BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 45 (1967), pp. 395-416

23. *Geomagnetic and Geoelectric Studies of the Matsushiro Earthquake Swarm* (5).

By Tsuneji RIKITAKE, Yoshio YAMAZAKI, Munehisa SAWADA, Yoichi SASAI, Toshio YOSHINO, Seiji UZAWA and Takafumi SHIMOMURA,

Earthquake Research Institute

and

Kan-ichi MOMOSE,

Shinshu University.

(Read Dec. 27, 1966.—Received March 31, 1967.)

Summary

Results of proton precession magnetometer observations over Nagano Prefecture are reported for a period from September to November 1966. After the sudden changes at the beginning of August, 1966, the total geomagnetic intensity at Hoshina and Matsushiro shows considerably different variations towards the end of October. No significant changes were observed at other array stations during the period concerned. The fifth dip survey was carried out over the Matsushiro area, but the poor accuracy of the present survey prevented the finding of something new to supplement the proton precession magnetometer observations.

1. Introduction

A remarkable activity of the Matsushiro Earthquake Swarm started at the beginning of August, and lasted until the end of September, 1966. The total sum of the seismic energy of the individual earthquakes during that period was a little smaller than that during a period from March to May in 1966 (so-called the second activity). But the third activity of the Matsushiro Earthquake Swarm is characterized by its land deformation of a far greater scale. Repeated levelling surveys brought to light an enormous land upheaval centered at the northern foot of Mt. Minakamiyama[1], where a number of cracks had broken out in April, the movement of which had been moderate from June to July and again

1) I. TSUBOKAWA *et al.*, *Personal Communication.*

became very active in August[2]. The geodimeter survey revealed a large extension between Mt. Minakamiyama and the Sorobeku pass (about 3 km north from the former), together with a smaller contraction in the $E-W$ direction[3]. All these facts suggest the existence of such a stress pattern as compressive in the $E-W$ direction and extensive in

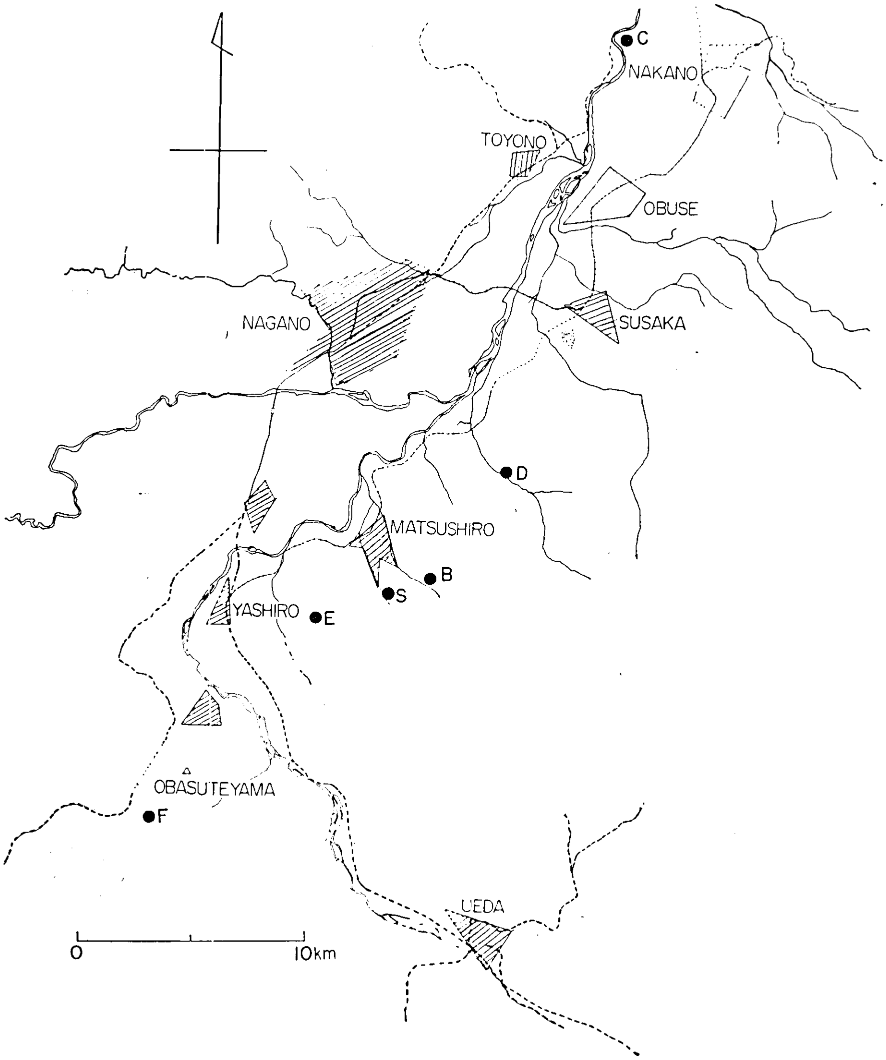

Fig. 1. Locations of the stations equipped with a proton precession magnetometer.

2) K. NAKAMURA *et al., Personal Communication.*

3) K. KASAHARA, *Personal Communication.*

the $N-S$ direction centered at the northern foot of Mt. Minakamiyama. The systematic distribution of cracks and their movements seem to reflect an underground strike slip fault caused by such a stress field[2].

Changes in the geomagnetic total intensity observed around the earthquake area would have, no doubt, a close relation to the abovementioned stress pattern. Continuous geomagnetic observations by proton precession magnetometers have been conducted over Nagano Prefecture[4),5),6),7)], and we could detect some changes in the total intensity associated with the seismic activity. As has been preliminarily reported in the fourth paper[7], we observed an increase in the total force amounting to 5 gammas or so at Matsushiro, together with a decrease of nearly the same amount at Hoshina at the beginning of August.

Further observations at these two stations brought to light a rather complicatied feature of time variations of the geomagnetic field accompanying the seismic activity. It was also reported in the previous paper[7] that an array observation with seven sets of proton precession magnetometers was planned by the Earthquake Research Institute. They have been fully at work since November. In Section 2 will be given the results of the array observation during a period from September to November, 1966.

A geomagnetic dip survey was carried out around Mt. Minakamiyama from September 20 to 24, the results of which will be briefly described in Section 3.

2. Proton Precession Magnetometer Observation

2-1. *Changes in the total geomagnetic intensity at Matsushiro relative to Kanozan*

Total geomagnetic intensity (F) observations by a proton precession magnetometer have been conducted at Matsushiro (Station B in Fig. 1) since the earlier stage of the Matsushiro Earthquake Swarm, and F values observed simultaneously at Kanozan have been used in order to eliminate non-local changes in the geomagnetic field[5]. The present report will cover the observation from September 9 to November 30. The observed results at Station B are summarized in Table 1. The daily

4) T. RIKITAKE *et al.*, *Bull. Earthq. Res. Inst.*, **44** (1966), 363.
5) T. RIKITAKE *et al.*, *Bull. Earthq. Res. Inst.*, **44** (1966), 409.
6) T. RIKITAKE *et al.*, *Bull. Earthq. Res. Inst.*, **44** (1966), 1335.
7) T. RIKITAKE *et al.*, *Bull. Earthq. Res. Inst.*, **44** (1966), 1735.

