

23. Summary of the Seismographic Observation of Matsushiro Swarm Earthquakes.

By Takahiro HAGIWARA and Takayuki IWATA,

Earthquake Research Institute.

(Read February 28, 1968.—Received March 30, 1968.)

Introduction

The Matsushiro swarm earthquakes commenced in August 1965 and still continue even now when more than two years have passed since the outbreak. The Earthquake Research Institute dispatched a field party for seismographic observation and set up a temporary seismographic network surrounding the area where the earthquakes seemed to occur. The result of the observation carried out by this party during the period from October 1965 to February 1967 has been reported successively^{1)~4)}.

The present paper will describe an outline of the activity of the Matsushiro earthquakes with its repeated rise and fall during the period of twenty seven months, from August 1965 to October 1967, summarizing the reports aforementioned and adding new data of observation in the later period from March to October 1967.

1) The Party for Seismographic Observation of Matsushiro Earthquakes and the Seismometrical Section, Earthquake Research Institute, "Matsushiro Earthquakes Observed with a Temporary Seismographic Network. Part 1," *Bull. Earthq. Res. Inst.*, **44** (1966), 309-333.

2) The Party for Seismographic Observation of Matsushiro Earthquakes and the Seismometrical Section, Earthquake Research Institute, "Matsushiro Earthquakes Observed with a Temporary Seismographic Network. Part 2," *Bull. Earthq. Res. Inst.*, **44** (1966), 1689-1714.

3) The Party for Seismographic Observation of Matsushiro Earthquakes and the Seismometrical Section, Earthquake Research Institute, "Matsushiro Earthquakes Observed with a Temporary Seismographic Network. Part 3," *Bull. Earthq. Res. Inst.*, **45** (1967), 197-223.

4) The Party for Seismographic Observation of Matsushiro Earthquakes and the Seismometrical Section, Earthquake Research Institute, "Matsushiro Earthquakes Observed with a Temporary Seismographic Network. Part 4," *Bull. Earthq. Res. Inst.*, **45** (1967), 887-917.

1. Temporary seismographic network

Temporary seismographic stations were set up in four places around Mt. Minakami, i.e., at Zôsan, Akashiba, Hoshina and Mori in the beginning, each station being equipped with an Ishimoto acceleration seismograph and a short period electromagnetic seismograph of the type HES 1-0.2.

Since April 1966 when the seismic area extended, seismographic stations were successively added at Nire, Hirashiba, Naganuma, Sakaki and Sanada. In March 1967 when the earthquakes decreased in number, the seismographic network was rearranged so as to cover a wider area, as the repeated precise leveling revealed remarkable changes in the height of the ground covering a wide area in the northern part of Nagano Prefecture and accordingly there was a fear that earthquakes might occur in some place other than the hitherto active

area. The seismographic stations available through October 1967 are shown in Fig. 1. The constants of the instruments used at these stations and the observation periods were listed in Table 1.

As an example, a part of the acceleration seismogram obtained at Hoshina on 10th April 1966 when the activity was most violent is shown in Fig. 2, in which we can see more than 20 earthquakes recorded in an hour.

2. Distribution of foci in each period

We divided the twenty-seven months from August 1965 to October 1967 into five periods as follows:

1st stage of activity...August 1965 to February 1966 (7 months)

2nd stage of activity...March 1966 to July 1966 (5 months)

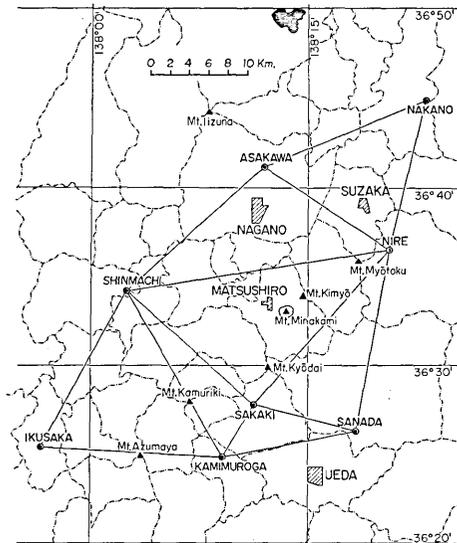


Fig. 1. Distribution of temporary seismographic stations through October 1967.

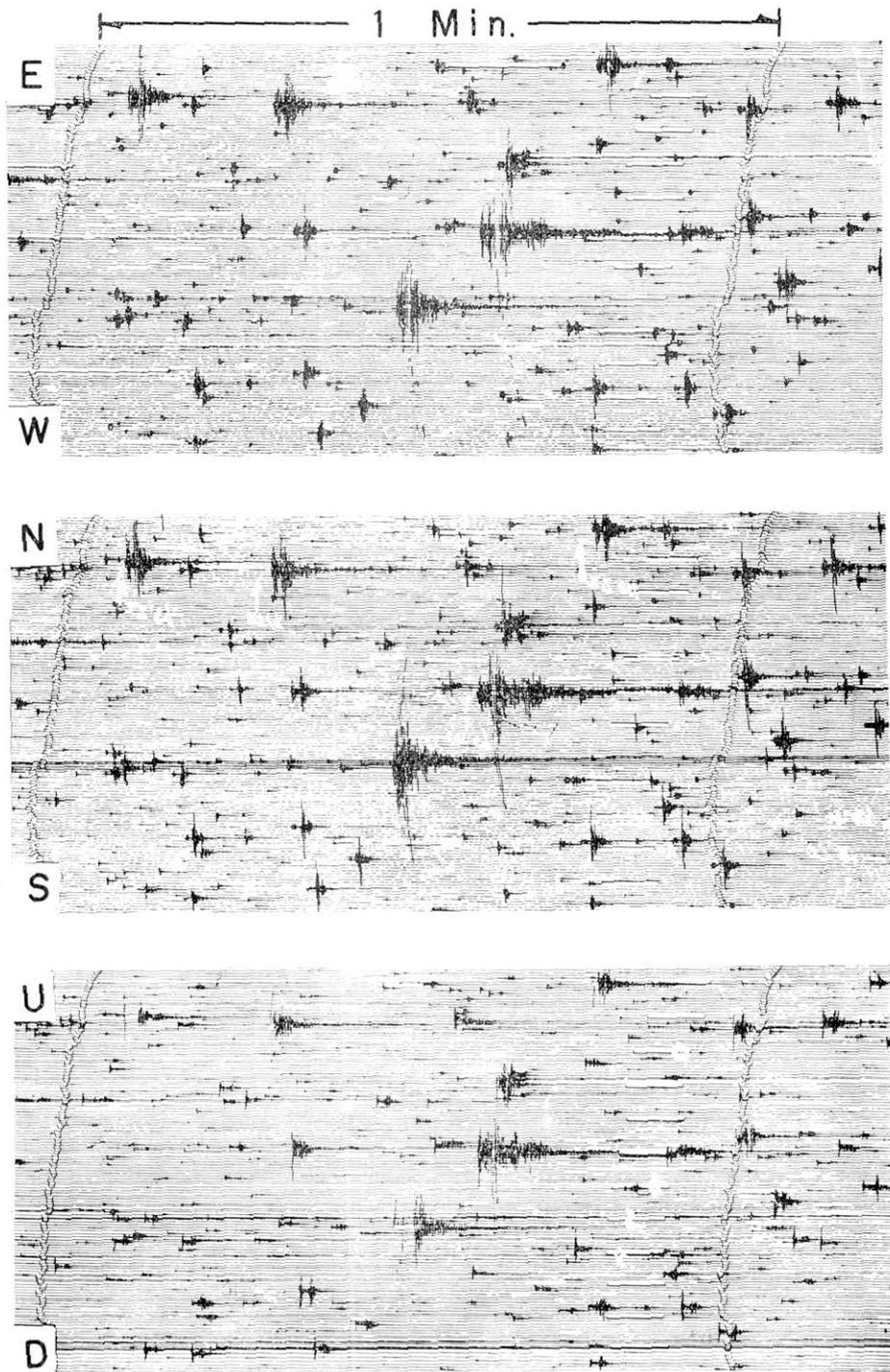


Fig. 2. Examples of the Ishimoto Acceleration Seismograms at the Hoshina station on April 10-11, 1966.

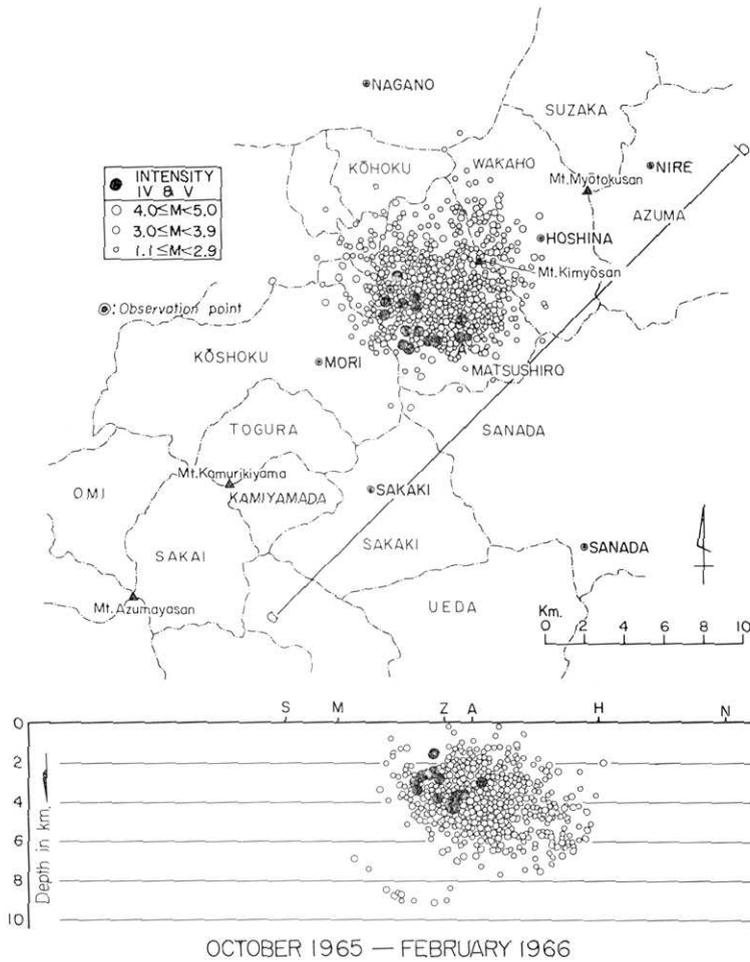


Fig. 3. Above: Epicentral distribution of the felt earthquakes during the period from October 1965 to February 1966.

