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81. *Geomagnetic and Geoelectric Studies of the Matsushiro Earthquake Swarm (4).*

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Summary

A number of proton precession magnetometers have been set up over the Matsushiro earthquake area. One at Matsushiro indicated a definite increase in the total geomagnetic intensity and the other at Hoshina a decrease towards the end of August, 1966. These changes amount to some 5γ or a little larger. A marked change in the geomagnetic dip during a seven month's period was found around Mt. Minakamiyama in the central area of the earthquake swarm. These local anomalous changes are unlikely to be accounted for by an intrusion of hot material. An alternative interpretation due to a piezo-magnetic effect is considered.

1. Introduction

The activity of the Matsushiro Earthquake Swarm has been very high in April and May, 1966 and moderate during the following months until another high activity seems to have started in the beginning of August. Most of the earthquakes prior to the latest activity have been occurring around Mt. Minakamiyama and a town named Hoshina, a few kilometers north of Mt. Minakamiyama. According to the recent seismic observations, the epicentral area has been extending to the south covering parts of Koshoku City. Observations of ultra-microearthquakes made it clear that very small earthquakes are taking place further to the south-west.

In view of the most unusual seismic activity, it has been planned to intensify geomagnetic observation over the area. In addition to the proton precession magnetometer stations at Matsushiro (Station B) and Nakano (Station C), a similar observation was started at Hoshina (Station D) from June 16. Since Aug. 12 another magnetometer has been set up at Nobeyama in Nagano Prefecture in the hope of providing a standard station which is far enough from the seismic area, the distance between Matsushiro and Nobeyama amounting to about 60 km. Towards the end of September and the beginning of October, two proton precession magnetometer stations will be set up at Kurashina, Koshoku City by the Earthquake Research Institute and at Sakai Village by the Geological Institute, Shinshu University. The writers also gathered that a proton

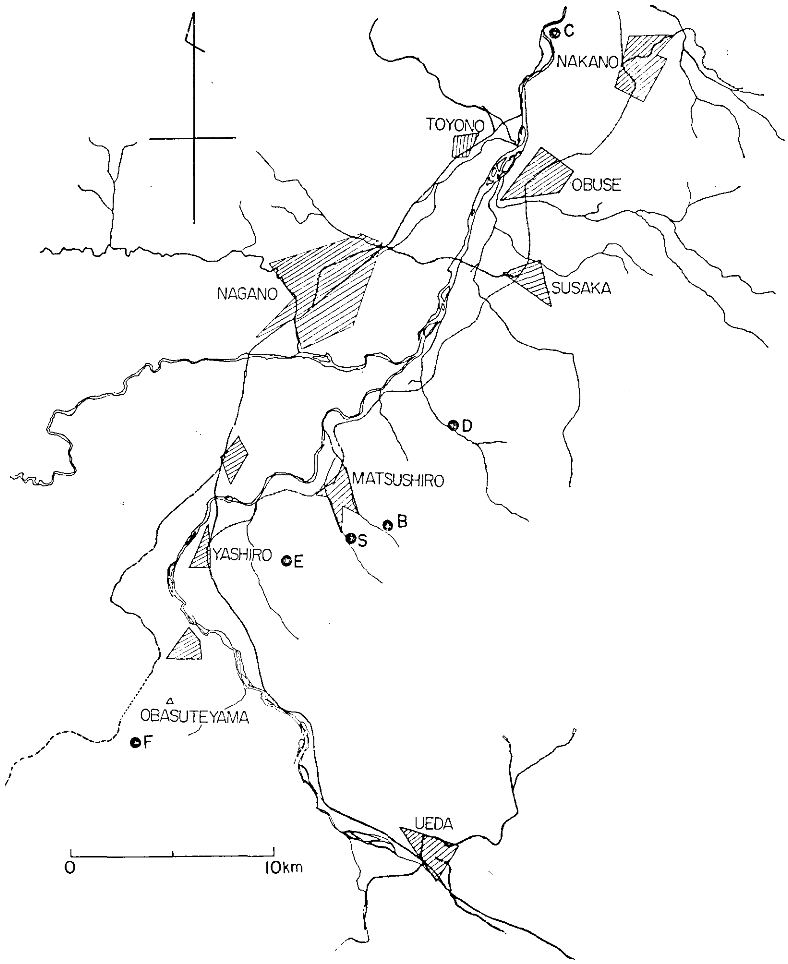

Fig. 1. Locations of station equipped with a proton precession magnetometer. B: Hirabayashi, Matsushiro, C: Omata, Nakano, D: Hoshina, Wakaho, E: Kurashina, Koshoku, S: Seismological observatory (Operated by the Kakioka Magnetic Observatory.), F: Sakai (Operated by the Shinshu University).

precession magnetometer has been at work at the Seismological Observatory at Matsushiro operated by the Kakioka Magnetic Observatory, Central Meteorological Agency. The locations of these magnetometers are indicated on a map in Fig. 1. It may be said, therefore, that an observation of possible changes in the earth's magnetic field in association with seismic activity is now going on around the Matsushiro area with a surprisingly dense array of proton precession magnetometers.

In Section 2 will be reported the results of the proton magnetometer observation although only those from Station B, C and D are available this time.

A magnetic dip survey was carried out over the Nakano-Matsushiro area during a period from June 8 to 12. The results will be examined in Section 3 in comparison with those of the previous surveys.

2. Proton precession magnetometer observation

2-1. Changes in the total geomagnetic intensity at Matsushiro (Station B) relative to Kanozan

The results of the proton precession magnetometer observation at Station B at the southern foot of Mt. Minakamiyama have been reported in the previous reports.[1),2),3)] The present report will cover the observation during a period from May 1 to September 9. As mentioned in the last paper,[3)] it is planned to make observations 6 times with a time-interval of 2 minutes at about 1-h in local time by making use of a clock work. This kind of observation system will be adopted throughout the stations covering the earthquake area. As we have to ask local people to take care of the instruments, the observation should be automatic. It is therefore given up to trace short-term changes in the geomagnetic field. Study on such changes, if any, will be later made by introducing a rubidium magnetometer.

