Komoro, and installed completely equipped low magnification seismographs of displacement type. The observations were begun on June, 1966. Further, on November the same year, the array line turned about 90 degrees for the first line which was extended from Matsushiro to Toyoshina through Akashina. The observations are still being continued at present.

As had been planned in the earthquake prediction program in Japan, mobile observations were carried out three times from June to November, 1966, for the purpose of investigating the field problems of this observation system and the seismic activity outside the so-called seismic region of Matsushiro swarm earthquakes. Although this is a simple method by which only the frequency distribution of S-P duration times were observed, notwithstanding its simplicity the mobile observation system for the purpose of surveying the seismic activity was proved useful in the region where the dense observation network had not then been set up.

Though the idea that the earthquakes are almost always generated in the vicinity of the fault is exceedingly Americanized, we carried out the observation of ultramicro-earthquakes by the seismometer-array, with an expectation that some relation between the cracks around Mt. Minakami and ultramicro-earthquakes may exist. However this expectation has been proved completely to the contrary.

Part I. Continuous Observations

By Yoshimichi KISHIMOTO, Michio HASHIZUME, Kazuo OIKE, Kazuo MINO, Tsuneto KURITA, Ryohei NISHIDA, Kunihiko WATANABE and Shigemitsu MATSUO.

(1) Observation at Shinko

From December, 1965 to January, 1966, joint observations of the Matsushiro earthquake swarm were carried out by several universities and institutes in Japan. This co-operative work included a precise observation by the data-recorder system at many stations for five days, and a continuous observation by use of drum-recorder with pen-writing galvanometer for a month. The former observation was planned mainly to investigate the precise determinations of hypocenters and mechanism of this earthquake swarm. On the other hand, the latter was done for the purpose of clarifying the time variation of various natures of this swarm. The latter continuous observation was participated in by four institutes, namely, Faculty of Science, Hokkaido Univ. (at Maruko Town), Faculty of Education, Gifu Univ. (at Mure Village), Abuyama Seismological Observatory (at Koshoku City) and Disaster Prevention Research Institute (at Shinko Village), both belonging to Kyoto Univ.. The result of this continuous co-operative observation for a month is now being worked out at the Disaster Prevention Research Institute, and a seismological bulletin will be issued in the near future. In this sub-section, the continuous observation at Shinko will be briefly described.

Observations at Shinko Village started on December 20, 1965 with the two kinds of joint observations mentioned above. After the end of the joint work on January 20, 1966, the observation at Shinko was continued to watch for seismic activity in the western area of Matsushiro, and is still being continued at present in February, 1967.

Shinko station is situated, as shown in Fig. 1 nearly west of and about 13

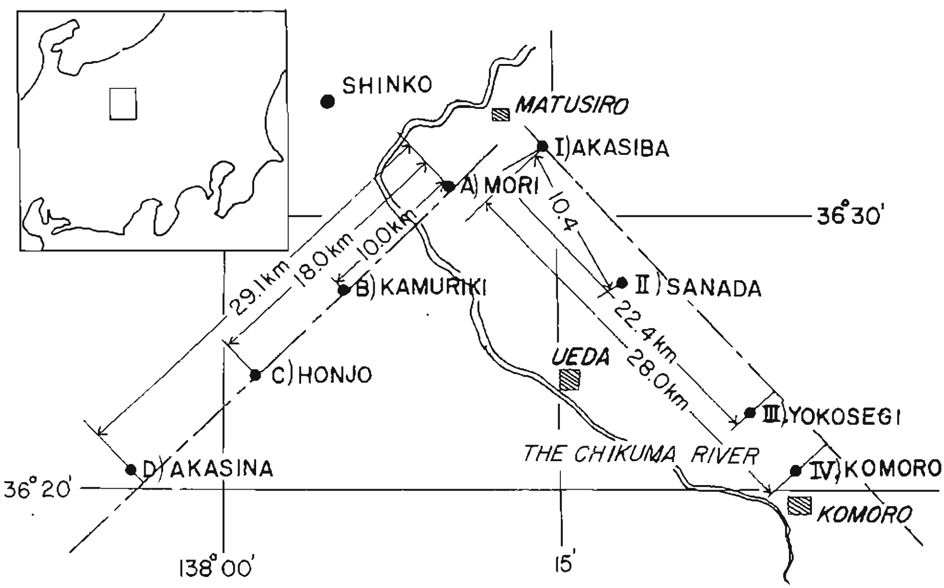

Fig. 1. Map which shows the observation points in the vicinity of Matsushiro.

km distant from Matsushiro. Its latitude, longitude and height above sea level are 36°34.1'N, 138°03.9'E and 260 m, respectively. The observation system at Shinko is the same as that used at Tottori Micro-earthquake Observatory, Disaster Prevention Research Institute[1]. Output of 1 cps seismometer is connected, through electronic amplifier, to drum-recorder with ink-writing pen-galvanometer. Sensitivity of the whole system has been kept as 1 mkine/cm on the seismogram.

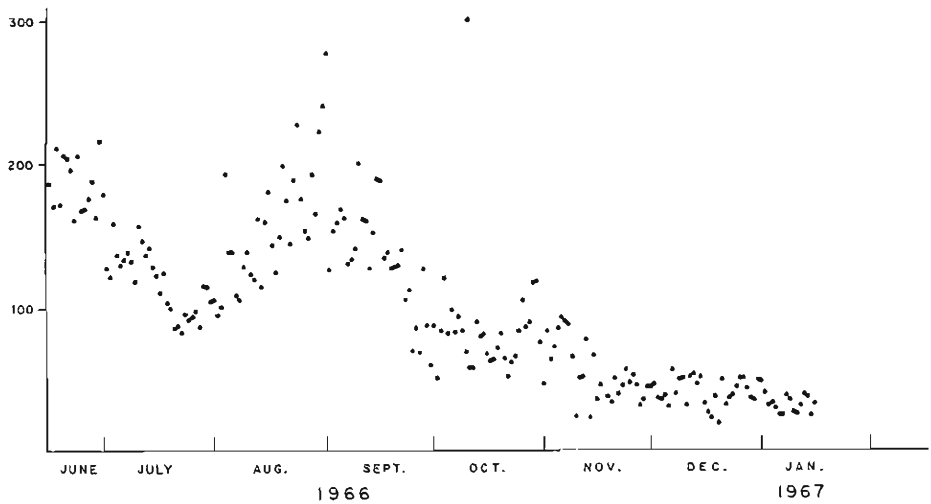

Fig. 2. Time variation of daily number of earthquakes observed at Shinko.

In Fig. 2, the number of earthquakes a day observed at Shinko and its time variation are shown. In this figure, the earthquake is adopted of which velocity amplitude is larger than 200 μkine, the observable upper limit of amplitude being about 5 mkine. Almost all of these earthquakes are, as seen in Fig. 3, in a range of S-P interval of about 1.5 to 3.0 sec..