Table 1. Total intensity values (F_M) observed at Station B.

Date	Time	F_M
1966 Sept. 6	1h03m	46896.6γ
	05	96.6
	07	99.0
	09	99.0
	11	46901.3
7	1 01	06.0
	03	06.0
	07	06.0
	09	06.0
	11	06.0
8	1 01	10.7
	03	10.7
	05	10.7
	07	10.7
	09	10.7
	11	08.4
9	1 01	01.3
	03	01.3
	05	01.3
	07	03.7
	09	03.7
	11	03.7
10	1 01	13.1
	03	13.1
	05	13.1
	07	15.4
	09	15.4
	11	15.4
12	1 01	17.8
	03	15.4
	05	17.8
	07	15.4
	09	15.4
	11	15.4
13	1 01	13.1

Date	Time	F_M
1966 Sept. 13	1h03m	46913.1γ
	05	13.1
	07	13.1
	09	15.4
	11	15.4
14	1 01	13.1
	03	13.1
	05	13.1
	07	13.1
	09	13.1
	11	10.7
15	11	22.5
16	1 03	13.1
	07	13.1
	09	13.1
	11	13.1
17	1 01	15.4
	03	15.4
	05	15.4
	07	17.8
	09	17.8
	11	17.8
18	1 01	15.4
19	1 01	17.8
	03	17.8
	05	17.8
	07	20.1
20	1 01	15.4
	03	15.4
	05	15.4
	07	15.4
	09	15.4
	11	15.4
21	01	10.7

Date	Time	F_M
1966 Sept. 21	1h03m	46908.4γ
	05	10.7
	07	10.7
	09	10.7
	11	10.7
22	1 01	15.4
	03	15.4
	05	15.4
	07	15.4
	09	17.8
	11	15.4
23	1 01	22.5
	03	22.5
	05	22.5
	07	20.1
	09	22.5
	11	22.5
24	1 01	17.8
	03	17.8
	05	20.1
	07	20.1
	09	22.5
	11	22.5
25	1 01	17.8
	03	17.8
	05	17.8
	07	17.8
	09	15.4
	11	17.8
26	1 01	17.8
	03	17.8
	05	17.8
	07	17.8
	09	20.1
	11	17.8

(to be continued)

Table 1 (continued)

Date	Time	F_M
1966		
Sept. 27	1^{h}01^m	46941.3$^\gamma$
	03	38.9
	05	36.6
	07	34.2
	09	34.2
	11	31.9
28	1 01	24.8
	03	22.5
	05	24.8
	07	22.5
	09	22.5
	11	20.1
Oct. 1	1 01	27.2
	03	29.5
	05	27.2
	11	29.5
2	1 01	17.8
	03	15.4
	05	17.8
	07	15.4
	09	15.4
	11	17.8
3	1 03	15.4
	05	17.8
	07	15.4
	09	15.4
4	1 01	20.1
	03	20.1
	05	20.1
	07	22.5
	09	20.1
	11	20.1
5	1 03	27.2
	07	31.9
	09	29.5

Date	Time	F_M
1966		
Oct. 5	1^{h}11^m	46927.2$^\gamma$
6	1 03	17.8
	05	20.1
	09	17.8
	11	22.5
7	1 01	08.4
8	1 01	15.4
9	1 01	13.1
	03	13.1
	05	13.1
	07	13.1
	09	13.1
	11	13.1
10	1 01	13.1
	03	15.4
	05	15.4
	07	17.8
	09	15.4
	11	17.8
11	1 01	13.1
	03	15.4
	05	15.4
	07	13.1
	09	15.4
	11	13.1
12	1 01	15.4
	03	17.8
	05	17.8
	07	20.1
	09	17.8
13	1 01	15.4
	03	13.1
	05	22.5
	07	17.8

Date	Time	F_M
1966		
Oct. 13	1^{h}09^m	46915.4$^\gamma$
	11	15.4
14	1 01	17.8
	03	17.8
	05	17.8
	07	20.1
	09	20.1
	11	17.8
15	1 01	17.8
	03	15.4
	05	17.8
	07	17.8
	09	17.8
	11	17.8
16	1 01	24.8
	03	24.8
	05	27.2
	07	27.2
	09	24.8
	11	24.8
17	1 01	46891.9
	03	91.9
	05	94.3
	07	94.3
	09	94.3
	11	94.3
18	1 01	46913.1
	03	10.7
	05	10.7
	07	13.1
	09	10.7
	11	10.7
19	1 01	10.7
	03	13.1
	05	13.1

(to be continued)

Table 1 (continued)

Date	Time	F_M
1966 Oct. 19	1^h07^m	46915.4^{γ}
	09	15.4
	11	15.4
20	1 01	15.4
	03	17.8
	05	17.8
	07	17.8
	09	17.8
	11	17.8
21	1 01	15.4
	03	15.4
	05	15.4
	07	13.1
	09	17.8
	11	15.4
22	1 01	08.4
	03	10.7
	05	10.7
	07	10.7
	09	08.4
	11	10.7
23	1 01	13.1
	03	15.4
	05	15.4
	07	13.1
	09	13.1
	11	13.1
24	1 01	20.1
	03	20.1
	05	22.5
	07	22.5
	09	20.1
	11	22.5
25	1 01	46896.6
	03	96.6

Date	Time	F_M
1966 Oct. 25	1^h05^m	46896.6^{γ}
	07	96.6
	09	96.0
	11	99.0
26	1 01	46903.7
	03	06.0
	05	06.0
	07	06.0
	09	06.0
	11	06.0
27	1 01	17.8
	03	17.8
	05	20.1
	07	20.1
	09	17.8
	11	17.8
28	1 01	01.3
	03	01.3
	05	03.7
	07	01.3
	09	01.3
	11	01.3
29	1 01	08.4
	03	06.0
	05	08.4
	09	08.4
	11	08.4
30	1 01	08.4
	03	10.7
	05	08.4
	07	08.4
	09	06.0
	11	08.4
31	1 01	13.1
	03	13.1

Date	Time	F_M
1966 Oct. 31	1^h05^m	46913.1^{γ}
	07	15.4
	09	13.1
	11	08.4
Nov. 1	1 01	46889.6
	03	89.6
	05	89.6
	07	89.6
	09	89.6
	11	89.6
3	1 01	03.7
	03	03.7
	05	06.0
	07	06.0
	09	03.7
	11	03.7
4	1 01	06.0
	03	06.0
	05	08.4
	07	06.0
	09	06.0
	11	06.0
5	1 01	01.3
	03	01.3
	05	03.7
	07	03.7
	09	03.7
	11	03.7
6	1 01	46899.0
	03	99.0
	05	46901.3
	07	46899.0
	09	99.0
	11	99.0
7	1 01	46901.3

(to be continued)

Table 1 (continued)

