18. *A Preliminary Study on the Anomalous Behavior of Geomagnetic Variations of Short Period in Japan and Its Relation to the Subterranean Structure.*

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1. Introduction.

A recording of changes in the three geomagnetic components has been carried on at Aburatsubo (35°09′ *N*, 139°37′ *E*) by the Earthquake Research Institute since September, 1951. The magnetograms show strong parallelism between short period changes in horizontal (H) and vertical (Z) components. The writers also find out that changes in Z-component (ΔZ) are anomalously large there, usually amounting to as much as 60 per cent of changes in H-component (ΔH). Since similar tendencies at Kakioka Magnetic Observatory has been already pointed out by T. Nagata[1)], the said parallelism and anomalously large amplitude of ΔZ may be regarded as the characteristics peculiar to the central part of Japan.

In order to bring out the peculiarity more clearly, the writers analysed the geomagnetic data at the occassion of the 32nd cooperative observation of the Ionosphere Research Committee, Japan. The geomagnetic data[2)] related to a solar eclipse that occurred near Japan on June 19, 1936 were also analysed, the data at that occasion being the best for the purpose because of the proper distribution of temporary stations in Japan and her vicinity.

Although the writers arrived at no decisive conclusion concerning the detailed nature and origin of the anomalous behavior of geomagnetic variations in Japan, it may be of some use to report here the results of the analysis, referring especially to the special conditions in the earth's interior below Japan.

1) T. NAGATA, *Rep. Ionos. Res. Japan*, **5** (1951), 134.

2) A. TANAKADATE and others, *Japanese Journ. Astro. Geophys.*, **14** (1938), 85.

2. Geomagnetic observation at Aburatsubo.

(1) *Outline of the observation.*

It was already reported by T. Hagiwara[3] and others that a geophysical station for observing the deformation of the earth's surface was set up at Aburatsubo (35°09′ N, 139°37′ E), near the southern extremity of the Miura Peninsula. A continuous observation of the three geomagnetic components were added there for the purpose of finding out changes in the earth's magnetic field that might occur at the time of an earthquake and also of recording geomagnetic variations of short period.

The magnetic variometers are installed in a cave drilled in the Tartiary sandstone, the cave being just adjacent to the gallery for the

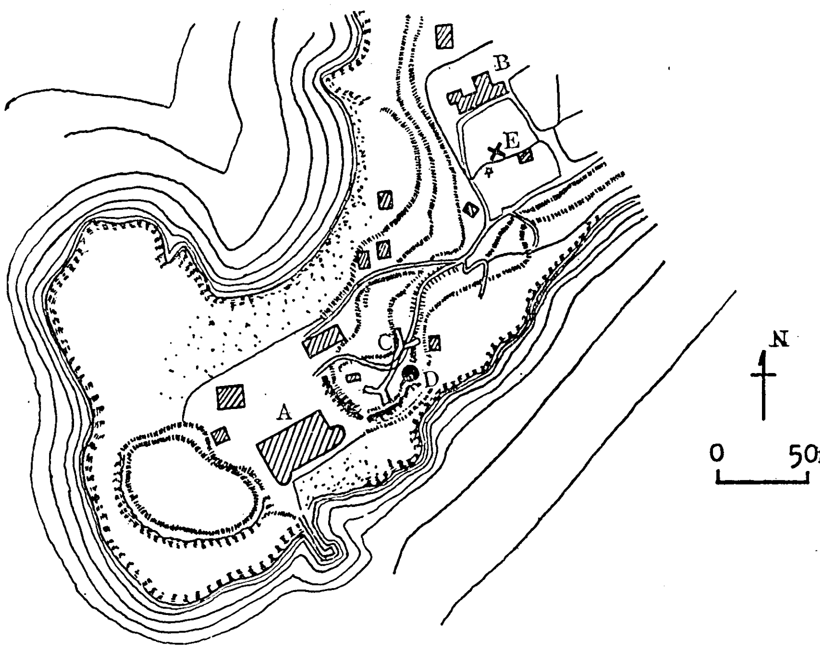

Fig. 1. The sketch map near the magnetometer room. A: Marine Biological Station, B: Dormitory, C: Gallery for the observation of crustal deformation, D: Magnetometer room, E: The place on which the absolute measurements had been made.

3) T. HAGIWARA, T. RIKITAKE and J. YAMADA, *Bull. Earthq. Res. Inst.*, **26** (1948), 23.

observation of crustal deformation. The topography near the magnetometer-room is shown in Fig. 1. The arrangement of the magnetometers are shown in Fig. 2 and Plate I. The sensibility of the D (declination)-variometer is $0.648'/mm$ with $2.7\,m$ optical lever, a M.K. magnet being suspended by a fine phosphorbronze wire.

