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1. *The Anomalous Behaviour of Geomagnetic Variations of Short Period in Japan and Its Relation to the Subterranean Structure. The 7th report.*

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Summary

The writers carried out simultaneous observations of three geomagnetic components at four stations situated in the central part of Japan. With the aid of magnetograms sent from five other magnetic observatories distributed all over Japan, analyses of various phases of a magnetic storm that occurred on March 10, 1957 are made. It is found that all the components change regularly throughout all the stations in the case of the main phase in spite of anomalous behaviour of vertical component at central Japan in the cases of *SC* and bay, so that it is presumed that the particular distribution of electrical conductivity which seems to play an important role for short-period variations is nearly transparent for slower variations such as *Dst*.

1. Introduction

The writers have been investigating the anomalous behaviour of short-period geomagnetic variations in Japan and their findings have been published in a series of papers in this bulletin[1),2)] and elsewhere[3),4)]. Although it had been clarified that the anomalously large amplitudes of the vertical component of geomagnetic variations are observed only at stations situated in the central part of Japan and that this anomaly

1) T. RIKITAKE, I. YOKOYAMA and Y. HISHIYAMA, *Bull. Earthq. Res. Inst.*, **30** (1952), 207; **31** (1953), 19, 89, 101 and 119.

2) T. RIKITAKE and I. YOKOYAMA, *Bull. Earthq. Res. Inst.*, **33** (1955), 297.

3) T. RIKITAKE and I. YOKOYAMA, *Journ. Geomagn. Geoeletr.*, **5** (1953), 59.

4) T. RIKITAKE and I. YOKOYAMA, *Naturwissenschaften*, **41** (1954), 420.

originates from inside the earth, more detailed observations have been required in order to see the real cause of this rather extraordinary phenomenon.

In February and March, 1957, the writers had an opportunity to test the magnetic variometers which were constructed for observations in the Antarctica by the Japanese Antarctic Research Expedition. At the same time, magnetograms from three magnetic stations belonging to the Earthquake Research Institute were also available. Furthermore, copies of magnetograms were kindly supplied at the writers' request from five more observatories distributed all over Japan.

With these magnetograms, the writers were able to conduct fairly detailed analyses with respect to various phases of a magnetic storm that occurred on March 10, 1957. It is intended to bring out differences between the distribution for respective phases such as *SC*, polar storm and *Dst*, because there is a possibility of inferring the depth of the peculiar distribution of induced electric currents by analysing variations of different duration.

2. Magnetic stations, instruments and data

Since last year, variometers of three geomanetic components have been working at the Komoro Branch Station of the Earthquake Research Institute near Mt. Asama, while those at Aburatsubo and Maze are also at work as usual. The magnetometer room at Komoro is shown in Fig. 1.

One of the writers (T. R.), who has been appointed chief of the section of geomgnetism, Special Committee for Antarctic Observation, Science Council of Japan, designed a magnetograph (*RMM* magnetograph), specially constructed so as to make observations easy even at very low temperatures. Although the *D*(declination), *H*(horizontal intensity) and *Z*(vertical intensity) magnetometers are of the usual type, all adjustable screws are made bigger than those of usual magnetometers. The clamping devices of the magnets are also specially designed so as to be able to be handled with gloved fingers. The suspending wire of the *MK* magnets of the *D* and *H* magnetometers are quartz fibres of respectively 10 and 50 *microns* in diameter for ordinary use. A sensibility of a few *gammas* per *mm* is easily attained in the case of *H* magnetometer with a 2*m* optical lever. The *MK* magnet of the *Z* magnetometer is horizontally suspended with a fine quartz fibre as usual. With a 1*m* optical lever, a sensibility of a few *gammas* per *mm* is normally adopted. The sensibilities of the three magnetometers can be checked by the Helmholtz coils attached. These magnetometers are set on a frame work together with the recorder and lamp houses as can be seen in Fig. 2. The general arrangement is also shown in Fig. 3.

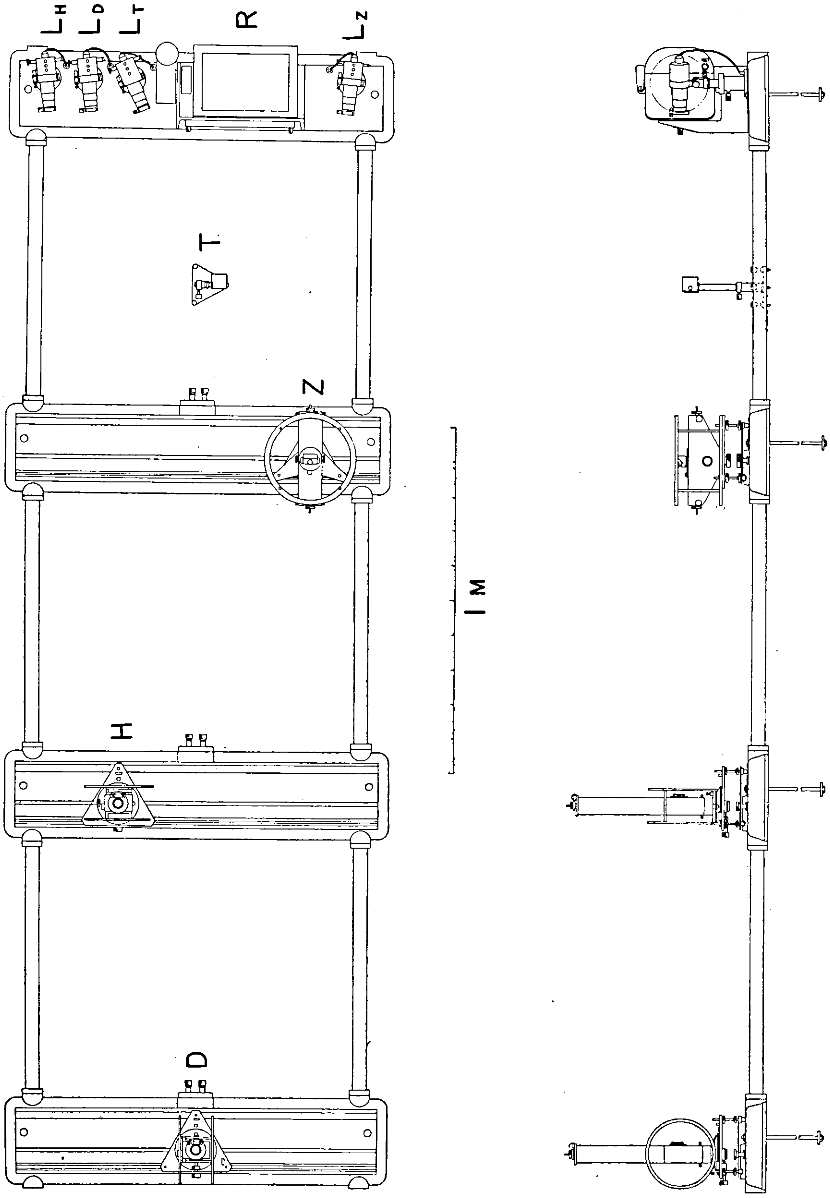

Fig. 3 The plan and elevation of RMM magnetograph. D: declination-, H: horizontal intensity- and Z: vertical intensity variometers. T: temperature change detector, R: recorder, L_H, L_D, L_T and L_Z: lamp houses.