Below: Vertical distribution of the felt earthquakes during the period from October 1965 to February 1966.

a-b: Plane of projection, A: Akashiika, H: Hoshina, M: Mori, N: Nire, S: Sakaki, Z: Zōzan.

3rd stage of activity...August 1966 to December 1966 (5 months)

4th stage of activity...January 1967 to May 1967 (5 months)

5th stage of activity...June 1967 to October 1967 (5 months)

Such division of time has been defined only for the sake of convenience but the daily number of earthquakes and the seismic active area gave

a different aspect in the respective periods so that it seems to have some geophysical significance.

The distribution of foci of the earthquakes in each period will be outlined in the following.

1) 1st stage of activity (August 1965~February 1966)

Concerning the seismic activity in the early stages, when our seismographic network was not yet established, we have to refer to the report published by the Nagano Local Meteorological Observatory⁵⁾. According to this report, small earthquakes occurred in a small limited area in the southwestern part of Mt. Minakami in August and September but no earthquakes were observed at Wakaho at that time. In October, when our network was set up, small earthquakes were observed also around Mt. Kimyo situated at a distance of 3 km northeastwards from Mt. Minakami. In November, the number of earthquakes increased noticeably and some of them were so strong that the town of Matsushiro was slightly damaged.

The epicenters of the earthquakes that gave a larger intensity determined by our seismographic network during this period are shown in Fig. 3 (Above) and the vertical distribution of hypocenters which were projected to a vertical plane placed NE-SW wards are shown in Fig. 3. (Below). As seen in the figure, the epicenters of earthquakes distribute, say roughly, in a circle 5 km in radius from its center in the northeast of Mt. Minakami. The depths of earthquakes were mostly between 2 and 8 km and, as a general tendency, they were deeper on the northeastern side and shallower on the southwestern side of the seismic area. Larger earthquakes took place at depths of 2~4 km. It is noticed that there was another group of earthquakes which gathered at depths 8~9 km apart from the main cluster.

2) 2nd period of activity (March to June 1966)

In this period, the seismic area extended to the northern part of Matsushiro, the northern part of Sanada and the southern part of Wakaho as shown in Fig. 4. The number of earthquakes also increased tremendously. In April and May, the activity was most violent and earthquakes of intensity of more than IV on the JMA scale occurred 35 times.

5) Report of Matsushiro Earthquakes published by Tokyo District Meteorological Observatory and Nagano Local Meteorological Observatory, January 1966.

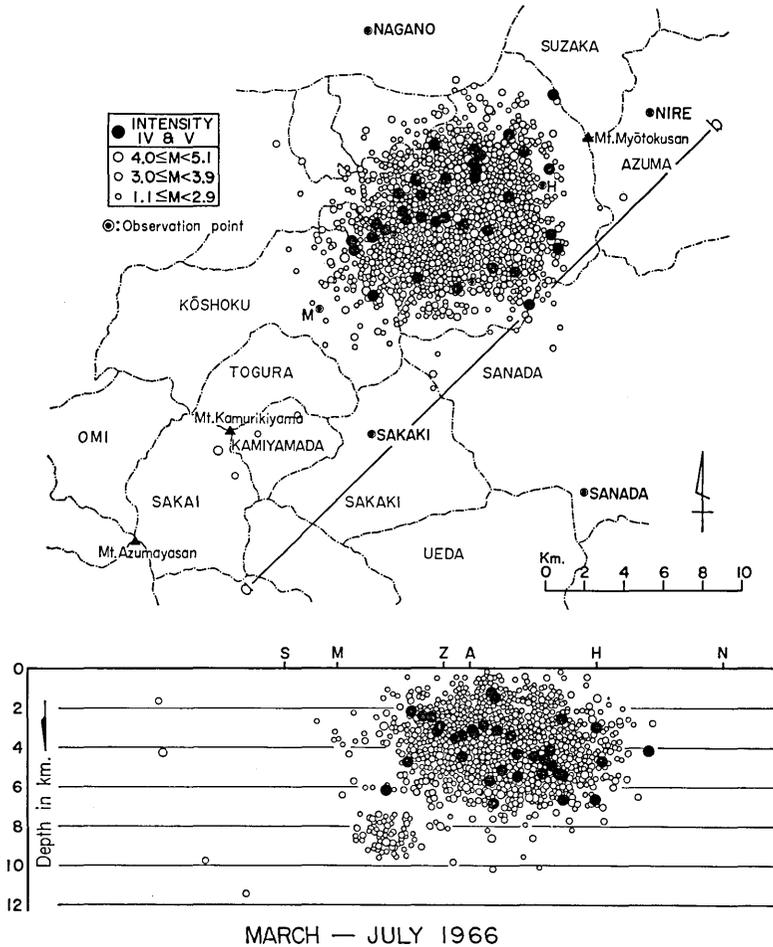


Fig. 4. Above: Epicentral distribution of the felt earthquakes during the period from March to July 1966.
 Below: Vertical distribution of the felt earthquakes during the period from March to July 1966.
 a-b: Plane of projection, A: Akashiba, H: Hoshina, M: Mori, N: Nire, S: Sakaki, Z: Zōzan.

In parallel with such violent seismic activity, the crustal deformations proceeded in this area. The precise leveling repeated by the Earthquake Research Institute showed that the upheaval of the ground with its maximum on the northeastern side of Mt. Minakami increased its speed since April⁶⁾. The water-tube tiltmeters installed in the deep horizontal

6) I. TSUBOKAWA et al., "Levelling Resurvey Associated with the Area of Matsushiro Earthquake Swarms. (1)," *Bull. Earthq. Res. Inst.*, 45 (1967), 265-288.

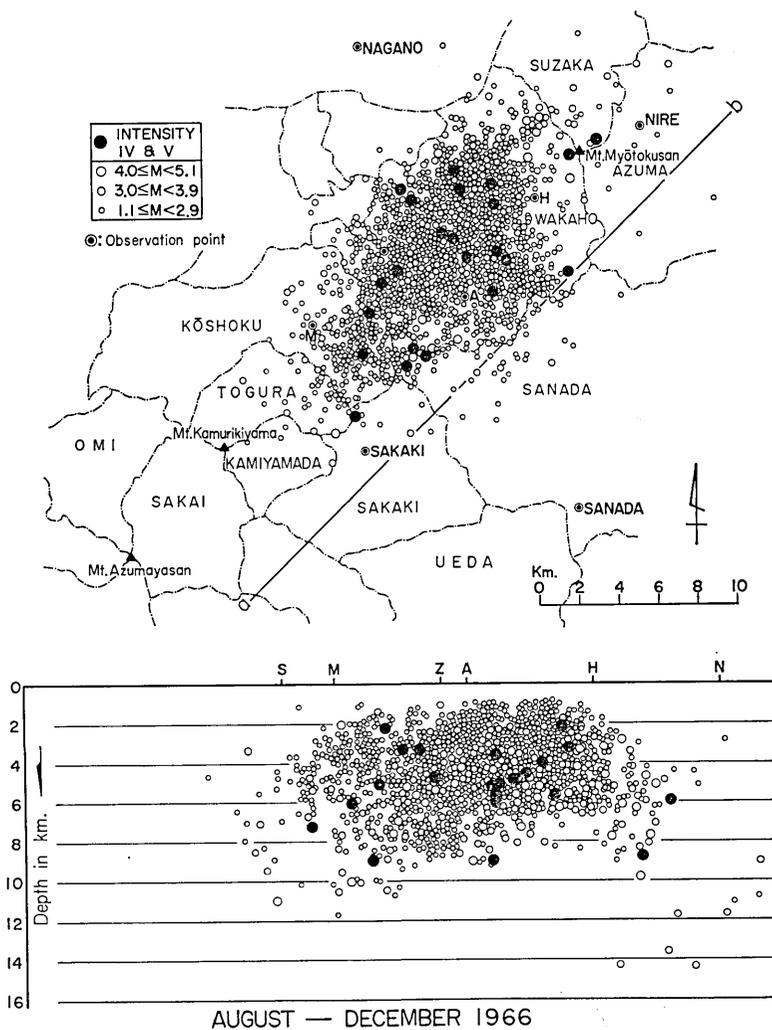


Fig. 5. Above: Epicentral distribution of the felt earthquakes during the period from August to December 1966.
 Below: Vertical distribution of the felt earthquakes during the period from August to December 1966.
 a-b: Plane of projection, A: Akashiba, H: Hoshina, M: Mori, N: Nire, S: Sakaki, Z: Zōzan.

underground gallery at Matsushiro showed also remarkable changes in inclination of the ground since the middle of March⁷⁾. The geodimeter

7) T. HAGIWARA, J. YAMADA and M. HIRAI, "Observation of Tilting of the Earth's Surface Due to Matsushiro Earthquakes. Part 1," *Bull. Earthq. Res. Inst.*, **44** (1966), 351-361.

measurement conducted in this area also showed a large elongation of the ground progressing in the north-south direction in this period⁸⁾.

The earthquakes in the eastern part of Koshoku increased in number since May and became very active in June. From 19h 14th to 06h 15th May, felt earthquakes occurred in the neighbourhood of Mt. Kamuriki at a distance of more than 10 km from the seismic area, the largest one having the magnitude of 4.2. The earthquakes in this place continued for only twenty hours and then stopped but revived again six months after, in January 1967.

3) 3rd stage of activity (August~December 1966)

Fig. 5 shows the distribution of hypocenters of the earthquakes determined by our observation during this stage. In this period, the seismic activity extended to Koshoku, Tokura, Kamiyada, and the northwestern part of Sanada, so that the seismic area became of elliptical form with a major axis 28 km long lying in NE-SW direction and a minor axis 15 km long lying in NW-SE direction.