The suspending wire of H (horizontal intensity)-variometer is a quartz fibre of $60\,\mu$, the sensibility being usually $1.5\gamma/mm$. A Z (vertical intensity)-variometer of Watson type with a sensibility-range $2\sim5\,\gamma/mm$ is also used. An example of the record is shown in Fig. 3 in which we find small fluctuations probably due to the stray electric currents from an electric railway at a distance of about $10\,km$.

Absolute measurements of the three components were carried out with a G.S.I. type magnetometer on April 27 and 28, 1951 in the garden of the dormitory of the Marine Biological Station, the place on which the measurements were made being also shown in Fig. 1. The results

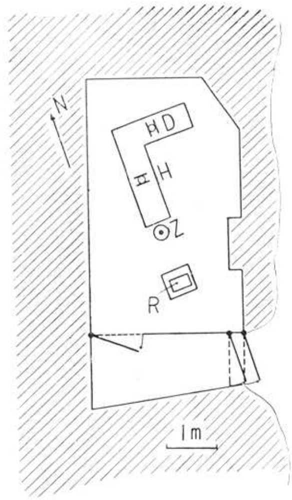

Fig. 2. The arrangement of the D (declination)-, H (horizontal-intensity)-, and Z (vertical intensity)-magnetometers and R (recording drum) in the magnetometer room.

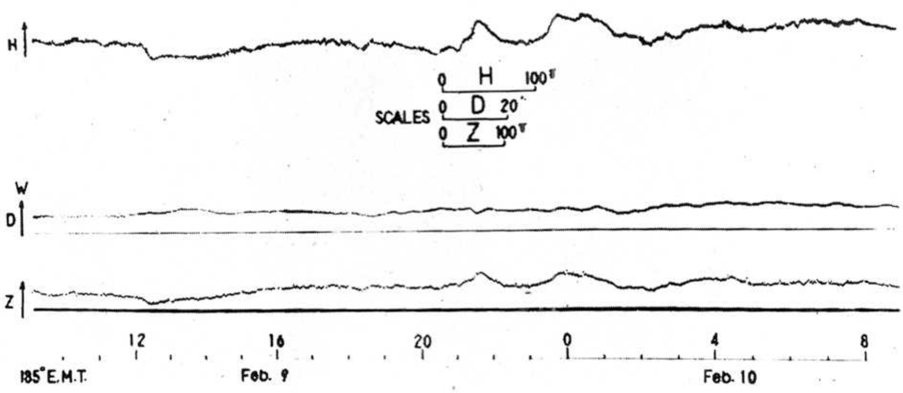

Fig. 3. An example of the record. (Feb. 9 and 10, 1952)

are given in the footnote[4] for future use.

(2) *Characteristics of short period variation.*

As early as in the year 1909, T. Terada[5] carried out an observation of the three geomagnetic components at almost the same place with the present one. He studied in great detail the behavior of rapid periodic variations and concluded that the vertical component of the waves is a reduced reproduction of the *NS*-component though some

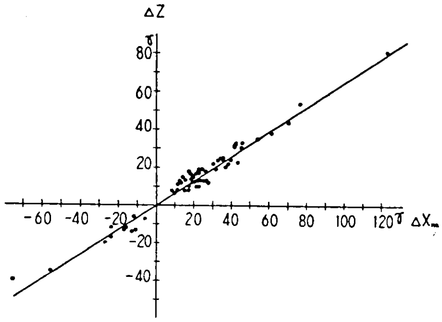

Fig. 4. The relations between ΔX_m and ΔZ for short period variations during the period from Sept. 9 to Oct. 14, 1951.

phase retardation could be found, especially with regards to rapid variations having period of several *minutes*. In Fig. 4, ΔZ is plotted against ΔX_m (change in magnetic north component) for variations having duration-time of scores of *minutes*, the phase difference being almost

4) The results of the absolute measurements are as follows:

Declination and Dip

Time	*D*	*I*
April 27th		
19^h14^m	6°35′.3	48°23′.4
20 20	34 .6	23 .1
22 32	34 .4	23 .3
23 52	32 .8	22 .0
28th		
9 34	30 .7	21 .0
10 44	34 .0	21 .6
11 35	34 .8	21 .7
12 30	35 .8	21 .2
13 28	35 .7	20 .6
14 27	34 .8	20 .8
15 46	34 .2	20 .9
17 00	32 .7	21 .0

Horizontal Intensity

Time	*H*
April 27th	
19^h26^m	30371γ
20 30	374
22 44	365
28th	
0 02	384
9 44	370
10 50	361
11 42	367
12 36	384
13 34	390
14 32	397
16 00	402
17 20	395

5) T. TERADA, *Journ. Coll. Sci. Tokyo Imp. Univ.* **37** (1917) Article 9.

negligibly small for these variations. The mean value of $\Delta Z/\Delta X_m$ is estimated at 0.62 that seems to harmonize well with Terada's results.