The observed results are given in Table 1. In a similar fashion to the previous papers, mean values of individual measurement are classified as the daily mean. The daily mean values of total intensity observed at Station $B(F_M)$ and Kanozan (F_K) are given in Table 2. Although the observations at the Oshima magnetic Observatory have so far been used for the purpose of comparison in the previous papers, the writers intend hereafter to use only the observations at Kanozan because the changes

1) T. RIKITAKE et al., *Bull. Earthq. Res. Inst.*, **44** (1966), 363-408.
2) T. RIKITAKE et al., *Bull. Earthq. Res. Inst.*, **44** (1966), 409-418.
3) T. RIKITAKE et al., *Bull. Earthq. Res. Inst.*, **44** (1966), 1335-1370.

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

Date	Time	F_M
1966 May 1	1^h01^m	46906.0γ
	03	06.0
	07	06.0
	09	06.0
2	1 03	17.8
	07	20.1
	09	20.1
	11	17.8
3	1 01	10.7
	03	10.7
	05	06.0
	07	10.7
	09	10.7
	11	10.7
4	1 01	17.8
	03	17.8
	05	19.0
	07	19.0
	11	17.8
5	01	16.6
	03	17.8
	05	19.0
	11	16.6
6	1 01	21.3
	03	21.3
	05	21.3
	07	21.3
	09	22.5
	11	21.3
7	1 03	22.5
	07	22.5
	09	22.5
8	1 03	15.4
	07	19.0
1966 May 8	1^h09^m	46919.0γ
9	1 01	24.8
	07	24.8
	09	24.8
	11	22.5
10	1 03	19.0
	05	19.0
	07	19.0
	09	21.0
	11	19.0
11	1 01	28.4
	05	28.4
	07	29.5
	09	29.5
	11	28.4
12	1 01	30.7
	07	31.9
	09	31.9
	11	29.5
13	1 01	24.8
	03	24.8
	05	26.0
	11	24.8
14	1 01	23.7
	07	22.5
	09	22.5
	11	22.5
15	1 01	24.8
	03	24.8
	05	24.8
	07	26.0
	09	26.0
	11	26.0

(to be continued)

Table 1. (Continued)

Date	Time	F_M
1966		
May 16	1^h01^m	46924.8γ
	03	24.8
	5	23.7
	07	23.7
17	1 07	29.5
	09	29.5
18	1 01	22.5
	03	21.3
	09	22.5
	11	22.5
19	1 03	23.7
	05	23.7
	17	23.7
	09	23.7
	11	23.7
21	1 01	20.1
	03	21.3
	07	22.5
	09	23.7
	11	22.5
22	1 01	21.3
	05	21.3
	07	21.3
	09	22.5
	11	21.3
23	1 01	23.7
	05	23.7
	07	23.7
	09	23.7
24	1 01	23.7
	03	24.8
25	1 01	27.2
	03	26.0
	05	27.2
1966		
May 25	1^h07^m	46926.0γ
	11	27.2
26	01	24.8
	03	24.8
	05	26.0
	07	26.0
	09	26.0
27	03	46889.6
	07	91.9
	09	91.9
	11	90.8
28	1 01	95.5
	03	95.5
	05	94.3
	07	94.3
	09	95.5
	11	96.6
29	1 01	46908.4
	05	07.2
	07	08.4
	11	08.4
30	1 01	07.2
	03	07.2
	05	08.4
	07	08.4
	09	08.4
	11	09.6
13	01	15.4
	03	16.6
	05	15.4
	07	16.6
	09	16.6
	11	16.6
June 1	103	13.1

(to be continued)

Table 1. (Continued)

Date	Time	F_M	Date	Time	F_M
1966			1966		
June 1	1^h05^m	46913.1γ	June 8	1^h05^m	46922.5γ
	07	13.1		07	22.5
	09	13.1		09	22.5
	11	13.1		11	24.8
2	01	03.7	9	1 01	20.1
	03	03.7		05	17.8
	05	06.0		07	20.1
3	01	13.1		09	20.1
	03	13.1		11	17.8
	05	13.1	10	1 01	20.1
	07	13.1		03	20.1
	09	13.1		05	20.1
	11	13.1		07	20.1
4	01	17.8		09	22.5
	03	17.8	11	1 03	24.8
	05	17.8		05	27.2
	07	17.8		07	27.2
	11	20.1		09	27.2
5	01	15.4	12	1 03	22.5
	03	15.4		05	24.8
	05	17.8		07	23.7
	07	15.4		09	24.8
	09	15.4	13	1 01	13.1
	11	17.8		03	13.1
6	03	22.5		05	13.1
	09	24.8		09	15.4
	11	24.8	16	1 01	20.1
7	01	22.5		03	20.1
	03	22.5		05	20.1
	05	22.5	17	1 01	17.8
	07	22.5		03	17.8
	09	22.5		05	22.5
8	01	20.1		07	22.5
	03	20.1		09	22.5

(to be continued)

Table 1. (Continued)

Date	Time	F_M	Date	Time	F_M
1966			1966		
June 18	1^h01^m	46922.5γ	July 4	1^h11^m	46917.8γ
	03	24.8	5	1 05	29.5
	05	24.8		07	29.5
	07	24.8		09	29.5
	09	24.8		11	29.5
	11	24.8	6	1 01	15.4
19	1 01	31.9		03	15.4
	05	31.9		05	15.4
	07	31.9		07	15.4
20	1 01	31.9		09	17.8
	03	31.9		11	17.8
22	1 01	17.8	13	1 03	06.0
	03	20.1		09	06.0
	05	20.1		11	03.7
	07	17.8	14	1 03	10.7
	09	17.8		05	13.1
	11	20.1		09	10.7
24	1 01	06.0		11	13.1
	03	06.0	Aug. 18	1 01	22.5
July 1	1 01	17.8		03	22.5
	05	15.4		05	22.5
	09	15.4		07	22.5
	11	15.4		09	22.5
2	1 01	17.8		11	22.5
	03	17.8	19	1 01	27.2
	05	17.8		03	24.8
	07	17.8		05	27.2
	11	17.8		07	24.8
3	1 01	22.5		09	24.8
	07	22.5		11	24.8
4	1 01	17.8	20	1 01	13.1
	03	17.8		03	13.1
	07	17.8		05	13.1
	09	17.8		07	13.1

(to be continued)

Table 1. (Continued)

