Bulletin of the Earthquake
Research Institute
Vol. 45 (1967), pp. 919-944

47. *Geomagnetic and Geoelectric Studies of the Matsushiro Earthquake Swarm (6).*

By Tsuneji Rikitake, Takesi Yukutake,
Munehisa Sawada, Yoichi Sasai, Teruhiko Watanabe
and Hiroko Tachinaka,

Earthquake Research Institute.

(Read April 25, 1967.—Received June 30, 1967.)

Summary

A rubidium vapour magnetometer was operated at the top of Mt. Minakamiyama during the period from November 1966 to February 1967. Time variations in the field gradient over 100 m were observed. In order to eliminate the electric railway noises, magnetic variations were averaged during the period from one hour before to one hour after the earthquakes. Although random noises were reduced to the level less than 0.03γ, no marked variations that might be associated with earthquake occurrences were recognized.

Extremely local variations were noted in the field difference between the points of 100 m distance at the time of externally applied magnetic disturbances such as bays, diurnal variations and magnetic storms.

1. Introduction

Since October, 1965, we have been conducting magnetic measurements over the Matsushiro area to investigate any possible effects of seismic activity on the electromagnetic phenomena[1),2),3),4)]. Continuous

1) T. Rikitake, Y. Yamazaki, Y. Hagiwara, K. Kawada, M. Sawada, Y. Sasai, T. Watanabe, K. Momose, T. Yoshino, K. Otani, K. Ozawa and Y. Sanzai, "Geomagnetic and Geoelectric Studies of the Matsushiro Earthquake Swarm (1)", *Bull. Earthq. Res. Inst.*, **44** (1966), 363-408.

2) T. Rikitake, Y. Yamazaki, Y. Hagiwara, K. Kawada, M. Sawada, Y. Sasai and T. Yoshino, "Geomagnetic and Geoelectric Studies of the Matsushiro Earthquake Swarm (2)", *Bull. Earthq. Res. Inst.*, **44** (1966), 409-418.

3) T. Rikitake, T. Yukutake, Y. Yamazaki, M. Sawada, Y. Sasai, Y. Hagiwara, K. Kawada, T. Yoshino and T. Shimomura, "Geomagnetic and Geoelectric Studies of the Matsushiro Earthquake Swarm (3)" *Bull. Earthq. Res. Inst.*, **44** (1966), 1335-1370.

4) T. Rikitake, Y. Yamazaki, M. Sawada, Y. Sasai, T. Yoshino, S. Uzawa and T. Shimomura, "Geomagnetic and Geoelectric Studies of the Matsushiro Earthquake Swarm (4)", *Bull. Earthq, Res. Inst.*, **44** (1966), 1735-1758.

observation of the magnetic field gradient by a rubidium vapour magnetometer was newly enrolled in the geomagnetic survey project over the area, with special interest in a rapidly changing small variation which might be caused by seismic activity, as was reported by Breiner at the time of Californian earthquakes[5]. The rubidium vapour magnetometer was operated at the top of Mt. Minakamiyama from November 12, 1966 to April 4, 1967. This is a report of the results of the measurement by the magnetometer.

In section 2, the surroundings of the measuring points are described briefly. Whether or not there is any relation between earthquakes and the geomagnetic variations are examined in section 3. Extremely local variations caused by external origin field were revealed by the present observation and are discussed in section 4.

2. Location of the observation point

A rubidium vapour magnetometer was set up at the top of Mt.

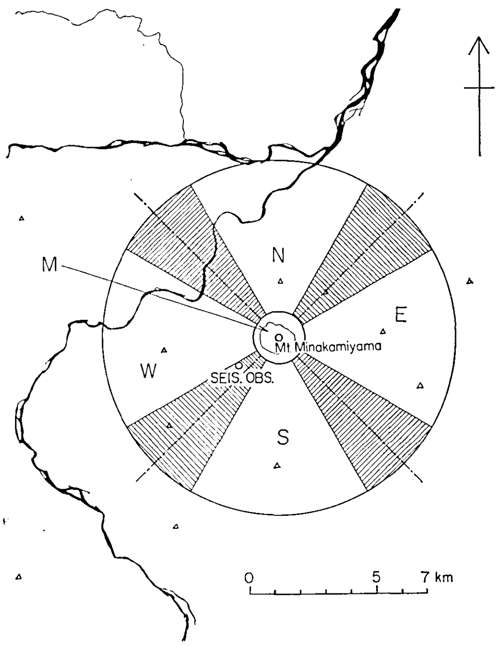


Fig. 1. Locality of observation point.

5) S. BREINER, "Piezomagnetic Effect at the Time of Local Earthquakes", *Nature*, **202** (1964), 790-791.

Minakamiyama in Matsushiro (Fig. 1) and operated as a gradiometer with two sensors from November 12, 1966 to February 22, 1967 and as a magnetometer of total force intensity with a single sensor from February 22, 1967 to April 4, 1967.

During the period of observation, the seismic activity continued to decrease. Average number of felt shocks during the period was 15.4 a day, which are only 4% of the number of felt shocks at the last peak of seismic activity observed on September 2, 1966 ($n=389$).

Two sensors were installed 98.5 m apart from each other. A sensor (B) was 65° east from the magnetic north of another sensor (A), being at a level approximately 16 m heigher than A. Total force intensity was measured as 47460γ at the site of sensor A and 47030γ at that of sensor B. Accordingly the magnetometer, when operated as a gradiometer, always measured the change in the field at A relative to B sensor.

As has already been reported, Mt. Minakamiyama, mainly composed of andesite lava[6], is the most magnetically anomalous in the Matsu-

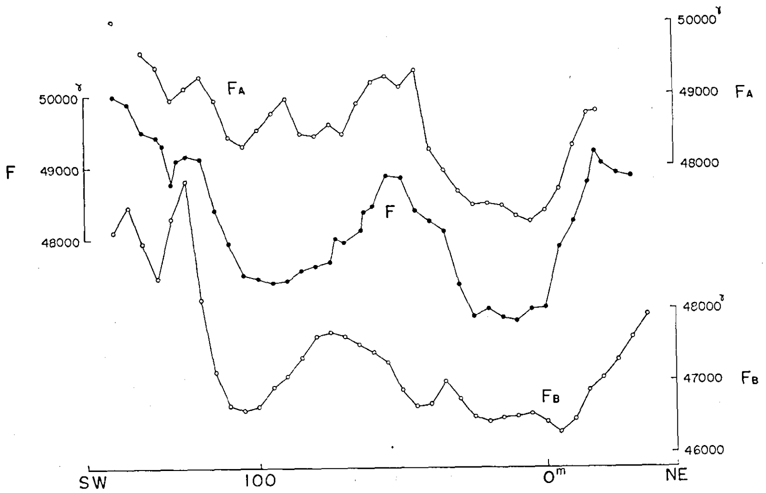


Fig. 2. Magnetic anomalies at the top of Mt. Minakamiyama. F is the anomaly profile on the track connecting the sensors A and B. Sensor B is located at the origin and sensor A at 100 m from the origin.

F_A is the anomaly profile on a track parallel with that of F, running 15 m southeast of the F-track. F_B is the anomaly profile on a track parallel with that of F, running 15 northwest of the F-track.

6) R. MORIMOTO, I. MURAI, T. MATSUDA, K. NAKAMURA, Y. TSUNEISHI and S. YOSHIDA, "Geological Consideration on the Matsushiro Earthquake Swarm since 1965 in Central Japan", *Bull. Earthq. Res. Inst*, **44** (1966), 423-445.

shiro area[7]. Natural remanent magnetization of rocks collected on the mountain is approximately 3×10^{-3} emu/gr on an average[7]. A quick survey at the top of the mountain indicates that a strongly localized anomaly runs from northwest to southeast as is seen in Fig. 2. F is the distribution of the total force intensity along the two sensors. Locality of sensor B is taken as origin. Sensor A is situated at a point 100 m from the origin. F_A and F_B are the results of surveys conducted along tracks parallel to that of F_A, each running along different sides of the F_A route at 15 m distance. An anomaly of 2000 γ can be seen in this narrow area. The two sensors were placed at approximately two minimum points in the area.

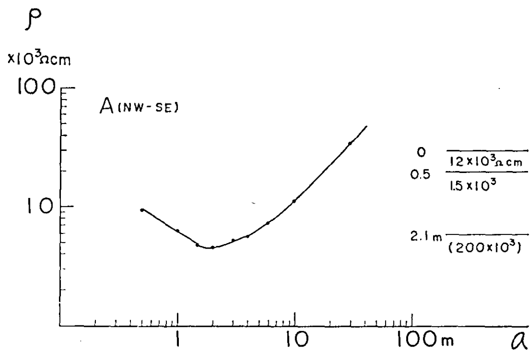


Fig. 3-a. Results of measurements at the A site in the NW-SE direction.