The large earthquakes with intensity larger than IV on the JMA scale occurred 23 times in this period. Most of them occurred in Matsushiro and Wakaho as they did in the previous period but a few took place in Koshoku and in the neighborhood of Mt. Myotoku (northeast of Wakaho).

A group of earthquakes that occurred in the neighborhood of Mori at depths 8~10 km in the previous stage gradually extended its domain in this period and distributed in depths 2~8 km in September. In November, a certain number of small earthquakes occurred in the southern part of Susaka at depths of more than 9 km.

The special feature of this period was that the earthquakes decreased in number on the northeastern side of Mt. Minakami where many cracks in echelon developed on the ground surface⁹⁾. The feature was noticed in October and became very clear in November. These cracks in the ground suggested an earthquake fault newly created in the bed rocks. We may consider that a fracture zone was also created in the bed rock along this fault and the energy released in the form of seismic waves came to an end. In connection with such phenomenon,

8) K. KASAHARA et al., "Electro-Optical Measurement of Horizontal Strains Accumulating in the Swarm Earthquakes Area. (2)," *Bull. Earthq. Res. Inst.*, **44** (1966), 1715-1733.

9) K. NAKAMURA and Y. TSUNEISHI, "Ground Cracks at Matsushiro Probably of underlying Strike-slip Fault Origin, I-Preliminary Report," *Bull. Earthq. Res. Inst.*, **44** (1966), 1371-1384.

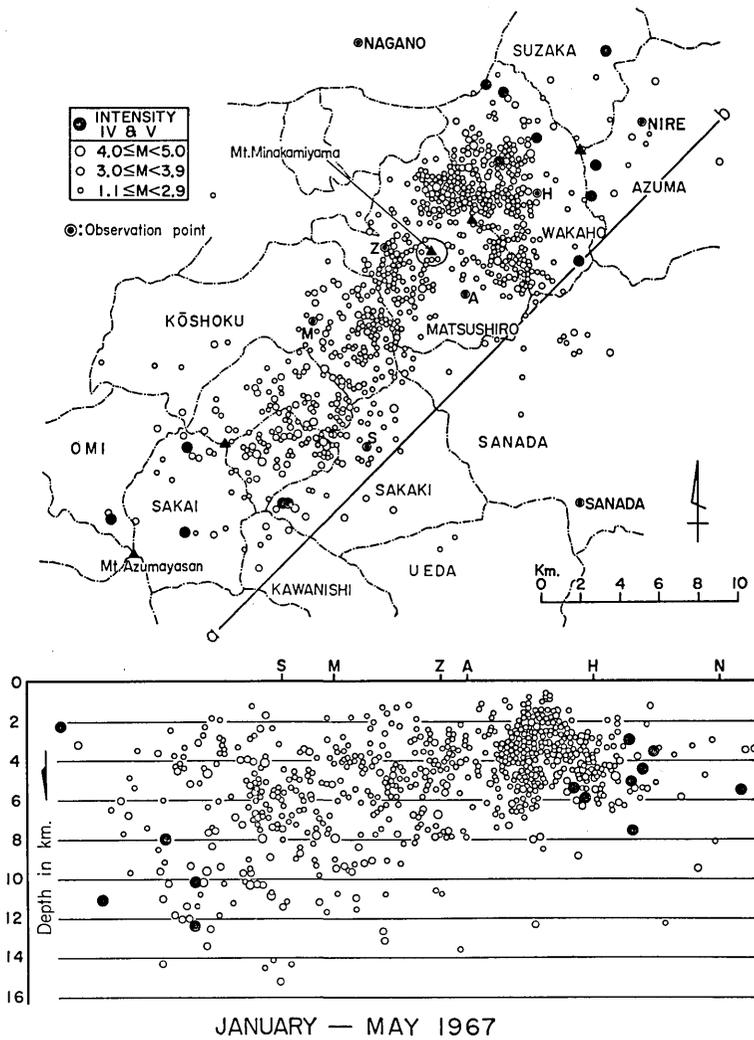


Fig. 6. Above: Epicentral distribution of the felt earthquakes during the period from January to May 1967.

Below: Vertical distribution of the felt earthquakes during the period from January to May 1967.

a-b: Plane of projection, A: Akashiba, H: Hoshina, M: Mori, N: Nire, S: Sakaki, Z: Zōzan.

the precise leveling repeated in Matsushiro showed that the upheaval of the ground in Matsushiro was suspended and then the ground turned to slight subsidence since October 1966. In addition, the geodimeter

measurement conducted in November 1966 also showed that the elongation of the ground in the north-south direction that continued in the previous periods turned to slight contraction¹⁰. We can say that such phenomena observed in this area harmonize well with the noticeable decay of the seismic activity there.

4) 4th stage of activity (January to May 1967)

Fig. 6 shows the distribution of hypocenters of the earthquakes determined by our seismographic observation in this period. The number of earthquakes in this period decreased greatly in the southern part of Matsushiro and in the eastern part of Koshoku but many earthquakes still occurred in Tokura, Kamiyamada, Sakai and near Mt. Myotoku. Large earthquakes took place intermittently in Sakai and near Mt. Myotoku but the frequency of such large ones also decreased.

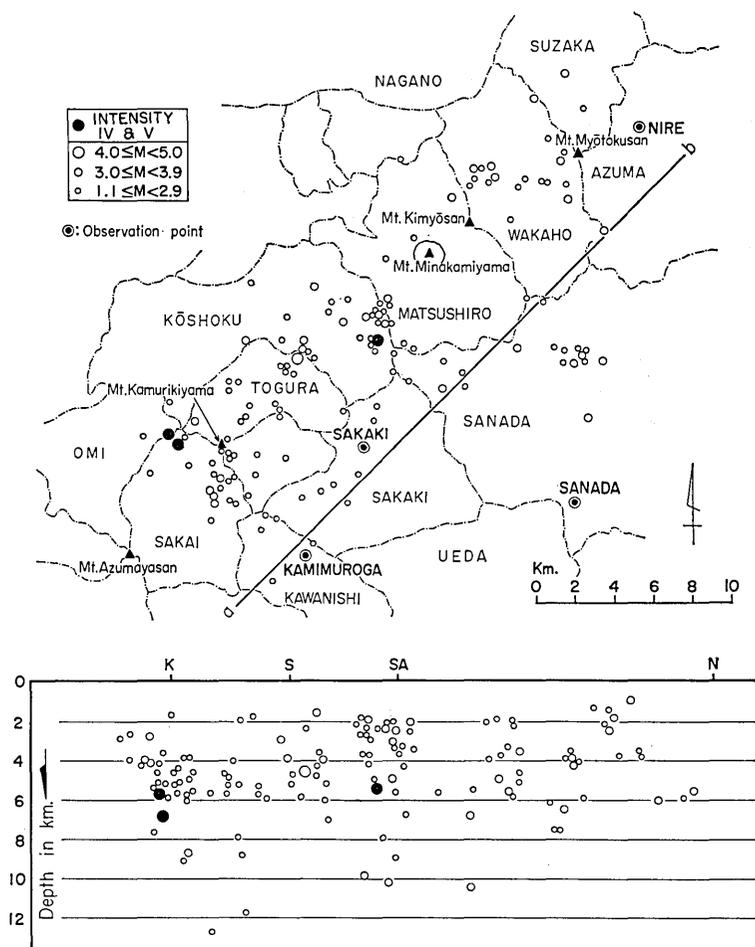
The seismic area in this period extended to a wider area than the previous period and took an elliptical form with major axis 34 km long lying in NE-SW direction and minor axis 18 km long in NW-SE direction.

As regards the depths of the earthquakes, they occurred at depths of 2~6 km in and around Wakaho and at depths of 2~15 km in the eastern part of Koshoku and in Sakai. The number of small earthquakes indicated in the figure is not very large in the neighborhood of Mt. Myotoku in spite of the frequent occurrence of large ones. The station of Nire (Azumamura) situated in the neighborhood of Mt. Myotoku recorded many small earthquakes with P-S interval of 1 sec or less and this showed that small earthquake activity existed in that area but many of them were not recorded clearly in the other stations so that we could not determine the hypocenters of those earthquakes.

5) 5th stage of activity (June to October 1967)

Fig. 7 shows the distribution of hypocenters of earthquakes determined by our seismographic network. In this period, the number of earthquakes decreased greatly throughout the whole area. Sensible earthquakes seldom originated in Matsushiro where the activity was most violent in the earlier stages. The area where the occurrence of earthquakes was comparatively frequent was Koshoku, Tokura, Sakai and their surroundings. We can notice that there was a group of earthquakes occurring in the northern part of Sanada at depths of 2~6 km. Such

10) K. KASAHARA et al., "Electro-Optical Measurement of Horizontal Strains Accumulating in the Swarm Earthquake Area (3)," *Bull. Earthq. Res. Inst.*, 45 (1967), 225-239.



JUNE — OCTOBER 1967

Fig. 7. Above: Epicentral distribution of the felt earthquakes during the period from June to October 1967.
 Below: Vertical distribution of the felt earthquakes during the period from June to October 1967.
 a-b: Plane of projection.

occurrence of small earthquakes in this area has continued from the earlier stages but there have been no large earthquakes yet.