3. Study on the remarkable geomagnetic variation on Sept. 27, 1951.

At about 7 *h* 30 *m* *GMT* on Sept. 27, 1951, we had a rapid change in the earth's magnetic field. Since the 32nd cooperative observation of the Ionosphere Research Committee was under way at that date, the writers could collect copies of magnetograms from Wakkanai (45.4 *N*, 141.7 *E*), Kakioka (36.2 *N*, 140.2 *E*), and Aso (32.9 *N*, 131.0 *E*) Observatories together with that from Aburatsubo.

In order to pick up variations of short duration-time, the writers made running averages by averaging 13 readings of every 5 *minutes* of the magnetograms. Subtracting the running averages thus calculated from the original curves, we got the short period variations as shown in Fig. 5 for each observatory. The figures show a remarkable parallelism between ΔH and ΔZ at both Kakioka and Aburatsubo. And we

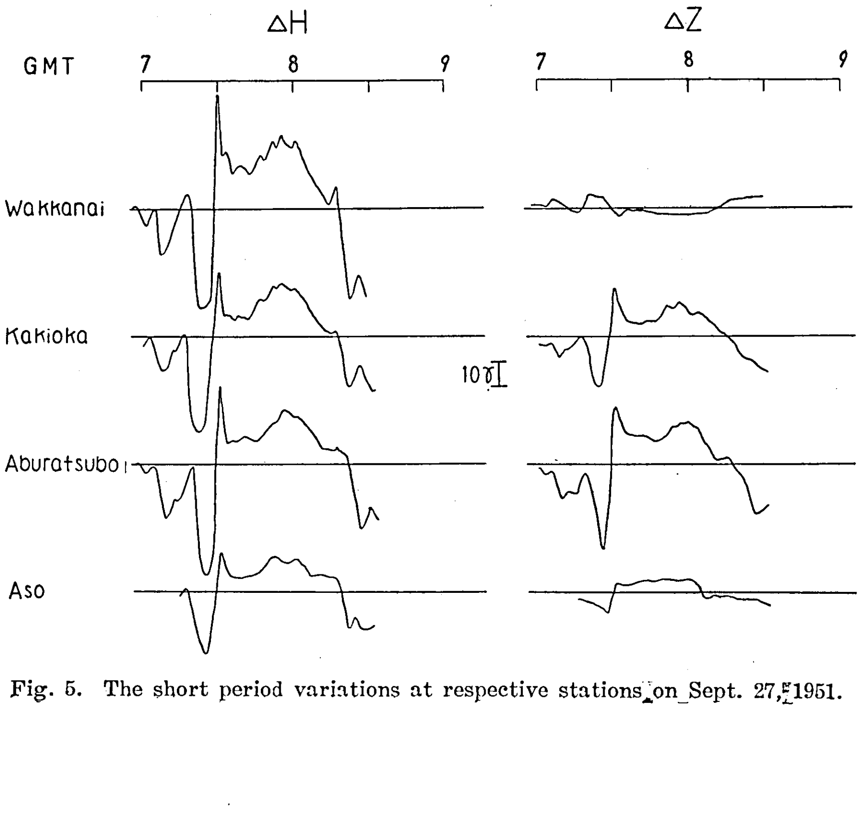

Fig. 5. The short period variations at respective stations on Sept. 27, 1951.

found out also the anomalously large amplitude of ΔZ at these stations. Though the forms of ΔH seem to be almost the same throughout the four observatories, ΔZ becomes small in its amplitude and also the parallelism becomes less at the northern and southern parts of Japan. Even the direction of ΔZ reverses at Wakkanai. As was manifested in Fig. 5, the curious distributions of geomagnetic variations, especially in Z-component, should be examined in fuller detail though the geomagnetic data cited here are unsatisfactory for that purpose.

4. Study on the geomagnetic variation at the time of the solar eclipse on June 19, 1936.

A total solar eclipse[2] occurred in the vicinity of Japan on June 19, 1936. In order to detect the influence of a solar eclipse on geomagnetic variation, many temporary stations were prepared in Japan, Manchuria, North China and Saghalien. Since a magnetic storm began at $9h$ $41m$ *GMT* on June 18, we could investigate in detail the hehavior of geomagnetic variations of short period with the magnetograms from these well-distributed stations. The positions of the stations are tabulated in Table I together with their abbreviations. The distribution of the stations is also shown in Fig. 6.