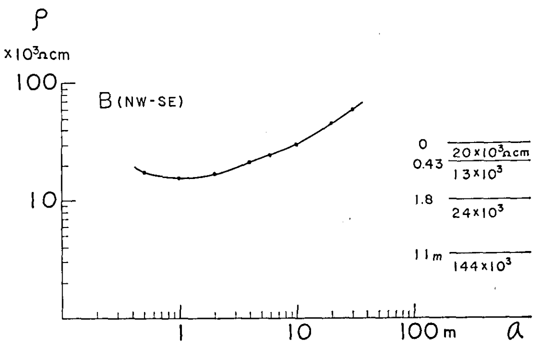


Fig. 3-b. Results of measurements at the B site in the NW-SE direction.

Fig. 3. Results of resistivity measurements at the top of Mt. Minakamiyama. ρ, apparent resistivity: a, distance between the electrodes.

Resistivities of the ground under the two sensors and under an intermediate point between the sensors were measured with an L-10 instrument which was similar to a Megger instrument[8]. Measurements were conducted with four electrodes buried in the direction of the two sensors (NE-SW) first and then in an orthogonal direction (NW-SE). Since the magnetic anomaly is lineated from northwest to southeast, the measurements along the NW-SE direction are more likely to represent the vertical distribution of the electrical resistivity under the measuring points.

Fig. 3 (a) through (e) show the results of the measurements on diagrams of apparent resistivity (ρ) versus the distance between the

7) *ibid.*, 1).

8) K. KAWADA, "Electric Resistivity Measurement along and across a Ground Fissure in the Matsushiro Area", *Bull. Earthq. Res. Inst.*, **44** (1966), 1759-1770.

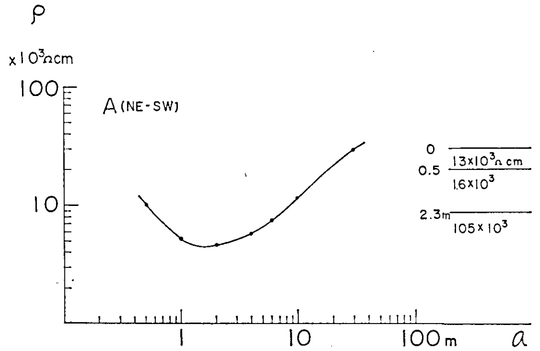


Fig. 3-c. Results of measurements at the A site in the NE-SW direction (along the line connecting the two sensors).

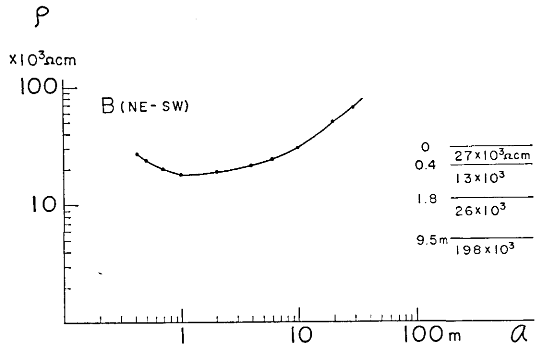


Fig. 3-d. Results of measurements at the B site in the NE-SW direction (along the line connecting the two sensors).

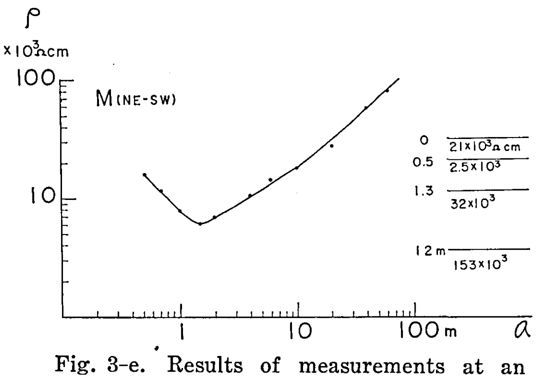


Fig. 3-e. Results of measurements at an intermediate point between the A and B sites in the NE-SW direction (along the line connecting the two sensors).

electrodes (a). Resistivity distributions obtained from $\rho-a$ relation are together shown on the diagrams. These indicate that the ground is covered with sediments of approximately 0.5 m thickness with relatively high resistivity of $10\sim20\times10^3\Omega$ cm and a low resistive layer underlying the surface sediments with a highly resistive layer appearing at about $10\sim20$ m depth. The resistivity distribution at the B site differs from that at the A site in the second layer of which the resistivity is large by approximately a factor of ten.

Although magnetic variations larger than 0.03γ can be read on a magnetogram, irregular fluctuations due to stray currents by electric railways amount to 0.2γ in the day time, the accuracy of measurements being restricted by this noise level.

3. Magnetic variation at the time of earthquakes

There are phenomena of various time durations which might cause geomagnetic variation before and after an earthquake. Temperature variation under the ground is one of the possible causes for producing a magnetic change at the surface as in the case of volcanic eruption[9]. If this happened to be the case, the magnetic variation expected should be very gradual, perhaps over several months. Accumulation or release of stress is noted as a possible mechanism to produce magnetic change[10],[11]. The process of stress accumulation or release under the ground has not been made clear as yet. If the magnetic variation due to the stress effect could be successfully detected, continuous observation of geomagnetic field might provide an important clue to the study of stress distribution and its changes under the ground. In this case, it is expected that the magnetic variation might cover wide range of phenomena from several months phenomena to instantaneous ones, corresponding to very slow accumulation of stresses preceding an earthquake and a sudden release of it. In this paper, an attempt is made to detect rather rapid change which might be associated with stress variation during two hours before and after the earthquake.

The variation in the field gradient is more pronounced in the area where the magnetic field distributes irregularly than in the area of uniform field. Accordingly, the present location where the magnetic field is highly anomalous is most suited to detect magnetic changes in the field gradient, if they exist, associated with earthquakes.

Magnetograms during the period from November 13, 1966 to February 22, 1967 were carefully examined. But no marked change beyond the noise level (approximately 0.2γ) caused by electric railway currents was observed at the time of earthquakes, of which the magnitudes were larger than 3.5 and took place within 7 km distance from Mt. Minakami-yama.

Magnetic fields caused by electric railway currents vary at random in time. In the hope of detecting the seismomagnetic variation, we attempted to reduce the random noises by superposing the records with reference to a seismic event. Magnetograms were read at 1 minute intervals during two hours, taking the time of earthquake occurrence as the origin, from one hour before to one hour after the earthquake. Field values thus read from different magnetograms were averaged to give a single magnetogram in which random noises were obliterated by

9) T. RIKITAKE and I. YOKOYAMA, "Volcanic Activity and Changes in Geomagnetism", *J. Geophys. Res.*, **60** (1955), 165-172.

10) F. D. STACEY, "The Seismomagnetic Effect", *Pure Appl. Geophys.*, **58** (1964), 5-22.

11) T. YUKUTAKE and H. TACHINAKA, "Geomagnetic Variation Associated with Stress Change within a Semi-infinite Elastic Earth Caused by a Cylindrical Force Source", *Bull. Earthq Res. Inst.* in press.

superposition and any variations inherent to seismic event were left unaltered as an averaged form with respect to the origin time.

Study of the initial motions of earthquakes which took place in the Matsushiro area has revealed that more than 90% of the earthquakes examined start with "push" motion in the north and south quadrant and with "pull" motion in the east and west quadrant[12),13),14)]. The nodal lines so far determined lie in the direction N 45±15° E and N 45±15° W. This fact substantially simplifies the present analysis. The earthquakes in each quadrant of Fig. 1 exert the same effect on magnetization of rocks around Mt. Minakamiyama. When an earthquake takes place at any part of the northern quadrant, for example, Mt. Minakamiyama is always included in the southern push area. Taking into consideration that the directions of the nodal lines change within a range of ±15° from time to time, the earthquakes which occurred within the hatched areas (±15° from NE-SW and NW-SE), were excluded from the present analysis.

The earthquakes examined here are restricted to those of which the magnitude is greater than 3.0, their foci being shallower than 7 km depth and distributed within a distance of 7 km from Mt. Minakamiyama (Fig. 1). The largest earthquakes during the observed period took place in the north of Mt. Minakamiyama on Dec. 6 and 12, 1966 and Jan. 4, 1967, having a magnitude of 4.5. The numbers of the earthquakes used for the present study are listed in Table 1.

Table 1. Numbers of the earthquakes examined in this study

	$M \geqq 4.5$	$4.5 > M \geqq 4.0$	$4.0 > M \geqq 3.5$	$3.5 > M \geqq 3.0$	
North quadrant	3	3	6	17	29
South quadrant		2	1	2	5
East quadrant		4	2	13	19
West quadrant		1	1	5	7
M-area				6*	6
	3	10	10	43	66

*) Earthquakes of magnitude less than 3.0 are also included.