In Fig. 3, the distribution of S-P interval is shown. Each of these distributions is a summation of successive three days. As mentioned above, there exists a predominant peak of S-P distribution in the range of 1.5 to 3.0 sec. Earthquakes very near to Shinko, of which S-P interval is less than 1.5 sec., were rarely observed over the whole period of observation.

(2) *Observation at Sanada*

For about three months from June 15, 1966, another observation had been carried out at Sanada Town. This observation was planned for a particular purpose of investigating the "Ishimoto-Iida's relation" in the case of Matsushiro earthquake swarm. Observation was made by the same instruments mentioned in earlier subsection (1), but four ranges of amplification for the same seismometer were utilized in order to cover a wide range of magnitude. These four ranges, classified as Channel 1 to 4 below, are as follows:

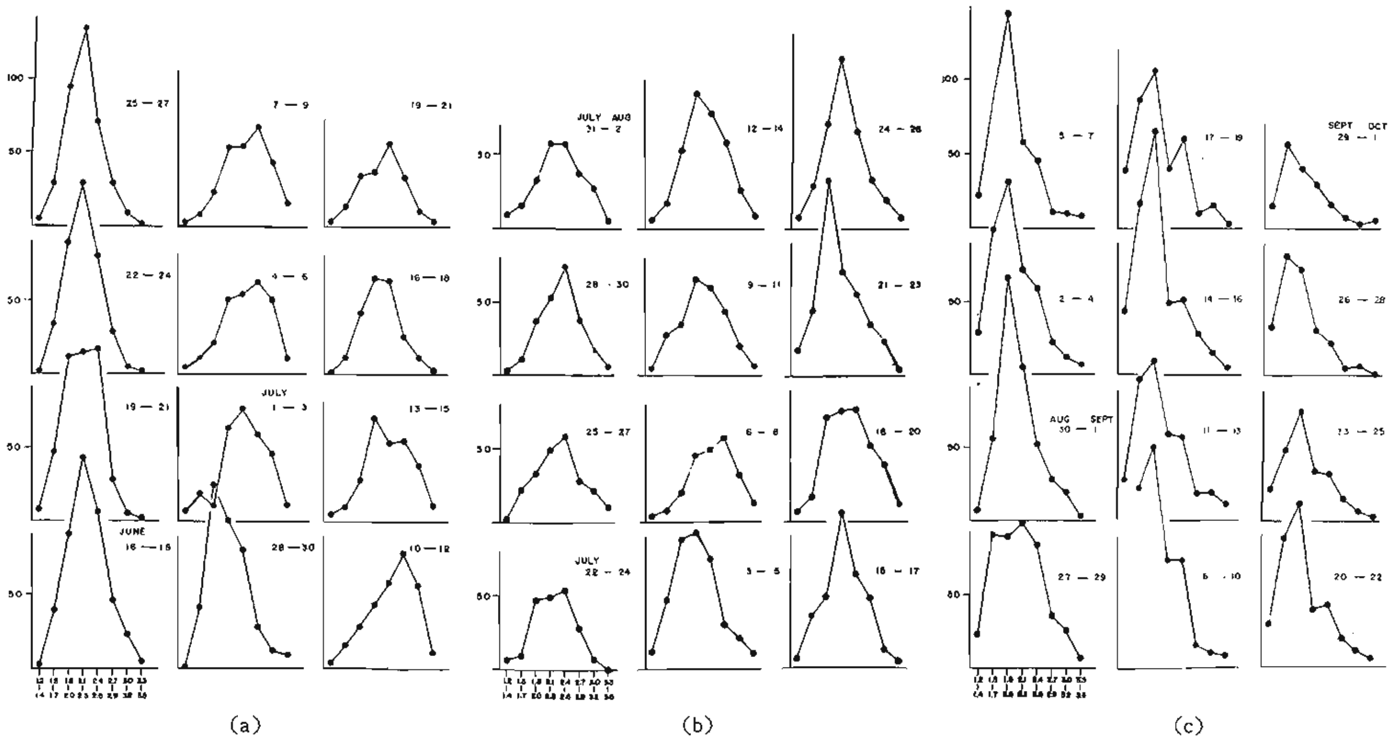

Fig. 3. Time variation of frequency distributions of S-P duration times at Shinko.

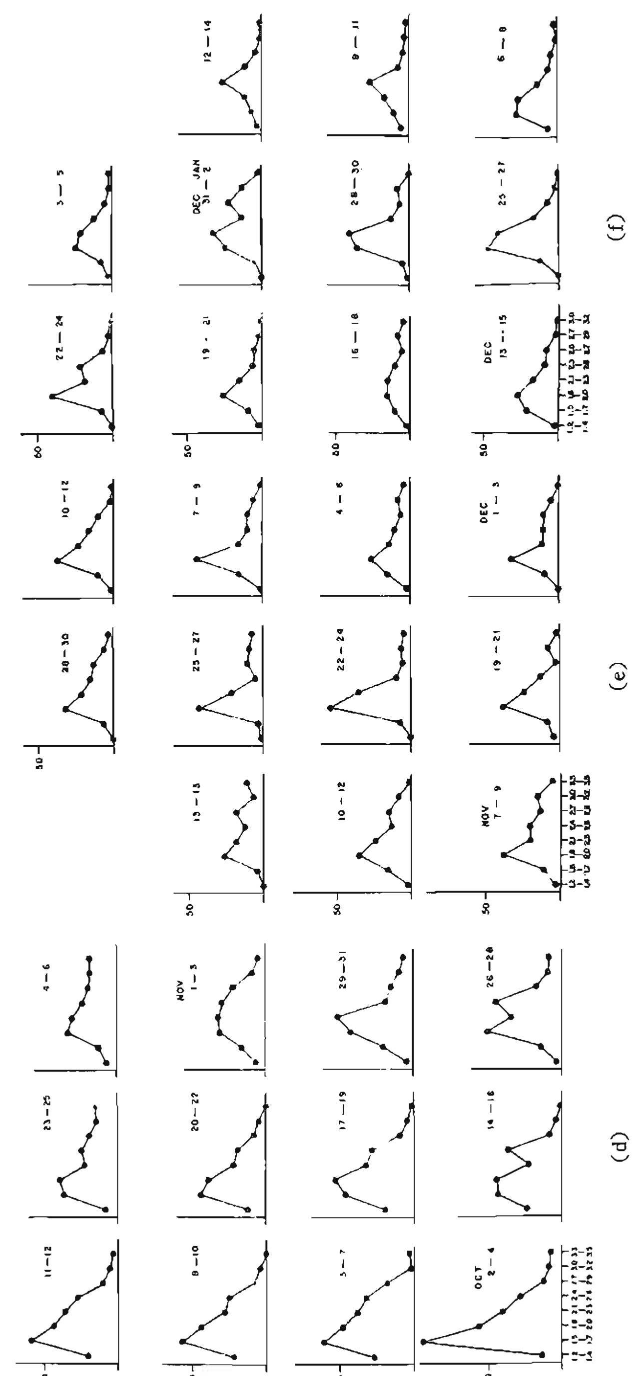

Fig. 3.