Date	Time	F_M	Date	Time	F_M
1966			1966		
Aug. 20	1^h09^m	46913.1γ	Aug. 26	1^h07^m	46920.1γ
	11	13.1		09	24.8
				11	22.5
21	1 01	15.4	27	1 01	22.5
	03	15.4		03	22.5
	05	13.1	28	1 01	24.8
	07	15.4		03	27.2
	09	15.4		05	27.2
	11	15.4		07	27.2
22	1 01	20.1		09	27.2
	03	20.1		11	27.2
	05	20.1	29	1 01	24.8
	07	20.1		03	24.8
	09	20.1		05	24.8
	11	20.1		07	24.8
23	1 01	20.1		09	24.8
	03	22.5		11	24.8
	05	22.5	30	1 01	31.9
	07	22.5		03	31.9
	09	22.5		05	31.9
	11	22.5		07	31.9
24	1 01	20.1		09	31.9
	03	20.1		11	31.9
	05	20.1	31	1 03	24.8
	07	20.1		05	22.5
	09	20.1		07	24.8
	11	20.1		09	27.2
25	1 01	15.4		11	24.8
	03	17.8	Sept. 1	1 01	46899.0
	05	17.8		03	96.0
	07	17.8		05	46901.3
	09	17.8		07	01.3
	11	17.8		09	01.3
26	1 01	22.5		11	01.3
	03	22.5			
	05	22.5			

(to be continued)

Table 1. (Continued)

Date	Time	F_M
1966		
Sept. 2	1^h01^m	46915.4γ
	03	17.8
	05	17.8
	09	17.8
	11	15.4
3	1 01	20.1
	03	20.1
	05	22.5
	07	20.1
	09	20.1
	11	20.1
4	1 01	46887.3
	03	87.3
	05	89.6
	07	89.6
	09	89.6
	11	89.6
5	1 01	80.2
	03	82.5
	05	82.5
	07	82.5
	09	84.9
	11	84.9
1966		
Sept. 6	1^h03^m	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

in F_M relating to the two observatories have been almost identical and, being an observatory on an active volcano, there would be a possibility that changes at Oshima might be contaminated by some volcano-magnetic effect.

In Table 2 are also included simple and weighted differences, i. e. F_M-F_K and $F_M-\alpha_K F_K$, where proportional constant α_K has already been determined. F_M, F_K, F_M-F_K and $F_M-\alpha_K F_K$ are graphically shown in Fig. 2. It is regrettable that the magnetometer at Station B was out of order some time in July and August because of certain defects in the amplifier and the recorder. It is noticed that in Table 2 the differences between F_M and F_K do not agree with the corresponding values of F_M-F_K. This is caused by the fact that some of the records of six F_M

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	$F_M-\alpha_K F_K$
May	1	46906.0$^\gamma$	45516.5$^\gamma$	1389.5$^\gamma$	−3.4$^\gamma$
	2	18.9	32.8	86.1	−1.9
	3	10.7	20.6	90.1	−1.5
	4	18.3	26.0	92.3	2.3
	5	17.5	24.8	92.7	2.3
	6	21.5	30.3	91.2	2.5
	7	22.5	34.2	88.3	0.7
	8	17.8	26.7	91.1	1.3
	9	24.2	33.0	91.2	3.3
	10	19.4	31.0	88.4	−0.1
	11	28.8	42.8	86.0	1.0
	12	31.0	44.8	86.2	1.0
	13	25.1	37.8	87.3	0.8
	14	22.6	34.8	87.8	0.4
	15	25.4	38.8	86.1	0.4
	16	46924.3	45536.5	1387.8	0.9
	17	29.5	41.5	88.0	−2.6
	18	22.2	33.3	88.9	1.1
	19	23.7	33.4	90.3	2.5
	20	—	—	—	—
	21	21.9	32.7	89.2	1.2
	22	21.6	31.0	90.6	2.0
	23	23.7	35.0	88.7	1.4
	24	24.3	37.5	86.8	0.2
	25	26.7	39.2	87.5	1.4
	26	25.5	37.2	88.3	1.6
	27	46891.1	45491.5	99.6	−0.7
	28	95.3	45503.2	92.0	−4.7
	29	46908.1	18.8	89.3	−2.8
	30	08.2	20.2	88.0	−3.8
	31	16.2	27.2	89.0	−0.7
June	1	13.1	45527.8	1384.3	−4.9
	2	04.5	12.5	92.1	−1.9
	3	13.1	21.0	92.1	0.6
	4	18.2	28.3	89.6	0.4

(to be continued)

Table 2. (Continued)

		F_M	F_K	F_M-F_K	$F_M-\alpha_K F_K$
June	5	46916.2$^{\gamma}$	45527.5$^{\gamma}$	1388.7$^{\gamma}$	−0.8$^{\gamma}$
	6	24.1	35.0	89.0	1.7
	7	22.5	32.8	89.5	1.6
	8	22.1	35.3	86.8	−0.5
	9	19.2	28.7	90.6	1.4
	10	20.6	31.5	89.2	0.8
	11	26.6	37.5	88.8	2.3
	12	24.0	35.2	78.4	−8.8
	13	13.9	26.0	97.7	7.6
	14	—	—	—	—
	15	—	—	—	—
	16	20.1	31.0	89.1	0.6
	17	20.6	32.5	88.6	0.4
	18	24.4	35.0	89.4	2.1
	19	31.9	41.8	90.5	5.1
	20	31.9	44.3	87.9	3.2
	21	—	—	—	—
	22	19.0	28.0	91.0	1.5
	23	06.0	09.7	95.5	0.9
	24	06.0	09.7	95.5	0.9
July	1	16.0	25.4	90.5	0.4
	2	17.8	27.8	89.8	0.3
	3	22.5	34.0	88.5	0.9
	4	17.8	30.0	87.8	−1.0
	5	29.5	44.9	84.1	−0.1
	6	16.2	25.8	90.4	0.3
	13	05.2	13.3	90.9	−1.9
	14	11.9	22.3	89.6	−1.5
Aug.	18	22.5	29.0	93.5	4.4
	19	25.6	31.0	94.6	6.1
	20	13.1	16.7	96.4	3.6
	21	15.0	19.3	95.7	3.7
	22	20.1	24.8	95.3	4.9
	23	22.1	27.0	95.1	5.4
	24	20.1	23.8	96.3	5.6
	25	17.4	22.2	95.2	4.1

(to be continued)

Table 2. (Continued)

		F_M	F_K	F_M-F_K	$F_M-\alpha_K F_K$
Aug.	26	46922.5γ	45527.5γ	1395.0γ	5.4γ
	27	22.5	28.5	93.5	4.4
	28	26.8	35.2	91.6	4.3
	29	24.8	29.8	95.0	6.1
	30	31.9	37.5	94.4	7.8
	31	24.8	29.8	94.6	5.9

observations each day are so poor that they have to be omitted. However, the mean values of F_M-F_K are made on the basis of individual observations for which both F_M an F_K are good enough.