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

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

14) M. ICHIKAWA, "Statistical Study of the Focal Mechanism of Matsushiro Earthquake Swarm," *Zisin*, **20** (1967), 116-127.

Magnetograms read at 1 minute intervals were averaged for the earthquakes of each quadrant. Those which took place in the region M (Fig. 1) were treated separately, because the distribution of stresses in the epicentral area is not known for certain.

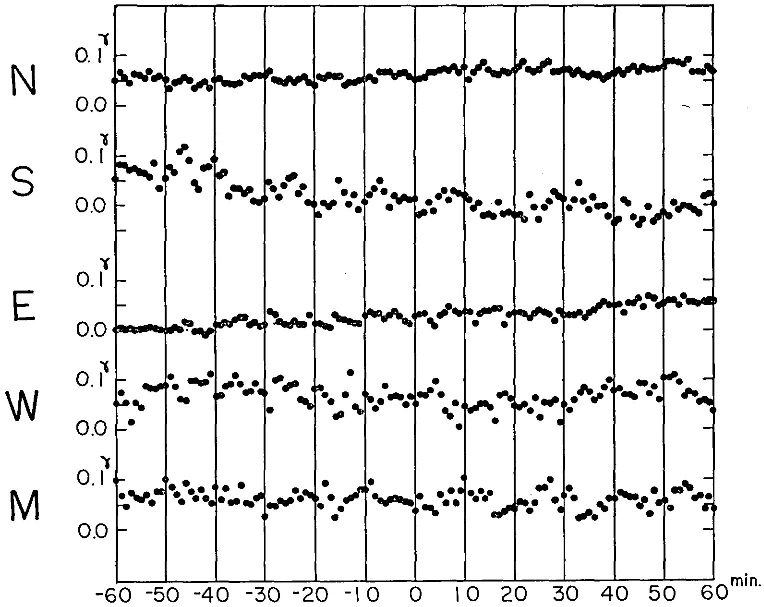


Fig. 4. Averaged variations in the field difference for each quadrant, taking the time of earthquake occurrence as the origin.

The results are shown in Fig. 4. Mean values for the south quadrant are considerably scattered. It is probably due to the scarcity of samples examined with the noises of the electric railways still contaminating the result. When the number of samples becomes large, such as for the north quadrant, the noises due to electric railways are nearly cancelled out. However, no such fluctuation in the magnetic field as can be ascribed to the seismomagnetic effect is recognizable.

In Fig. 5 magnetograms read for the earthquakes which occurred at midnight are shown for comparison, indicating that the railway noises become very slight in the night-time.

It may be concluded that the magnetic variation exceeding the noise level of 0.2γ cannot be observed at the time of shallow earthquakes having a magnitude greater than 3.0 and that, when a sufficient number of magnetograms are averaged, the noise level can be lowered to less

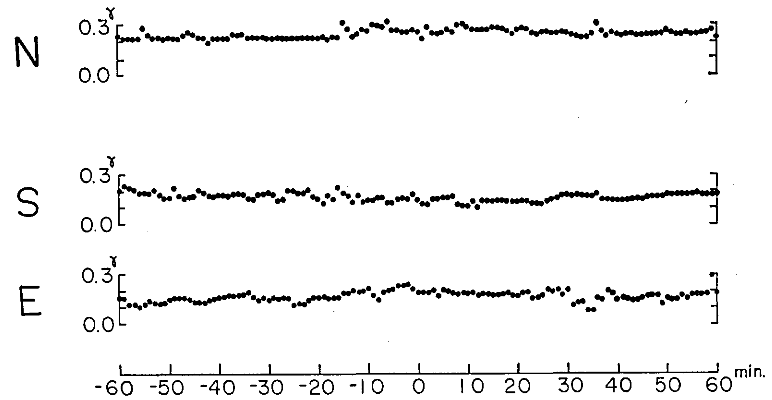


Fig. 5. Field differences when earthquakes took place at midnight.

N: Magnetogram when an earthquake of M=4.5 occurred at a depth of 4.7 km in the north quadrant at $1^h 12^m$ on December 12, 1966.

S: Magnetogram when an earthquake of M=4.1 occurred at a depth of 5.1 km in the south quadrant at $2^h 04^m$ on November 25, 1966.

E: Magnetogram when an earthquake of M=4.0 occurred at a depth of 3.9 km in the east quadrant at $3^h 08^m$ on January 30, 1967.

than 0.03γ but no magnetic change which might be associated with seismic activity is noted during two hours, one hour before and after the earthquakes.

4. Extremely local variation in the geomagnetic field

4-1. Local variation in the geomagnetic field

It was to eliminate magnetic disturbances of external origin such as magnetic storms, bay type disturbances etc. and to extract purely local variation originating from under the ground that the two sensors were used and the field gradient was measured. It has been widely accepted that such external variations extend over several hundred kilometers and no difference is recognizable within a distance of a few kilometers.

However, continuous observation of field gradient by a rubidium magnetometer revealed the existence of extremely local variation caused by external magnetic disturbances. Records on magnetically disturbed days were read at two minute intervals and are plotted as in Fig. 6. ΔF shows the field differences in total intensity between the two sensors set up at a distance of 99 m at the top of Mt. Minakamiyama. H_s and F_s are the horizontal component and the total force intensity observed

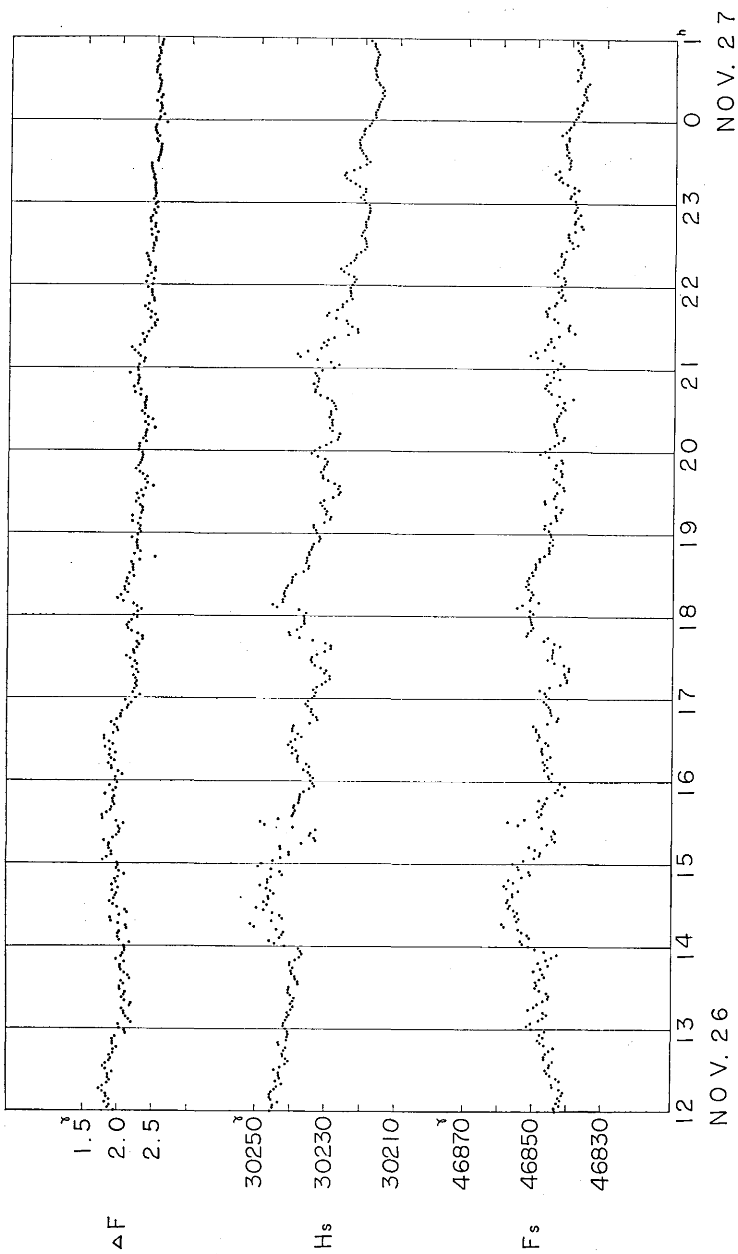
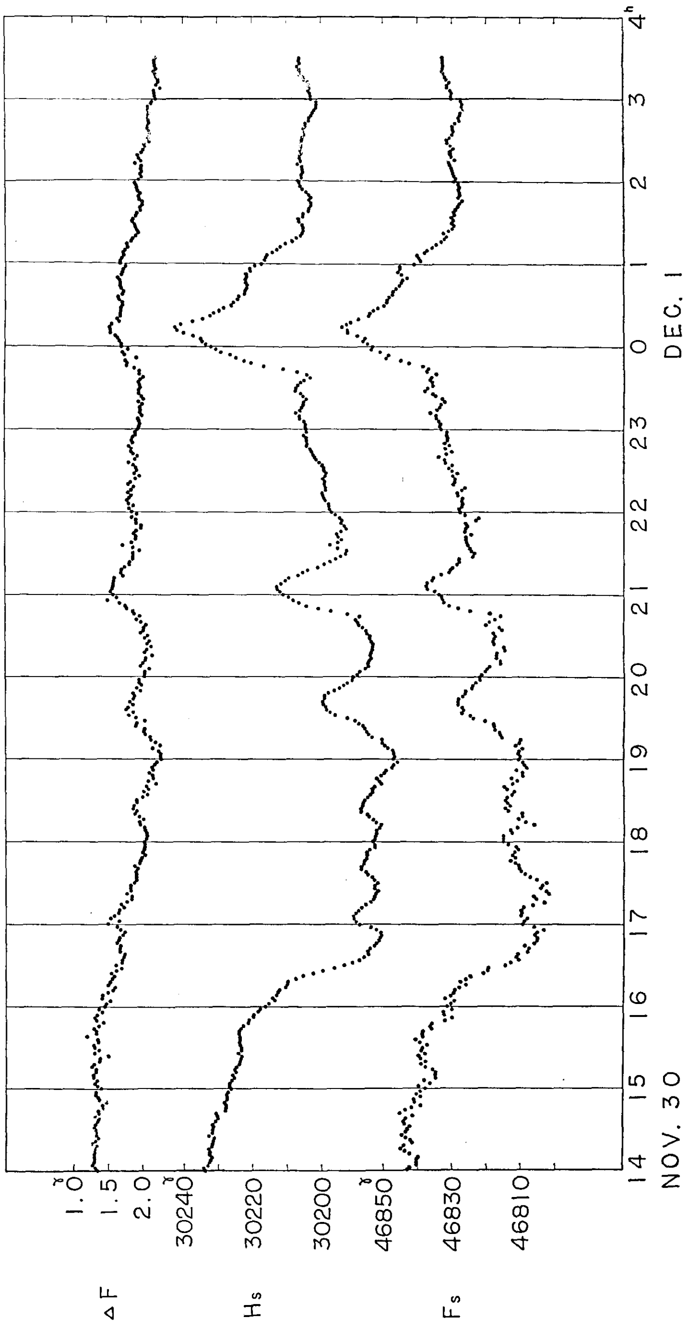