Date	Time	F_M
1966 Nov. 7	1^h03^m	46901.3^γ
	05	01.3
	07	01.3
	09	01.3
	11	01.3
8	1 01	06.0
	03	08.4
	05	08.4
	07	08.4
	09	06.0
	11	08.4
9	1 01	08.4
	03	08.4
	05	08.4
	07	08.4
	09	08.4
	11	08.4
10	1 01	08.4
	03	10.7
	05	08.4
	07	10.7
	09	10.7
	11	08.4
11	1 01	03.7
	03	01.3
	05	03.7
	07	03.7
	09	03.7
	11	01.3
12	1 01	03.7
	03	01.3
	05	06.0
	07	08.4
	09	06.0
	11	06.0

Date	Time	F_M
1966 Oct. 13	1^h01^m	46908.4^γ
	03	06.0
	05	08.4
	07	08.4
	09	08.4
	11	08.4
14	1 01	03.7
	03	06.0
	05	06.0
	07	03.7
	09	03.7
	11	06.0
15	1 01	10.7
	03	13.1
	05	13.1
	07	10.7
	09	10.7
	11	10.7
16	1 01	06.0
	03	08.4
	05	08.4
	07	06.0
	09	08.4
	11	06.0
17	1 01	06.0
	03	06.0
	05	08.4
	07	06.0
	09	06.0
	11	06.0
18	1 01	13.1
	03	13.1
	05	13.1
	07	13.1
	09	13.1

Date	Time	F_M
1966 Oct. 18	1^h11^m	46913.1^γ
19	1 01	03.7
	03	03.7
	05	03.7
	07	03.7
	09	03.7
	11	01.3
20	1 01	01.3
	03	03.7
	05	03.7
	07	06.0
	09	03.7
	11	03.7
21	1 01	08.4
	03	08.4
	05	08.4
	07	10.7
	09	08.4
22	1 01	06.0
	03	08.4
	05	08.4
	07	08.4
	09	06.0
	11	08.4
23	1 01	08.4
	03	10.7
	05	10.7
	07	10.7
	09	10.7
	11	10.7
24	1 01	08.4
	03	10.7
	05	10.7
	07	10.7
	09	10.7

(to be continued)

Table 1 (continued)

Date	Time	F_M	Date	Time	F_M	Date	Time	F_M
1966			1966			1966		
Oct. 24	1^h11^m	46908.4^{γ}	Oct. 27	1^h01^m	46899.0^{γ}	Oct. 29	1^h01^m	46906.0^{γ}
25	1 01	08.4		03	46901.3		03	06.0
	03	08.4		05	01.3		05	06.0
	05	10.7		07	03.7		07	06.0
	07	08.4		09	03.7		09	03.7
	09	08.4		11	03.7		11	03.7
	11	06.0	28	1 01	01.3	30	1 01	03.7
26	1 01	08.4		03	03.7		03	03.7
	03	10.7		05	03.7		05	01.3
	05	10.7		07	03.7		07	01.3
	07	13.1		09	03.7		09	01.3
	09	08.4		11	01.3		11	01.3
	11	10.7						

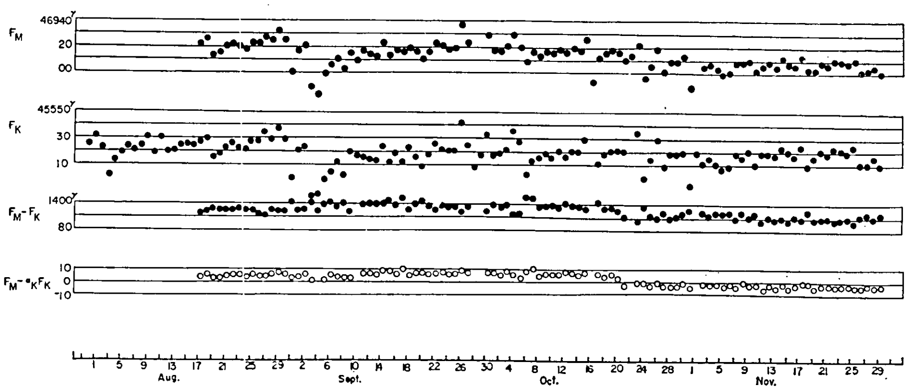

Fig. 2. Changes in F_M, F_K, $F_M - F_K$ and $F_K - \alpha_K F_K$.

Table 2. Daily mean values of total intensity at Station B (F_M) and Kanozan (F_K). Simple and weighted differences are also given, the latter being computed from an arbitrary datum line.

	F_M	F_K	$F_M - F_K$	$F_M - \alpha_K F_K$
Sept. 1	46900.2γ	45499.0γ	1391.6γ	4.3γ
2	16.8	45521.8	95.0	3.8
3	20.5	24.7	95.9	5.4
4	46888.8	45486.8	1402.0	0.3
5	82.9	88.2	1394.8	−6.5
6	98.5	99.2	99.1	1.2
7	46906.0	45504.8	1401.2	4.9
8	10.4	12.7	1397.7	3.7
9	02.5	02.3	1400.2	3.1
10	14.3	20.5	1393.8	2.1
11	09.2	—	—	—
12	16.2	16.7	99.5	6.8
13	13.9	14.3	99.5	6.0
14	12.7	13.0	99.7	5.8
15	22.5	23.8	99.5	8.6
16	13.1	11.5	1402.1	7.6
17	16.6	18.3	1398.3	6.0
18	15.4	11.5	1404.4	9.9
19	18.4	23.0	1395.4	4.5
20	15.4	15.8	99.6	6.6
21	10.4	08.8	1401.5	6.4
22	15.8	17.7	1398.2	5.7
23	22.1	26.7	95.4	5.6
24	20.1	22.0	98.1	6.9
25	17.4	20.3	97.1	5.4
26	18.2	20.7	97.5	5.9
27	36.2	42.8	93.3	8.4
28	22.9	25.3	97.5	7.3
29	—	—	—	—
30	—	—	—	—
Oct. 1	28.4	33.0	94.6	6.9
2	16.6	45.0	98.9	6.4
3	16.0	18.8	97.3	5.1
4	20.5	22.0	98.5	7.3
5	28.9	36.0	91.7	5.0

(to be continued)

Table 2 (continued)

	F_M	F_K	F_M-F_K	$F_M-\alpha_K F_K$
Oct. 6	46919.5^{γ}	45527.3^{γ}	1392.3^{γ}	2.7^{γ}
7	08.4	03.3	1404.4	7.8
8	15.4	13.5	03.4	9.2
9	13.1	16.0	1397.1	4.1
10	15.8	18.2	97.7	5.3
11	14.3	16.0	98.3	5.3
12	17.8	21.0	96.8	5.3
13	16.6	16.8	99.8	7.0
14	18.6	20.3	98.2	6.5
15	17.4	20.2	97.2	5.5
16	25.6	30.0	95.6	6.8
17	46893.5	—	—	—
18	46911.5	11.2	1400.4	5.9
19	14.6	18.5	1396.1	3.9
20	17.4	20.7	96.7	5.1
21	15.4	21.0	94.4	2.9
22	10.0	20.5	89.5	−2.2
23	13.9	—	—	—
24	21.3	34.4	87.0	−0.6
25	46897.0	00.0	97.0	−0.7
26	46805.6	14.8	90.8	−2.5
27	18.6	29.7	88.9	0.0
28	01.7	09.0	92.7	−2.4
29	08.4	19.0	88.9	−3.2
30	08.4	18.7	89.7	−2.5
31	12.7	20.0	92.7	0.9
Nov. 1	46889.6	45494.8	94.8	−4.5
2	—	—	—	—
3	46904.5	45511.5	93.0	−1.4
4	06.4	15.8	90.6	−2.4
5	02.9	10.7	92.2	−2.3
6	46899.4	07.3	92.0	−3.5
7	46901.3	08.8	92.5	−2.6
8	07.6	18.8	92.4	−0.6
9	08.4	16.0	92.4	−0.6
10	09.6	20.5	89.1	−2.6
11	02.9	10.8	92.1	−2.5
12	05.3	19.2	86.1	−6.0