The beams reflected from the mirrors attached to the magnets and fix-mirrors are focussed on photographic paper wound on a rotating drum which is driven by clock work. No spring is used in the clock work, its driving force being provided by a falling weight hung on a nylon string. Possible influences of very low temperatures on the clock work would thus be avoided. The speed of photographic paper is 2*cm* per *hour* as has been decided internationally. The recording drum is mounted in a box with a shutter which is opened automatically when the box is placed in the right position. By providing two drums, the exchange procedure of photographic paper can be made very quickly.

Temperature changes in the observation room can be recorded on the same paper with the aid of a bimetal detector even in an extremely low temperature. The magnetograph has four lamp houses, one for the temperature change and three for the magnetometers. The breadth of the slits and the directions of the beams can be adjusted precisely and easily in a wide range with microscrews. The brightness of the images are changeable by adjusting variable resistances. A stabilizer of the electric voltage and a transformer are also used. The lamp houses and recorder are shown in Fig. 4.

Time marks for every one *hour* are sent from a clock through an electric contact. They can be recorded on the photographic paper either by putting the light off or showing fine lines with an auxiliary electric lamp.

In February and March, 1957, a *RMM* magnetograph was installed

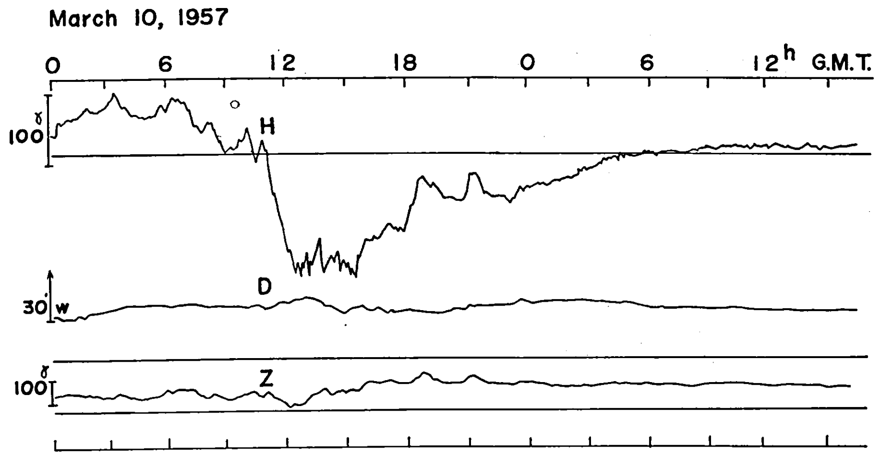

Fig. 6 The magnetogram obtained at Aburatsubo station. The magnetic storm occurred at 0*h* 21*m* *GMT* on March 10, 1957.

in a small hut at Hosono on the foot of Mt. Shirouma, Nagano Prefecture, where we usually have a lot of snow during the winter. The observation hut is shown in Fig. 5. It was proved that the magnetograph works satisfactorily in low temperatures, the lowest temperature inside the hut during the observation period being $-8°C$.

A fairly large magnetic storm with an *SC* occurred at $0h$ $21m$ *GMT* on March 10. The magnetogram obtained at Aburatsubo is illustrated in Fig. 6 for example. In addition to the magnetograms obtained at four stations operated by the Earthquake Research Institute, copies of magnetograms are kindly supplied to the writers from five magnetic observatories, Memambetsu, Onagawa, Kakioka, Simosato and Aso. The geographic and geomagnetic latitudes and longitudes of these observatories are summarized in Table 1. The distribution of these

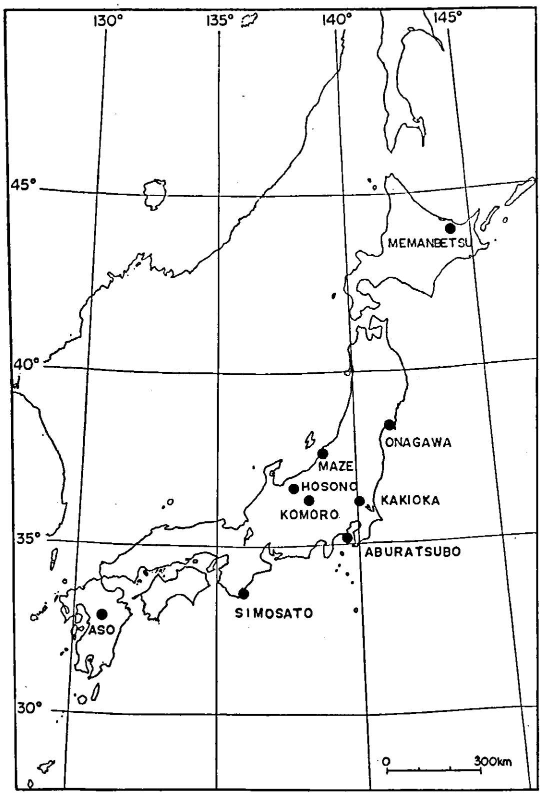

Fig. 7 The locations of magnetic stations.

Table 1. Magnetic station

Station	Geographic latitude	Geographic longitude	Geomagnetic latitude	Geomagnetic longitude
Memambetsu	43°.9*N*	144°.2*E*	34°.1*N*	208°.3*E*
Onagawa	38 .4	141 .5	28 .4	206 .7
Maze	37 .7	138 .8	27 .3	204 .5
Hosono	36 .7	137 .8	26 .2	203 .8
Komoro	36 .3	138 .4	26 .0	204 .4
Kakioka	36 .2	140 .2	26 .0	206 .0
Aburatsubo	35 .2	139 .6	24 .0	205 .6
Simosato	33 .6	135 .9	23 .1	202 .3
Aso	32 .9	131 .0	22 .1	198 .1

stations can be seen in Fig. 7. It may be said that we had fairly many stations in the central part of Japan, though it is regrettable that we could not have any observation on islands in the south sea.