Earthquakes with intensity larger than IV on the JMA scale occurred only once in June, September and October respectively. However, the one which occurred in Sakai ($M=5.0$) at 19h 38m 14th September 1967

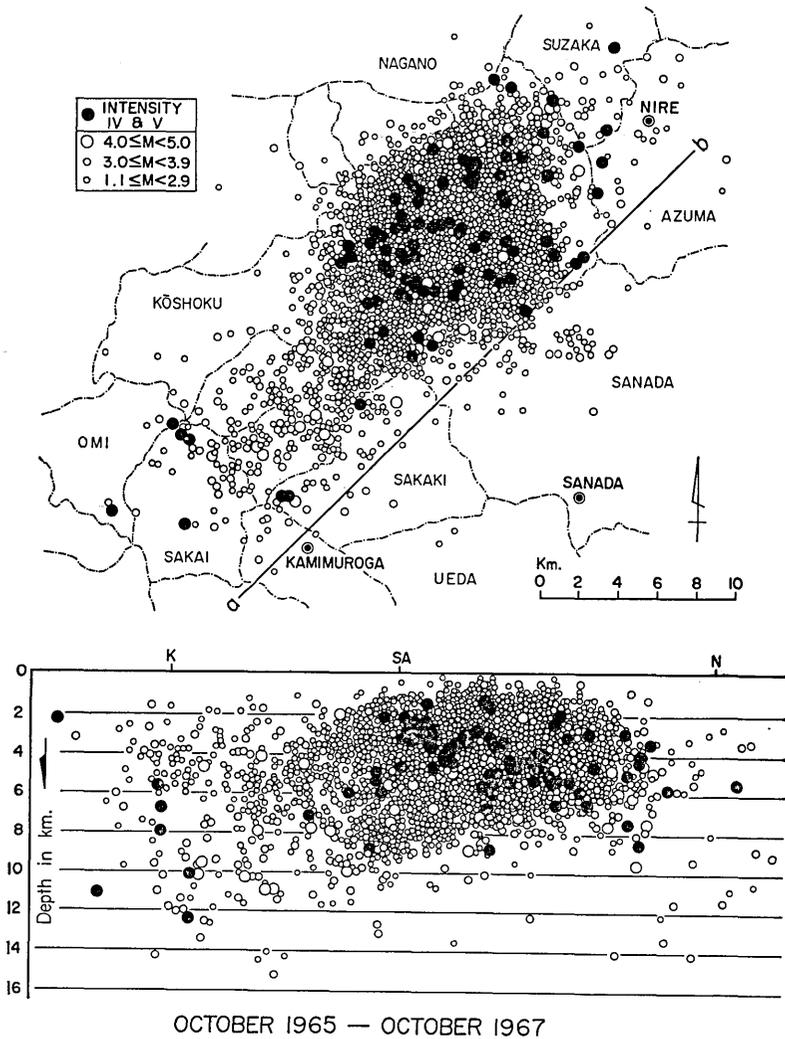


Fig. 8. Above; Epicentral distribution of the felt earthquakes during the period from October 1965 to October 1967.

Below: Vertical distribution of the felt earthquakes during the period from October 1965 to October 1967.

a-b: Plane of projection, K: Kamimuroga, N: Nire, SA: Sanada.

inflicted slight damage on houses in Sakai, Koshoku and Kamiyamada, etc. The earthquake which occurred in Koshoku at 04h 48m 14th October 1967 also inflicted damage on houses in Koshoku and in a part of Matsushiro.

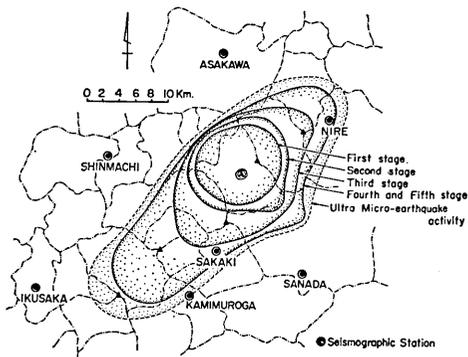


Fig. 9. Seismic active area in each stage.

The determination of the hypocenters described in this paper was made under the assumption of uniform structure of the ground beneath but the actual structure seems to be more complicated so that the determination must have some degree of error. Seismic prospecting by the use of explosion is now under way in this area so that we have the

intention of redetermining the hypocenters after obtaining a complete report of this work.

In order to see the distribution of hypocenters throughout all the periods of activity as a whole, the hypocenters indicated in Figs. 3~7 were put together as shown in Fig. 8.

Fig. 9 shows the spread of seismic area in each stage of activity determined by our seismographic observation. For the sake of comparison, the area where the ultra micro-earthquakes were occurring was also drawn in the figure, following the data obtained by the other parties of our Institute^{11)~15)}.

3. Large earthquakes

The large earthquakes that gave intensity larger than IV on the JMA scale (VI on the modified Mercalli scale) are listed on Table 2. The distribution of hypocenters of these earthquakes is shown in Fig. 10. The number of such large earthquakes throughout the whole period was 48 in Matsushiro, 21 in Wakaho, 4 in Koshoku, 4 in Sakai, 3 in

11) K. HAMADA and T. HAGIWARA, "High Sensitivity Tripartite Observation of Matsushiro Earthquakes. Part 1," *Bull. Earthq. Res. Inst.*, **44** (1966), 1213-1238.

12) K. HAMADA and T. HAGIWARA, "High Sensitivity Tripartite Observation of Matsushiro Earthquakes. Part 2," *Bull. Earthq. Res. Inst.*, **44** (1966), 1239-1268.

13) K. HAMADA and T. HAGIWARA, "High Sensitivity Tripartite Observation of Matsushiro Earthquakes. Part 3," *Bull. Earthq. Res. Inst.*, **44** (1966), 1665-1687.

14) K. HAMADA and T. HAGIWARA, "High Sensitivity Tripartite Observation of Matsushiro Earthquakes. Part 4," *Bull. Earthq. Res. Inst.*, **45** (1967), 159-196.

15) M. OHTAKE, H. CHIBA and T. HAGIWARA, "Ultra Micro-earthquake Activity at the Southwestern Border of the Area of Matsushiro Earthquakes. Part 1," *Bull. Earthq. Res. Inst.*, **45** (1967), 861-886.

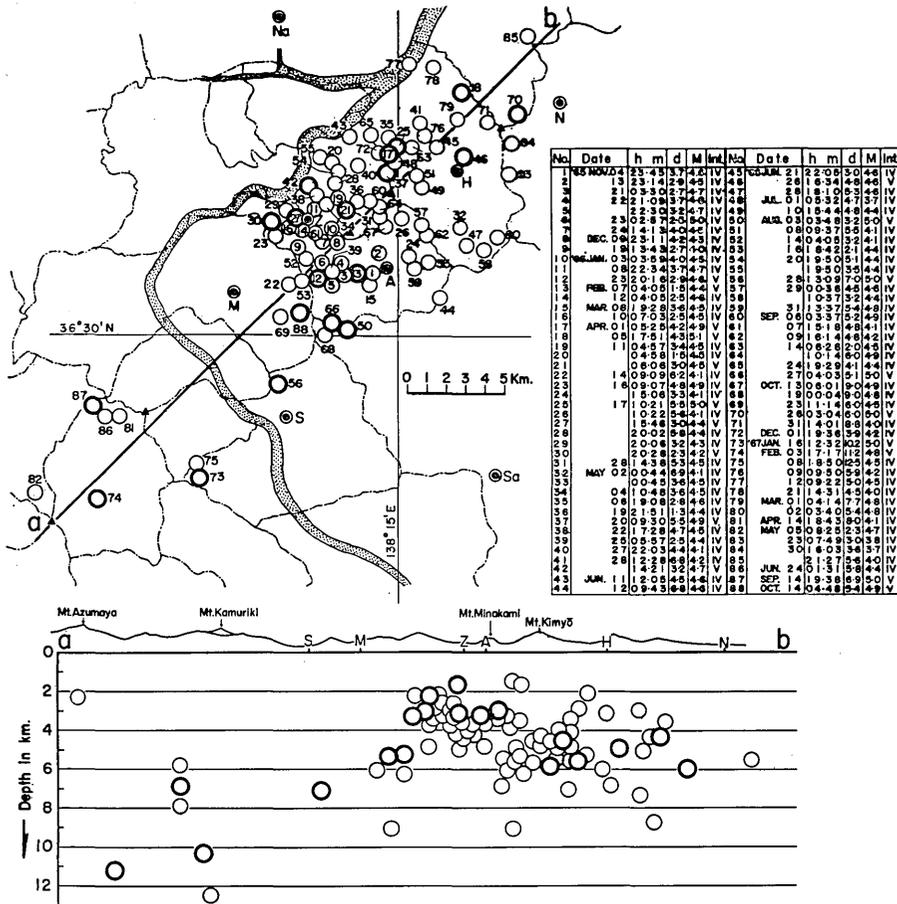


Fig. 10. Above: Epicentral distribution of the Matsushiro earthquakes that gave maximum intensity larger than IV during the period from November 1965 to October 1967.

Below: Vertical distribution of the Matsushiro earthquakes that gave maximum intensity larger than IV during the period from November 1965 to October 1967.

(Projected to the vertical plane a-b)

Sanada, 3 in Sakaki, 2 in Azumamura, 2 in Susaka and 1 in Omi. The depths of these earthquakes were 2~5 km in the Matsushiro area, 3~8 km in the Wakaho area and 6~12 km in the southwestern region.

We traced the epicenters of these earthquakes on a map in order of occurrence as shown in Fig. 11. As seen in the figure, the large earthquakes in the first stage of activity occurred in a small limited

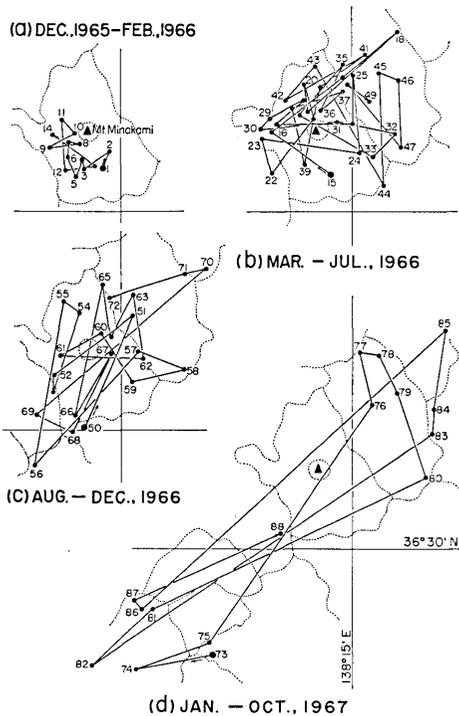


Fig. 11. Trace of epicenters of large earthquakes in the order of occurrence.

area on the southern side of Mt. Minakami ((a) No. 1~11). They took place first on the southeastern side of that mountain, moved clockwise along the foot of the mountain towards the western side of the mountain and returned to the original place. In the second stage of activity, large earthquakes occurred in the western and northern parts of Mt. Minakami and then moved towards Wakaho ((b) 16~23). In the third stage of activity, large earthquakes occurred in the northeastern and southwestern parts of Matsushiro including the southwestern part of Wakaho. In the fourth stage of activity, no more large earthquakes occurred in Matsushiro but they took place intermittently near the northeastern and southwestern boundary of the seismic area.