(to be continued)

Table 2 (continued)

	F_M	F_K	$F_M - F_K$	$F_M - \alpha_K F_K$
Nov. 13	46908.0^{γ}	45519.0^{γ}	1389.0^{γ}	-3.1^{γ}
14	04.9	17.2	87.7	−4.9
15	11.5	23.2	88.4	−2.5
16	07.2	20.3	86.9	−4.8
17	06.4	17.0	89.4	−3.3
18	13.1	24.2	88.9	−1.6
19	03.3	10.0	93.3	−1.5
20	03.7	15.8	87.9	−5.2
21	08.7	21.0	87.9	−3.6
22	07.6	19.0	88.6	−3.5
23	10.4	23.7	86.7	−4.0
24	10.0	22.3	87.6	−3.5
25	08.4	20.3	88.1	−3.6
26	10.3	24.8	85.5	−4.8
27	02.1	12.0	90.1	−4.1
28	02.9	11.3	91.6	−2.8
29	05.3	16.5	88.8	−4.1
30	02.1	11.2	91.0	−3.5

mean values of the total intensity at Station B (F_M) and Kanozan (F_K) are given in Table 2, including simple and weighted differences between the two stations.

In Fig. 2 are shown the daily mean values at Matsushiro (F_M), those at Kanozan (F_K), simple ($F_M - F_K$) and weighted ($F_M - \alpha_K F_K$) differences between Matsushiro and Kanozan, covering a period from August to November, 1966. The terms "daily mean," "weighted difference" and so on have already been explained in the previous papers[5]. As shown in $F_M - \alpha_K F_K$ curve, F_M values seem to have stayed at a high level (5–10 gammas increase relative to the initial value before July) during a period from August to the middle of October, although fluctuations of several gammas are seen. Then a sudden decrease amounting to 10 gammas occurred on October 22, and F_M's have thereafter remained at a level smaller than the initial value by an amount of 5 gammas or so. We first wondered if the indicated sudden change was caused by some artificial disturbances. But the Station B has been conserved in good condition by courtesy of local people and it was ascertained that no magnetic matter had ever been placed or taken away around the detector coil of the magnetometer. It is also clear that such a gap could not have been brought forth by changes of F_K or some anomalous current system, because no systematic differences could be found between Kanozan and other array stations, i.e. Nobeyama, Nakano and Koshoku. We are now convinced that the observed change on October 22 is a "natural" one and has something to do with the local changes in the underground physical state around Station B.

The $F_M-\alpha_K F_K$ curve also indicates that F_M values seem to decrease 5 gammas or so during a period from September 1 to 10. Examining standard-run three component magnetograms obtained at Oshima, we found that, almost every night during that period, a bay-like event took place at about 1 o'clock in local time, when the observations have been made automatically by a clock mechanism. It is a well-known fact that the vertical component of short-period variations such as bays shows an anomalously large amplitude along the Pacific Ocean side of Honshu Island including Kanozan, while no such an enhancement of Z is observed at inland stations such as Matsushiro. Since the anomalous Z variations of short period are fairly in phase with the H ones, the total intensity also shows a considerable increase at Kanozan at the time of bays and the like. The apparent decrease of F_M at the beginning of September would certainly be caused by the above-mentioned spatial discrepancy of short-period variations. The weighting factor α_K was defined as the amplitude ratio of Dst and night-time level of Sq between Matsushiro and Kanozan[5], so that, in the case of short-period variations, the amplitude ratio of Matsushiro relative to Kanozan would become much smaller than that of longer-period variations. On September 3 and 7, both moderately disturbed days but with no remarkable geomagnetic event seen at about 1 o'clock in local time ; $F_M-\alpha_K F_K$ values show about 5 gammas higher than the initial level. This fact enables us to suggest that the total intensity peculiar to the Station B remained at an increased level during that period.

2-2. *Changes in the total geomagnetic intensity at Hoshina*

In the fourth paper it was reported that the total geomagnetic intensity at Hoshina showed a decrease of 5 gammas or so at the beginning of August[7]. The observed values at Hoshina are, as before, compared with those at Nakano and shown graphically in Fig. 3, together with the F_H's. Unfortunately, F_N values during a period from August 26 to September 10 were not available because of some instrumental errors. But the F_H-F_N curve indicates a gradual recovery of F_H to the initial level towards the middle of September after a definite decrease at the beginning of August. Even an increase of about 5 gammas or so higher than the initial level is found from the end of September to the middle of October. Unlike the $F_M - F_K$ curve, no significant change of the $F_H - F_N$ value could be found on October 22, but the $F_H - F_K$ value seems to have recovered to the initial level at that time.

The $F_M - F_N$ curve shows, as a whole, a tendency quite similar to the $F_M - F_K$. A sudden decrease in F_M on October 22 is also confirmed

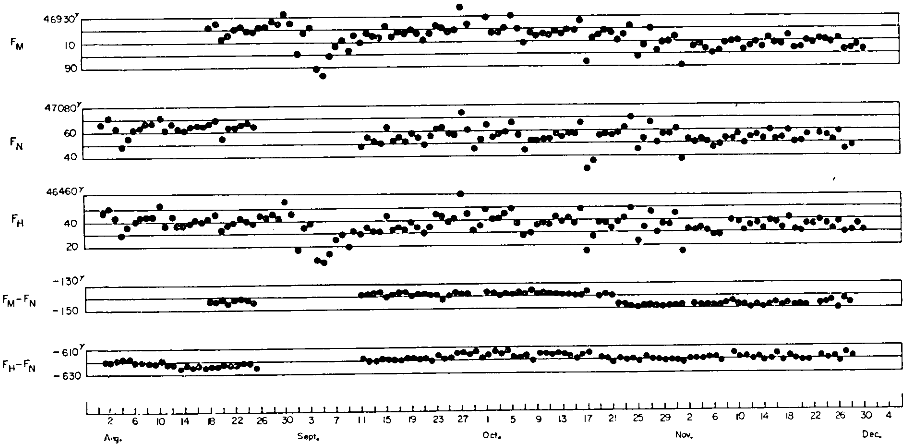

Fig. 3. Changes in $F_M, F_N, F_H, F_M - F_N$ and $F_H - F_N$.