3. Analysis of *SC*

With the intention of analysing a very rapid geomagnetic variation,

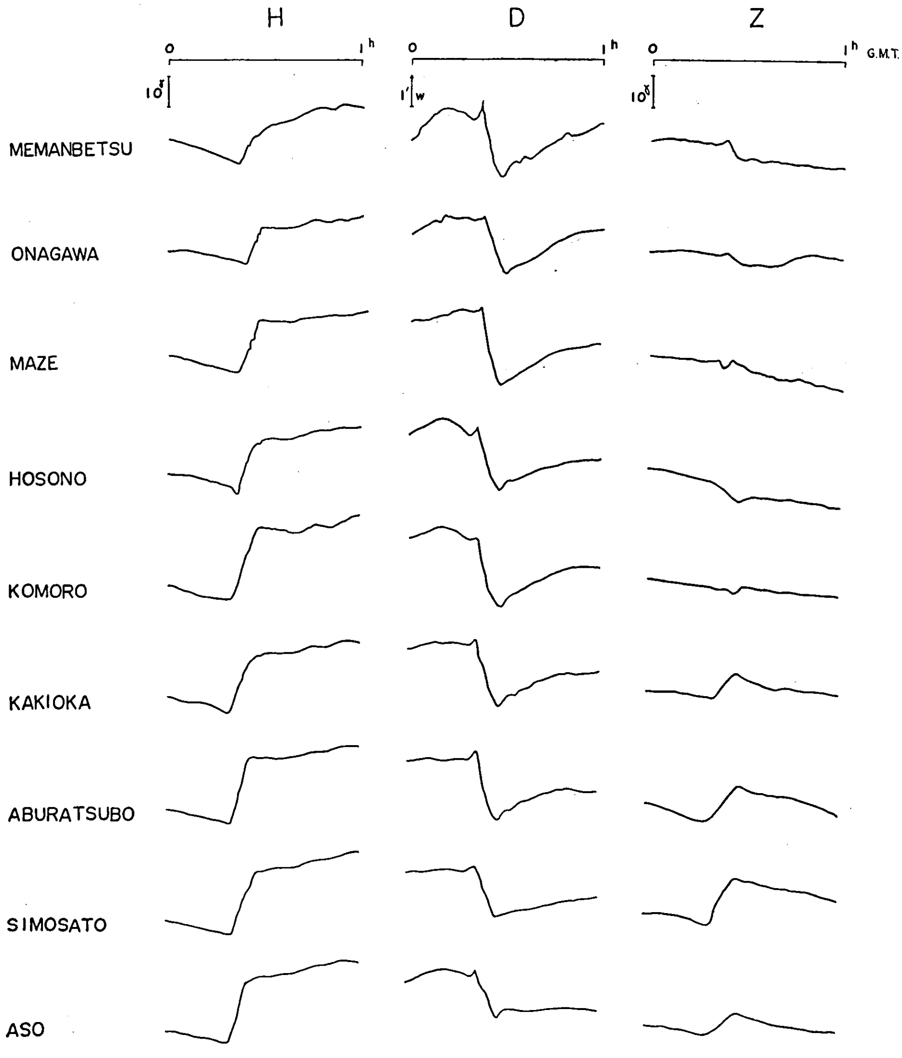

Fig. 8 The changes in the three geomagnetic components at the time of the *SC* on March 10, 1957.

the *SC* with which the magnetic storm begins is studied. The changes in the three geomagnetic components ΔH, ΔD, and ΔZ from $0h$ to $1h$ *GMT* are reproduced in Fig. 8 for respective stations. The amounts of main changes in respective components are given in Table 2 in which the calculated values of changes in geomagnetic north (ΔX_m) and east (ΔY_m) components are also shown.

Table 2. *SC* at $0h$ $21m$ on March 10, 1957.

Station	ΔH	ΔD	ΔZ	ΔX_m	ΔY_m
Memambetsu	11.5γ	−2′.4	1.5γ	15.9γ	−15.2γ
Onagawa	11.6	−1 .8	1.0	14.9	−12.0
Maze	17.0	−2 .4	−2.0	21.3	−16.3
Hosono	17.0	−2 .0	−5.2	20.4	−13.4
Komoro	22.1	−2 .2	−1.5	25.8	−13.9
Kakioka	19.0	−2 .1	8.0	22.5	−13.9
Aburatsubo	20.6	−2 .1	10.5	24.3	−13.9
Simosato	20.3	−1 .6	15.0	22.7	−10.5
Aso	20.4	−1 .5	7.0	23.5	−10.0

It is well known that ΔZ associated with an *SC* is distributed very irregularly in spite of fairly regular distribution of horizontal component. One of the most famous examples is the opposition of sign of ΔZ at Greenwich (near London) and Paris[5]. As measured by N. F. Barber[6], some electric currents are induced in the English Channel by geomagnetic change at the time of an *SC*, and they are so intense that the reversal of the sign of ΔZ on both sides of the channel may be approximately explained by the magnetic field produced by these currents. Hence, it is apparent that the distribution of *SC* is affected by irregular distribution of land and sea. However, we sometimes observe that the signs of ΔZ of *SC* differ from one another at relatively near observatories on land areas. H. Wiese[7] has demonstrated some examples in Europe. He has shown a few examples in which it can be seen that ΔZ is negative at Niemegk, Istanbul-Kandilli, Surlai and Helwan, positive at Rude Skov, Abinger, Ebro and very small at Chambon-la-Forêt, Witteveen, Fürstenfeldbruck and Wingst. It is likely that the distribution is closely related to the underground high conducting zone which is

5) S. CHAPMAN and J. BARTELS, *Geomagnetism*. Oxford (1940), 297.
6) N. F. BARBER, *M.N.R.A.S. Geophys. Suppl.*, **5** (1948), 258.
7) H. WIESE, *Meteorol. Hydrol. Dienst. DDR Abh. Geomag. Inst. Obs. Potsdam-Niemegk* **No. 18** (1956).

supposed to exist beneath North Germany as has been thoroughly studied by geomagnetic bays[7),8),9)], though the mode of distribution seems a little different for *SC's* and bays.

The behaviour of *SC* in Japan has been examined in one of the previous papers[1)]. It has been pointed out by the writers that ΔZ at Kakioka is usually positive and large, while that at Wakkanai, the northern extremity of Japan, is always negative. Since, however, we had not as many stations as at this time, no detailed distribution over Japan could be obtained.

ΔZ, that has been given in Table 2, is shown on a map as can be seen in Fig. 9. It is interesting that we observe large positive ΔZ at Kakioka, Aburatsubo, Simosato and Aso, while the signs are reversed at Maze, Hosono and Komoro.

Taking into consideration the fact that the distance between Komoro and Aburatsubo or Kakioka amounts to only 170 *km*, it is striking that ΔZ shows such a great gradient. It is also interesting that the area in which we observe large positive ΔZ is slightly narrower than that for bays. But detailed comparisons between the distributions for different variations will be made later.

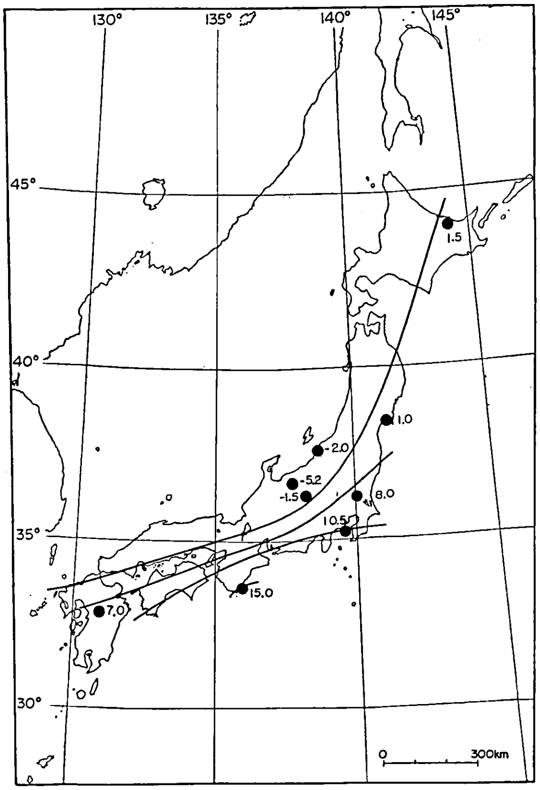

Fig. 9 The distribution of ΔZ of the main pulse of the *SC*. (Unit: *gammas*)