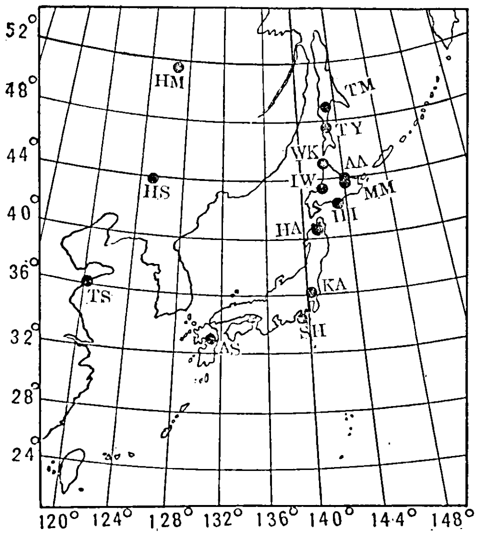

Fig. 6. The distribution of the stations for geomagnetic observation at the time of the solar eclipse on June 19, 1936.

Table I. The position and abbreviation of the stations.

Station	Abbreviation	Latitude	Longitude
Huma	HM	51.7°N	126.7°E
Tomarigishi	TM	49.0	142.9
Toyohara	TY	47.0	142.8
Wakkanai	WK	45.4	141.7
Abashiri	AA	44.0	144.3
Hsingking	HS	43.9	125.3
Memanbetsu	MM	43.9	144.4
Iwamizawa	IW	43.2	141.8
Hiroo	HI	42.3	143.3
Hirosaki	HA	40.6	140.5
Kakioka	KA	36.2	140.2
Tsingtau	TS	36.1	120.3
Shimoda	SH	34.7	138.9
Aso	AS	32.9	131.0

A very rapid change that occurred at about $5h$ $50m$ GMT was investigated in the main. For that purpose, the writers made running averages of every component during the period from $4h$ to $8h$ by means of the same method as stated in the last section, the original variations for respective stations being shown in Fig. 7. After subtracting the running averages from the original curves, ΔH, ΔD and ΔZ are obtained as shown in Fig. 8.

As may be seen in the figures, we found out again the large amplitude of ΔZ and the marked parallelism between ΔH and ΔZ at Kakioka and Shimoda. In order to study the distribution quantitatively, the distribution of ΔX (change in the north-component) and ΔZ at $5h$ $50m$ are plotted against the latitude under the assumption that the geomagnetic disturbance is uniform along the latitude circle and the earth's surface is approximately a plane. Then the distribution of ΔX and ΔZ is approximated by using six trigonometric terms as shown in Fig. 9. As has been used by A.G. McNish[6] and T. Nagata[7] in their studies on the auroral zone current and also by one of the present writers[8] in his analysis of SF-variation (geomagnetic variation associated with solar flare or Dellinger-effect) in European region, the said disturbance field is analysed by use of the Fourier series.

6) A. G. McNish, *Terr. Mag.*, **43** (1938), 67.
7) T. Nagata, *Rep. Ionos. Res. Japan.* **4** (1950), 87.
8) T. Rikitake, *Bull. Earthq. Res. Inst.*, **28** (1950), 219.