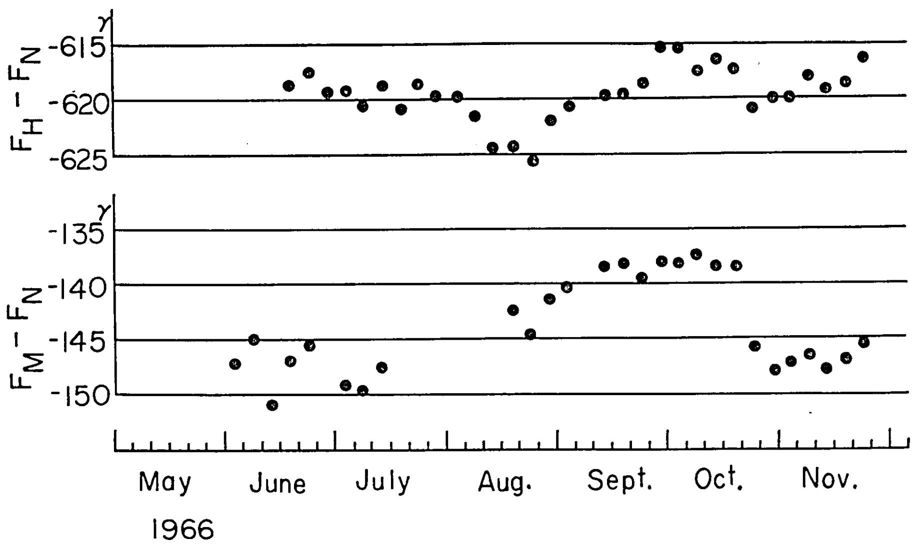

Fig. 4. Changes in the 5-day means of $F_H - F_N$ and $F_M - F_N$.

in Fig. 3.

Finally, the 5-day mean values of $F_H - F_N$ and $F_M - F_N$ are calculated and shown in Fig. 4, in order to see the over-all variations of the total intensity at Hoshina and Matsushiro during a period from May to November. A scattering of $F_M - F_N$ in June and July would possibly be due to some instrumental errors at Nakano. Both the curves indicate a better demonstration of the afore-mentioned variations of the total intensity associated with the seismic activity.

2-3. *Array observations covering Nagano Prefecture*

A proton precession magnetometer array with seven temporary stations was established over Nagano Prefecture in Autumn of 1966. Location of stations around the earthquake area is shown in Fig. 1, their operating facilities being briefly described in the previous paper[7]. Of these, Station A (Nobeyama), B (Matsushiro), C (Nakano) and D (Hoshina) had already been at work in August. Observations at Station S (Matsushiro Seismological Observatory) and E (Koshoku) were started in Sep-

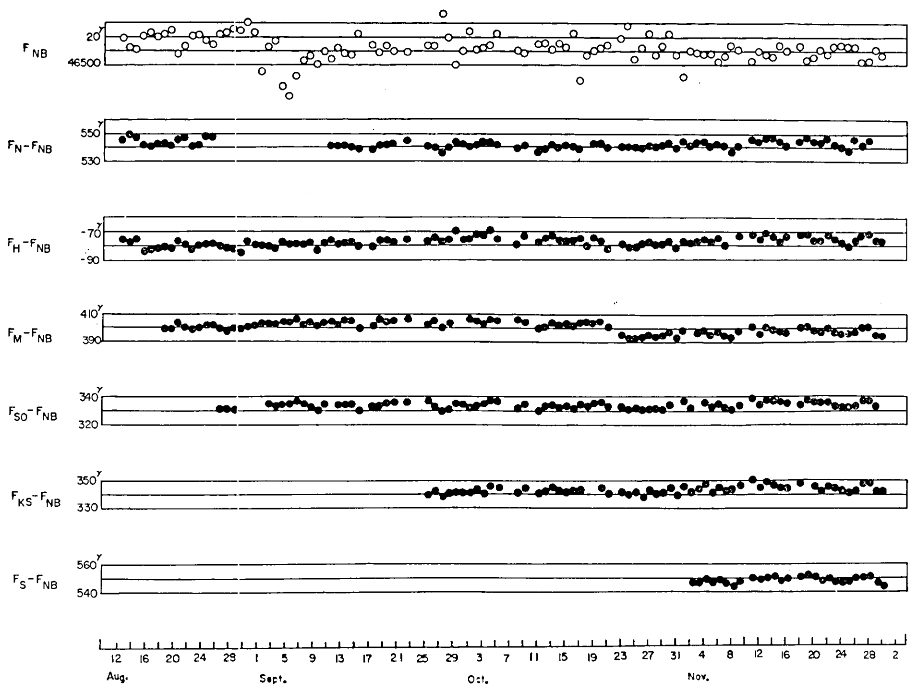

Fig. 5. Changes in F_{NB}, $F_N - F_{NB}$, $F_H - F_{NB}$, $F_M - F_{NB}$, $F_{SO} - F_{NB}$, $F_{KS} - F_{NB}$ and $F_S - F_{NB}$.

tember, while Station F (Sakai) started in Novmber. Station A is about 60 km south of Matsushiro, far enough from the seismic area, so that it was planned to serve as a standard one.

In Fig. 5 are shown the total intensity values at Station A (F_{NB}) and simple differences between F_{NB} and those at Stations C, D, B, S, E and F, denoted respectively as F_N-F_{NB}, F_H-F_{NB}, F_M-F_{NB}, $F_{SO}-F_{NB}$, $F_{KS}-F_{NB}$, and F_S-F_{NB}. Scatterings of a few gammas are always seen on each simple-difference curve. This might be partly due to an inequality of non-local changes of the geomagnetic field between Station A and each array station, as we often stated in comparing F_M with F_K. But another possible cause would certainly be some artificial disturbances at Station A. Although Station A is situated in a rather solitary district, the detector coil picks up noises of nearly 2 kc/s or so, which is very close to the Larmor precession frequency observed there. Earth current observations made clear fluctuations of about 10 minutes' period amounting to several tens of milivolt per kilometer, so prevailing that natural variations are thoroughly masked. However, ordinary magnetograms by a three component flux-gate magnetometer show no corresponding magnetic disturbances. Noisy records of the proton precession magnetometer would be due to the above-mentioned disturbances of high frequency. It is rather disappointing that Station A is inadequate to serve as a standard observatory.

Disregarding the indicated fluctuations of simple-difference curves, no significant changes seem to have taken place at Stations C, S, E and F. The sudden decrease at Matsushiro on October is again verified on the F_M-F_{NB} curve. Unlike the variation at B, F_{SO} showed no evident change on October 22. This might contradict the actuality of the sudden change at B, because these two stations are only 1.7 km apart from each other. We will come back to this point later.

3. Geomagnetic dip survey around Mt. Minakamiyama

The geomagnetic dip survey by a 2nd order G.S.I. magnetometer has been conducted over the Matsushiro area four times since the beginning of the Matsushiro Earthquake Swarm, the results of which have been reported in the previous papers.[4),5),6),7)] The fifth survey was carried out from September 20 to 24. In view of the most unusual land deformation that developed around Mt. Minakamiyama in September, the present survery was expected to provide an opportunity to resister the seismomagnetic effects as revealed by the proton precession magnetometer

Table 3. The geomagnetic dip values related to Survey V over the Matsushiro area.