Since it has been approximately proved by the writers in their previous paper that the part of *SC* which originates from outside the earth has nothing particular, this sort of anomalous distribution is certainly caused by the electric currents induced in the earth beneath Japan where we naturally expect

8) U. FLEISCHER, *Naturwissenschaften*, **41** (1954), 114.
9) H. WIESE, *Zeits. f. Meteorol.*, **8** (1954), 77.

a complicated distribution of the electrical conductivity. Even in a uniformly conducting earth, the theory of electromagnetic induction shows that some changes of internal origin should come out in connection with changes in the external magnetic fields. In order to detect the changes purely due to the anomalous distribution of electrical conductivity under Japan, the general part of ΔZ which is caused by the electric currents induced in the earth of which the conductivity is determined as an average for the whole earth should be eliminated. But no accurate analysis of *SC* has been made yet because of local irregularities. The writers' previous analysis of the *SC* on June 18, 1936 suggests that mean ΔZ is nearly zero. This would be due to the fact that, as far as the conductivity takes non-zero value, no matter how small it is, the induced currents at the very beginning will flow on the earth's surface so as to cancel the normal component of the inducing field applied suddenly from outside, while the rate of decay of the induced currents necessarily depends on the conductivity. At any rate, the proportion of the general field which originates from inside the earth would be very small for a rapid variation such as *SC*, so that the anomalous distribution of ΔZ obtained above can be approximately regarded as the one produced by the electric currents induced in the earth having some particular conditions. As has been emphasized in one of the previous papers[2)], the influence of the Pacific Ocean would not be of the type which accounts for the occurrence of such a distribution.

4. Analysis of polar magnetic storm

At about 18*h* and 21*h* on March 10, two marked changes were observed. Being superposed on the recovery phase of the storm, they are likely to be polar magnetic storms, the origin of such changes being overhead electric current systems similar to that of a bay. As has been studied in the 4 th report, the anomaly of ΔZ in Japan can be seen most clearly in the cases of polar magnetic storms and bays so that it would add something to the previous knowledge of the anomalous behaviour of geomagnetic variations to study the changes in detail with so many stations as this time.

In order to pick up only the polar magnetic storm, the influence of *Dst* should be eliminated. For that purpose, the writers made running averages by averaging 13 readings of every 10 *minutes* for all the components. After subtracting the averages from the original values,

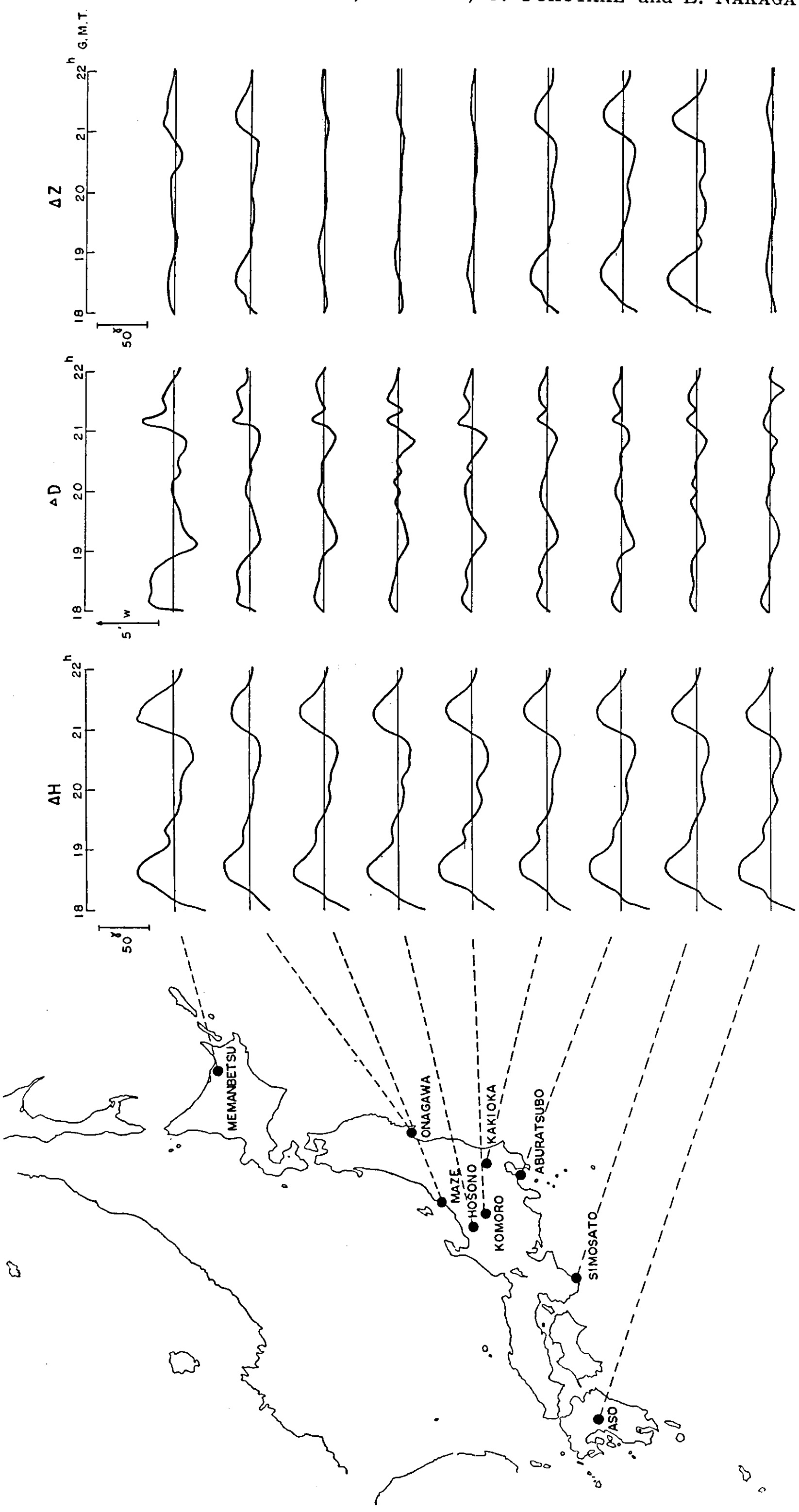

Fig. 10 The changes in the three geomagnetic components at the time of the successive polar magnetic storms on March 10, the locations of the magnetic stations being also shown.

we obtain ΔH, ΔD and ΔZ which are approximately free from the influence of long period variations. In Fig. 10, ΔH, ΔD and ΔZ during the period from $18h$ to $22h$ are graphically shown for the various stations. Looking at these curves, it is noticeable that ΔH and ΔD run quite regularly. We observe, however, a marked tendency for ΔZ to be extraordinarily large in the central part of Japan, the anomalous area seeming likely to extend along the main island with a roughly elliptical shape. At stations in the area, the shape of ΔZ-curve is nearly the same as that of ΔH-curve. It is again striking that ΔZ-curves at Komoro and Aburatsubo, the distance between these two stations amounting only 170 *km*, differ so much from one another.