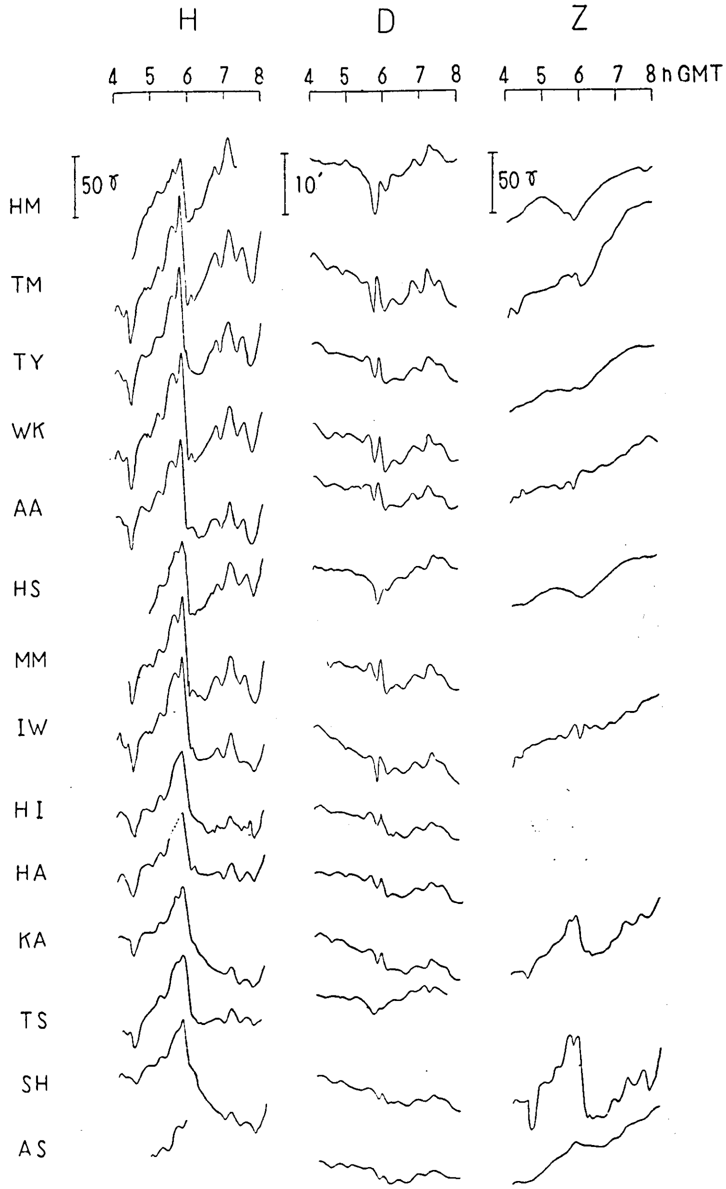

Fig. 7. The magnetograms for respective stations from 4 to 8 *h GMT* on June 19, 1936.

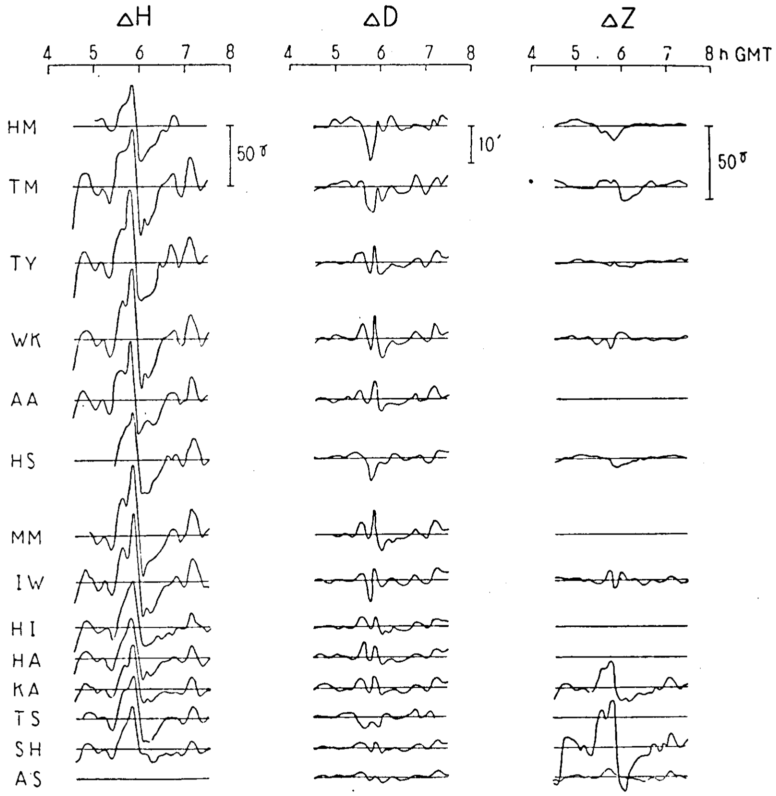

Fig. 8. The short period variations obtained from the original curves as shown in Fig. 7.

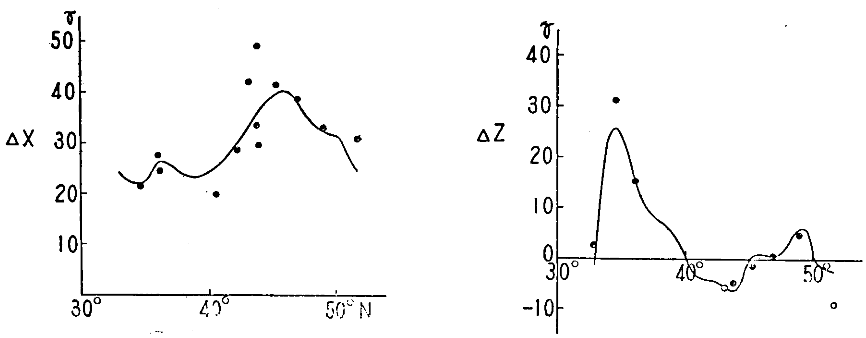

Fig. 9. The distribution of ΔX and ΔZ. The curves are the approximations with six trigonometric terms. (5 *h* 50 *m* *GMT*, June 19, 1936.)