The large earthquakes took place always in the area where small earthquakes clustered with only one exception in the area of Kamiyamada and Tokura, where no large earthquakes have occurred since the outbreak of the Matsushiro earthquakes in spite of the very frequent occurrence of small earthquakes in that area.

4. The monthly number of earthquakes and the energy released by the earthquakes

The monthly number of earthquakes of which the hypocenters were able to be determined by our seismographic observation is listed in Table 3. The determination of hypocenters was made according to the following criteria: 1) The earthquake was recorded at least three stations. 2) The P and S phases were clear. 3) When too many earthquakes were recorded on a seismogram in the one day beyond the

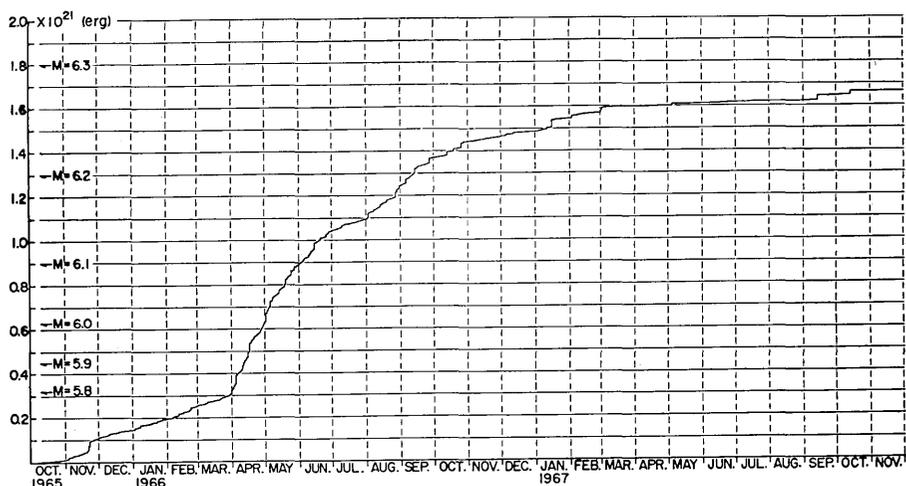


Fig. 12. Cumulative sum of energy released by Matsushiro earthquakes.

capability of the seismogram interpreters (normally two persons engaged in the interpretation of the acceleration seismograms), 50 of the larger earthquakes were selected to be read off. Referring to the frequency curves of the magnitude of the Matsushiro earthquakes determined by our observation, it is to be expected that we were able to determine the hypocenters of almost all the earthquakes with magnitude larger than 2.5 under such criteria. In the period from April to June 1966 when the seismic activity was most violent, the number of determined hypocenters was not very large in spite of the large number of earthquakes which actually occurred in this period. This was due to the fact that so many earthquakes were recorded on seismograms that they were superimposed on each other on the seismogram and we found it difficult to read off the P and S phases.

The monthly number of earthquakes of which the maximum amplitude was larger than 3 mm on the acceleration seismograms is listed on Table 4. The monthly number of earthquakes recorded by the HES electromagnetic seismographs is also listed in on Table 5.

The cumulative sum of energy released by the earthquakes is shown in Fig. 12 and the monthly value of the released energy is listed in Table 6. The energy released in each stage of activity was as follows:

1st stage (August 1965~February 1966)	252.5×10^{18} erg (M=5.7)
2nd stage (March~July 1966)	841.4×10^{18} erg (M=6.1)
3rd stage (August~December 1966)	392.1×10^{18} erg (M=5.8)

Table 1. Constants of Seismographs.

No.	Station	Comp.	Seismographs			Observation term
			HES 1-0.2	Acceleration Seismograph		
			V max	V	S(gal/ mm)	
1	Zozan	E	50,000	220	2.0	(HES) Oct. 6, 1965—Mar. 7, 1967 (Acc.) Oct. 7, 1965—Mar. 7, 1967
		N	10,000	220	2.0	
		Z	10,000	220	2.0	
2	Akashiba	E	10,000	220	2.0	(HES) Oct. 7, 1965—Mar. 7, 1967 (Acc.) Oct. 8, 1965—Mar. 6, 1967
		N	10,000	220	2.0	
		Z	10,000	220	2.0	
3	Hoshina	E	50,000	220	2.0	(HES) Oct. 8, 1965—Mar. 31, 1967 (Acc.) Oct. 8, 1965—Mar. 7, 1967
		N	10,000	220	2.0	
		Z	10,000	220	2.0	
4	Mori	E	10,000	220	2.0	(HES) Oct. 21, 1965—Nov. 10, 1965 (Acc.) Feb. 13, 1966—Mar. 7, 1967
		N	10,000	220	2.0	
		Z	10,000	220	2.0	
5	Toyono	E	10,000	220	2.0	(HES) Feb. 10, 1966—Feb. 20, 1967
		N	10,000	220	2.0	
		Z	10,000	220	2.0	
6	Toyoda	E	10,000	220	2.0	(HES) Mar. 17, 1966—Jun. 17, 1966 (Acc.) Mar. 16, 1966—May 5, 1966
		N	10,000	220	2.0	
		Z	10,000	220	2.0	
7	Nagano	E	10,000	220	2.0	(HES) Apr. 22, 1966—Apr. 24, 1967 (Acc.) Apr. 22, 1966—Apr. 25, 1967
		N	10,000	220	2.0	
		Z	10,000	220	2.0	
8	Naganuma	E		220	2.0	(Acc.) May 11, 1966—Feb. 17, 1967
		N		220	2.0	
		Z		220	2.0	
9	Nakano	E	50,000	220	2.0	(HES) Apr. 3, 1967—Continued (Acc.) Dec. 3, 1966—Mar. 23, 1967
		N	10,000	220	2.0	
		Z	10,000	220	2.0	
10	Nire	E	10,000	220	2.0	(HES) Apr. 13, 1966—Continued (Acc.) Apr. 13, 1966—"
		N	10,000	220	2.0	
		Z	10,000	220	2.0	
11	Sakaki	E		220	2.0	(Acc.) Jun. 18, 1966—Dec. 14, 1967
		N		220	2.0	
12	Sanada	E	10,000	220	2.0	(HES) Sep. 6, 1966—Continued (Acc.) Aug. 20, 1966—"
		N	10,000	220	2.0	
		Z	10,000	220	2.0	
13	Ikusaka	E	10,000	220	2.0	(HES) Feb. 25, 1967—" (Acc.) Mar. 24, 1967—"
		N	10,000	220	2.0	
		Z	10,000	220	2.0	
14	Asakawa	E	10,000	220	2.0	(HES) Apr. 24, 1967—" (Acc.) Apr. 28, 1967—"
		N	10,000	220	2.0	
		Z	10,000	220	2.0	
15	Kamimuroga	E	10,000	220	2.0	(HES) Sep. 8, 1967—" (Acc.) Aug. 1, 1967—"
		N	10,000	220	2.0	
		Z		220	2.0	
16	Shinmachi	E	10,000	220	2.0	(HES) Aug. 18, 1967—"
		N	10,000	220	2.0	

Table 2. List of the Matsushiro earthquakes that gave intensity larger than IV on JMA scale during the period from November 1965 to October 1967.

No.	Date	P.T. (h.m)	Station	S-P (sec)	M	Depth (km)	Intensity					Damage
							V	IV	III	II	I	
1	1965 Nov. 04	23:45	Ak Ho Zo	0.50 0.99 0.75	4.6	3.7		MAT	NAN	UED	MTM TAK	
2	13	23:14	Ak Ho Zo	0.40 0.85 0.65	4.5	2.9		MAT	NAN UED	MTM	KOF TAK	
3	21	03:30	Ak Ho Zo	0.45 1.05 0.56	4.7	2.7		MAT				
4	22	21:09	Ak Ho Zo	0.60 1.10 0.60	4.8	3.7		MAT	NAN		MTM	Nagano Matsushiro
5		22:30	Ak Ho Zo	0.60 1.20 0.60	4.7	3.2		MAT NAN	MTM UED	UTO TAK	NAO	Matsushiro
6	23	02:57	Ak Ho Zo	0.55 1.10 0.45	5.0	2.5		MAT NAN	UED	KOF KAR	MTM	Matsushiro
7	24	14:13	Ak Ho Zo	0.70 1.05 0.50	4.5	4.0		MAT	NAN	UED		Matsushiro Koshoku
8	Dec. 09	23:11	Ak Ho Zo	0.70 1.04 0.60	4.3	4.2		MAT		NAN		
9	19	13:43	Ak Ho Zo	0.70 1.14 0.40	4.0	2.7		KOS MAT	NAN	UED MTM		Nagano Matsushiro
10	1966 Jan. 03	03:59	Ak Ho Zo	0.70 1.00 0.55	4.5	4.0		MAT KOH	NAN UED	MTM KAR	UTS MIT	Matsushiro
11	08	22:34	Ak Ho Zo	0.81 0.99 0.50	4.7	3.7		SHI KOH	NAN SUZ	KOM TAK		
12	23	20:16	Ak Ho Zo	0.60 1.19 0.54	4.6	2.9	MAT KOH	NAN	MTM UED	KAR TAK	MEB TOK	Matsushiro Kohoku
13	Feb. 07	04:05	Ak Ho Zo	0.30 0.99 0.50	4.4	1.5	MAT	KOH SHI	NAN SUZ	MTM KAR	KOF KUM	Matsushiro
14	12	04:05	Ak Ho Zo	0.70 1.09 0.35	4.6	2.5		MAT KOH	NAN KOS	UED		
15	Mar. 08	19:28	Ak Ho Zo	0.50 1.04 0.75	4.5	3.6		MAT KOH	NAN SUZ	UED MTM		

(to be continued)

Summary of the Seismographic Observation of Matsushiro Swarm Earthquakes 503

(continued)