Channel	Sensitivity (on the seismogram)
1	0.32 mkine/cm
2	1.6
3	8.0
4	40

Also, continuous observation had been carried out by use of the drum-recorder with the same sensitivity as that of Channel 2.

The problem of the Ishimoto-Iida's relation in this case is now being investigated, and will be discussed in the near future. In the present subsection, only the number of observed earthquake and its S-P distribution will be shown. Fig. 4 represents the time variation of observed earthquakes on Channel 2. In this figure, the earthquakes are adopted of which amplitude is larger than 5 mm (about 0.8 mkine) on the seismogram of Channel 2.

Fig. 5 shows the distribution of S-P interval of earthquakes in Fig. 4. Fig. 6 represents the same kind of S-P distribution of larger earthquakes of which amplitude lies between 8 and 80 mkine.

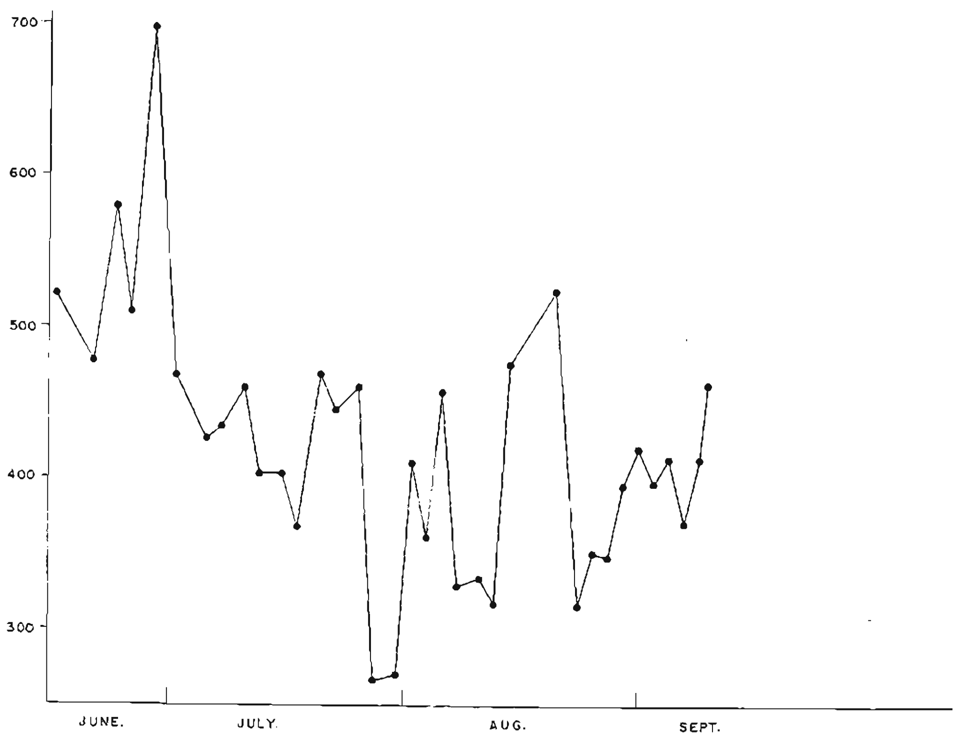

Fig. 4. Time variation of numbers of earthquakes observed at Sanada.

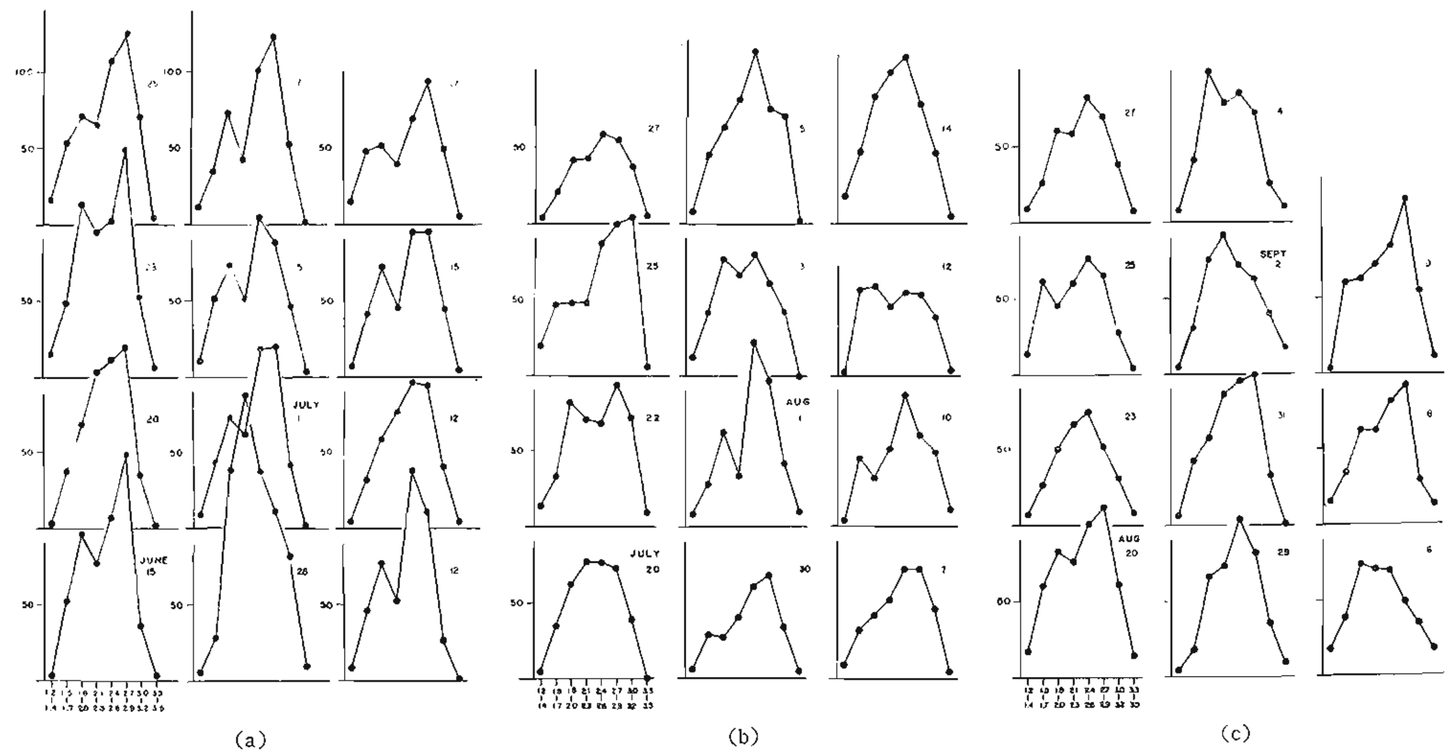

Fig. 5. Time variation of frequency distributions of S-P duration times at Sanada, observed through Channel 2.