Station No.	Date	Time	I_M	I_K	ΔI_V	ΔI_{IV}	$\Delta I - \Delta I_{IV}$
1	Sept. 24	16^h15^m	50°07.8′	47°53.4′	2°14.4′	2°13.6′	0.8′
2	24	16 44	49 48.5	53.4	1 55.1	1 54.2	0.9
3	24	14 45	50 20.2	53.1	1 27.1	1 26.5	0.6
4	22	17 47	49 57.2	54.4	2 02.9	2 01.2	0.5
5	22	18 35	49 57.2	54.3	2 02.9	2 04.5	(−1.6)
6	24	18 12	49 44.9	54.5	1 50.4	1 48.3	(2.1)
7	24	9 41	50 10.1	55.0	2 15.1	2 14.8	0.3
8	24	13 36	49 08.2	53.2	1 15.0	1 15.0	0.0
9	24	13 09	49 50.8	53.5	1 57.3	1 57.4	−0.1
10	24	17 36	49 54.4	54.0	2 00.4	1 55.7	(4.7)
11	24	10 07	50 06.2	55.2	2 11.0	2 10.3	0.7
12	24	20 04	49 56.3	55.1	2 01.2	2 02.1	−0.9
13	21	18 52	49 52.3	54.5	1 57.8	1 55.7	(2.1)
14	22	9 35	50 14.7	55.4	2 19.3	2 15.7	(3.6)
15	21	15 37	51 12.5	53.9	3 18.6	3 17.8	0.8
16	21	17 13	49 26.1	54.1	1 32.0	1 31.6	0.4
17	21	17 58	49 14.0	54.4	1 19.6	1 18.6	(1.0)
18	24	12 31	49 33.7	54.2	1 39.5	1 39.7	−0.2
19	21	12 43	54 19.6	55.5	6 24.1	6 23.2	0.7

observations.

Table 3 indicates the time and the dip values observed at stations over the Matsushiro area. As usual, the dip values at Kanozan at the corresponding time are also quoted. Differences between the dip values at these stations and those at Kanozan are denoted by ΔI. ΔI's for the last and the present survey are designated by subscripts IV and V respectively, and $\Delta I_V - \Delta I_{IV}$ can be regarded as local changes at each station relative to Kanozan during a period from Survey IV to Survey V.

Fig. 6 shows the distribution of $\Delta I_V - \Delta I_{IV}$. At each station, a brass peg was buried as a bench mark, but, unfortunately, some were found to be missing in the course of a few months' period between the present survey and the last one. In addition, two stations on the northern side of Mt. Minakamiyama had been demolished by underground water which spouted from some cracks already mentioned in the Introduction of this paper. Stations 6 and 10 just above these cracks had to be moved a few meters away from the initial locations. Although Table 3 tells us of an enormous gap of ΔI_V's at these stations, such changes are hardly

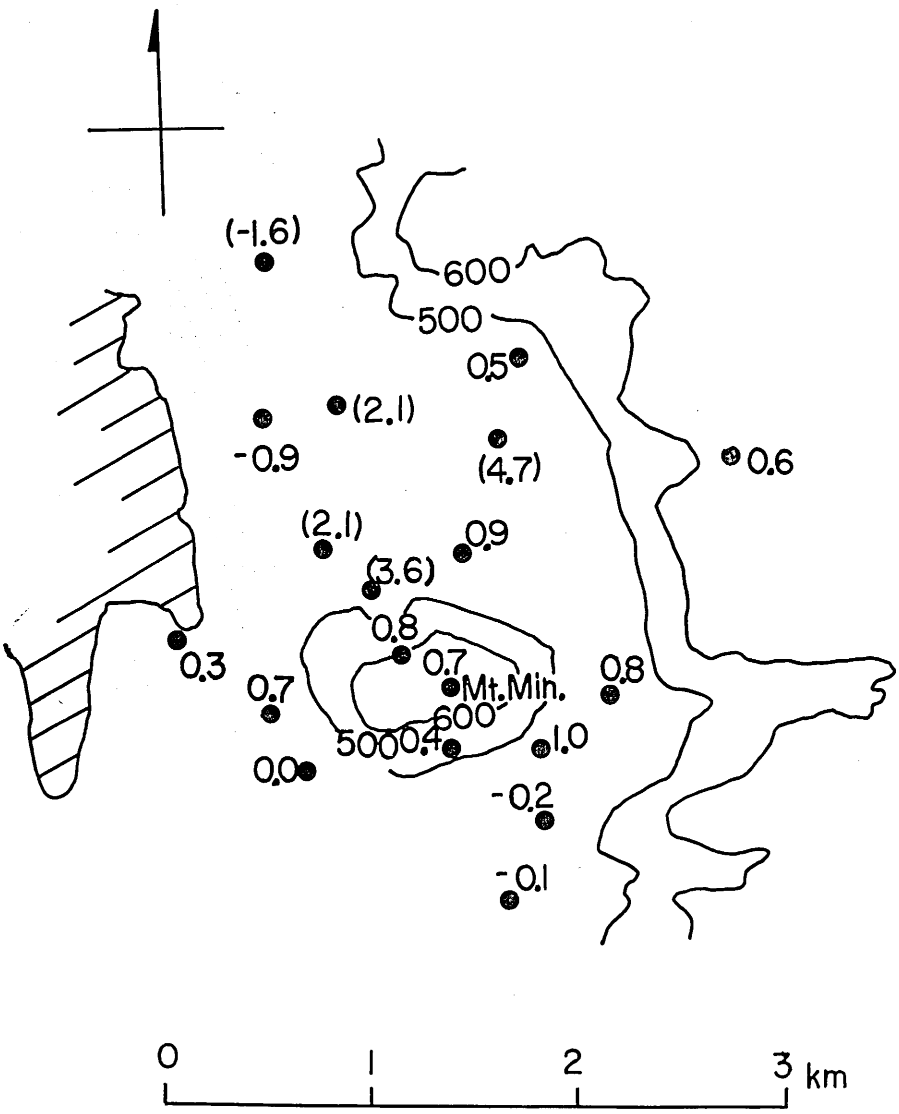

Fig. 6. Changes in the geomagnetic dip over the Matsushiro area during the period from Survey *IV* to Survey *V*.

thought to have had something to do with the unusual crack movement.