The values of ΔZ at the stations situated in the central part of Japan are plotted against the latitude for epochs of every 10 *minutes* as can be seen in Fig. 11. It is noticeable that the line passing the points corresponding to Aburatsubo, Komoro and Hosono is always parallel to that connecting Kakioka with Maze. As we can see in Fig. 7, the direction of the Aburatsubo-Komoro-Hosono line is nearly parallel to that of the Kakioka-Maze line, so that we see that the fact shown in Fig. 11 suggests that the gradient of ΔZ is approximately directed to the direction of the two lines. The direction is roughly $N 45° W$ and perpendicular to the general trend of Japan Islands.

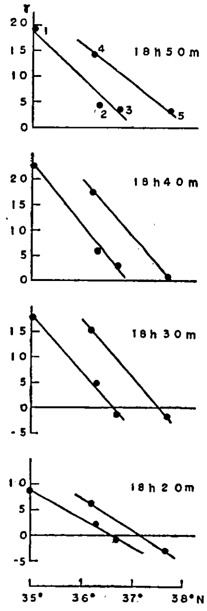

Fig. 11 The distribution of ΔZ at epochs of every 10 *minutes* for the magnetic stations situated in the central part of Japan. 1: Aburatsubo, 2: Komoro, 3: Hosono, 4: Kakioka, 5: Maze.

In order to see the geographic distribution of the anomaly, the values at $18h$ $40m$, when the polar magnetic storm reached its maximum, are selected and given in Table 3 in which ΔX_m and ΔY_m are also obtained from ΔH and ΔD.

The internal part of ΔZ thus deduced will consist of two parts, one caused by the anomalous conditions underneath Japan and the other produced by the induced currents flowing in the high conducting part of the earth below a depth a few hundred *kilometers*.

We call the latter the normal internal part, the nature of which has been examined by a number of authors.[10),11),12),13)] Strictly speaking, these two parts should electro-

10) A. SCHUSTER, *Phil. Trans. Roy. Soc. London A*, **208** (1908), 163.

Table 3. Polar magnetic storm at 18*h* 40*m* on March 10, 1957.

Station	ΔH	ΔD	ΔZ	ΔX_m	ΔY_m
Memambetsu	35.5γ	−1′.5	4.1γ	37.3γ	−2.5γ
Onagawa	22.9	−0 .9	14.4	23.0	−2.3
Maze	29.5	−0 .4	0.8	29.4	3.7
Hosono	31.1	−0 .2	2.9	30.7	5.6
Komoro	32.8	−0 .5	4.8	32.9	3.2
Kakioka	26.1	−0 .5	17.5	26.4	1.6
Aburatsubo	30.1	−0 .1	22.4	29.4	6.1
Simosato	30.4	−0 .3	25.3	30.3	3.3
Aso	29.5	−0 .1	5.8	29.2	4.5

magnetically couple with one another, but the coupling may be neglected for the first appoximation.

As to the normal internal part, the relation between the inducing and induced fields has been well known. Meanwhile, magnetic potential of polar magnetic storms or bays may be expressed approximately by

$$\Delta W = a\left\{\left(\frac{r}{a}\right)e + \left(\frac{r}{a}\right)^{-2} i\right\}\sin\phi\, Q_1^1(\cos\theta)\,, \qquad (1)$$

as far as low and middle latitudes are concerned, where ϕ, θ, a, e and i denote respectively geomagnetic longitude, co-latitude, radius of the earth, external and internal parts of the coefficient of the potential. Q_1^1 denotes the associated Legendre function of the second kind. The components of the magnetic field at $r=a$ then become

$$\left.\begin{aligned} \Delta X_m &= (e+i)\sin\phi \frac{dQ_1^1}{d\theta}\,, \\ \Delta Y_m &= -(e+i)\cos\phi \frac{Q_1^1}{\sin\theta}\,, \\ \Delta Z &= (e-2i)\sin\phi\, Q_1^1\,. \end{aligned}\right\} \qquad (2)$$

If the electrical conductivity that has been hitherto obtained[14] is adopted, the relation between e and i is given by

$$i = 0.415\, e\,. \qquad (3)$$

Although it is not possible to obtain e and i from data obtained

11) S. CHAPMAN, *Phil. Trans. Roy. Soc. London A*, **218** (1919), 1.

12) S. CHAPMAN and A. T. PRICE, *Phil. Trans. Roy. Soc. London A*, **229** (1930), 427.

13) B. N. LAHIRI and A. T. PRICE, *Phil. Trans. Roy. Soc. London A*, **237** (1939), 509.

14) T. RIKITAKE, *Bull. Earthq. Res. Inst.*, **28** (1950), 45, 219 and 263; **29** (1951), 61 and 539.

only in a restricted area of the earth's surface, we may estimate $e+i$ from ΔX_m in Table 3 by assuming that ΔX_m is of the type given by (2) and that the influence of the anomaly is not so large for horizontal components. Actually, no marked differences such as found in ΔZ are observed in the case of ΔH. If the assumption is taken for granted, $e+i$ can be obtained by least square method, hence, by taking into account (3), e and i of the normal part can be calculated. With these, $e-2i$ and consequently ΔZ_n (subscript n means normal part) can be easily calculated for respective stations as given in Table 4. The differences between ΔZ and ΔZ_n would then be regarded as due to the anomaly peculiar to Japan.

Table 4.

Station	ΔZ_n	$\delta Z=\Delta Z-\Delta Z_n$
Memambetsu	-2.1γ	6.2γ
Onagawa	-1.8	16.2
Maze	-1.7	2.5
Hosono	-1.6	4.5
Komoro	-1.6	6.4
Kakioka	-1.6	19.1
Aburatsubo	-1.5	23.9
Simosato	-1.4	26.7
Aso	-1.4	7.1

Since ΔZ_n does not much exceed 2γ, no large errors would be possible in δZ in spite of the crude estimate. ΔZ_n shows the vertical component which should have been observed if the anomaly did not exist, hence the influence of the anomalous field is so large that we actually observe variations of reversed sign all over Japan as well as extraordinarily large amplitude in the central part. The distribution of δZ is shown on a map in Fig. 12 which should be compared with Fig. 2