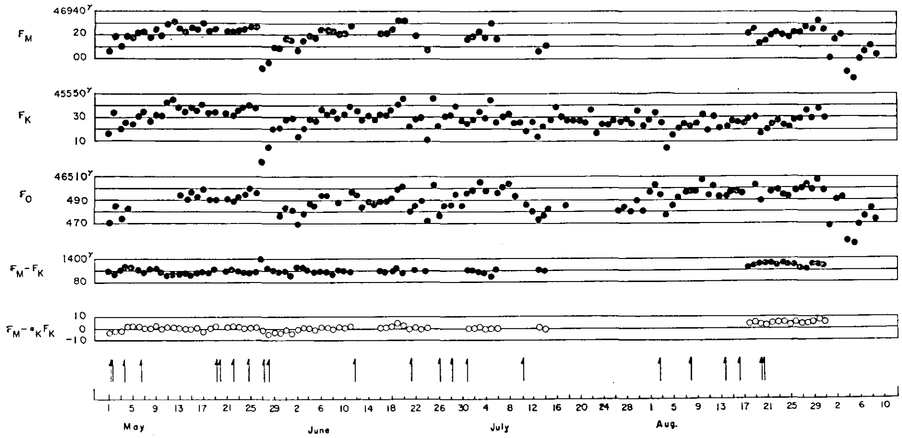

Fig. 2. Changes in F_M, F_K, F_O, F_M-F_K and $F_M-\alpha_K F_K$. Occurrences of large earthquakes having magnitudes 4 or so are indicated with arrows.

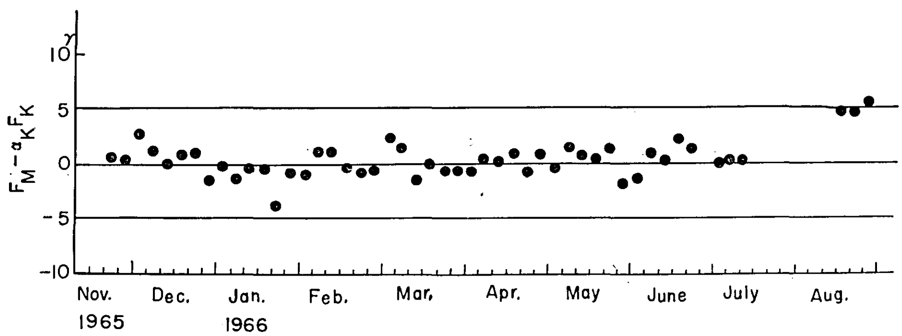

Fig. 3. Changes in the 5-day means of $F_M-\alpha_K F_K$.

In Fig. 2 is seen an increase in F_M relative to F_K towards the end of August. In order to bring out such an increase more clearly, 5-day means of $F_M-\alpha_K F_K$ are made and shown in Fig. 3. The definition of the 5-day mean has been given in the previous paper. Although the 5-day means have been fluctuating within a range of $\pm 2\gamma$ since the beginning of observation until July, it is noticeable that they jump up to the 5γ level in the later part of August. As has been thoroughly discussed by one of the writers (T. R.)[4], standard deviation of such a mean value would be 2γ or a little smaller, so that it can definitely be said that the total intensity of the geomagnetic field at Station B increased relative to that at Kanozan by an amount of 5γ or so.

It seems hard to correlate the day-to-day changes in F_M-F_K or $F_M-\alpha_K F_K$ to occurrences of individual earthquake. But it is interesting to note that the marked increase in F_M relative to F_K started when the seismic activity began to increase. It is also reported that an enormous speed of tilting of the ground, 0.5 sec. of arc per day or so say, has come to be observed by water-tube tiltmeters installed at the Seismological Observatory. An anomalously large extension of the ground in the north-south direction as well as an enormous land upheaval around Mt. Minakamiyama were also reported at the same time.

2-2. Changes in the total geomagnetic intensity as revealed by the Nakano-Hoshina-Matsushiro array

Although an anomalous upheaval of land had been reported around Toyono Town in December, 1965, repeated levelling surveys made it clear that no further progress of land deformation is going on there. Station C first aimed at catching geomagnetic changes, if any, that might be associated with the anomalous land deformation. Being far north of the Matsushiro area, Station C is thought unlikely to be very much affected by the seismic activity. Compared with the distance between the Kanozan Geodetic Observatory and stations in the Matsushiro area, however, the distances between B and C and D and C are much smaller. It is therefore natural to think that difference values of the total intensity between these stations would not be contaminated by unwanted fields originating from inequalities of S_q, D_{st} and the like. A reconnaissance study of day-to-day variations of F_M (Station B) and F_N (Station C) actually proved that ΔF_M and ΔF_N are nearly the same. If a proportional constant like α_K should be introduced, it is almost exact unity.

4) T. RIKITAKE, *Bull. Earthq. Res. Inst.*, **44** (1966), 1041–1070.

In Fig. 4 are shown F_M, F_N, F_H (Station D), F_M-F_N, F_H-F_N and F_M-F_H. F_N has been observed since the end of April at Station C, while F_H at Station D has been available only since the middle of June. Observation of F_M was suspended in some periods of July and August. F_N became unavailable towards the end of August because of an unexpected leakage of the water from the detecting coil of the proton precession magnetometer at Station C.

In spite of the intermittent observations, there is no doubt about the fact that F_M and F_H have been subjected to gradual changes relative to F_N during July and August. Looking at the F_M-F_N curve, we see that F_M-F_N was almost constant or very slightly increasing witn fluctuations of a few gammas although the values towards the middle of August definitely indicate an increase amounting to 5γ or so. As seen in the last subsection, F_M increased relative to F_K as well, so that it would not be unreasonable to suppose that F_M has been affected by the seismic activity around Station B.

It is also extremely interesting that F_H exhibits a decrease even more clearly since the beginning of August at which time violent activity started. The decrease in F_H relative to F_N is also 5γ or a little larger. If we make the difference between F_M and F_H, we can clearly see that the increase in F_M relative to F_H amounts to some 15γ during a period from the beginning of July to the end of August.