ΔF
Hs
Fs
1.5
2.0
2.5
30250
30230
30210
46870
46850
46830
12
13
14
15
16
17
18
19
20
21
22
23
0
1h
NOV. 26
NOV. 27

Fig. 6-a.



ΔF
Hs
Fs
γ 1.0
1.5
2.0
γ 30240
30220
30200
γ 46850
46830
46810
14
15
16
17
18
19
20
21
22
23
0
1
2
3
4h
NOV. 30
DEC. 1

Fig. 6-b.

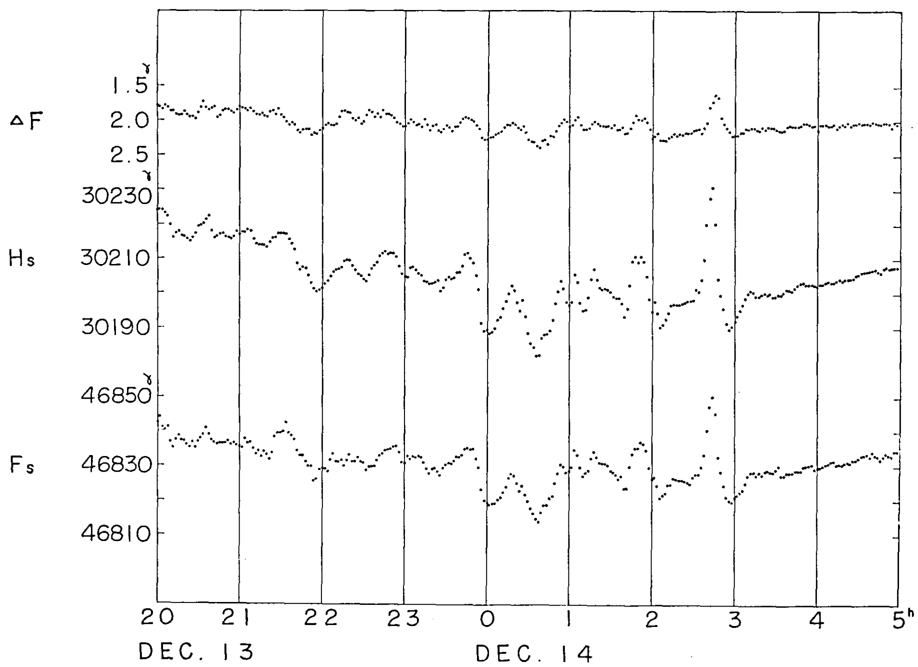


Fig. 6-c.

Fig. 6. Geomagnetic variations on magnetically disturbed days. ΔF is the field difference observed at the top of Mt. Minakamiyama. H_s and F_s denote the horizontal intensity and the total force intensity at the Matsushiro Seismological Observatory.

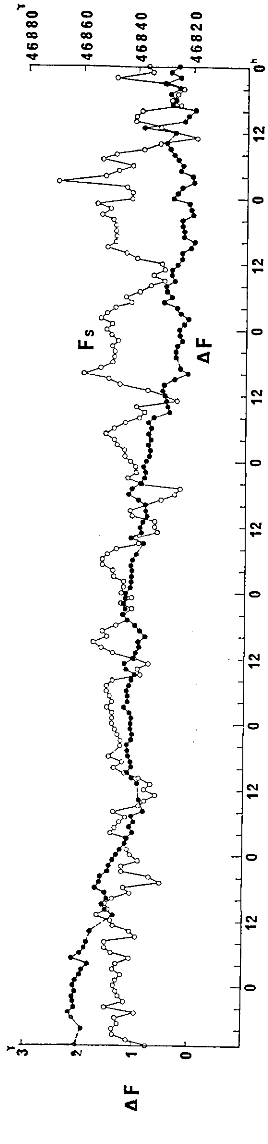


Fig. 7-a1.

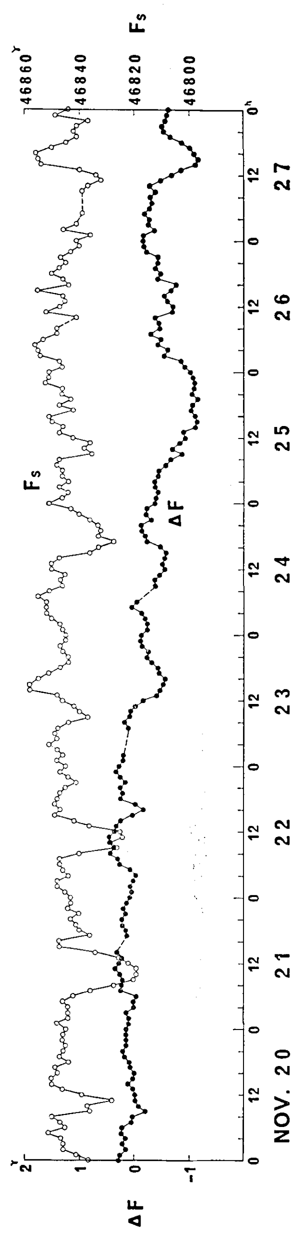


Fig. 7-a2.

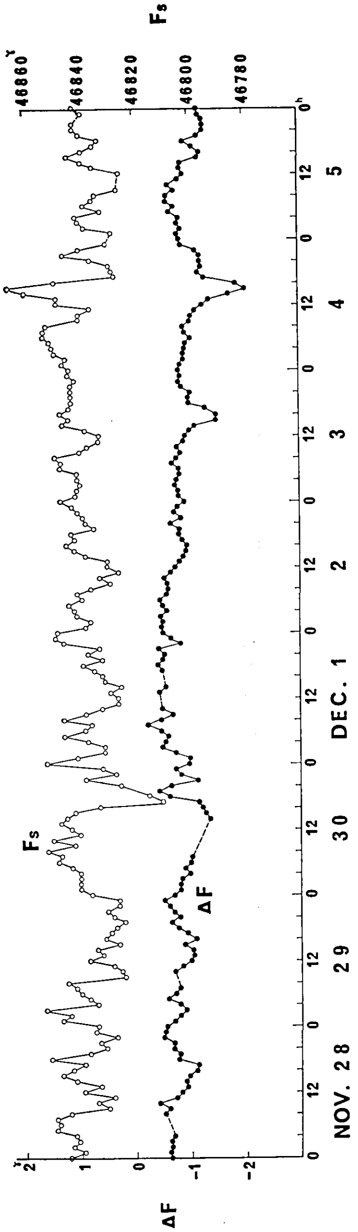


Fig. 7-b1.