The magnetic potential of the variation is generally expressed as follows,

$$W=\sum_m \sum_n (e_{mn}e^{-kz}+i_{mn}e^{kz}) {\cos \atop \sin} mx {\cos \atop \sin} ny \quad \text{.................(1)}$$

where

$$k^2=m^2+n^2. \quad \text{.................(2)}$$

If we take x, y and z to the directions north-, east-, and downwards, the terms which include negative indices of exponential correspond to the potential originating above the earth and positive indices to that within the earth respectively.

The components of the magnetic field on the earth's surface $z=0$ are given as

$$\left.\begin{aligned} X&=-\sum_m \sum_n (e_{mn}+i_{mn})\frac{\partial V_{mn}}{\partial x}, \\ Y&=-\sum_m \sum_n (e_{mn}+i_{mn})\frac{\partial V_{mn}}{\partial y}, \\ Z&=-\sum_m \sum_n k(-e_{mn}+i_{mn})V_{mn}, \end{aligned}\right\} \quad \text{.................(3)}$$

in which we write V_{mn} in place of the harmonic functions.

On the other hand, we get from the analysis of the observed data

$$\left.\begin{aligned} X&=-\sum_m \sum_n a_{mn}\frac{\partial V_{mn}}{\partial x}, \\ Y&=-\sum_m \sum_n b_{mn}\frac{\partial V_{mn}}{\partial y}, \\ Z&=-\sum_m \sum_n c_{mn}V_{mn}. \end{aligned}\right\} \quad \text{.......................(4)}$$

Hence, equating the corresponding coefficients in the series of X and Z in (3) and (4), we have

$$\left.\begin{aligned} e_{mn}+i_{mn}&=a_{mn}, \\ k(-e_{mn}+i_{mn})&=c_{mn}, \end{aligned}\right\}$$

from which we get

$$\left.\begin{aligned} e_{mn}&=\frac{a_{mn}-c_{mn}/k}{2}, \\ i_{mn}&=\frac{a_{mn}+c_{mn}/k}{2}. \end{aligned}\right\} \quad \text{........................(5)}$$

Thus we can separate the coefficients of the magnetic potential into the external and internal parts. The same solution is also possible by combining Y with Z. However, it is of course impossible to separate the constant parts of the magnetic potential and force into the external origin and internal origin parts.

In practice, a smoothed curve was arbitrarily drawn through the points in Fig. 9. The curve was then subjected to a Fourier analysis with six trigonometric terms.

The external origin and internal origin parts of the non-uniform field determined by the above-mentioned procedure are illustrated in Fig. 10 respectively for ΔX and ΔZ at $5h\ 50m$. Looking at the figures, we find out that the internal parts (X_i, Z_i) are not always small compared with the external ones (X_e, Z_e) and their distributions are complicated.

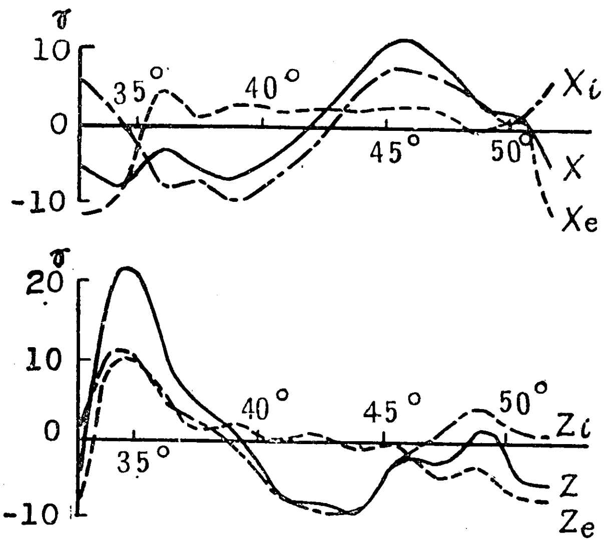

Fig. 10. The external and internal origin parts of ΔX and ΔZ.

As has been shown by S. Chapman[9], A.T. Price,[10] and one of the present writers[11], the internal part of various variations such as S_q, S_D, D_{st}, bay-type disturbance, and 27-day period variation usually amounts to $\frac{1}{4}\sim\frac{1}{3}$ of the external one in case the analyses are of world-wide scale. Even in the cases of the analyses with respect to a limited region of North Europe[6),7),8)], the said relation between the external

9) S. Chapman, *Phil. Trans. Roy. Soc. London A*, **218** (1919), 1.

10) S. Chapman and A. T. Price, *Phil. Trans. Roy. Soc. London A*, **229** (1930), 427.