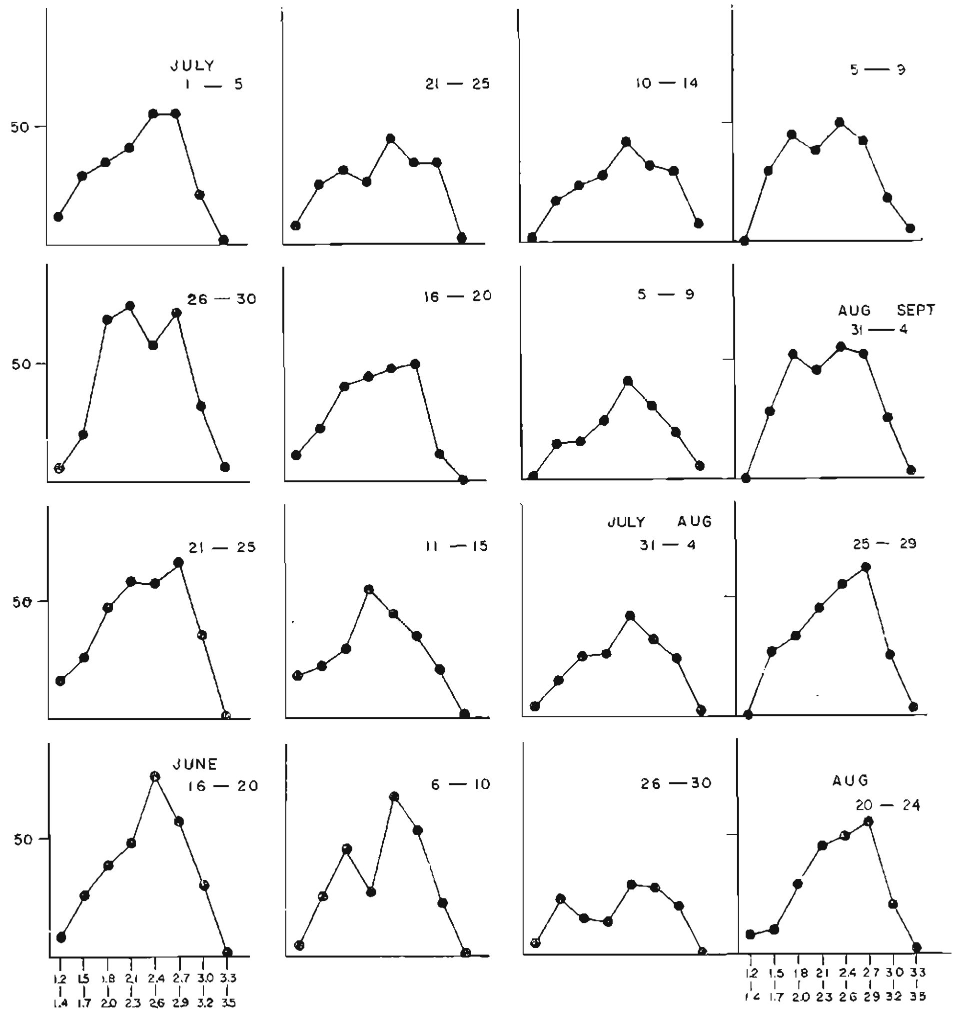

Fig. 6. Time variation of frequency distributions of S-P duration times at Sanada, observed through Channel 3.

Part II. Magnitudes of Matsushiro Swarm Earthquakes

By Haruo MIKI, Kennosuke OKANO, Isamu HIRANO, Shozo KIMURA, Yasuhiro UMEDA and Hiroshi WATANABE

The magnitude of earthquake defined by C. F. Richter should be calculated from the ground motion at a place where the hypocentral distance is 100 km. In practice, however, hypocentral distance is not always 100 km, therefore, we ought to calculate the magnitude of earthquake assuming the attenuation of seismic wave with hypocentral distances. But it is not easy to establish the attenuation of seismic wave, especially in the case of a near earthquake, because we cannot set the special station array in order to study the attenuation of seismic wave on account of the difficulty of forecasting an earthquake in its position, occurrence time and magnitude.

Now, Matsushiro swarm earthquakes have been occurring in the limited domain since the summer of 1965. This fact means that Matsushiro swarm earthquakes present a good opportunity to study the attenuation of seismic wave in a short hypocentral distance and to calculate the magnitudes of earthquakes.

For this purpose, the arrays of temporary seismographic stations were set up in the neighbourhood of Matsushiro and observations were carried out over two periods from the summer of 1966. Using the observed data in the early period, we calculated the coefficient of attenuation of seismic wave and determined the magnitudes of earthquakes in the later period of which the trace amplitudes were larger than 2 mm and S-P intervals were definitely read at Honjo.

The observations in the first period were carried out from June 20 to August 20, 1966. The observations in the second period were begun on November 12, 1966 and are still continuing at present. The observation points are shown in Fig. 1. The directions of lines of array stations are NW-SE in the first period and NE-SW in the second period.

The seismometers used are of horizontal components and of displacement types having the natural period 0.6 sec. and damping ratio 5 : 1. Their magnification curve is seen in Fig. 7. Each magnification of seismometer at each observation point was regulated from 50 to 120, in proportion to increase of the distance from Matsushiro to each point, and arranged to vibrate normal to the array line. The system of smoked paper recording is used, the paper speed being 12 cm/min.

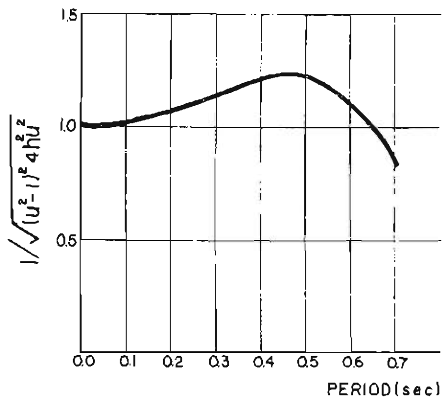

Fig. 7. Period characteristics of low magnification seismographs used to study the attenuation of seismic wave.

For the attenuation of the maximum amplitude, the next equation is assumed:

$$A=\frac{A_0}{r}\exp(-hr) \tag{1}$$

where A is maximum amplitude and r is hypocentral distance. Twenty-five earthquakes were analyzed and the value of attenuation coefficient "h" was estimated as 0.067. Then the attenuation curves are drawn in accordance with Richter's definition.

Let A_{100} be the maximum ground amplitude at the point where the hypocentral distance is 100 km. The magnitude of earthquake is defined by B. Gutenberg and C. F. Richter as follows:

TABLE 1.