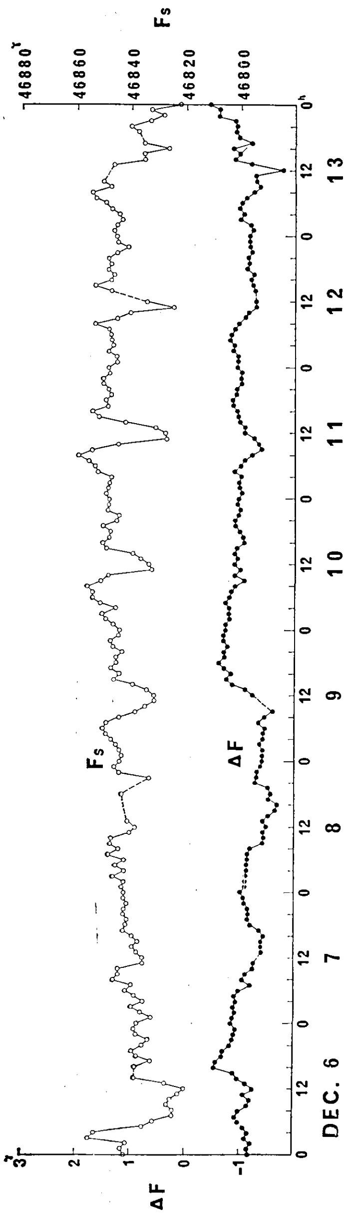


Fig. 7-b2.

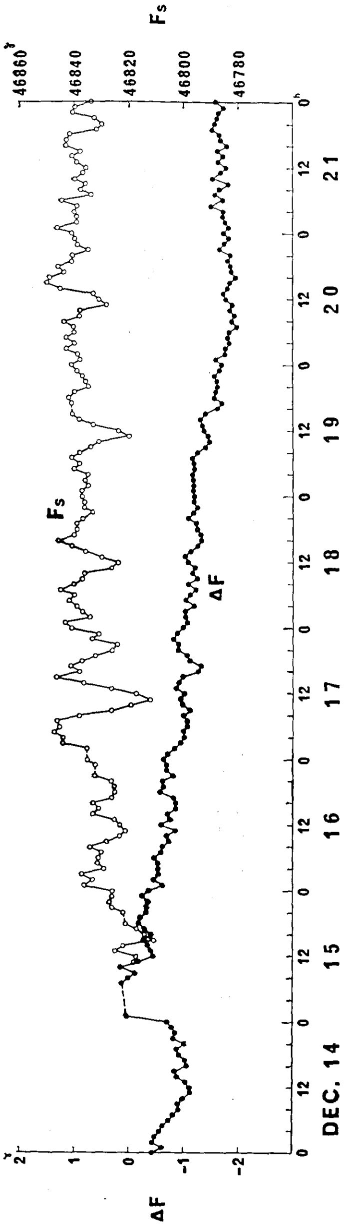


Fig. 7-c1.

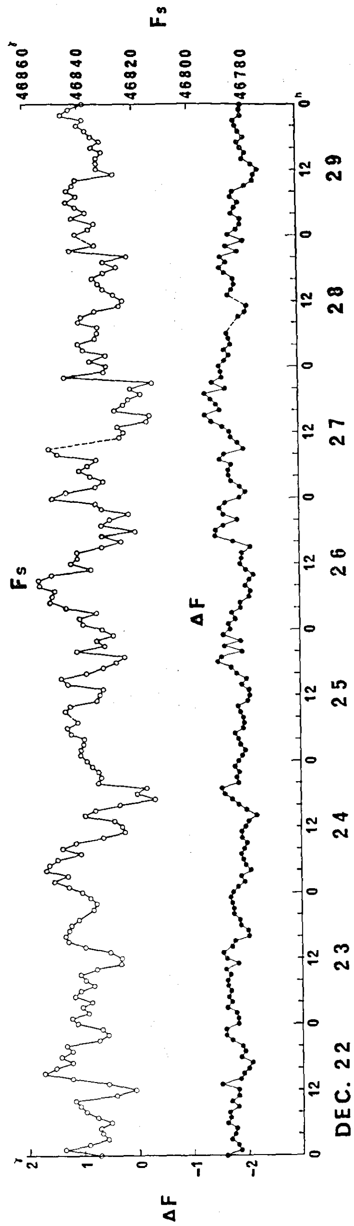


Fig. 7-c2.

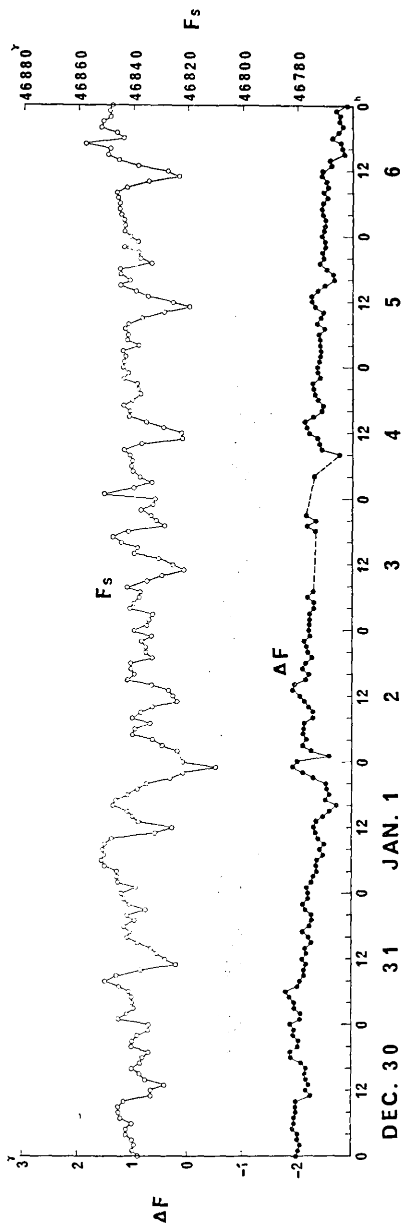


Fig. 7-d1.

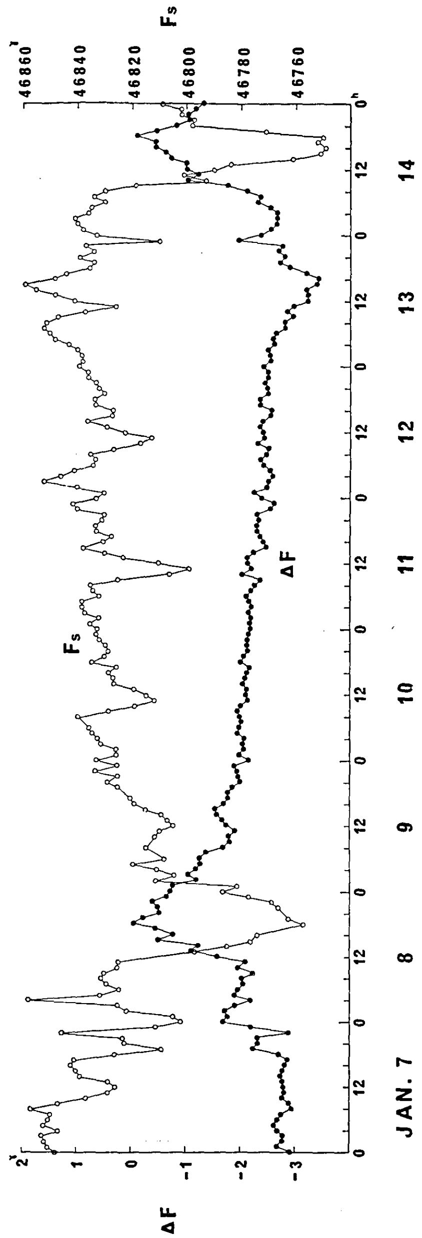


Fig. 7-d2.