11) T. Rikitake, *Bull. Earthq. Res. Inst.*, **28** (1950), 45, 219, **29** (1951), 61.

and internal parts seems to hold true. Hence, the curious distribution of both parts of geomagnetic variation in the vicinity of Japan as revealed in Fig. 10 can hardly be explained from the viewpoint of the electromagnetic induction theory within a homogeneous earth notwithstanding the success of the theory in the explanation of geomagnetic changes of world-wide scale. We, therefore, suspect the existence of some peculiar conditions in the earth's interior under Japan.

5. The electrical condition in the earth's interior below Japan and her vicinity.

Although the analysis of the geomagnetic variation treated in the last section is one-dimensional and not sufficient for studying the source of the peculiarity, we shall make a preliminary investigation concerning the underground structure from the standpoint of electromagnetic induction.

If the anomalous behavior of geomagnetic variation is caused by an abnormal distribution of magnetic permeability in the earth's crust, the permanent magnetic field and its secular variation must be greatly disturbed there. Since we have no evidence of such a disturbed magnetic field in Japan, especially in her central part, the origin of the anomaly of geomagnetic variation of short period may be attributed in the main to the induced electric currents flowing in the earth's interior, the depth of the currents being less than 100 *km* because of the reason mentioned later. Under the assumption that a plane electric current sheet having current function $J(x, y)$ at depth $z=D$ is responsible for the internal origin field, we have

$$J(x, y)=\frac{1}{2\pi}\sum_m \sum_n e^{kD} \boldsymbol{i}_{mn} V_{mn}, \qquad (6)$$

from which we can get the current intensity by the following relations

$$I_x=\frac{\partial J}{\partial x}, \quad I_y=-\frac{\partial J}{\partial y}. \qquad (7)$$

With these relations, the current density by which the internal origin field at $5\,h\,50\,m$ would be produced is calculated for $D=0$, 50, 100 and 200 *km* as illustrated in Fig. 11. As may be seen in the figures, the distribution of the current density becomes more complicated according as the depth of the current sheet becomes great. The distribution for $D=200\,km$ seems to be too much oscillatory to be adopted as a real distribution, while that for $D=100\ km$ seems to be fairly convergent. Hence, we may tentatively assume that the main part of the electric currents, which produce the anomalous geomagnetic variation in Japan, are flowing in the earth's interior at a depth less than about 100 *km*.

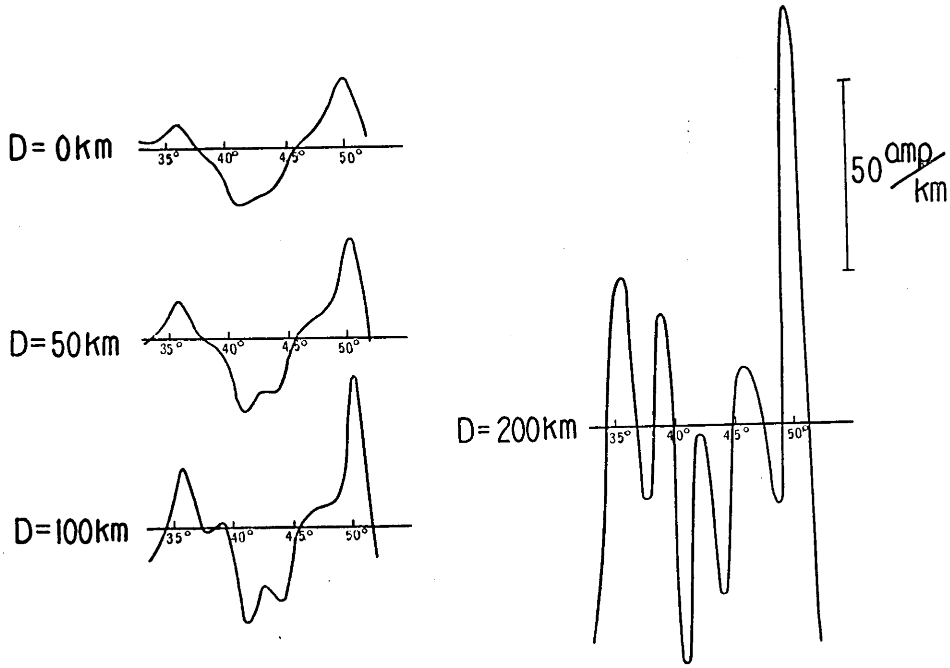

Fig. 11. The electric current density for the internal origin part of the geomagnetic variation, the depth of the current sheet being assumed respectively to be 0,50,100 and 200 *km*.

Though we have no convincing method to clarify the reason why the abnormal distribution of electric currents occur at the time of short period variation in the earth's magnetic field, it may be naturally regarded as the electric current induced by changes in the magnetic field of external origin, the special distribution of the currents being ascribed to a heterogeneous distribution of the electrical conductivity in the earth. The constant part of external origin field, which can not be analysed on a plane earth, would of course play an important rôle in the case of a heterogeneous distribution of the electrical conductivity.