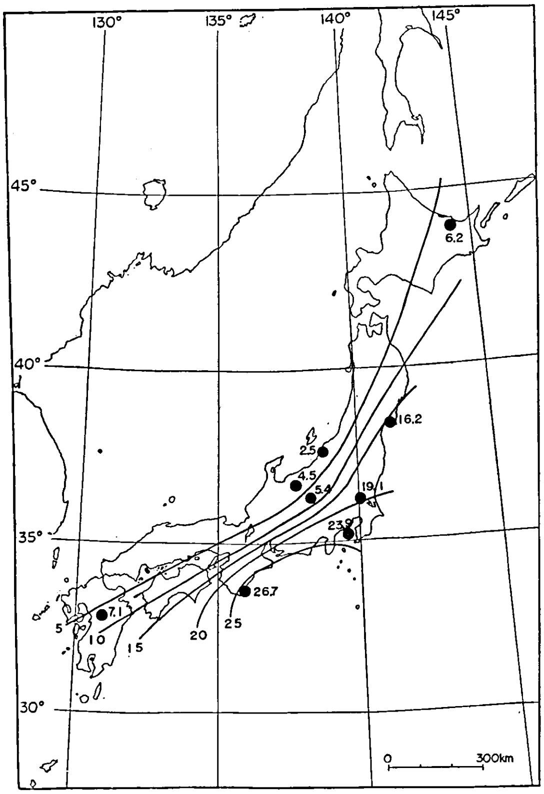

Fig. 12 The distribution of δZ for the polar magnetic storm. (Unit: *gammas*)

of the 6 th report. We see that the anomalous area extends roughly elliptically covering Kii, Izu and Boso peninsulas, its southern boundary being still unknown. We may also compare Fig. 12 to Fig. 9, similar chart for the *SC*, whence it is observed that the area is slightly larger in this case and its centre is likely to be shifted a little to *NE*.

5. Analysis of main phase of *Dst*

It is of much interest to see whether or not geomagnetic variations of a different period show the same tendency as those which have been described in the previous two sections. Since we know daily variation on quiet days (*Sq*) behaves quite differently as has been discussed by

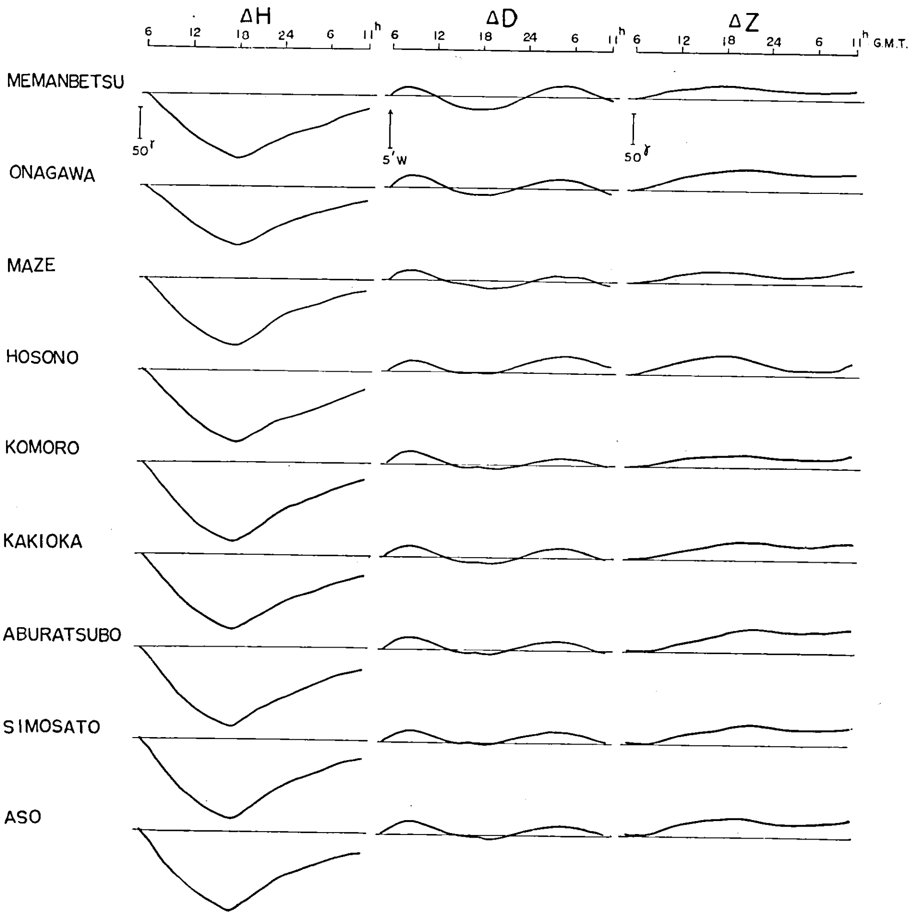

Fig. 13 The running average of the main phase of *Dst* for respective stations.

the writers[15], it is highly desirable to conduct an analysis of much slower variations with respect to geomagnetic data from well-distributed observatories in Japan. In order to carry out such a study, the writers would here like to analyse the main phase of *Dst* of the magnetic storm.

Short-period variations are eliminated by taking running averages every one *hour*. The averages of 13 readings are made and shown in Fig. 13 for each station.

The values at 18*h* are tentatively assumed as those of the initial state, so that these curves in Fig. 13 express the departures from the initial values. All the elements at the maximum stage of the main phase are given in Table 5.

Table 5. *Dst* at 18*h* on March 10, 1957.

Station	ΔH	ΔD	ΔZ	ΔX_m	ΔY_m
Memambetsu	-107γ	1'.7	21.6γ	-107γ	-15γ
Onagawa	−97	0 .8	32.9	−96	−17
Maze	−112	0 .7	21.1	−111	−20
Hosono	−118	0 .0	31.3	−115	−26
Komoro	−131	0 .3	17.0	−129	−26
Kakioka	−112	0 .7	23.0	−111	−19
Aburatsubo	−129	0 .4	26.4	−127	−25
Simosato	−131	0 .1	21.5	−129	−24
Aso	−128	0 .3	26.8	−126	−19

At a glance of Fig. 13, we see that the curves are almost the same throughout all the stations. Unlike *SC* or polar magnetic storm, no anomalous distribution of ΔZ can be found at stations in Central Japan. The fact would suggest that the underground conditions which give rise to the anomalous behaviour of short-period variations are insensitive to much slower variation such as the main phase of *Dst*. This finding is of great interest because the writers have found that *Sq* is not affected by the conditions to which variations of short period are sensitive. However, another sort of anomaly has been found from the study of *Sq* in Japan, the anomaly being probably due to the fact that the electrical conductivity at the depth of several hundred *kilometers* underneath Japan is lower than the average of the earth as a whole.

Since we have no world-wide data of the magnetic storm on March 10, no complete analysis of the storm is possible at present. On

15) T. RIKITAKE, I. YOKOYAMA and S. SATO, *Bull. Earthq. Res. Inst.*, **34** (1956), 198.

assuming some nature of *Dst*, however, separation of the internal part of the magnetic potential from the external one will be effected in the following. It has been well known that the magnetic potential of *Dst* can be expressed fairly well by

$$\Delta W=a\{(r/a)e+(r/a)^{-2}i\}P_1(\cos\theta)\,, \tag{4}$$

where all the notations have the same meaning as those related to (1). It follows that

$$\left.\begin{aligned}\Delta X_m&=-(e+i)\sin\theta\,,\\ \Delta Z&=(e-2i)\cos\theta\,.\end{aligned}\right\} \tag{5}$$

Under the assumption that ΔX_m and ΔZ which are given in Table 5 can be used for the determination of e and i, we make use of least square methods from which we obtain

$$e+i=131\gamma,\ e-2i=55\gamma\,,$$

and then

$$e=105\gamma\,,\ i=25\gamma,\ e/i=4.2\,.$$

Meanwhile, the ratio e/i of *Dst* at the maximum stage of the main phase has been obtained to be 3 or thereabout from analyses of world-wide data[12),16)]. It is of interest that the internal part is considerably small when the coefficients are determined from observations in Japan only. The fact would suggest that the electrical state at a depth of several hundred *kilometers* underneath Japan is likely to differ from what we have obtained for the mean state of the earth. Under Japan, it may be presumed that either the conductivity below a depth of a few hundred *kilometers* is smaller than the mean value of the earth as a whole or the depth of the non-conducting layer is larger than that for the mean earth. Although it is difficult to determine which conclusion is more likely, the results seem to agree very well with that deduced from the study[15)] on *Sq* in Japan.