No.	Date	P.T. (h.m)	Station	S-P (sec)	M	Depth (km)	Intensity					Damage
							V	IV	III	II	I	
16	1966 Apr. 10	07:03	Ak Ho Zo	0.80 1.14 0.30	4.5	2.5		MAT KOS	NAN	UED	TAK	Matsushiro
17	01	05:25	Ak Ho Zo	1.00 0.64 0.94	4.9	4.2	WAK	MAT NAN		UED KAR	MEB	Wakaho Matsushiro
18	05	17:51	Ak Ho Zo	1.50 0.79 1.54	5.1	4.3	NAN YUD	MAT	UED MTM	TAK KAR	MIT UTS	Nagano Matsushiro
19	11	04:57	Ak Ho Zo	0.74 0.89 0.50	4.5	3.4		MAT	NAN SUZ	KAR MEB	TAK	Matsushiro Nagano
20		04:58	Ak Ho Zo	0.84 0.74 0.45	4.5	1.5		MAT	NAN SUZ	UED		
21		06:06	Ak Ho Zo	0.64 0.79 0.50	4.5	3.0	MAT	KOH KOS	NAN	UED	TAK MEB	
22	14	09:09	Ak Ho Zo	1.09 1.58 0.95	4.1	6.2		MAT	NAN UED		TAK KAR	
23	16	09:07	Ak Ho Zo	1.05 1.39 0.70	4.9	4.8		MAT KAW	NAN UED	WAK	MTM	Matsushiro
24		15:06	Ak Ho Zo	0.48 0.84 0.85	4.1	3.3		MAT	NAN	UED	MTM KAR	
25	17	10:21	Ak Ho Zo	1.15 0.79 1.10	5.0	5.5	MAT	NAN WAK	UED	MTM		Matsushiro Wakaho
26		10:22	Ak Ho Zo	0.84 0.89 1.00	4.7	5.6		MAT	NAN			
27		15:46	Ak Ho Zo	0.80 1.09 0.40	4.4	3.0	MAT	SHI KOH	NAN SUZ		KAR	
28		20:02	Ak Ho Zo	1.05 1.04 1.29	4.4	5.8		MAT	NAN			
29		20:06	Ak Ho Zo	0.89 0.79 0.45	4.3	3.2		MAT		NAN		
30		20:28	Ak Ho Zo	0.90 1.25 0.40	4.2	2.3	MAT	KOS	NAN			
31	28	14:38	Ak Ho Zo	0.80 0.95 0.85	4.5	5.3		WAK MAT	SUZ	UED	MTM TAK	

(to be continued)

(continued)

No.	Date	P.T. (h.m)	Station	S-P (sec)	M	Depth (km)	Intensity					Damage
							V	IV	III	II	I	
32	1966 May 02	00:44	Ni Na Ho	1.40 2.10 0.99	4.7	6.9		MAT NAN		UED	TAK	
33		00:45	Zo Ni Na	1.00 1.50 2.00	4.5	3.6		MAT NAN		UED	TAK	
34		04 10:48	Ak Ho Zo	0.80 1.10 0.50	4.5	3.6		NAN WAK	SUZ	UED	TAK	
35		06 19:08	Ak Ho Zo	1.00 0.65 0.90	4.6	2.8		NAN MAT		TAK UED	KAR	Wakaho
36		19 21:51	Ak Ho Zo	0.50 0.75 0.40	4.4	1.3		MAT	NAN WAK	UED	FUN MTM	
37		20 09:30	Ak Ho Zo	1.04 0.90 1.00	4.9	5.5	WAK	MAT KAW	UED	MAT KAR	TAK KOF	Nagano Matsushiro
38		22 17:28	Ak Ho Zo	0.50 0.75 0.40	4.5	4.7		MAT	KAW NAN		UED	
39		25 05:57	Ak Ho Zo	0.50 1.15 0.50	4.4	2.5		MAT	NAN WAK	UED	SUW MTM	Wakaho
40		27 22:03	Ak Ho Zo	0.95 0.90 0.80	4.1	4.4		NAN	MAT	UED	MTM TAK	
41		28 12:28	Ak Ho Zo	1.39 1.00 1.40	4.2	6.8		SUZ WAK	NAN	UED MAT	KAR	
42		14:21	Ak Ho Zo	0.90 1.10 0.50	4.7	3.2	MAT SHI	NAN	UED SUZ	TAK CHI	NI I MIT	Matsushiro Nagano
43	Jun. 11	12:05	Ak Ho Zo	1.15 1.00 0.90	4.6	4.5		WAK NAN	MAT	UED	SUW MTM	
44		12 09:43	Ak Ho Zo	1.00 1.25 1.39	4.6	6.8		NAN MAT	UED	KAR MIT	TAK UTS	Matsushiro Nagano
45		21 22:05	Ak Ho Zo	1.10 0.50 1.20	4.6	3.0		NAN	MAT		UED	
46		26 16:34	Ak Ho Zo	1.19 0.69 1.39	4.6	4.8	WAK	NAN SUZ	MAT	MTM	TAK IID	Wakaho
47		28 18:10	Ak Ho Zo	0.99 0.90 1.40	4.6	5.3		SUZ WAK	NAN	MAT		

(to be continued)

Summary of the Seismographic Observation of Matsushiro Swarm Earthquakes 505

(continued)

No.	Date	P.T. (h.m)	Station	S-P (sec)	M	Depth (km)	Intensity					Damage
							V	IV	III	II	I	
48	1966 Jul. 01	05:32	Ak Ho Zo	1.05 0.85 1.00	3.7	4.7		WAK	NAN SUZ	UED	TAK MEB	
49	10	15:44	Ak Ho Zo	0.95 0.75 1.10	4.4	4.8		NAN MAT		UED	KAR MTM	
50	Aug. 03	03:48	Ak Ho Mo	0.65 1.44 1.00	5.0	3.2	MAT	NAN	MTM UED	TAK KOF	NI I CHO	Matsushiro Sanada
51	08	09:37	Ak Zo Mo	1.05 1.15 1.73	4.7	5.5		NAN SUZ	MAT UED	KAR MTM	TAK KUM	Wakaho
52	14	04:05	Ak Ho Zo	0.75 1.35 0.50	4.1	3.2		MAT	NAN			
53	16	18:42	Ak Ho Zo	0.75 1.49 0.50	4.4	2.1		MAT		NAN UED		Matsushiro
54	20	19:50	Ak Ho Mo	1.09 1.15 1.36	4.4	5.1		MAT				Nagano Matsushiro
55		19:50	Ak Ho Mo	1.05 1.10 1.26	4.4	3.5		MAT	UED SUZ	MTM		
56	28	13:09	Ak Sk Sa	1.60 1.00 1.95	5.0	7.0	KOS	NAN MAT	SUZ KAR	TAK NI I	MIT NGO	Koshoku Nagano
57	29	00:36	Ni Ak Ho	1.51 0.75 0.80	4.6	4.5		MAT NAN	UED	MTM TAK		
58		10:37	Ak Ho Zo	0.91 0.74 1.42	4.4	3.2		WAK	NAN	MAT		
59	Aug. 31	13:37	Sk Ak Mo	1.65 0.80 1.52	4.8	5.4		MAT		NAN UED		
60	Sep. 06	03:37	Sk Ak Mo	2.02 1.01 1.51	4.9	5.2		NAN KOS	SUZ WAK	MTM	TAK MEB	Matsushiro
61	07	15:18	Sk Ak Mo	1.70 1.00 1.15	4.1	4.8		MAT		NAN		
62	09	16:14	Ak Ho Mo	0.90 1.00 1.85	4.2	4.8		WAK	NAN MAT	UED	SUW MTM	
63	14	06:26	Ak Ho Zo	1.00 0.50 1.10	4.5	2.0		WAK	NAN SUZ			

(to be continued)

(continued)

No.	Date	P.T. (h.m)	Station	S-P (sec)	M	Depth (km)	Intensity					Damage
							V	IV	III	II	I	
64	1966 Sep. 14	10:14	Sa	2.61	4.9	6.0		NAN	UED	MTM	UTS	Wakaho Nagano
			Mo	1.68				SUZ			MIT	
65	24	19:29	Ak	1.25	4.4	4.1		WAK	MAT	NAN		Wakaho
			Ho	1.00								
			Zo	1.10								
66	27	04:03	Ak	1.05	5.0	5.1	KOS	SHI	NAN	UED	MEB	Matsushiro Koshoku
			Ho	1.88								
			Sk	1.20								
67	Oct. 13	06:01	Sk	2.29	4.9	9.0		NAN	SUZ	MEB	IID	Wakaho
			Ak	1.50								
			Mo	2.02								
68	19	00:04	Sk	1.65	4.8	9.0		KOS	MAT	KAR	MTM	
			Ak	1.66								
			Mo	1.69								
69	23	11:14	Sk	1.25	4.5	6.0		KOS	NAN	KAR		
			Ak	1.41								
			Mo	1.09								
70	26	03:04	Ak	1.97	5.0	6.0	AZU	NAN	MAT	MEB	SUW	Azumamura Takayama- mura
			Ho	1.19								
			Mo	2.23								
71	31	14:01	Ng	2.16	4.0	8.8		AZU			MAT	
			Ho	1.49								
			Zo	2.24								
72	Dec. 01	19:36	Ak	1.10	4.2	3.9		WAK	NAN	MAT		
			Ho	0.90								
			Zo	1.05								
73	1967 Jan. 16	12:32	Sk	1.49	5.0	10.2	SAI	UED	MTM	MAT	KOF	Tokura Omimura
			Ho	2.98								
			Sa	2.35								
74	Feb. 03	17:17	Ak	2.70	4.8	11.2	SAI		NAN	UED	TOK	Sakai Omimura
			Ho	3.40								
			Zo	2.59								
75	08	18:50	Sk	1.80	4.5	12.5		SAI				
			Ak	2.50								
			Mo	2.08								
76	09	09:50	Ak	1.50	4.2	5.9		AZU	NAN	MAT	MTM	
			Ho	1.05								
			Zo	1.55								
77	12	09:22	Ak	1.94	4.5	5.0		SUZ	NAN	MAT	MTM	Suzaka
			Ho	1.29								
			Zo	1.80								
78	21	14:31	Ak	1.86	4.0	4.5		SUZ		NAN	MAT	Suzaka
			Ho	1.15								
			Zo	1.80								
79	Mar. 01	04:14	Ak	1.60	4.8	7.7		AZU	WAK	NAN	UED	
			Ho	1.29								
			Zo	1.74								