In Fig. 7 are illustrated the over-all variations of the geomagnetic dip during a period from Survey *I* to *V*. It was reported in the last paper that the distribution of changes in the geomagnetic dip during a period from Survey *I* to Survey *IV* shows a fairly regular pattern tenta-

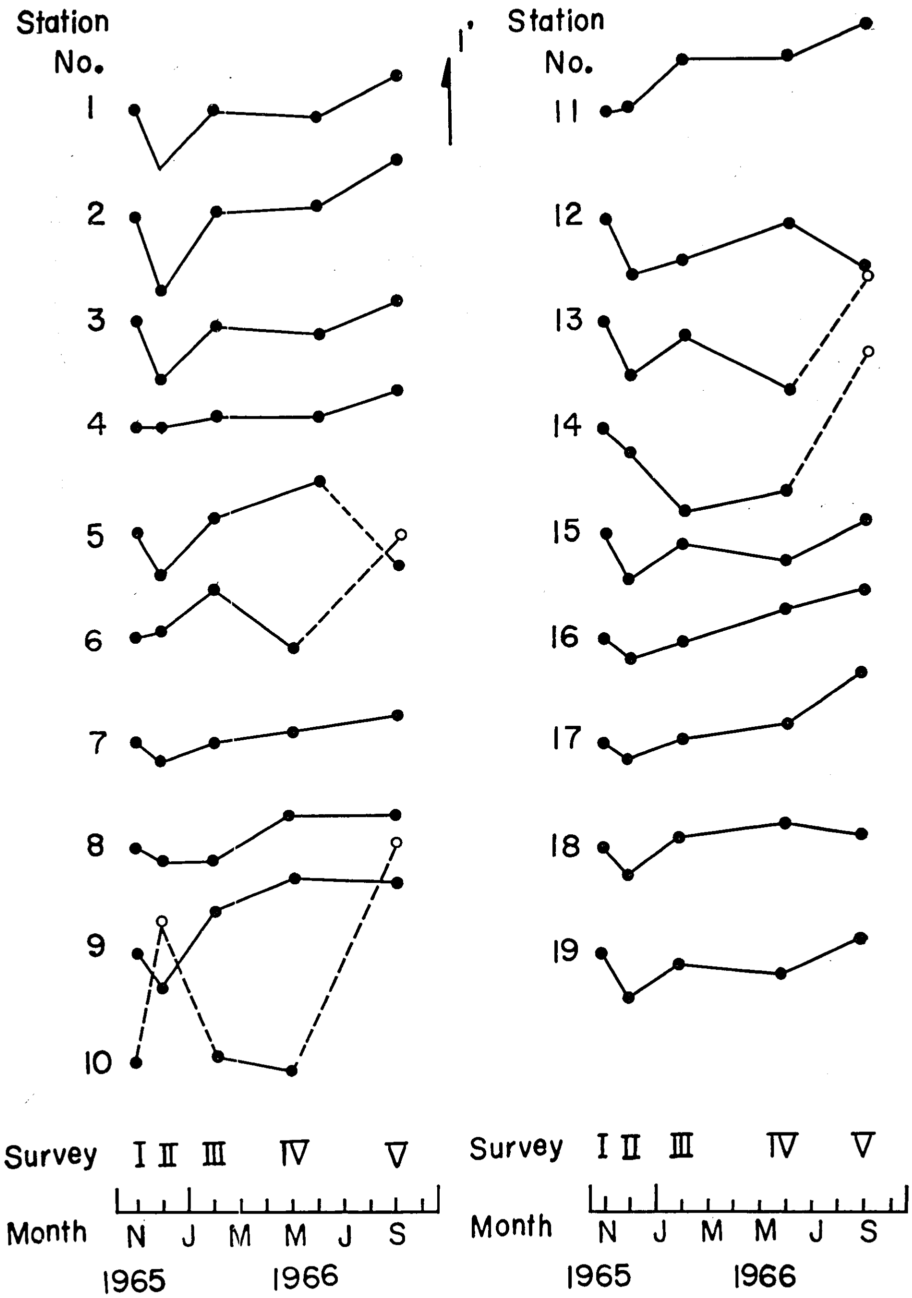

Fig. 7. Changes in the geomagnetic dip at each station over the Matsushiro area as observed by repeating magnetic dip survey.

tively explained by assuming a dipole-like source under Mt. Minakami-yama[7]. As has been briefly discussed before, the range of error in the present dip survey would be at most 1 minute of arc[4]. No station shows a larger change of $\Delta I_V - \Delta I_{IV}$ than this accuracy range, except those under unavailing conditions. It might be said, therefore, that no conspicuous changes could be found during a period from June to September, 1966. But it might not contradict the results of proton precession magnetometer observations, taking into account the smallness of changes in the total geomagnetic intensity observed at Station B (which corresponds to Station No. 18 in Table 3).

4. Discussion and concluding remarks

The activity of the Matsushiro Earthquake Swarm has become moderate since the middle of October, with larger earthquakes occurring sporadically around the edge of the seismic area. Although the array observation with a complete set of stations was not ready for the start

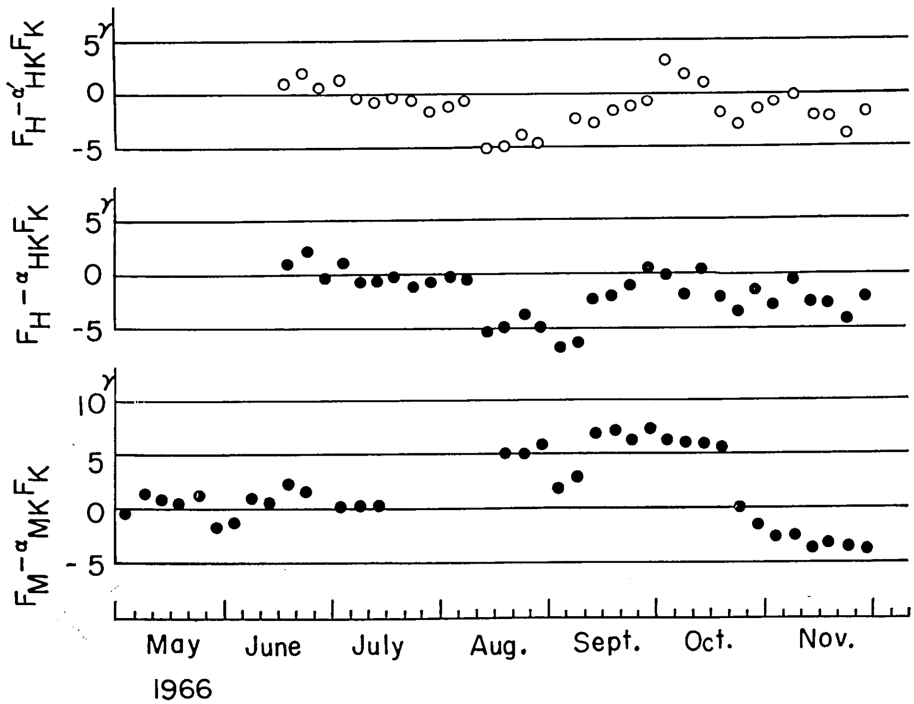

Fig. 8. Changes in the 5-day means of $F_H - \alpha'_{HK}F_K$, $F_H - \alpha_{HK}F_K$ and $F_M - \alpha_{MK}F_K$.

of the third activity, observational results at Matsushiro and Hoshina would give one of the best-established views of the so-called "seismo-magnetic effect" at the present stage. In order to see how the total geomagnetic intensity changed at these stations, it would be better to compare the observed values at Matsushiro and Hoshina with those at Kanozan, because other standard stations A and C had often suffered some instrumental errors. In case the data at Kanozan was used, we should take care of the spatial discrepancies of the natural geomagnetic disturbances between these stations. For a combination of Hoshina and Kanozan, the weighting factor α_{HK} was determined by the least squares method using data from June 16 to July 31. Weighted differences between Hoshina and Kanozan $(F_H-\alpha_{HK}F_K)$ were calculated in a fashion similar to the case of $F_M-\alpha_{MK}F_K$. The 5-day means were then estimated for $F_M-\alpha_{MK}F_K$ and $F_H-\alpha_{HK}F_K$, and are illustrated in Fig. 7.