Date	Time	(S-P) Time (sec)	Ground Motion (μ)	M	Date	Time	(S-P) Time (sec)	Ground Motion (μ)	M
1966	h m				1966	h m			
Nov. 12	00 04	4.6	52.4	2.8	Nov. 30	22 00	1.3	28.2	1.2
13	03 00	3.2	28.3	2.1	Dec. 1	12 21	2.4	25.4	1.8
13	09 47	3.1	105.6	2.6	1	18 34	1.9	636.0	3.0
14	15 50	3.1	34.1	2.2	1	18 44	1.9	54.5	1.9
16	08 02	3.8	76.0	2.8	1	19 36	3.4	220.0	3.1
17	05 56	3.9	46.0	2.6	1	19 37	3.4	27.1	2.1
17	06 57	4.0	30.2	2.4	1	20 09	2.1	397.0	2.8
17	21 41	1.9	110.0	2.2	2	03 26	1.9	36.4	1.8
18	13 37	1.2	40.6	1.4	2	03 35	3.3	22.8	2.1
19	02 15	1.2	852.0	2.6	2	04 46	2.7	47.3	2.1
19	02 25	1.1	50.1	1.5	2	09 22	2.0	50.9	1.9
19	04 40	1.2	69.4	1.6	3	19 57	2.4	27.3	1.8
20	01 33	1.5	19.0	1.2	3	23 05	1.5	18.0	1.2
20	04 44	1.3	34.5	1.4	4	21 47	1.3	242.5	2.2
20	14 55	1.2	223.0	2.1	5	04 25	2.8	65.4	2.3
20	14 58	0.9	20.0	1.0	5	22 12	3.5	23.4	2.1
20	17 23	3.8	41.8	2.6	6	22 33	3.8	28.9	2.5
20	19 16	2.7	54.5	2.2	8	08 37	3.1	17.0	1.8
22	07 17	3.6	19.5	2.1	8	12 49	3.4	79.3	2.6
22	10 35	1.5	28.6	1.4	8	14 29	3.5	22.2	2.1
22	18 48	0.9	19.1	1.0	8	22 57	0.8	263.0	2.0
22	19 47	2.4	62.3	2.1	8	23 33	0.8	34.8	1.0
22	21 43	3.4	26.0	2.1	8	23 42	0.8	84.4	1.4
23	09 06	4.6	32.3	2.7	9	05 13	3.4	85.2	2.7
24	06 28	2.7	36.9	2.0	9	07 47	0.7	25.2	0.8
24	07 39	2.7	223.0	2.8	9	12 47	3.4	34.1	2.2
24	16 10	3.2	45.5	2.3	12	01 12	3.5	157.6	3.0
24	19 53	3.4	86.6	2.7	12	05 14	2.8	39.2	2.1
24	22 06	2.7	19.0	1.8	13	18 30	2.6	16.3	1.7
24	22 07	2.5	19.0	1.7	13	18 57	3.9	40.0	2.6
25	02 04	2.4	337.0	2.9	14	12 39	3.9	50.3	2.8
25	17 03	1.9	55.5	1.9	15	05 22	1.6	47.4	2.0
25	21 54	3.3	21.8	2.0	16	18 41	3.6	19.3	2.1
27	09 53	1.8	18.2	1.3	17	02 55	3.9	19.6	2.2
27	16 27	1.2	33.7	1.2	18	03 12	3.1	26.8	2.1
27	23 37	4.2	31.9	2.5	18	15 33	1.2	47.1	1.5
29	21 21	3.4	21.0	2.1	18	17 56	2.5	14.5	1.6
29	21 44	3.4	21.8	2.2	20	10 34	2.0	19.4	2.5
30	15 29	2.5	22.7	1.8	20	17 29	3.4	16.7	2.0
30	16 35	1.8	36.4	1.6	20	21 46	3.5	13.8	1.9
30	21 18	0.6	27.2	0.8	21	12 55	3.9	60.8	2.3

Date	Time	(S–P) Time (sec)	Ground Motion (μ)	*M*	Date	Time	(S–P) Time (sec)	Ground Motion (μ)	*M*
1966	h m				1967	h m			
Dec. 22	00 44	1.9	20.3	2.5	Jan. 13	08 33	1.2	32.6	1.3
22	12 55	2.2	31.4	1.8	13	14 51	1.4	30.2	1.4
22	23 38	1.2	21.7	1.1	13	14 55	1.5	56.5	1.7
23	04 04	2.3	94.2	2.3	13	15 17	1.3	50.0	1.5
24	03 51	1.1	23.9	1.1	13	23 47	1.8	29.7	1.6
24	07 47	2.8	45.7	2.2	14	01 54	1.6	120.0	2.1
24	10 46	2.5	38.4	1.9	14	08 16	1.5	22.5	1.3
24	13 10	1.2	63.8	1.6	15	10 29	2.3	67.4	2.1
25	02 02	1.2	74.6	1.6	16	03 03	1.5	56.5	1.7
25	17 15	2.5	47.3	2.0	16	03 04	1.6	9.8	1.0
25	20 24	2.5	21.8	1.7	16	09 09	1.7	61.6	1.9
25	23 35	3.9	32.0	2.4	16	12 31	3.1	780.0	3.5*
26	07 37	2.3	27.5	1.7	16	12 39	1.3	239.0	2.2
26	13 05	2.0	91.0	2.2	16	12 42	1.3	55.8	1.6
28	02 11	2.6	21.5	1.8	16	12 45	1.3	26.8	1.3
28	16 32	1.2	216.0	2.1	16	12 50	1.3	87.0	1.7
31	23 51	3.8	23.1	2.2	16	12 54	1.2	45.6	1.4
1967					16	15 07	1.3	23.2	1.2
Jan. 4	03 12	3.9	60.0	2.7	16	15 14	1.3	63.8	1.6
5	13 35	2.4	41.0	2.0	16	15 21	1.3	21.7	1.1
6	04 27	3.6	30.0	2.3	16	17 00	1.0	105.7	1.7
7	20 50	1.9	365.0	2.7	16	17 01	1.0	25.4	1.0
10	12 00	1.7	16.0	1.3	16	19 36	1.0	43.5	1.3
10	17 30	3.5	1027.0	3.7*	16	20 17	1.1	75.3	1.6
10	18 03	1.0	27.5	1.1	16	22 13	1.2	26.8	1.2
10	18 44	1.4	50.0	1.6	16	23 30	1.3	197.0	2.1
10	19 10	1.1	105.8	1.8	17	00 11	1.1	49.3	1.4
11	02 11	1.2	34.7	1.3	17	01 50	1.3	52.8	1.5
11	02 34	1.4	64.5	1.7	17	14 11	1.3	495.0	2.5
11	02 35	1.4	554.0	2.7	17	14 12	1.3	50.7	1.5
11	03 09	2.7	24.6	1.9	17	14 14	1.3	35.5	1.3
11	03 28	1.6	312.0	2.5	17	14 28	1.3	18.1	1.0
11	04 43	1.3	78.3	1.7	17	14 47	1.3	44.2	1.5
11	07 00	1.2	111.0	1.9	17	14 58	1.4	19.6	1.1
11	22 56	3.5	18.1	2.0	17	15 14	1.2	261.5	2.3
12	04 44	1.4	83.5	1.8	17	22 49	1.2	28.3	1.2
12	21 24	2.2	877.0	3.2	19	00 55	1.3	24.7	1.2
13	07 01	1.4	88.7	1.9	19	01 58	1.7	418.0	2.7

$$M=3+\log 2.8A_{100} \tag{2}$$

Let A_i be the maximum ground motion at the observation point where the hypocentral distance is r km, then by our assumption the next equation holds,

$$A_i=\frac{A_0}{r}e^{-hr}\ ; \qquad A_{100}=\frac{A_0}{100}e^{-100h} \tag{3}$$

From (2) and (3), using $h=0.067$, the next equation is deduced.

$$M=\log 28A_ir+0.029(r-100) \tag{4}$$

If we assume the Omori constant is 7.8, and denote S-P interval as t, then $r=7.8t$. Then

$$M=\log 2.18A_it+0.226t-0.90 \tag{5}$$

Equation (4) is modified as follows,

$$\log A_i=\log(10M/2.18t)-0.026t-0.90 \tag{6}$$

The graph to indicate the relation between A_i and t was drawn, for the purpose of reporting the magnitude easily and quickly (Fig. 8). If we know only the ground amplitude and the S-P interval from seismogram, we can estimate the magnitude of each earthquake easily from this figure. The magnitudes of Matsushiro swarm earthquakes of which the trace amplitudes are larger than 2 mm and S-P intervals are clear at Honjo are shown in Table 1.