(to be continued)

Summary of the Seismographic Observation of Matsushiro Swarm Earthquakes 507

(continued)

No.	Date	P.T. (h.m)	Station	S-P (sec)	M	Depth (km)	Intensity					Damage
							V	IV	III	II	I	
80	1967 Mar. 02	03:40	Ak	1.30	4.8	5.4		U E D	N A N	K A R		Sanada
			Sa	1.73			A Z U	M A T	M T M			
			Sk	2.02								
81	Apr. 14	18:43	Sk	1.75	4.1	8.0		S A I	O M I	M A T	M T M	
			Sa	2.70				U E D				
			Ni	3.70								
82	May 05	08:25	Sk	2.00	4.7	2.3		S A I	M A T	M T M	I I D	Shinonoi
			Sa	3.00				K A R	C H I	K U M		
			As	4.01								
83	23	07:49	Sk	2.30	3.8	3.0		A Z U	N A N	M A T	U E D	Azumamura Suzaka
			Sa	2.08				S U Z		M E B		
			Ni	0.90								
84	30	16:03	Sk	2.49	3.7	3.6		W A K	N A N	M A T		Suzaka
			Sa	2.30				A Z U	S U Z	U E D		
			Ni	0.80								
85	21:27		Sk	2.99	4.0	5.6		A Z U	S U Z	N A N	M T M	
			Sa	2.91				M A T	U E D			
			Ni	1.51								
86	Jun. 24	01:31	Sk	1.61	4.4	5.8		S A I	N A N	M T M	I I D	Sakaimura Omimura
			Sa	2.65				M A T				
			Ni	3.67								
87	Sep. 14	19:38	Sk	1.75	5.0	6.9	S A I	N A N	M T M	S U W	I I D	Sakaimura
			Sa	2.76				M A T	S U Z	K A R	U T S	
			Ni	3.70								
88	Oct. 14	04:48	Sk	1.29	4.9	5.4	M A T	U E D	M T M	N I I		Koshoku Sakaki
			Sa	2.00			K O S	T A K	N A O			
			Ni	2.39								
1965	Nov. 05	10:07	Ak	0.55	4.7*			M A T		N A N	U E D	
			Ho	—								
1967	Aug. 21	16:50	Sk	4.51		2.0*		K A S			N A N	
			As	—					I I Y			
			Ni	1.90								

1) Abbreviation of the names of station:

Ak: Akashiba Mo: Mori Ng: Naganuma Sa: Sanada
 As: Asakawa Ni: Nire Sk: Sakaki Zo: Zozan
 Ho: Hoshina Na: Nagano

2) Abbreviation of the names of places:

A Z U: Azumamura K O F: Kofu N A N: Nagano S U Z: Suzaka
 C H I: Chichibu K O H: Kohoku N A O: Nagaoka T A K: Takada
 C H O: Choshi K O M: Komoro N G O: Nagoya T O K: Tokyo
 F U N: Funatsu K O S: Koshoku N I I: Niigata U E D: Ueda
 I I D: Iida K U M: Kumagaya S A I: Sakaimura U T S: Utsunomiya
 I I Y: Iiyama M A T: Matsushiro S A K: Sakakimachi W A K: Wakaho
 K A R: Karuizawa M E B: Maebashi S H I: Shinonoi Y U D: Yudanaka
 K A S; Mt. Kasagatake M I T: Mito S U W: Suwa
 K A W: Kawanakajima M T M: Matsumoto

*: Reported by JMA

Table 3. The number of earthquakes of which the hypocenters were determined.

	$M \leq 3.9$	$M > 4.0$	$M > 5.0$	Total
1965 October	132	1		133
November	225	18	1	244
December	256	16		272
1966 January	242	9		251
February	149	9		158
March	206	16		222
April	545	67	2	614
May	734	69		803
June	848	47		895
July	758	18		776
August	770	33	2	805
September	680	26	1	707
October	393	12	1	406
November	411	9		420
December	351	9		360
1967 January	323	10	1	334
February	275	6		281
March	145	7		152
April	43	1		44
May	51	2		53
June	29	1		30
July	12			12
August	13			13
September	43		1	44
October	30	2		32
Total	7,664	388	9	8,061

Table 6. Monthly and cumulative sum of energy released by the Matsushiro earthquakes.

	Monthly	Cumulative
1965 October	8.62×10^{18} ergs.	8.62×10^{18} ergs.
November	96.59	105.21
December	40.15	145.36
1966 January	49.35	194.89
February	57.60	252.50
March	53.13	305.62
April	320.03	625.65
May	262.46	888.11
June	151.61	1039.72
July	54.14	1093.87
August	149.69	1243.56
September	125.56	1369.12
October	72.59	1441.71
November	20.84	1462.55
December	23.44	1485.99
1967 January	58.89	1544.88
February	24.43	1569.31
March	27.51	1596.82
April	2.79	1599.61
May	10.84	1610.45
June	4.53	1614.98
July	3.38	1618.36
August	1.24	1619.60
September	25.07	1644.66
October	17.07	1661.73

4th stage (January~May 1967)	124.5×10^{18} erg (M=5.5)
5th stage (June~October 1967)	51.3×10^{18} erg (M=5.3)

The number in parentheses on the above table indicates the magnitude of a single earthquake releasing correspondent energy. The total energy released by the earthquakes through November 1967 is 1.66×10^{21} ergs which corresponds to the energy released by a single earthquake with a magnitude of nearly 6.3.

Through December 1967, the earthquakes were felt by people only two or three times a day in Wakaho, Matsushiro and in the northeastern and southwestern boundaries of the seismic area. However earthquakes with larger magnitude, some of them destructive, still occur intermittently in Azumamura, Koshoku and in the southwestern parts of the seismic area.

The authors express deep thanks to Miss Kazuko Makino, Miss Mieko Matsubara and Miss Ryoko Kawashima for their assistance in compiling the data for completing this paper.

23. 松代群発地震の経過概要

地震研究所 { 萩原 尊礼
岩田 孝行

はしがき

1965年8月にはじまった松代地震は、2年余を経た今日なお終熄したとは言えないが、その発生回数は著しく減少している。地震研究所では、この群発地震発生地域に観測班を派遣し臨時観測網を設けて観測を続けてきた。1965年10月~1967年2月の期間の観測結果については、既に観測班により第1報~第4報が出されている。

本文は、前記の観測班の報告を基とし、これに1967年3月~10月の期間の観測資料を加え、1965年8月~1967年10月の27カ月にわたる間のこの群発地震の推移について総括的な記述を試みたものである。

1. 臨時地震観測網の推移と現状

松代町地域における地震研究所の臨時地震観測網は、1965年10月6日以降皆神山周辺の諸地点、すなわち松代町象山、同町赤柴、若穂町保科において始まり、やゝおくれで更埴市森が増設され、いずれも石本式加速度計およびHES: 1-0.2型電磁式地震計が据えられた。その後、1966年4月の第2活動期に入って地震域が著しく拡大したので、前記の諸地点の外に、東村仁礼、長野市平築、同市長沼、中野市、坂城町および真田町の諸地点でも地震観測を行った。この観測網による地震観測は約1カ年継続されたが、地震活動の減少に伴い、1967年3月を境に変更され、一部観測中止または別の地点に移動した所もある。第1図は1967年10月現在における臨時地震観測網であり、第1表は現在までに各観測点において使用された地震計とその主な定数および観測経過期間を示してある。なお第2図は若穂町保科にある石本式加速度計の記象で、第2活動期にあたる1966年4月10日~11日

の一部分である。この記象は約3時間分の観測時間であるが、有感地震が約70回記録されている。この頃は奇妙山附近の地震活動が活発なときであった。

2. 各活動期ごとの震源分布

1965年10月～1967年10月に至る25カ月間を5カ月ごとに区切り、主な有感地震の震源をまとめて、その分布を第3図～第7図に示す。便宜上、これらの期間を第1期～第5の活動期と呼ぶことにしたが、地震回数の日別頻度の変化や活動区域の移動などから見ても、意味のある分け方と言えよう。

以下、各活動期の主な有感地震の震源分布とその活動状況について述べ、また、地殻変動、極微小地震との関係などについても述べる。なお、月別の震源分布については既報の論文を参照されたい。

1) 第1期(1965年8月～1966年2月)

われわれの観測が始る前の1965年8月～9月の期間については長野地方気象台の報告を参照すると、有感地震は松代町西条と赤柴地区の附近に分布しているのみで、この頃では未だ若穂町地域に出現していないようである。10月になると皆神山附近に加えて奇妙山附近にも若干の震源が現われた。11月になると地震回数は著しく増加して、大きい地震が続発しあるものは松代町に軽い損害をあたえた。

第3図の上部は加速度計により観測した主な有感地震の震央分布である。同図の下部は、NE-SWの鉛直面に投影した震源の鉛直分布である。この期間の有感地震の大部分は松代町地域で発生しているが、若穂町、更埴市東町にも若干発生しており、地震域は皆神山を中心とする半径約5kmの円と言える。大きい地震の震源は総て皆神山の南部および南西部に集中している。

震源の鉛直分布については、2～8kmに大部分存在し、大きい地震は3km前後の深さをもっている。全体的に見て北東側が深く、南西側が浅い傾向を示している。なお、注目すべきは、8～9kmの深さのところ孤立した一群の地震が、1966年2月頃から更埴市東部に現われたことである。

この期に発生した最も大きい規模の地震は11月23日02h57m(M=5.0)、また、最初の被害を与えた地震は11月22日21h09m(M=4.8)であり、松代町では壁のひび割れ、屋根がわらの落下など小被害が続出した。

2) 第2期(1966年3月～7月)

第4図は第2期における主な有感地震の震央分布と鉛直分布を示してある。第2期の地震域は、第1期に比較してやや拡大し、新たに有感地震の震源が出現した地域としては、松代町北部、真田町北部、若穂町中部、北部の各地域である、この期における活動の特異な点は、震源域の拡大よりも有感地震の発生回数が著しく多いことである。