Unlike the observations by tiltmeters, geodimeters and the like, no appreciable changes related to the seismic activity have been observed

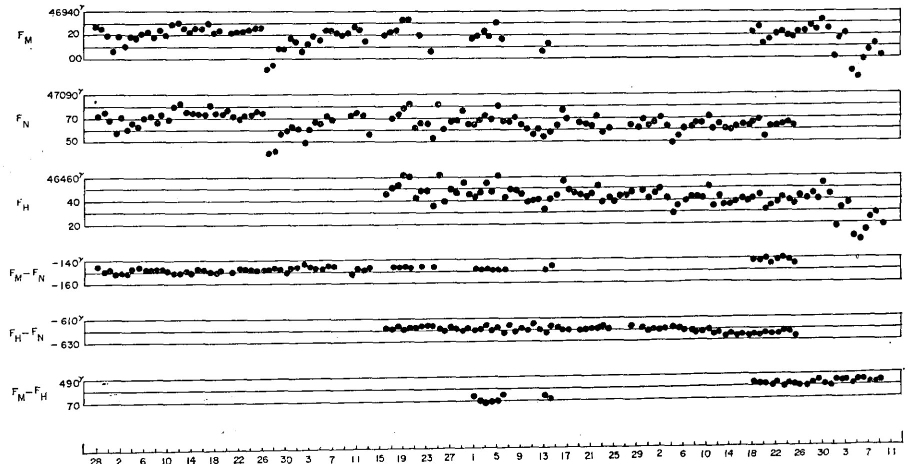

Fig. 4. Changes in F_M, F_N, F_H, F_M-F_N, F_H-F_N and F_M-F_H.

by magnetometers until the activity started at the beginning of August. The writers have become quite convinced, however, that significant geomagnetic changes are now taking place in the earthquake area around Matsushiro.

2-3. Proton precession magnetometer array covering Nagano Prefecture

As has already been briefly mentioned in the Introduction of this paper, seven sets of proton precession magnetometers will be at work in Nagano Prefecture from October, 1966. Of these, five will be operated by the Earthquake Research Institute and the remaining two by Shinshu University and the Kakioka Magnetic Observatory respectively. Although the magnetometer at the Matsushiro Seismological Observatory can measure the total geomagnetic force every minute, the others will usually be measuring 6 times with a time-interval of 2 minutes at about 1-h in local time. It is planned from the present time on to trace possible geomagnetic changes with the array of proton precession magnetometers over the Matsushiro earthquake area. It will be convenient to assume

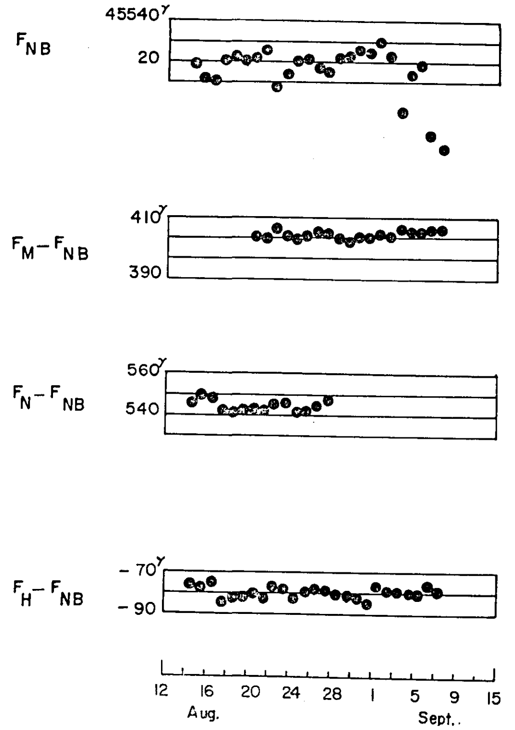

Fig. 5. Changes in F_{NB} and $F_N - F_{NB}$, $F_M - F_{NB}$ and $F_H - F_{NB}$.

that the geomagnetic field at Nobeyama, which is about 60 km distant from the earthquake area, is not affected by the seismic activity concerned.

Up to the present time, only F_M, F_N, F_H and F_{NB} (total intensity at Nobeyama) have been available since August, 1966. Fig. 5 shows the changes in F_{NB} and F_N, F_M and F_H relative to F_{NB}. As the period of observation is very short, however, Fig. 5 reflects the geomagnetic changes over the earthquake area only preliminarily. It is apparent that there was an increase in F_M and a decrease in F_H during August as can be seen in Fig. 5. Why we observe small fluctuations in $F_N - F_{NB}$ is not at present clear.

3. Magnetic dip survey over the Nakano-Matsushiro area

A magnètic dip survey by a second-order GSI magnetometer was carried out over the Nakano-Matsushiro area during a period from June 8 to 12. This is the fourth survey over the Matsushiro area and the

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

Station No.	Date	Time	I_M	I_K	ΔI_{IV}	ΔI_I	$\Delta I_{IV} - \Delta I_I$
1	June 8	11^h06^m	50°08.0′	47°54.4′	2°13.8′	2°13.7′	−0.1′
2	9	08 55	49 47.9	53.7	1 54.2	1 54.0	+0.2
3	8	17 00	50 20.5	54.0	2 26.5	1 26.7	−0.2
4	8	17 29	49 55.5	54.3	2 01.2	2 01.0	+0.2
5	8	18 21	49 58.9	54.4	2 04.5	2 03.5	+1.0
6	8	16 26	49 42.2	53.9	1 48.3	1 48.6	−0.3
7	9	11 24	50 07.8	53.0	2 14.8	2 14.6	+0.2
8	9	10 23	49 08.3	53.3	1 15.0	1 14.4	+0.6
9	9	9 53	49 50.7	53.3	1 57.4	1 56.0	+1.4
10	9	8 29	49 49.3	53.6	1 55.7	1 56.0	−0.3
11	9	10 49	50 03.5	53.2	2 10.3	2 09.3	+1.0
12	8	18 45	49 56.5	54.5	2 02.1	1 02.2	−0.1
13	8	15 00	49 49.8	54.5	1 55.7	1 57.0	−1.3
14	8	14 24	50 10.0	54.3	2 15.7	2 16.9	−1.2
15	8	13 52	51 12.1	54.3	3 17.8	3 18.3	−0.5
16	8	12 25	49 26.0	54.4	1 31.6	1 31.0	+0.6
17	8	11 49	49 13.3	54.7	1 18.6	1 18.2	+0.4
18	9	9 21	49 33.0	53.3	1 39.7	1 39.2	+0.7
19	8	12 53	54 17.7	54.5	6 23.2	6 23.6	−0.4

third one over the Nakano-Susaka area. The stations occupied by the present survey have frequently been shown on maps in the previous papers.