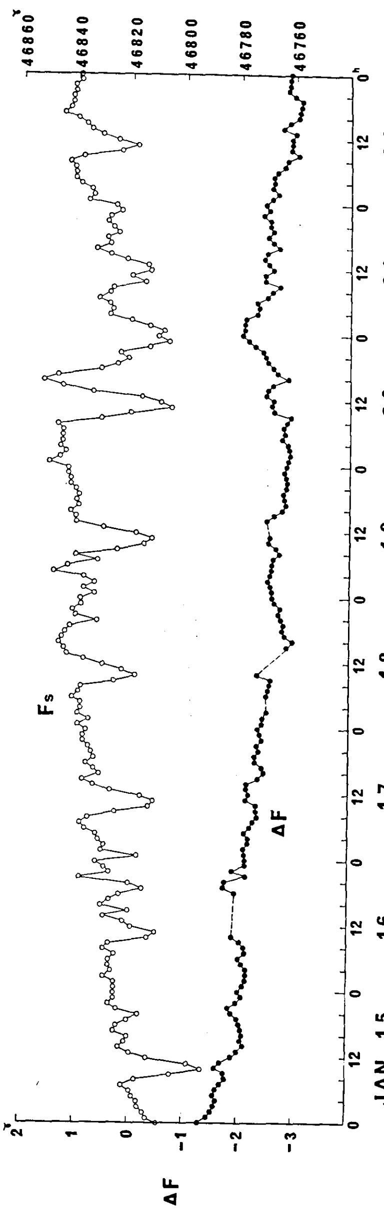


Fig. 7-e1.

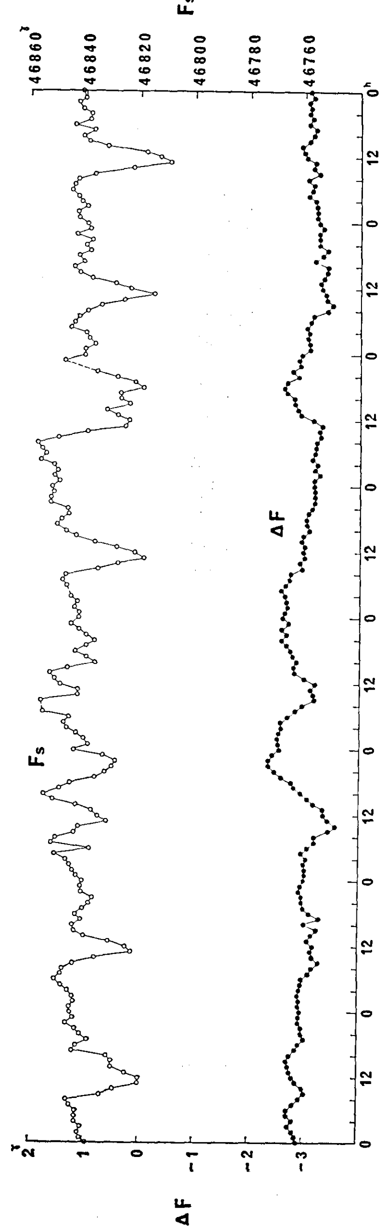


Fig. 7-e2.

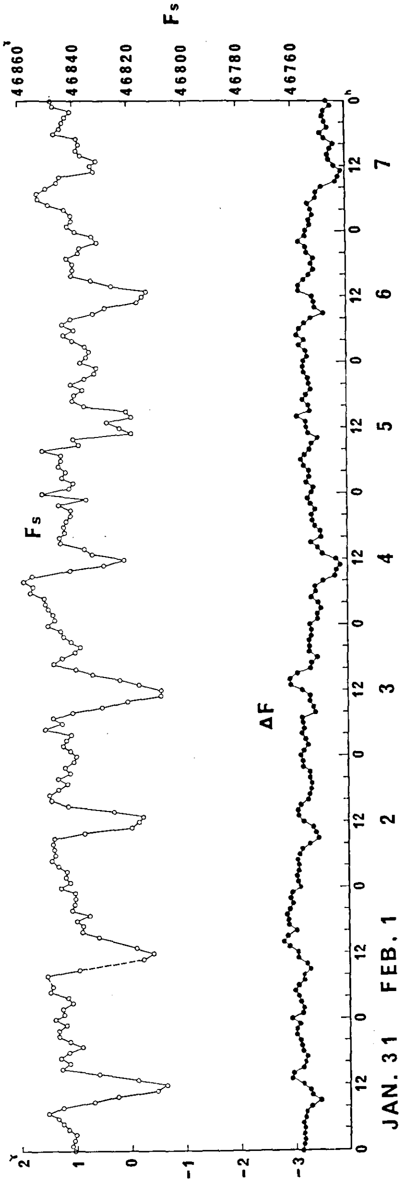


Fig. 7-f1.

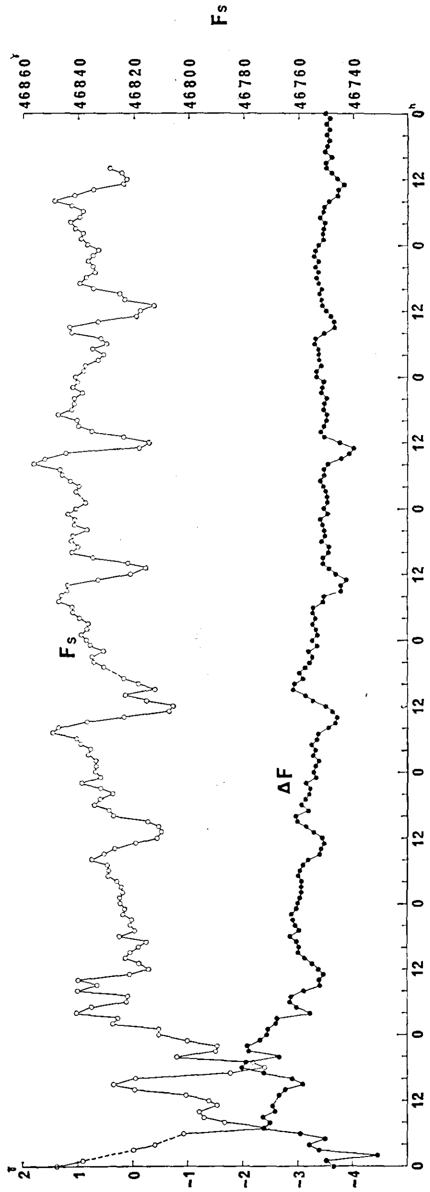


Fig. 7-f2.

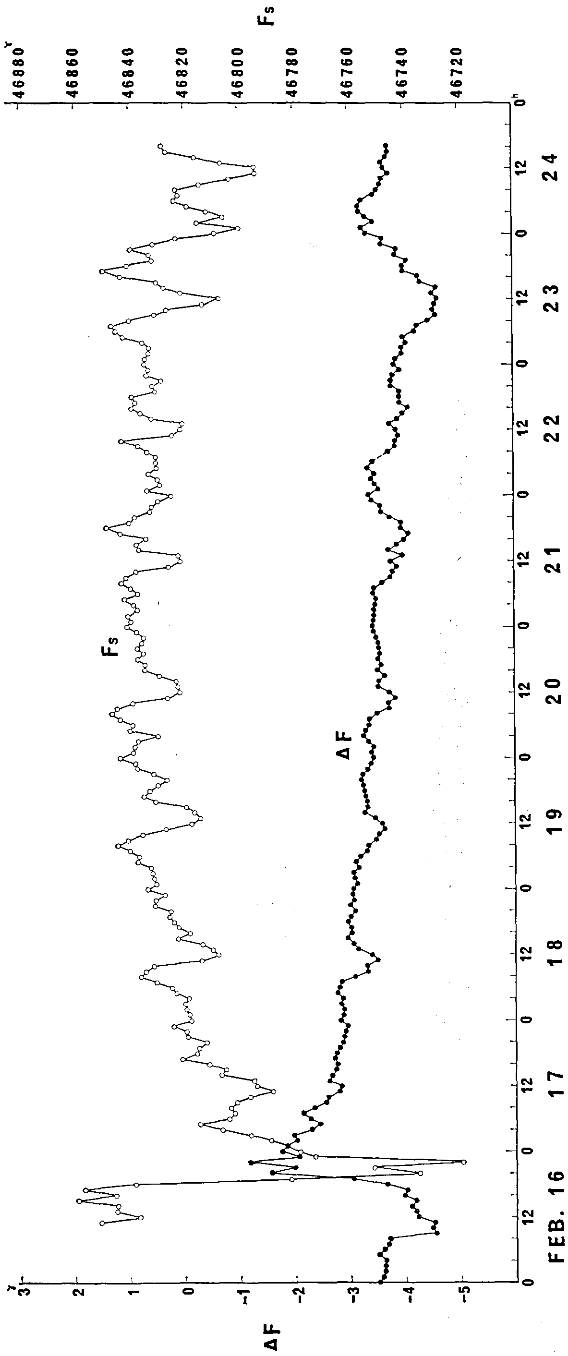


Fig. 7-g.