第2期で活動の激しかったのは4月と5月で、大きい地震は総計35回起っているが、これらの震源は第1期に発生した大きい地震の震源位置以外はかなり広い地域にわたっていることが注目される。この期間の大きい地震活動と関連して地殻変動も進行した。すなわち1966年4月以降の水準測量の結果によれば、皆神山北東部を中心として土地の隆起速度が大きくなった。また、松代地震観測所の横坑内に設置された地震研究所の水管傾斜計は、1966年3月中頃から5月にかけてかなり大きな変化を示している。

更埴市東部に発生している地震は5月以降さらに増加しており、6月になると一段と活発化してきた。この期間の鉛直分布は第1期と大体同じであるが、2kmより浅い地震と、8～10kmの深い地震が特に多くなったように思われる。

5月14日19h～15日06hにかけて、冠着山周辺に初めて有感地震が続発し、このうち最も大きい地震はM=4.2程度であった。当時は、この一群の地震がこれまでの震源域から10数kmもかけ離れた所に起ったので、今後どう発展するかは全く不明であった。しかし、約6カ月後の1967年1月になってから、冠着山、上山田町方面に顕著な活動が起ることになる。

3) 第3期(1966年8月～12月)

第5図は第3期における主な有感地震の震央分布と鉛直分布とを示してある。第3期においては、地震活動は更埴市、戸倉町、上山田町および真田町北西部の各地域に拡大し、地震域の大きさは皆神山を中心にNE-SW方向に約28kmの長径、NW-SE方向に約15kmの短径をもつ楕円形となった。

この期における大きい地震の発生は総計 23 回で、これらの地震は大部分が松代町、若穂町に起っているが、新しく更埴市および妙徳山附近にも発生するようになった。

この期間の鉛直分布では、第 2 期の 5 月、6 月、7 月に更埴市森附近で発生していた深さ 8~10 km の地震群は次第に拡がり、9 月には 2~8 km の深さに分布するようになり、その発生回数も増している。11 月になると須坂市南部周辺に有感地震が発生したが、これらの深さは 10 km 前後と割合深いものであった。

第 3 期の地震活動の最も大きな特徴としては、10 月頃より皆神山北東部の地割れ地帯附近で地震が減少していることで、11 月になるとさらに明瞭にこの傾向が強くなった。このことは、皆神山北東部の地表に現われた エシェロン状の地割れ群が発生したことから、基盤に新しい地震断層が生じたものと推定されているが、この附近の地下では一種の破碎帯が生じて、もはや、地震エネルギーを放出できない状態となったものと考えられる。また、これらの現象と関連して水準測量は、これまで続いた松代町周辺の土地の著しい隆起が止まり、1966 年 10 月以後はやゝ下降に転じたことを示している。さらに、11 月に行われた光波測量の結果では、可俣基線 -5 cm、西寺尾 -2 cm、象山基線 -1 cm とこれまで著しく伸長していた土地が短縮に転じている。これらの諸現象と松代町地域の地震活動の著しい衰退とはよく調和していると言える。

4) 第 4 期 (1967 年 1 月~5 月)

第 6 図は第 4 期における主な有感地震の震央分布と鉛直分布とを示してある。第 4 期になると松代町南部の地震活動は大巾に減少し更埴市東部における活動も同様の傾向である。しかしながら、戸倉町、上山田町、坂井村および妙徳山の周辺ではなお活発である。

大きい地震は地震域の縁にあたる妙徳山および坂井村の各周辺に起ったその数は減り散発的になった。地震発生区域の大きさは、2 月以降坂井村方面に有感地震が多発したことにより、第 3 期よりもさらにのびて、NE-SW 方向に約 34 km の長径、NW-SE 方向に約 18 km の短径をもつ楕円形になった。

この期における鉛直分布の特徴は、若穂町周辺に発生している地震は深さ 2~6 km で、更埴市東部から坂井村周辺の地震は深さ 2~15 km と比較的広い範囲にばらついている。

なお、妙徳山周辺に大きい地震がかなり多く発生したにもかかわらず、図において小さい地震の分布が少ないのは、この地域がわれわれの観測網の位置の関係から 3 点で同時に観測される地震が少ないことによると思われる。妙徳山に最も近い観測点である東村仁礼の加速度計には、PS が 1.0 秒位と思われる地震が 5 月には 1 日当たり約 20 回程度観測されており、これらの震源が総て決定されれば、妙徳山周辺にはかなり多くの震源が現われたはずである。

5) 第 5 期 (1967 年 6 月~10 月)

第 7 図は第 5 期における主な有感地震の震央分布と鉛直分布とを示してある。第 5 期になると各観測点における地震回数の減少が目立ち、また、有感地震も著しく減少している。松代町地域に震源をもつ有感地震はほとんど無いものと見てよいであろう。なお、若干の有感地震が発生している地域としては、更埴市、戸倉町、坂井村およびその周辺である。また、真田町北部で深さ 2~6 km のところと小区域の活動が目につく。この活動は第 3 期から引続いていているものであるが、この場所ではこれまでに大きい地震の発生はない。

この期における大きい地震は、6 月、9 月、10 月に各 1 回発生しているが、これらのうち 9 月 14 日 19 h 38 m の地震 (坂井村: V, M=5.0) は、坂井村、更埴市、上山田町等の 5 町村で壁落下、ブロック塀倒壊などの被害が発生し、また、10 月 14 日 04 h 48 m の地震 (更埴市: V, M=4.9) では、更埴市、松代町の一部で家屋の小被害 9 軒、石垣のくずれ 35 カ所等を出している。第 8 図は 1955 年 10 月~1967 年 10 月に至る全期間の主な有感地震の震央分布と鉛直分布とを示してある。

本報告の震源の決定は、すべて地下構造を一樣と仮定しているが、実際の地下構造はかなり複雑のようである。1967 年 11 月に実施された人工地震による地下構造の決定結果をまち、改めて震源決定の再計算を行う予定である。

第 9 図はわれわれの観測網から決めた各活動期ごとの発生域である。比較のために極微小地震の発生区域を示してあるが、これは他の資料から決めたものである。

3. 大きい地震

松代群発地震のなかで、気象庁発表による震度 IV および V の地震について、各観測点の石本式加速度計記録から、3カ所の PS の値と主要な記事を第2表に示してある。なお、今回の表には、発震時、最大振幅、周期、初動などに関する資料は記載していないが、将来主な有感地震については詳細な験震表が報告される予定である。

第10図は1965年11月～1967年10月までに発生した大きい地震の震源分布図である。大きい地震の発生を地域別にみると、松代町48回、若徳町21回、更埴市、坂井村各4回、真田町、坂城町各3回、東村、須坂市各2回、麻積村の1回となっている。これらの大きい地震の鉛直分布については、松代町地域に発生したものは2～5km、若徳町地域では深く3～8km、南西部地域に発生したものは6～12kmと一段と深いところにある。

第11図はMの大きい地震について、その発現順に震央を追跡したものである。M>4.0の地震はこの外にも約300回発生しているが、今回は主要な88個の大きい地震に限定した。第11図a)の第1期では、No. 1～11と皆神山南部から起こり、順次時計回りに移動し、再び同南部に戻る順で比較的小区域内で発生した。b)の第2期になると、No. 16～23までは皆神山西部から同北部へと変化し、これから若徳町地域に移った後は、No. 44～47のように特徴のある発生順が見られる。c)の第3期では、皆神山の周辺では発生がなく、次第にNE-SWの方向に広がる傾向を示している。d)の期間になると、この傾向は一層強いことが示され、有感地震の発生区域の拡大方向とよく一致している。有感地震の多発区域には必ず大きい地震の発生を見ている。ただ一つの例外として、上山田町および戸倉町のみにはこれまでに有感地震が多発したにもかかわらず、いまだに大きい地震の発生がない。発生区域は全体的にNE-SWの方向にのび、NW-SE方向には限られた区域よりのびないという特徴ある現象を示している。

4. 地震回数および放出エネルギー

第3表には石本式加速度計が記録した主な有感地震のなかから、震源決定ができた地震の数を規模別に示してある。計測の基準は、1) 少なくとも3点で記録されていること。2) PSが明瞭であること。3) 計測の能力(計測者2名)に限界があるので、地震の数が非常に多い場合は、比較的大きい振幅のものを優先とし1日50個に限り計測することとした。結局マグニチュードの頻度曲線からみると、M=2.5程度以下の地震は多数おとされていることとなる。なお、第3表をみると、1966年4月～6月は第2活動期にあたり、地震がきわめて多数記録されているにもかかわらず、その割合に震源の決定した地震の数の少ないことは、計測の能力に限界のあったこと、地震が連続して発生しているために前後が重複しPSが読取れないか読取っても不正確であったことによる。第4表には加速度計記録から最大複振幅が3mm以上の地震(これは有感)の月別回数を、第5表にはHES: 1-0.2型に記録された地震(主に無感)の月別回数を示してある。なお()内の数字は欠測日数である。

第12図は地震波として放出されたエネルギーの積算量を、第6表には月別当りのエネルギー放出値を示してある。震源の決まらない小さい地震については、PSと振幅からMを求めこれよりエネルギーを算定してある。各活動期におけるエネルギー放出値は次の通りである。

第1期(1965年8月～1966年2月).....	252.5×10 ¹⁸ ergs. (M=5.7の地震1個分に相当)
第2期(1966年3月～7月).....	841.4×10 ¹⁸ ergs. (M=6.1 ")
第3期(1966年8月～12月).....	392.1×10 ¹⁸ ergs. (M=5.8 ")
第4期(1967年1月～5月).....	124.5×10 ¹⁸ ergs. (M=5.5 ")
第5期(1967年6月～10月).....	51.3×10 ¹⁸ ergs. (M=5.3 ")

なお、1967年11月30日現在のエネルギー放出値は1.66×10²¹ ergs. となり、M=6.3の地震1個分に近い量が放出されたことになる。

1967年12月現在における東村仁礼および川西村上室賀にある加速度計の観測から、1日当りの平均有感地震回数は2～3回程度に低下しているが、地震域外周部において比較的大きいMの地震が間歇的に発生している。

謝辞 当報告をまとめるに当り、資料整理に多くの御協力をいただいた地震研究所地震計測部の牧野和子、松原美栄子、川島亮子の各氏に厚くお礼申上げる次第である。