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 first, second, third and fourth surveys are denoted by subscripts I, II, III and IV respectively. $\Delta I_{IV} - \Delta I_{III}$ may give local changes at each station relative to Kanozan during a period from Survey III to Survey IV. The distribution of such changes are illustrated in Fig. 6. As

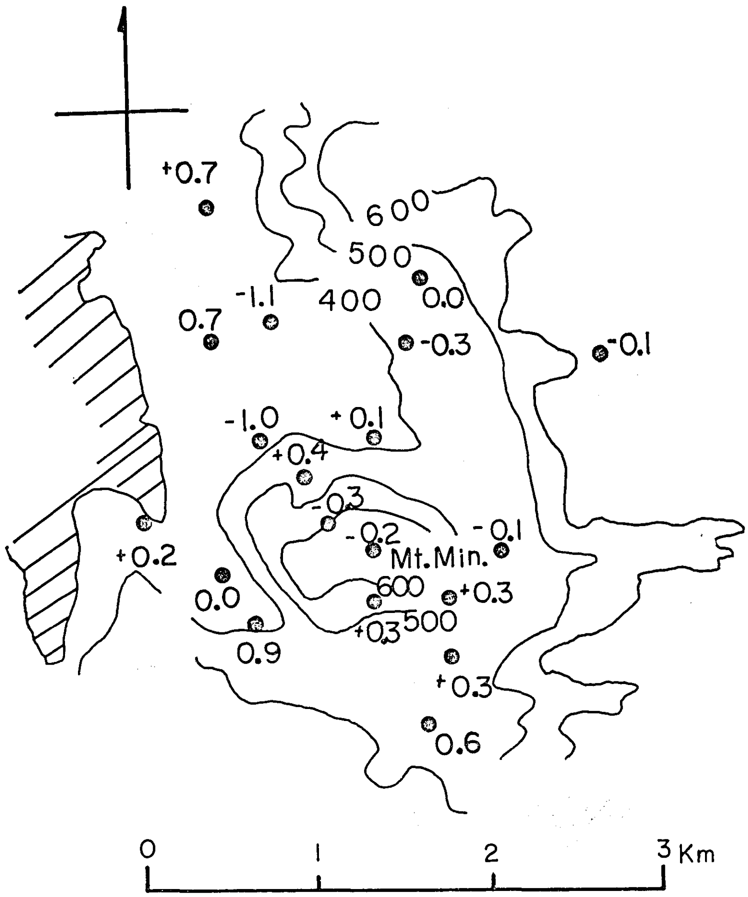

Fig. 6. Changes in the geomagnetic dip during the period from Survey III to Survey IV over the Matsushiro area.

discussed in the previous papers, however, most of the changes, which are so small that they do not exceed 1 minute of arc, may be within the range of error necessarily caused by the procedure of eliminating non-local changes. It is therefore concluded that no conspicuous changes in the geomagnetic field took place around Mt. Minakamiyama during a period from March to June, 1966.

Fig. 7 indicates how the geomagnetic dip changes at each station since Survey I. There is a tendency that the dip increased towards the south of Mt. Minakamiyama and decreased towards the north. The distribution of changes in the geomagnetic dip during the period from Survey I to Survey IV is shown in Fig. 8 on the basis of $\Delta I_{IV} - \Delta I_{I}$.

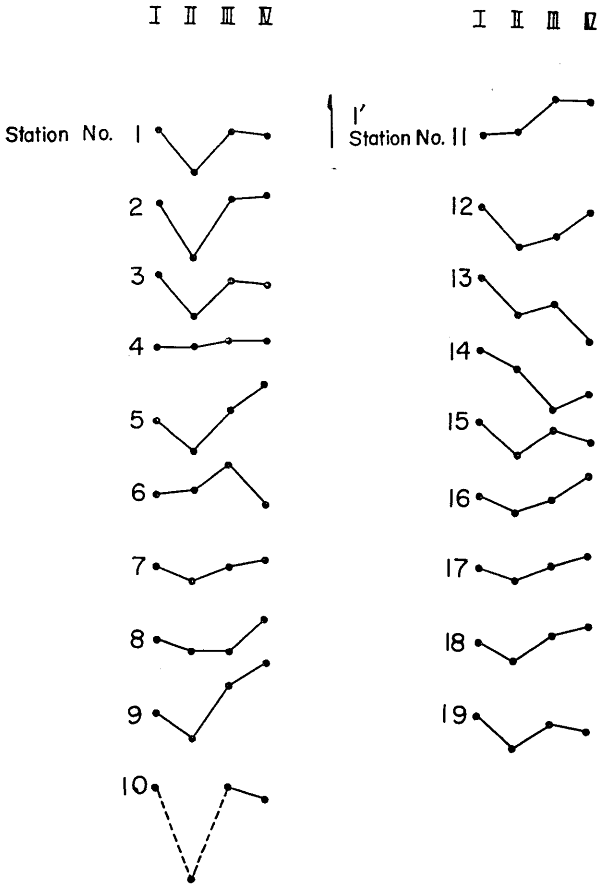

Fig. 7. Changes in the geomagnetic dip at each station over the Matsushiro area as observed by repeating magnetic dip surveys.

Although the changes thus detected are not very large, it may have something to do with the seismic activity judging from the fairly regular distribution as shown in Fig. 8. It is interesting that a regular pattern of local anomalous change in the geomagnetic dip is brought out by repeated surveys.

In a similar fashion, the results of the survey over the Nakano-Susaka area are listed in Table 4. The changes in dip between Survey II and Survey III are so small that they are probably of little significance although they are shown on a map in Fig. 9.

Table 4. The geomagnetic dip values related to Survey III over the Nakano-Susaka area. I_T denotes the surveyed data and I_K the data at Kanozan.