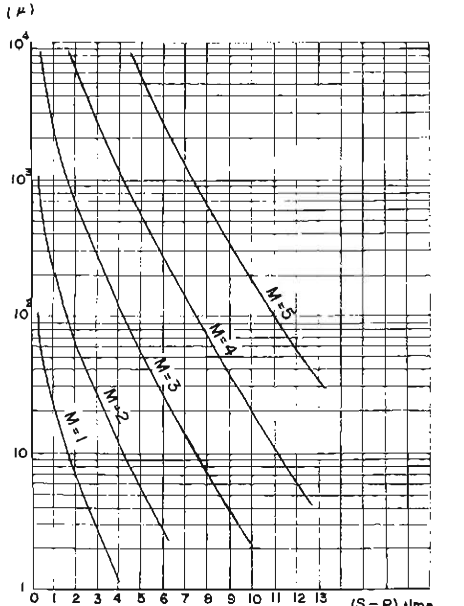

Fig. 8. Graph for the eastimation of magnitude. If one knows only the maximum trace amplitude and S-P times, one can know the magnitude of each earthquake easily from this figure.

Part III. Mobile Observations of Ultramicro-Earthquakes

By Haruo MIKI, Hikaru WATANABE, Masao NAKAMURA, Akio KUROISO, Shozo KIMURA; Yoshimichi KISHIMOTO, Michio HASHIZUME, Kazuo MINO and Shigemitsu MATSUO

In studying the seismicity or the seismic activity of a certain region, the hypocentral distribution and its variation with time may have to be deduced from the results of the observation on a routine basis or a temporary observation network. In many cases, however, these observation systems cannot always be set for the sudden unexpected outbreak of an earthquake because of insufficient budget or deficiency of operators. Instead of the hypocentral distribution of individual earthquakes, the frequency distribution of S-P duration

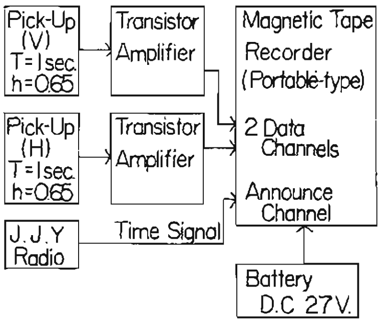

Fig. 9. Blockdiagram of the mobile observation system.

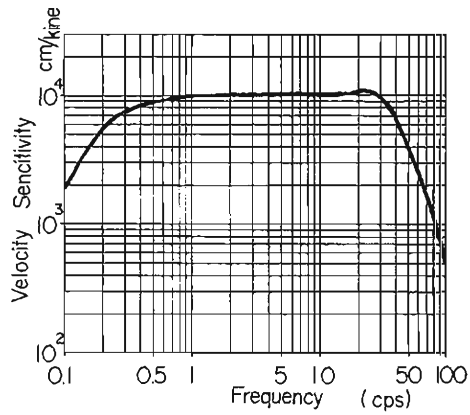

Fig. 10. Overall frequency response curve of seismograph used for mobile system.

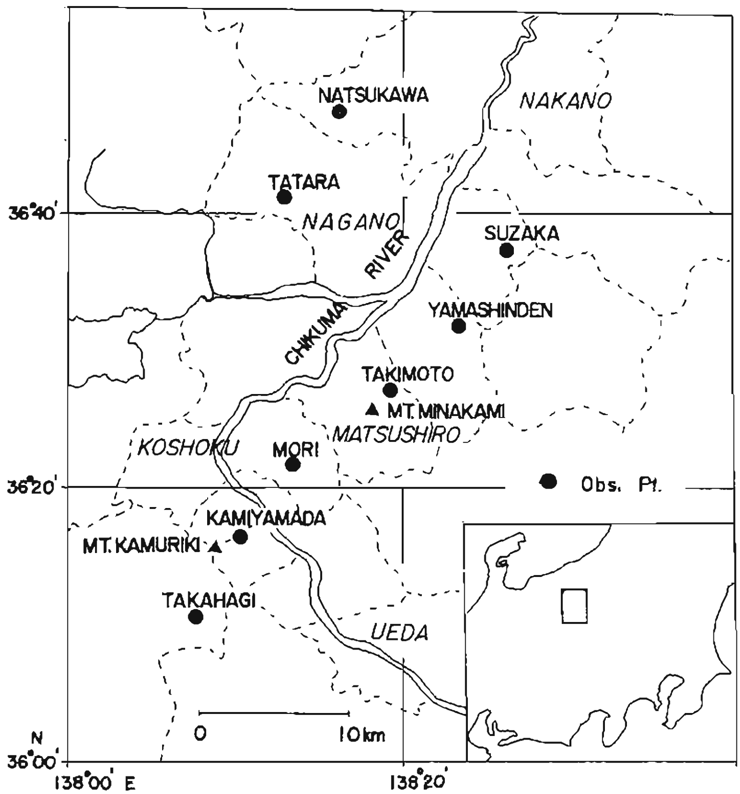

Fig. 11. Location of temporary observation stations, where the mobile observations were carried out.