6. Discussion

From the analyses of *SC*, polar magnetic storm and main phase of *Dst* of the magnetic storm that occurred on March 10, 1957, we have seen that the anomalies of ΔZ for rapid variations differ greatly from those for much slower variations. Since it has been well known that, in the case of an earth having a conductivity-distribution of spherical

16) T. RIKITAKE and S. SATO, *Bull. Earthq. Res. Inst.*, **35** (1957), 7.

symmetry, the longer the period of a geomagnetic variation is, the deeper the induced currents penetrate into the earth, the different behaviours between these variations, rapid and slow, would give some clue to the investigation of the cause of the anomaly concerned.

In one of the previous papers[1], it has been pointed out that there will be two kinds of local characteristics for geomagnetic variations of short period, one sensitive to *SC's* but not to bays or polar magnetic storms as can be found at British observatories, and the other sensitive to both variations. Although the anomaly in Japan is found to be of the latter type, it has been made clear that the detailed features of both the variations do not agree with one another. On comparing Fig. 9 with Fig. 12, we see that the area in which ΔZ of *SC* is anomalously large becomes wider and its centre is shifted to the *NE* direction in the case of polar storm. It has been also reported that the mode of distribution of ΔZ which is found in North Germany shows some differences for *SC's* and bays, the difference being likely to be of a similar character to that of Japan. If the anomaly is supposed to be caused by some particular distribution of electrical conductivity, we see that the response of this distribution is different when the inducing fields have different periods though some more observations would be necessary for clarifying the characteristics of the response.

As to the details of the underground distribution of electrical conductivity, nothing definite can be said yet. A roughly circular or elliptical circuit which has been imagined in the previous papers still seems to be the best model by which we can understand the peculiar behaviour of short-period geomagnetic variations in Japan. Let us imagine a circular circuit of a circular wire. The self-inductance of the circuit is given by

$$L=4\pi A\left(\log_e \frac{A}{\rho}+0.33\right),$$

where A and ρ are the radius of the circuit and the wire respectively. If a voltage E is applied to the circuit, the electric current I is described by

$$L\frac{dI}{dt}+RI=E,$$

where R denotes the resistance of the circuit. In the case of an alternating voltage of which the angular frequency is ω, therefore, the phase difference ψ between E and I is given as

$$\psi = \tan^{-1}(\omega L/R) .$$

Suppose that the underground circuit consists of the passage of electric currents, the radius of the section of which is assumed as $10 km$, L for $A=100$ and $1000 km$ become respectively 5.5×10^9 and 5.5×10^{11} *cm*. If we take the electrical conductivity of the material, of which the passage is composed to be 10^{-12}*e.m.u.* (that is the conductivity below the depth of $400 km$ for the normal part of the earth), R is obtained as 2.0×10^9 and 2.0×10^{11}*e.m.u.* respectively. Furthermore, the period of the alternating current is taken as 1 *hour*. In that case, $\omega L/R$ is estimated at 0.0041 and 0.041 respectively for $A=100$ and $1000 km$, so that there is practically no phase difference between the applied voltage and electric current in the circuit. The fact that we observe no phase difference between ΔH and ΔZ in the anomalous area may thus be understandable provided we suppose the existence of such a circuit whose radius has been thought to amount roughly to several hundred *kilometers*.

In the case of the main phase of *Dst*, it is of much interest that we do not observe any anomaly which seems to be related to the circuit supposed here. This is just the case for *Sq* as has been examined by the writers in the previous paper[15]. It is then presumed that the supposed circuit has nothing or very little to do with such slower variations as *Dst* and *Sq*. We may naturally speculate that the electric currents induced by these geomagnetic variations flow in deeper parts of the earth, so that no appreciable amount of electric currents is induced in the circuit which is supposed to exist at a depth of less than a few hundred *kilometers*. However, another sort of anomaly should be considered in relation to *Sq* and *Dst*. Although it is difficult to carry out an exact analysis, it is likely that, underneath Japan, the electrical conductivity below a depth of a few hundred *kilometers* is considerably lower than the usual value, which has been obtained for the mean state of the earth. It is not possible to determine the accurate boundaries of this region. However, one of the writers (T. R.)[17] has speculated that this sort of condition would have an important bearing on the formation of an orogenetic zone.

7. Concluding remarks

The analyses of various phases of the magnetic storm that occurred

17) T. RIKITAKE, *Bull. Earthq. Res. Inst.*, **34** (1956), 291.

on March 10, 1957, are described in this report. On the basis of data from four magnetic stations belonging to the Earthquake Research Institute together with those from five other magnetic observatories in Japan, analyses that are more detailed than those hitherto conducted are made with respect to the *SC* and polar magnetic storm. Although the present analyses serve only to confirm the local characteristics of short-period geomagnetic variations which have been so far known, the northern boundary of the area in which we observe anomalously large ΔZ is well located by magnetograms from Komoro and Hosono which are newly added. As for the origin or cause of the anomaly, the previous idea that presumes circular or elliptical electrical circuit would still be the best explanation.

The analysis of the main phase of *Dst* results in a notable finding that no anomaly such as found in the cases of short-period variations is associated, the result being agreed with the analysis of the *Sq* in Japan. We therefore presume that the hypothetical underground circuit of induced electric currents has no or very little effect on slower variations such as *Sq* and *Dst*. Meanwhile, anomaly of another kind is likely to exist in the earth's mantle as deep as several hundred *kilometers* beneath Japan. The relation between the external and internal parts of *Dst* as well as of *Sq* suggests that either the conductivity is low or the non-conducting outer layer is penetrating the mantle.

On summarizing all the results of the analyses of geomagnetic variations, it may be said that the electrical condition underneath Japan differs very much from the mean state of the earth which has been studied from the standpoint of the theory of electromagnetic induction. A crude picture, though very incomplete, of the conductivity distribution is speculated on as follows. Beneath Japan, the conductivity at a depth of several hundred *kilometers* seems likely to be very low, probably something of the order of 10^{-15}*e.m.u.* in contrast to 10^{-12}*e.m.u.* for the averaged value for the whole earth. The boundaries of the low conducting region are not known. Above the low conducting part, there would be a high conducting passage of electric currents. It is supposed that both the ends of the circuit are connected with the high conducting region extending outside the said low conducting part of the mantle in order to account for strong electric currents flowing in the circuit. Although no accurate estimate of the dimension of the circuit is possible, there seems no objection to assuming that the width of the roughly elliptical circuit amounts to more than a few hundred *kilometers*.