Station No.	Date	Time	I_T	I_K	ΔI_{III}	$\Delta I_{III}-\Delta I_{II}$	$\Delta I_{III}-\Delta I_{I}$
1	—	—	—	—	—	—	—
2	June 10	9^h51^m	50°11.1′	40°53.6′	2°17.5′	+0.6′	+0.7′
3	—	—	—	—	—	—	—
4	11	12 15	49 59.5	47 52.7	2 06.8	+0.3	+0.5
5	11	12 44	50 11.2	47 52.9	2 18.3	+2.5	+3.1
6	10	10 51	50 06.9	47 53.7	2 13.2	+0.6	+0.6
7	10	11 30	50 18.1	47 53.9	2 24.2	+0.7	+0.0
8	10	12 15	50 12.2	47 53.7	2 18.5	+1.0	+0.1
9	11	9 23	49 51.8	47 53.3	1 59.5	+0.7	+0.1
10	11	10 40	49 59.3	47 52.9	2 06.3	−1.0	+0.3
11	11	11 42	50 05.9	47 52.7	2 13.4	+0.3	+0.5
12	11	11 09	50 00.0	47 52.5	2 07.5	+0.2	+0.2
13	12	11 00	49 53.0	47 53.1	1 59.9	+0.1	+0.6
14	11	18 12	49 37.2	47 54.1	1 43.1	+1.6	+1.1
15	12	10 20	49 52.8	47 53.1	1 59.7	−0.3	+0.1
16	12	8 59	49 04.6	47 53.5	1 11.1	+0.6	−1.1
17	12	9 44	50 27.9	47 53.3	2 34.6	+0.5	−0.8
18	11	17 35	50 04.0	47 54.0	2 10.0	−0.8	+0.2
19	11	17 08	50 09.3	47 53.9	2 15.4	+0.5	+0.1
20	11	16 37	50 04.4	47 53.9	2 10.5	−0.9	−0.8
21	11	16 00	49 48.2	47 53.8	1 54.4	−0.1	−0.4
22	11	14 46	49 57.2	47 53.5	2 03.7	−0.7	−0.7
23	11	15 20	49 52.1	47 53.6	1 58.5	+2.4	−0.1
24	9	13 20	49 57.8	47 53.5	2 04.3	+0.1	+0.2
25	11	13 21	50.06.9	47 53.1	2 13.8	+0.1	−0.3
26	12	11 40	50 00.5	47 52.6	2 07.9	+0.3	—
27	11	10 01	48 58.0	47 53.2	1 04.8	+1.1	—

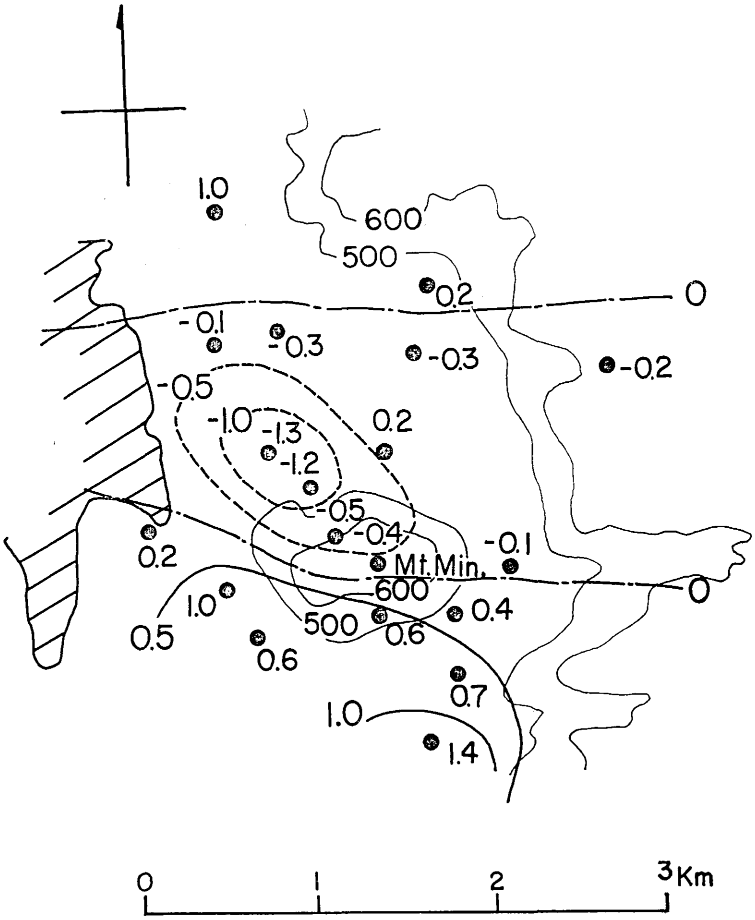

Fig. 8. Changes in the geomagnetic dip over the Matsushiro area during the period from Survey I to Survey IV.

4. Discussion and concluding remarks

Observation of the total geomagnetic intensity by proton precession magnetometers has been and will be intensified over the Matsushiro earthquake area. Up to the present time, the following can be concluded as a result of observation over a ten month's period.

The total intensity at Station B had been fluctuating within a range of $\pm 2\gamma$ since November, 1965 until a marked increase amounting to about 5γ in a month started in the beginning of August, 1966.

At the same time, the total intensity at Station D began to decrease with a speed of approximately 10γ per month. Such an increase and decrease seem to be slowed down at the middle of September.

Repeated magnetic dip surveys brought out a fairly regular decrease and increase, both amounting to approximately 1 minute of arc in the geomagnetic dip around Mt. Minakamiyama during a seven month's period. It seems likely that the change may be approximately accounted for if an underground magnetic dipole magnetizing roughly to the north is assumed beneath the mountain.

The relationship between the magnetic changes thus brought forth and the seismic activity is not clear. It should be noted, however, that no marked changes in the geomagnetic field were observed during a violent seismic activity in April. The numbers of earthquake occurrences per day during that activity were larger than those during the August activity when an increase and a decrease in the total intensity were clearly detected at Stations B and D respectively. However, land upheaval, extension and tilting of the ground as observed by other authors