6. Summary and conclusion.

A brief outline of geomagnetic observation at Aburatsubo is described. The anomalously large amplitude of ΔZ and the strong parallelism between ΔH and ΔZ are found on the magnetograms there. The anomalous behavior is studied with the aid of magnetograms from various observatories in Japan and her vicinity. And the anomalous behavior is confirmed at all the observatories situated in the central part of Japan, while the said parallelism and large amplitude of ΔZ become less in the southern and northern parts of Japan.

Analysing the geomagnetic data at the time of the solar eclipse on June 19, 1936, which proved to be most useful because of the proper distribution of temporary stations, it is found out that the anomalous distribution of geomagnetic force may be due to electric currents flowing under Japan, the currents seeming to be electromagnetically induced by changes in geomagnetic force of external origin in an electrically heterogeneous earth.

Since we know that the electrical state beneath North Europe agrees well with the electrical states determined on a world-wide analysis, some special conditions may be said to exist in the earth's crust beneath Japan. As is well known, Japan is the most seismically active country in the world. And we naturally suspect that there are some relations between the above-mentioned peculiar condition and the seismicity or volcanism in Japan.

In order to investigate in fuller detail, the writers are now collecting copies of magnetograms on June 19, 1936 from foreign observatories all over the world. A more complete analysis concerning the anomalous behavior of geomagnetic variations of short period in Japan will be made in the near future.

In conclusion, the writers are grateful to the Ionosphere Research Committee of Japan with whose data a part of the present study was carried out. Especially the writers wish to express their thanks to the Wakkanai, the Kakioka and the Aso Magnetic Observatories. The writers are also indebted to Professor T. Nagata and Mr. N. Fukushima for their helpful discussions.

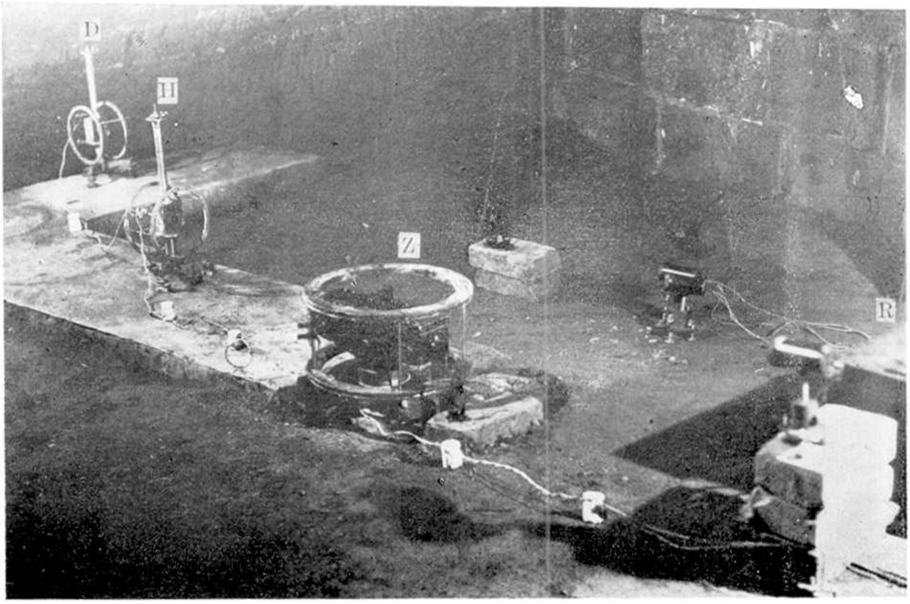

Plate I. The view in the magnetometer room.

H: Horizontal intensity variometer
D: Declination variometer
Z: Vertical intensity variometer
R: Recorder

18. 日本に於ける地磁氣短周期變化の異常と地下構造（序報）

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1951 年 9 月より神奈川縣油壺に於いて，地磁氣 3 成分の連續觀測が開始されたが，短周期變化に於いて水平分力と鉛直分力の著しい平行性が見出された．また鉛直分力の振幅がいちじるしく大きく水平分力の 60% に達する事實も見出された．このような事情はすでに柿岡に於ける地磁氣變化にも見られるところである．筆者等は電離層總合研究委員會の第 32 回協同觀測期間および 1936 年 6 月 19 日の日食時の地磁氣資料について檢討したところ，上記の短周期變化の異常は主として日本中部にのみ見られることを確認した．

この變化の分布を Fourier 級數の方法を用いて，地球内および外に原因をもつ部分にわける時は，その相互の關係は一様な地球内への電磁感應として說明することは出來ず，日本の地下に異常な電氣傳導度の分布を考えなければならないことになつた．