The bearing of the extraordinary distribution of the electrical conductivity on geophysical or geological problems is not known. However, as has been once speculated by one of the writers (T. R.), it would be possible to suppose that seismicity or volcanism might be correlated to the special condition beneath Japan.

In conclusion, the writers express cordial thanks to all the members of the Branch Stations of the Earthquake Research Institute who carried out magnetic observations. Their hearty thanks are also due to the members of Memambetsu, Onagawa, Kakioka, Simosato and Aso Magnetic Observatories. A part of this study has been made with the financial aid of a Research Grant from the Ministry of Education, for which the writers would like to extend their thanks to the Ministry.

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1. 日本に於ける地磁気短周期変化の異常と地下構造(第7報)

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南極地域観測用 *RMM* 磁力計の冬季テストをかねて，長野県細野，小諸，新潟県間瀬および神奈川県油壷に於て，地磁気3成分同時観測を行つた．この結果に女満別，女川，柿岡，下里および阿蘇観測所の観測結果を加えて，1957年3月10～11日の磁気嵐の各相について解析を行つた．磁気嵐の急始，極磁気嵐等については従来とほぼ同様な結果を得たが，主相については，短周期変化を起す地下構造の影響を受けないことをたしかめ，また内部磁場が地球の平均状態の場合にくらべて小さいことを見出した．

これらの結果および *Sq* の解析結果にもとづいて，日本地下の電気的状態を推測した．

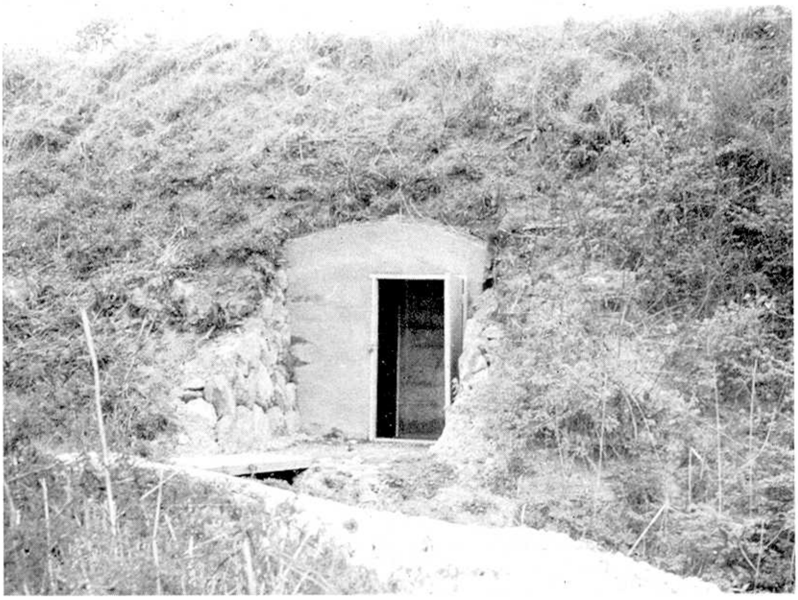

Fig. 1. The entrance of the magnetometer-room at Komoro Station.

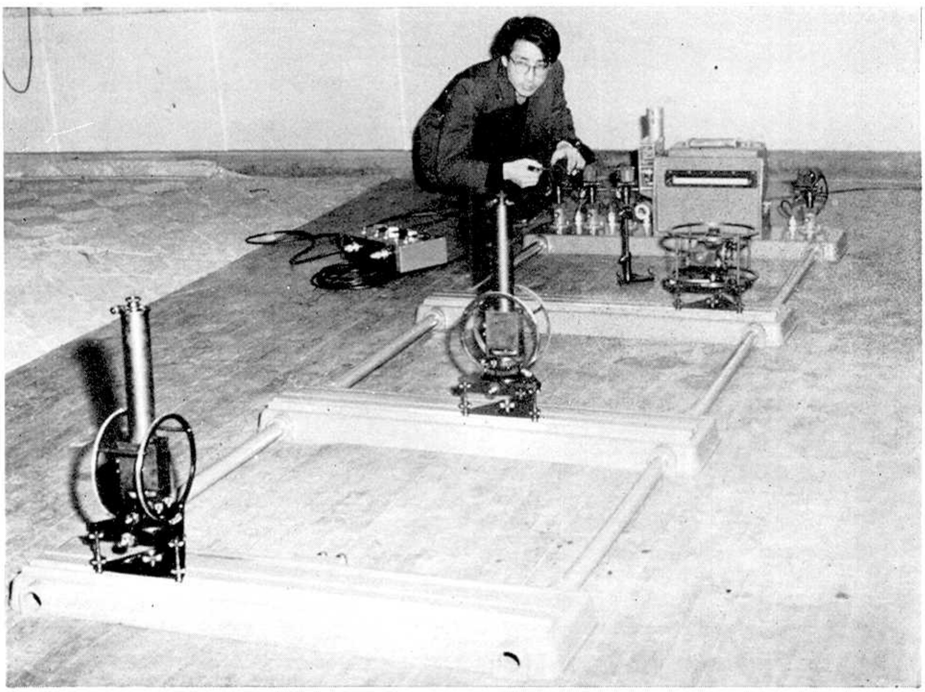

Fig. 2. General arrangement of *RMM* magnetograph.

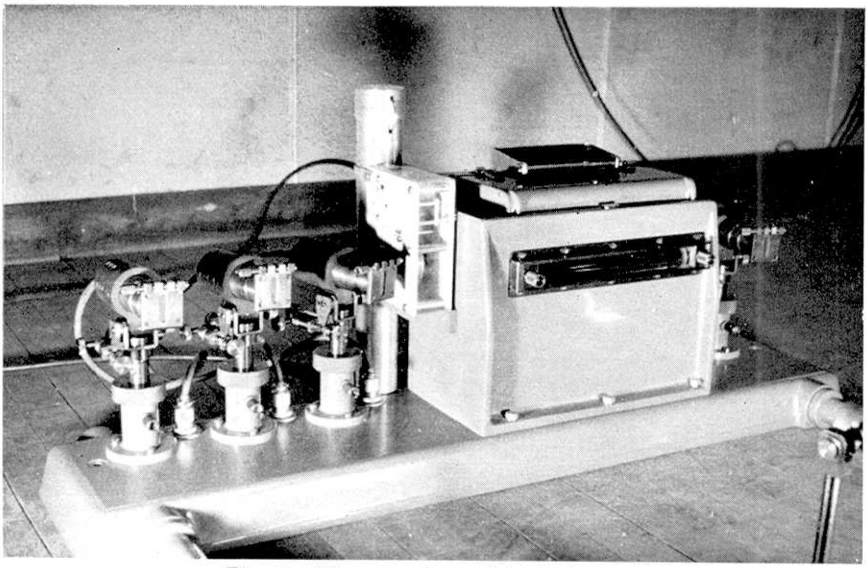

Fig. 4. The recorder and lamp houses.

Fig. 5. The observation hut at Hosono.