During the first ten days of September, we see a decrease of about 5 gammas on both the curves in Fig. 7. As has been explained in the sub-section 2-1, such an apparent gap is brought about by anomalously large amplitudes of short-period variations at Kanozan. The estimated weighting factors are inappropriate at the time of bays and the like. For the case of Hoshina-Kanozan, we tentatively omitted the data observing bay-like events and calculated averages of the remainder, which is shown in the upper graph in Fig. 7. Such a procedure smoothed the original curve, and revealed another peak at the beginning of October.

The indicated increase might have something to do with the earthquake swarm which occurred around Nire Village a few kilometers north of Hoshina, although nothing certain can be said.

Both the stations seem to have varied quite independently of each other, but to have got become steady as the seismic activity became moderate. The observed variations of the total intensity could be explained by changes in the magnetization of underground rocks around the earthquake area. Judging from the rapidity of the recovering period, such changes of the magnetization would be caused by the piezo-magnetic effect rather than by an intrusion of hot materials.

The initial change at the beginning of August made us imagine an increase in the magnetization under the ground between Matsushiro and Hoshina. But the succeeding process made it difficult for us to infer such a common source, because F_H's showed a gradual recovery after initial decrease while F_M's stayed at an increased level towards the middle of October. Any changes corresponding to the sudden decrease of F_M on October 22 could not be found at Hoshina and Station S (Matsushiro Seismological Observatory). It is certain that the indicated gap was not caused by any artificial disturbances, so that it might be required to suppose very shallow and local sources for the changes at respective stations. Actually, we had observed that the dip changes were completely out of phase between the top of Mt. Minakamiyama and Station S (both of which are only 2 km apart) at the time of the First Activity (November to December, 1965).

Since the extensive stress in the $N-S$ direction would produce a magnetization to the north, the initial increase at Station B might be explained by assuming a magnetic mass just under Mt. Minakamiyama suffering such stress. Although similar speculations might be possible for every change at respective stations, it seems of little value because of the lack of other geophysical information.

It would be of importance, however, that the seismomagnetic changes around the Matsushiro-Hoshina area were found to be very local. In order to detect such local changes, magnetic surveys with a denser network of observational points would be necessary, together with continuous observations at a standard station. The maximum change in the total intensity at Matsushiro was about 10 gammas, so that expected changes in the geomagnetic dip would be at most 1 minutes of arc. Since the error range of our dip survey is also nearly the same amount, it is difficult to detect some possible changes; hence a survey with a portable proton precession magnetometer will be desirable in the future.

In conclusion the writers would like to express their gratitude to the local people, Messrs. K. and H. Ogawa at Station B, Mr. F. Baba at Station C, Mr. M. Miyazawa at Station D, Mrs. K. Unno at Station E and Mr. S. Tamai at Station F, with whose aid the present work could be performed. Geomagnetic data have constantly been supplied from the Kanozan Geodetic Observatory and the Matsushiro Seismological Observatory for which the writers are also thankful.

23. 松代地震群の地球電磁気学的調査 (5)

地震研究所 力武常次, 山崎良雄, 沢田宗久, 笹井洋一, 吉野登志男, 鵜沢聖治, 下村高史
信州大学 百瀬寛一

松代を中心とした群発地震は 1966 年 8 月に至つて，いわゆる第三の活動期と呼ばれる新たな高まりを示し，同年 9 月末頃まで続いた．特に注目されるのは皆神山を中心とした異常な地形変動でありその規模は 4 月の活動期に比べ，格段に大きい．北信地域に設置されたプロトン磁力計網によつて，われわれはこの第三の活動期に伴なう地磁気変化を検出することができた．

松代町平林における観測結果　松代における全磁力値 F_M を鹿野山の値 F_K と比較したのが Fig. 2 である．F_M は 8 月上旬に 5γ 程度増加し，10 月中旬までほぼこの状態を続け，10 月 22 日に至り急激に 10γ 程度の減少を示した．この突然の変化が人為的な擾乱によるものでないことは確かめてある．

保科における観測結果　地震活動の影響を受けていないと思われる中野の値 (F_N) と保科 (F_H) 松代 (F_M) とを比較したのが Fig. 3 である．さらに F_M-F_N, F_H-F_N の 5 日平均を示した Fig. 4 にはつきり見られる通り，保科では松代と異なり，8 月上旬における 5γ 程度の減少の後，全磁力値は徐々に回復し，10 月に入つて 8 月以前に比べ 5γ 程度の増加を示し，その後再び元の値に戻るという経過を示している．

その他の観測点の変化　既報の如く，現在北信地域では 7 ヵ所においてプロトン磁力計による全磁力観測が続けられている．地震域から十分離れた野辺山の値 (F_{NB}) を基準に，中野 (F_N) 保科 (F_H) 松代町平林 (F_M)，松代地震観測所 (F_{SO})，更埴 (F_{KS})，坂井村 (F_S) における 8 月から 11 月までの全磁力値を比較したものが Fig. 5 である．F_M, F_H を除いては顕著な変化は認められない．特に 10 月 22 日頃に，松代地震観測所の値に目立つた変化がない点は，松代町平林の変化と比べると注目すべきであろう．

地磁気伏角測量結果　1966 年 9 月 20 日から 24 日にわたつて，皆神山周辺の第 5 回目伏角測量を行ない．前回との差を求めて Fig. 6 に示した．大きな差のある測点は，標識の紛失等で前回の測定状況を再現できなかつた所で，これらを除くと明瞭な変化は認め難い．全磁力の観測結果から見て，期待される変化量は測定誤差と同程度と見なされる．

最後に F_M および F_H と F_K との重価差の 5 日平均を Fig. 8 に示した．地震に伴なう地磁気変化については従来から多くの報告があるが，ここに明らかにされた変化は現段階で最も信頼できる観測事実といえる．松代および保科の全磁力値は各々独立に変化しているようであり，F_{SO} の変化と考えあわせると，これらの地磁気変化は極く浅い局所的な原因によるものと思われる．特にその回復期間の早さから見て，高温物質の上昇によるとするより，地殻表層の応力変化によつて岩石の帯磁が変化したと考える方がよい．

この観測のプロトン磁力計の維持は現地の人々の御協力で行われている．松代町平林の小川清，小川久雄，中野市大俣の馬場啓，馬場文明，若穂町保科の宮沢正則，更埴市倉科の海野香澄，坂井村の玉井茂樹の諸氏に厚く感謝する．さらに地磁気観測記録を提供して下さつた気象庁柿岡地磁気観測所，国土地理院鹿野山測地観測所の方々に厚く感謝する．