Fig. 7. Hourly values of the field difference at Mt. Minakamiyama (ΔF) and the total intensity at the Matsushiro Seismological Observatory (F_s) during the whole period of observation.

at the Seismological Observatory situated at about 2 km distance from Mt. Minakamiyama. Figs. 6 (a) through (c) indicate that the external magnetic disturbances cannot be removed by simply taking the difference of two sensors which are merely within 100 m distance from each other.

Compared with magnetograms at the Seismological Observatory, a few per cent of the applied field variation was always observed unremoved in the difference of total intensity at the two sites. Since the magnetometer recorded the difference of field at B subtracted from that at A, the figures indicate that the magnetic field at B always varies with the amplitudes a few per cent larger than that at A.

In Fig. 7, hourly values of field difference during the whole period of observation are shown together with the total intensity observed at the Seismological Observatory. Even for long period variations such as magnetic storms on Jan. 8 and 14, 1967, ΔF clearly corresponds to the applied variations, amounting to as large as 3γ in amplitude. On magnetically quiet days such as from Feb. 10 to Feb. 15, 1967, diurnal varia-

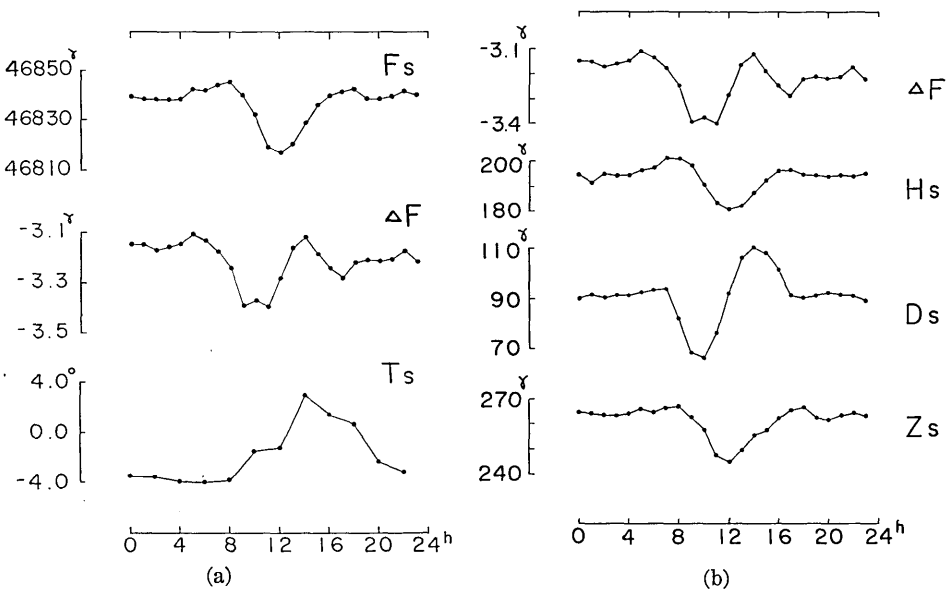


Fig. 8. Diurnal variation averaged for 12 quiet days.
ΔF: Field difference at the top of Mt. Minakamiyama
F_s: Total intensity at the Matsushiro Seismological Observatory
T_s: Mean temperatures at the Matsushiro Seismological Observatory
H_s: Horizontal intensity at the Matsushiro Seismological Observatory
D_s: Westward declination at the Matsushiro Seismological Observatory
Z_s: Vertical intensity at the Magnetic Seismological Observatory

tions are also noticed in ΔF. For 12 quiet days, hourly values of ΔF and F_s were averaged and are shown in Fig. 8. It is noteworthy, however, that ΔF behaves in a different way from the diurnal variation in F_s, showing rather better coherence with declination, whereas for such magnetic variations as bay type disturbances and magnetic storms ΔF changes nearly parallel with F_s. The ratio of ΔF to F_s for diurnal variation also differs from that for other variations, i.e. 0.01 for diurnal variations while 0.02 is obtained for the bay type variations.

It is also noted that there is a gradually decreasing tendency in ΔF during the whole period. Total amount of decrease reaches 6γ for 104 days.

4-2. Spectral analyses of the field difference

Detailed studies of spectral analysis have not yet been completed. Preliminary results are reported here.

For the magnetic records on disturbed days as are shown in Fig. 6, coherence[15] of the field difference (ΔF) to the total force intensity (F_s) or to the horizontal intensity (H_s) at the Matsushiro Seismological Observatory were computed on an IBM 7090. The mean of the analyses conducted for three samples are plotted in Fig. 9. Coherences sharply drop for the periods shorter than 25 min. This is supposedly due to contaminated noises in the short period range by electric railway currents. Comparing Fig. 9(a) with Fig. 9(b), it can be clearly seen that the

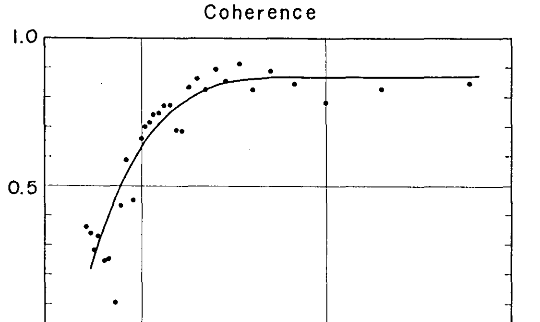


Fig. 9-a. Coherence of the field difference at the mountain (ΔF) to the horizontal intensity at the Matsushiro Seismological Observatory (H_s).

15) W. H. MUNK, F. E. SNODGRASS and M. J. TUCKER, "Spectra of Low-frequency Waves", *Bull. Scripps Inst. Ocean.*, **7** (1959), 283-362.

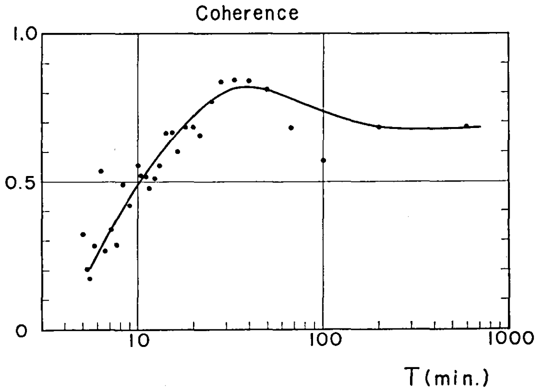


Fig. 9-b. Coherence of the field difference at the mountain (ΔF) to the total intensity at the Matsushiro Seismological Observatory (F_s).

variations in the field difference (ΔF) are more coherent to those in the horizontal intensity (H_s) rather than to those in the total intensity (F_s).

Ratios of power spectral density of ΔF to H_s are calculated and shown in Fig. 10. Although it is difficult to estimate the effect of the

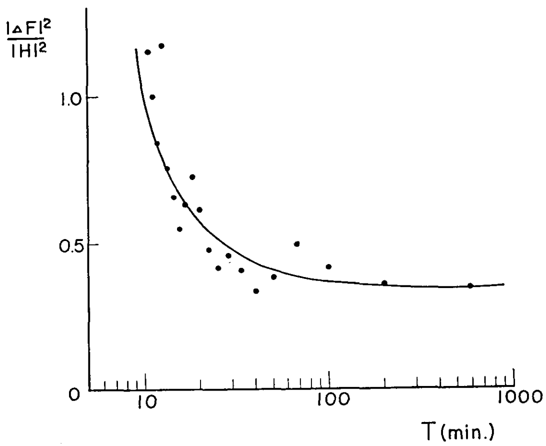


Fig. 10. Ratios of power spectral density of ΔF (field difference) to H_s (horizontal intensity at the Seismological Observatory). The unit of the ordinate is 10^{-3}.

noises due to the electric railways, the power density ratio seems to be dependent on the period of phenomenon, increasing in the range of short periods. For longer periods, the ratio remains approximately 0.4×10^{-3}.

4-3. Discussion

Since the observed variations are of small quantity, the slightest variation in magnetization of rocks under the measuring point could cause the fluctuations in the observed field. Let us tentatively assume that sensor B is placed on the surface of lava in a spherical shape and sensor A is suspended in the air. When temperature of the lava changes, the intensity of remanent magnetization will change. This could cause a difference in the magnetic field between the A and B sites.

The intensity of remanent magnetization of andesite on Mt. Minakamiyama was obtained as 3×10^{-3} emu/gr.[16]. In the case when the remanent magnetization vanishes at about 600°C, the mean rate of change in the intensity due to temperature variation becomes 0.5×10^{-5} emu/gr.°C. Since the rate of change at the lower temperature such as room temperature is usually much less than the mean rate, we tentatively assume it as 1×10^{-6} emu/gr.°C. Then a 10°C change in temperature produces a change in magnetization of 10^{-5} emu/gr.°C.