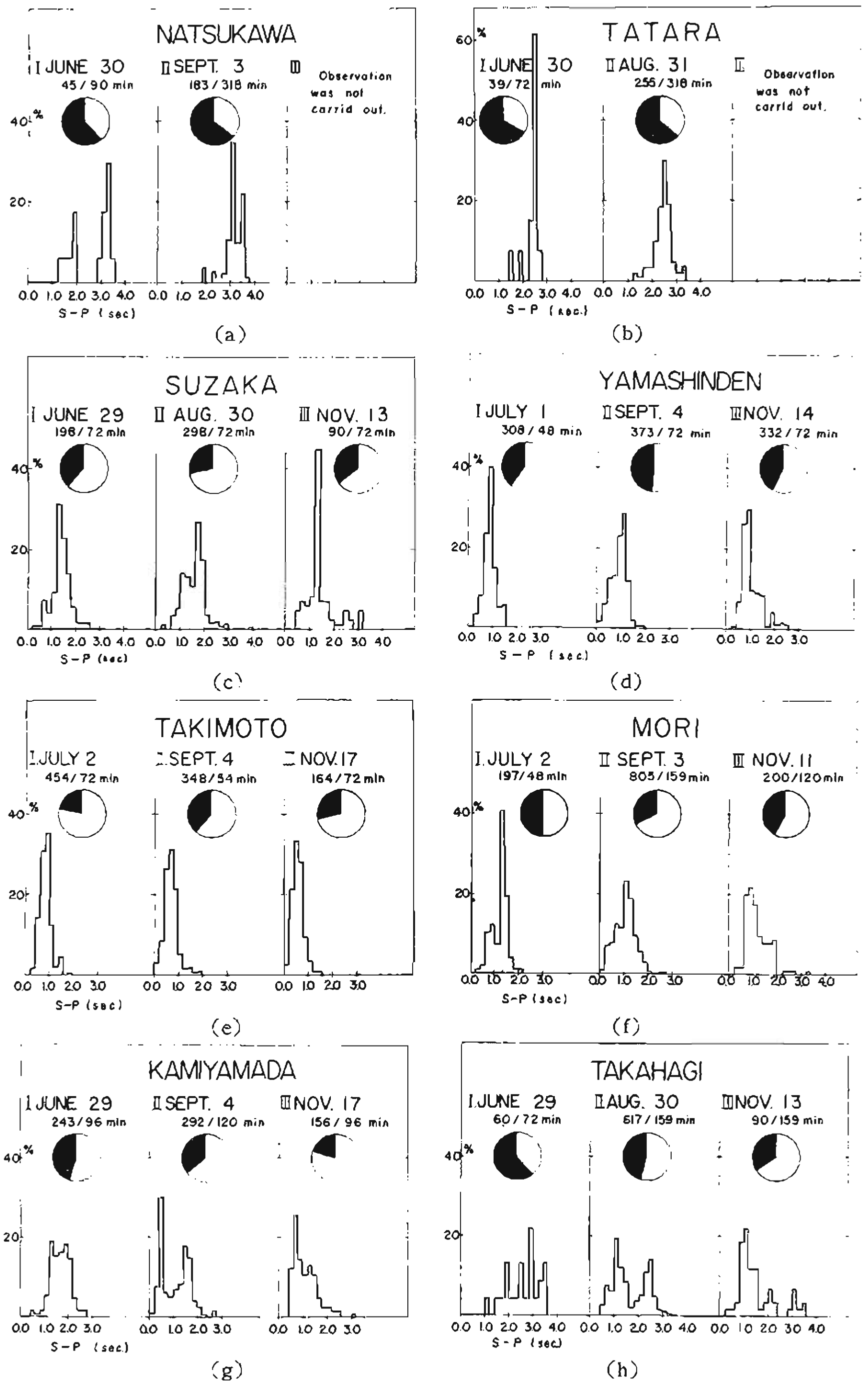

Fig. 12. Observation dates, numbers of earthquakes observed per each observation period and the frequency distribution of S-P duration times, at temporary stations shown in Fig. 11. Each circle divided into white and black shows the ratio of numbers of earthquakes whose S-P times are readable and not readable, respectively.

times at a single station is therefore adopted for a rough determination of the seismic region or the seismic region as a whole[2)3)4)]. In accordance with these analytical methods, mobile observations were carried out three times at several stations in the vicinity of Matsushiro for investigating effectively the seismic active region or its variation with time.

The observation system is illustrated as a block diagram in Fig. 9. The earthquakes were recorded by means of a magnetic tape recorder of portable type. They were played back on charts with pen writing galvanometer. Sensitivity is about 10000 cm/kine for each station and component. Paper speed is 25 mm/sec. Overall frequency response for the observation system is shown in Fig. 10. The observations were carried out three times in total, from June to November, 1966. Fig. 11 shows the location of temporary stations. All the apparatus shown in Fig. 9 were carried by the observation car.

The frequency distributions of S-P duration times observed at each station for three times are shown in Fig. 12. Referring to these figures, they may be considered representative of the seismic active region near Matsushiro. The distributions at Kamiyamada and Takahagi for the second and third observations, however, show clearly the appearance of another seismic active region near Mt. Kamuriki from July or August, 1966.

In studying seismicity by means of the analytical method of the frequency distribution of S-P duration times, some difficult problems are presented, for example, how to deal with earthquakes of which the S-P times are not readable, how to eliminate the distortion of frequency distribution according to the successive occurrence of local earthquakes, and so on.

Regarding this aspect, the following should be taken into consideration in order to obtain information about seismicity in more detail deduced by means of the mobile observation.

1. It is preferable that three component seismographs should be used in order to distinguish P and S phases in as many earthquakes as possible, though it necessitates a heavy load of equipment.
2. It is necessary to devise methods to account for earthquakes which have indistinct S-P times and are not accounted for consideration for the frequency distribution of S-P duration times.
3. The transducer should be set up on firm bed rocks to get rid of ground back noises.
4. The observations should be carried out for long periods, and for many times at each station suficient to get rid of the short period perturbations of seismicity.

However, in spite of the doubtful accuracy in determining the distribution of hypocenters from the frequency distribution of S-P duration times, the results of our observations proved the reliability and usefulness of the mobile observation system for the purpose of surveying the seismicity especially in unanticipated cases.

Part IV. Observation of Microearthquakes around Mt. Minakami

By Hikaru WATANABE, Masao NAKAMURA, Akio KUROISO, Junpei AKAMATSU; Takeshi MIKUMO, Kazuo OIKE and Kunihiko WATANABE