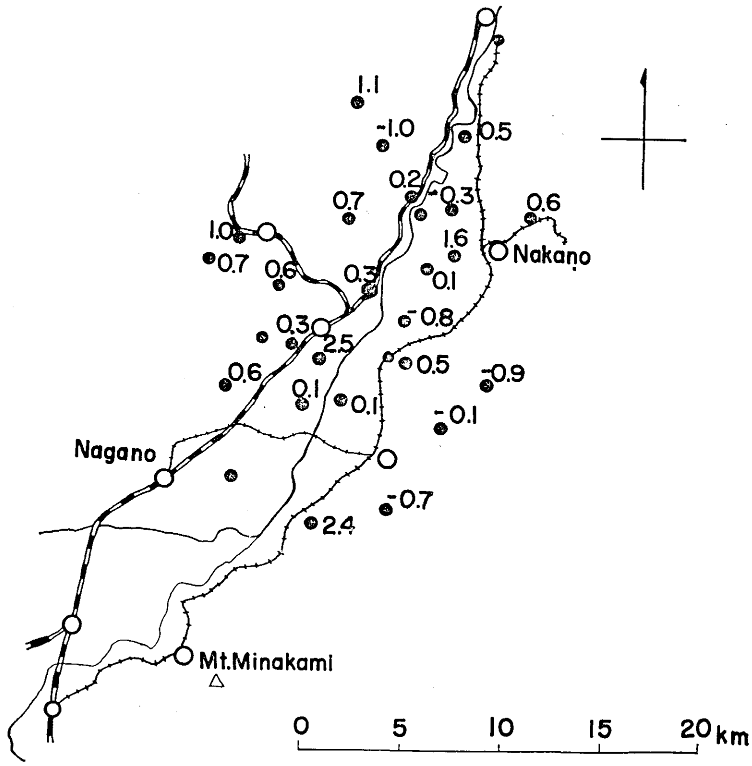

Fig. 9. Changes in the geomagnetic dip over the Nakano-Susaka area during the period from Survey II and Survey III.

were of a larger scale during the August activity than during the April one.

It is difficult to imagine what was taking place beneath the ground only from the changes as observed at Stations B and D. If it is assumed that the changes are caused by those in magnetization of a magnetic mass, the magnetization to the north would have been increased. The distance between B and D amounting to approximately 6 km, the depth of such a mass, if any, would be a few kilometers or so. It is hard to account for an increase in magnetization to the north by assuming an intrusion of high temperature magma or gases as far as an underground magnetic body situated somewhere between Stations B and D is presumed. It cannot be ruled out, however, that an explanation by magma or gases may be possible if a more tricky distribution of magma, rising under D and sinking under B say, is speculated.

A more likely cause would be some piezo-magnetic effect. In order to acquire a magnetization to the north as suggested by the observed results at Stations B and D, an extension in the north-south direction is required to have taken place. This is supported by the geodimeter work made by other authors. As mentioned in one of the previous papers[1], a geomagnetic change of the order of 10γ could be explained by assuming an underground magnetic mass of a few kilometers buried at a depth of a few kilometers provided the mass is subjected to a stress of the order 10–100 bars, intensity of magnetization being assumed as of the order of $10^{-3}-10^{-2}$ e. m. u. The stress prevailing at the earthquake area as suggested from the geodimeter work[5] amounts to the same order.

The change in the geomagnetic dip during the period from Nov., 1965 to June, 1966 also suggests that a volume underneath Mt. Minakamiyama acquired a magnetization approximately to the north direction. This is also difficult to be explained by an intrusion of hot material. If we assume an underground dipole magnetizing in the direction of the present geomagnetic field as the origin of the local anomalous field-change, the depth would be a few kilometers. The discussion about possible piezomagnetic effect is also applied to the present case. Although nothing is certain, the only possibility of accounting for the said change would seem to be to assume an extensional stress in the north-south direction.

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 and Mr. M. Miyazawa at Station D, with whose aid the

5) K. KASAHARA, *Personal communication.*

present work could be performed. Geomagnetic data have constantly been supplied from the Kanozan Geodetic Observatory, for which the writers are also thankful.

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81. 松代地震群の地球電磁気学的調査 (4)

地震研究所

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沢 田 宗 久
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鵜 沢 聖 治
下 村 高 史

松代地震は 1966 年 4 月頃に大きな活動期をむかえたが，8 月にはまたまた活発化している．この地震群を地球電磁気学的に研究するため，プロトン磁力計がつぎつぎに設置され，10 月初旬には長野県に 7 カ所になる予定で，かつてない精密観測といえよう．観測点は Fig. 1 に示すように，つぎの各点である．

B： 松代町平林――1965 年 11 月以降
C： 中野市大俣――1966 年 2 月以降
D： 若穂町保科――1966 年 6 月以降
E： 更埴市倉科――1966 年 9 月以降
S： 松代町地震観測所――気象庁所属．1966 年 8 月以降
F： 坂 井 村――信州大学所属．1966 年 10 月設置．

このほか，地震地域から約 60 km 離れた野辺山信州大学農場にも，8 月以降プロトン磁力計が設置され，地震活動の影響をうけない基準点となる予定である．

Station B の観測結果 毎日午前 1 時頃の 6 回の観測結果の平均値 F_M を，千葉県鹿野山測地観測所の値 F_K に対し比較した結果が Fig. 2 である．前報告に述べた重価差 $F_M-\alpha_K F_K$ の 5 日平均を示すと，Fig. 3 のようになり，8 月の活動期に際して，F_M が 5γ 程度増加していることがはつきりとわかる．

Station B, C および D の比較 中野は現在の地震域から遠く離れているので，一応ここの Station C を基準として，松代 (F_M) および保科 (F_H) との差をつくると，Fig. 4 のようになる．F_M-F_N の増加ならびに F_H-F_N の減少は非常にはつきりとみられ，F_M-F_H をつくると，約 15γ に達する変化が認められる．

このような結果から，保科――平林間の地下の帯磁が増加したことが想像されるが，もしそうだとすると，地下に高温物質が上昇したと仮定した場合に予想される変化とは逆になる．しかし保科と平林とで，独立に変化している可能性もあるので，断定的なことはいえない．

地磁気伏角測量 1965 年 11 月――1966 年 6 月の期間において，松代地域で 4 回，中野――須坂地域で 3 回の地磁気伏角測量が行なわれた．後者の場合には，いちじるしい変化が認められないが，松代地域では有意義と考えられる変化がとらえられている．

Fig. 7 は各測量ごとの相対的変化を各測点について示したものであるが，皆神山南方で伏角が増

加，北方で減少の傾向がみられる．Fig. 8は変化の分布を示したもので，皆神山地下にほぼ現在の地球磁場方向の帯磁が発生したとすれば説明できる．この結果も高温物質の上昇としては説明が困難で，南北方向の伸びに伴う帯磁の変化とするほうが考えやすい．

この観測のプロトン磁力計の維持は現地のひとびとに依頼して行なわれている．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，馬場忠司，若穂町保科の宮沢正則の諸氏に厚く感謝する．