When the magnetization of a spherical body varies by δJ, the variation in the magnetic field at the surface of the sphere is of the order of $4/3\,\pi\delta J$. Consequently the 10°C change in temperature of the spherical lava can cause a field difference of about 4γ between the A and B sites.

However, the above procedure is obviously irrelevant to account for the present local variations, because magnetic storms and bay type disturbances are not usually associated with temperature changes. Even for diurnal variations, temperature variation does not show such good coherence with the field difference (ΔF) as the magnetic components does. At the bottom of Fig. 8, the mean temperatures[17] on magnetically quiet days at the Matsushiro Seismological Observatory are plotted for comparison.

Although it is difficult to explain the short period variations, the gradual decrease in ΔF during the whole period of observation could be accounted for by the temperature effect. The temperature fell approximately 15°C during the period from November, 1966 to February, 1967 at the top of Mt. Minakamiyama[18]. This might produce 6γ's difference in the field, which is of the right order of magnitude. However, when the existence of sediments covering the lava is taken into account,

16) *ibid.*, 1).

17) N. YAMAGISHI, private communication.

18) N. MUTO and T. MUTO, private communication.

the temperature effect would become much smaller than the present estimate.

When there is a large contrast between the magnetic susceptibilities of rocks under the measuring sites, the magnetically induced field becomes different between the sites. Let us assume the previous model, a spherical mass of lava being embedded under the B site. The magnetic field induced by the sphere with the susceptibility χ can be approximated at the spherical surface as $4\pi/3\,\chi H$ where H is the externally applied field. Accordingly, the ratio of the field produced to the applied one H is $4\pi/3\,\chi$. Meanwhile the magnetic susceptibility of rocks collected on the mountain ranges from 10^{-4} emu/cc to 10^{-3} emu/cc[19]. On substituting 10^{-3} emu/cc into the above, we have the ratio of 4×10^{-3}. This is small by a factor of 5 to account for the observed ratio of 2×10^{-2}. It is also difficult to understand from this view-point that the ratio of the field difference to the applied one is dependent on the period and that the variations in ΔF is coherent to the horizontal intensity in the case of bay type disturbances and to the declination for the diurnal variations rather than to the total force intensity. Besides, the magnetic survey conducted at the top of the mountain does not indicate much difference between the two sites (Fig. 2).

As has already been mentioned, the only difference between the sites lies in the electrical resistivity. The second layer under the A site has the resistivity about ten times smaller than that under the B site, being saturated with ground water (Fig. 3).

Let us estimate the effect of electromagnetic induction when an electrically conducting semi-infinite layer with a conductivity σ is situated close to the ground surface at a depth of D and extends infinitely. Let δF be the varying field at the ground surface expressed in terms of the total force intensity with a wave length λ and δF_0 be the field variation when the conducting layer is removed. Then the relation between δF and δF_0 can be approximated as follows,

$$\frac{\delta F-\delta F_0}{\delta F_0}=i\frac{2\pi\sigma D\lambda}{T}\cdot\left(\frac{\delta X_0}{\delta Z_0}\right),$$

where δX_0 and δZ_0 are the north and the vertical component of the time varying field δF. We shall assume that $\sigma=6.3\times10^{-13}$ emu (resistivity of $1.5\times10^3\,\Omega$cm), $D=2\times10^2$ cm as are obtained by an electric survey over the area (Fig. 3) and $\delta Z_0/\delta X_0=0.1$ as can be estimated from the mag-

19) H. KINOSHITA, private communication.

netograms at the Matsushiro Seismological Observatory. On taking T as 1 hour and λ as 6×10^{8} cm, we have

$$\frac{\delta F-\delta F_0}{\delta F_0} \doteqdot 1.5\times10^{-3}\,i\ .$$

In the present simple model, the field difference between a conducting area and an insulating one can only vary 0.15 per cent of the applied field, which is much smaller than the observed ratio of 2 per cent. Phase difference is also different by $\pi/2$ from the observation.

Although we have failed to obtain a quantitative agreement between the observation and the present simple model, frequency dependent features of the field gradient could be accounted for almost exclusively by electromagnetic induction. It also seems to support this hypothesis that the resistivity difference is the only trait to discriminate the two observation points.

Acknowledgments

We would like to express our thanks to Mr. N. Muto who has helped us to maintain the observation at Mt. Minakamiyama. We are also thankful to Dr. Hirayama and other members of the Kakioka Magnetic Observatory to whom we owe magnetic records at the Matsushiro Seismological Observatory. Our thanks are due to Mr. Yamagishi of the Matsushiro Seismological Observatory who kindly allowed us to use his temperature data. Mr. T. Muto, a fifth-grade pupil of Toyosaka Primary School, is also acknowledged for his daily measurement of atmospheric temperature at the top of Mt. Minakamiyama that was useful for the present study.

---

47. 松代地震群の地球電磁気学的調査 (6)

地震研究所
力武常次
行武 毅
沢田宗久
笹井洋一
渡部暉彦
立中ひろ子

Varrian 社のルビディウム磁力計を皆神山頂上に設置し，1966 年 11 月より 1967 年 4 月まで 2 点

間の全磁力差を連続的に観測した．地震前後に比較的短時間の微小な地磁気変化が起るかどうかを調べるのが目的である．

観測状況

1966年11月より1967年2月までは，検出部2個を用い全磁力差を，以後1967年4月までは，検出部1個のみによつて1点での全磁力を観測した．この期間の地震活動は衰退の一途をたどり，有感地震の日別頻度は平均約15で，1966年9月の最後の活動期の約4% であつた．

B検出部はA検出部の北65°東の方向に98.5m離れた地点に設置した．A検出部での全磁力の平均は 47460γ，B 検出部では 47030γ で，両検出部を結ぶ測線上でおこなつた磁気測量によれば，約2000γ におよぶ局地的磁気異常がこの間に見られる (Fig. 2)．比抵抗の測定をも実施したが，両地点での相異は，A 検出部の下の第2層の抵抗が B 検出部のそれの約1/10に過ぎないことである．

また，この場所での電車による磁場の擾乱は昼間で約0.2γ であつた．

地震前後の地磁気変化

地震前後の比較的短時間の変化を検出する目的で，観測期間中にマグニチュード3.5以上の地震の起つた際の磁気記録を調べたが，電車による磁場擾乱をこえる変化は認められなかつた．

電車の擾乱を除去するために，地震前後1時間の記録を，地震の起つた時間を原点として重ね合わせた．応力変化によつて磁場変化が起るとすれば，この地域に起つた地震の発震機構を考慮に入れると，皆神山を原点として，東西南北各象限に起つた地震は，象限毎に違つた効果を皆神山の地磁気の上におよぼすことになる．マグニチュードが3以上の地震を象限毎にまとめ，その時の地磁気記録を重ね合わせたのが Fig. 4 である．地震の数が多くなると点のばらつきが小さくなることから，図上に見られるみかけ上の変化は，電車による擾乱と考えられる．地震の前後1時間では，地震に伴つて顕著な地磁気変化があつたとは認められない．

局地的地磁気変化

僅か 99m 離れた点でも，湾型変化，日変化，磁気嵐等の地磁変化に差のあることが，今回の観測で明らかになつた (Fig. 6, Fig. 7, Fig. 8)．湾型変化や磁気嵐の時は，外から加つた磁場の約 2% 程度が2地点間の全磁力差として観測される．

3個の磁気記録に対してスペクトル解析をおこなつた結果，2地点間の全磁力差 (ΔF) は全磁力 (F_s) の時間変化より，水平成分 (H_s) の時間変化と相関がよいことがわかつた．日変化については，ΔF はむしろ偏角の変化 (D_s) に似ていることも明らかになつた．また，ΔF と H_s の power densidy の比をとると，短周期で大きくなる傾向がみられる．

局地的な地磁気変化を起す原因としては，温度変化に伴う岩石帯磁の変化，2測点で岩石の帯磁率が異るための誘導磁場の差，電磁誘導の違い等が考えられるが，現在のところ，いずれも観測値を定量的に説明するには至らない．ΔF と H_s との比が周期によること，ΔF が全磁力よりは，水平成分または偏角の変化に似ていること，2点の地下で電気抵抗が異ることを考えると，地下の電磁誘導の相異が局地的地磁気変化をひき起しているようにみえる．

謝　辞

この観測にあたつて，磁力計の維持を，現地の武藤登氏にお願いした．厚くお礼を申し上げる．ここで使用した松代地震観測所での地磁気観測資料は，柿岡地磁観測所の平山操氏その他の職員のお世話によるものである．また松代地震観測所での気温の資料は，同観測所の山岸登氏の御好意による．皆神山頂の気温の測定は，豊坂小学校5年生の武藤孝君によるもので，ここに利用させて頂いた．以上の諸氏に厚く感謝の意を表する．