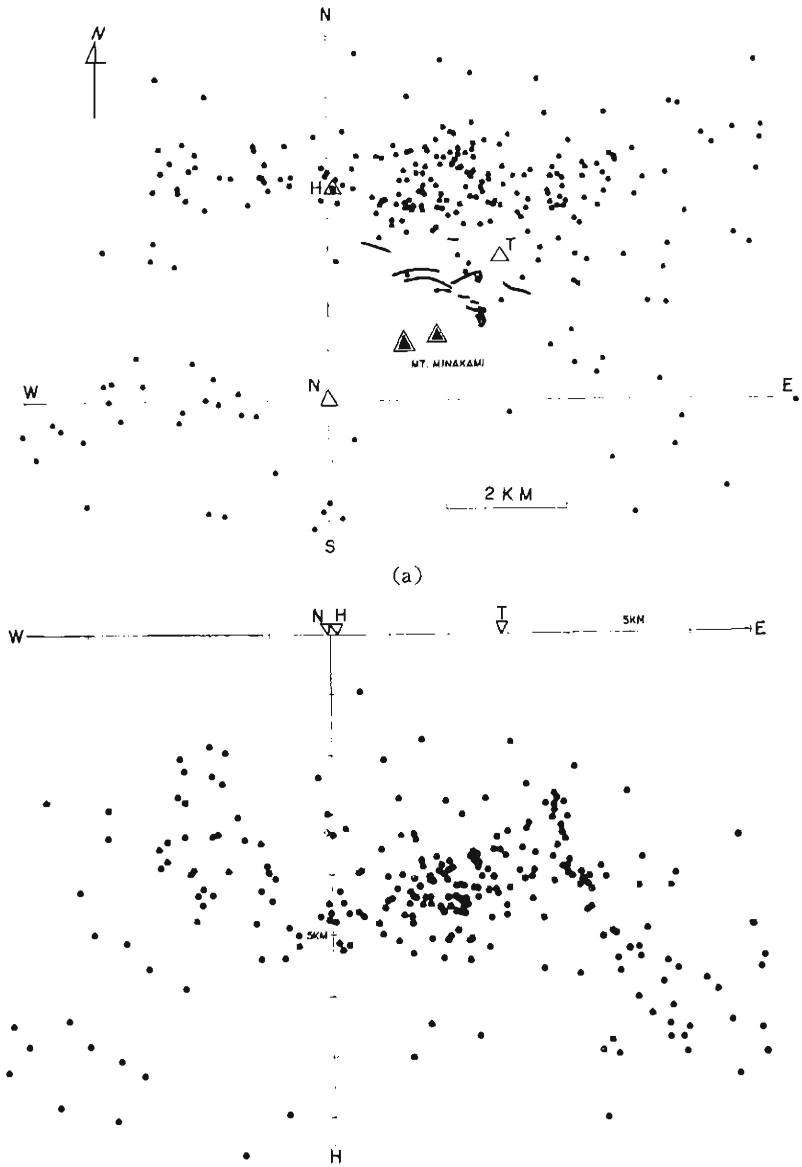

Fig. 13. Epicentral distribution (a) and projection of foci onto a vertical section along the E-W direction (b).

A remarkable swarm of earthquakes has been continuing in the Matsushiro region since August, 1965. The seismometric observations thus far made have shown that many of the earthquakes centered around Mt. Minakami within a radius of about 5 km and depths between 2 and 8 km[5)6)]. In 1966, local cracks were formed on the ground surface in the northeast area (Takehara and Sezeki, see Fig. 13) of Mt. Minakami. These cracks run almost parallel, and the general trend can be traced to a distance of 1.5 km in the NW-SE direction. The leveling survey made by the Earthquake Research Institute indicates an extraordinary uplift of the ground in the area relative to surrounding regions. The triangular survey by the Geographical Survey Institute covering a wider area also shows horizontal ground movements toward the NW and SE directions being bounded by the area. This situation suggests the possibility that the ground cracks might be related to a latent fault movement caused by tectonic forces working in the whole region. For this reason, we made a temporary observation of micro-earthquakes around the area concerned. The main purpose of the observation was focused to examine a possible correlation between the spatial distribution of micro-earthquakes and the local cracks or latent faults.

The observation was made from Dec. 16, 22h00m to Dec. 17, 05h00m and from Dec. 17, 21h00m to Dec. 18, 04h00m in 1966. Stations were set up at Nishijo (0, 0 km), Takimoto (2.89E, 2.35N km) and Higashi-Terao (0.11E, 3.49N km), surrounding Mt. Minakami and the area where the ground cracks can be traced. Recordings were made by the magnetic tape system with vertical and horizontal seismometers having a natural frequency of 1-4 cps and electronic amplifiers. The overall frequency characteristics have a flat response to velocity between 3 and 30 cps: the sensitivity was so adjusted as to record amplitudes between some mkine/mm and the ground noise level of about 50 μkine/mm. Besides these stations, a truck undertook a mobile observation inside the network, but the data will not be used together in the following discussion.

The number of earthquakes recorded during the two nights amounted to 1,500 or more, but the average number per hour was of an order of 1/5 compared with that observed in 1965. We picked up all the earthquakes of which P and S waves were commonly well recorded at the three stations. A diagram showing the relation between the S-P times and the arrival times of P waves has been drawn for each of the earthquakes to check the reliability of time readings, before their hypocenters were determined. Reasonable results were obtained for 255 shocks, for which Poisson's ratio can be estimated as being around 0.25. To determine the position of an earthquake focus from S-P times at three stations, we have to assume a constant k ($D=k\times t_{S\text{-}P}$). The observation of the E.R.I., covering a wider area by 4 stations, has yielded the average, $k=7.39\pm0.53$ for 113 shocks, while a P wave velocity of 5.0-5.1 km/sec has been observed by a mobile observation[7] made in the northeastern part of Matsushiro. The latter gives 6.8-7.0 for k if Poisson's ratio is taken to be 0.25. Since our observation is concerned with seismic waves traveling through a shallower part of the crust, k has been tentatively taken as 6.80 from the lower value of the above evidence. Fig. 13(a) shows the determined epicenters for the 255 shocks, and the distribution is projected onto a vertical section along the EW direction, in Fig. 13(b). To estimate possible variations of the distribution due to the uncertainty of k, the shifts of the positions of several shocks when k varies from 6.5 to 7.5 are illustrated in Fig. 14. Although the epicenters outside the network move away by an order of 1 km, and also a considerable number of weaker shocks have been excluded, the general pattern of the epicentral distribution shown in Fig. 14 would not be seriously modified.

It may be concluded from Fig. 13 with these considerations that a greater part of microearthquakes concentrated in the northeast of the main trace of cracks, and, on the other hand, no epicenter was located just in the southwest side. There seems to be a boundary of the distribution along the general trend

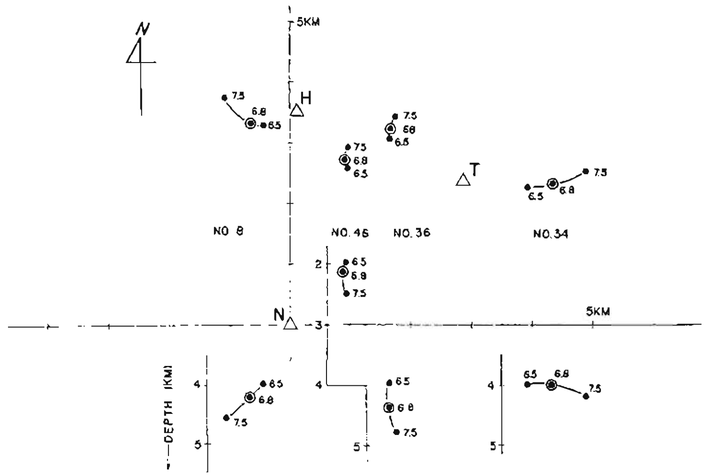

Fig. 14. Shifts of positions of 4 shocks with the change of values of *k* from 6.5 to 7.5.

of extended cracks, but it is not certain whether this boundary suggests the existence of a fault or not. It is also interesting to note that microearthquakes did not occur, in the above period, under and just around Mt. Minakami where there have been a number of earthquakes. This contrasts sharply with the former results. We can not say, however, without any additional information that the seismic strain energy stored under Mt. Minakami has been exhausted. More observations are needed to obtain conclusive evidence. It is also shown in Fig. 13 that most of the shocks occurred between 2 and 6 km deep. More results from the present observation will be reported in separate papers.

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