3. *Geomagnetic Anomaly on Mt. Haruna and Its Relation to the Reverse Thermo-Remanent Magnetism of the Pumice Covering the Place.*

By Izumi YOKOYAMA,

Earthquake Research Institute.

(Read Nov. 18, 1952.—Received Dec. 20, 1952)

1. Introduction.

Mt. Haruna is one of the extinct volcanoes standing at the north-western edge of Kwanto-plain, Central Japan. It consists of an older, dissected cone and four younger lava domes. Its topographical map is shown in Fig. 1. The history of the volcanic activity was summarized by S. Taneda[1] as follows: The older cone was built up by alternate eruption of lavas and pyroclastics largely of pyroxene andesite. The cone was then subjected to intense erosion during the succeeding period of quiescence. During the next period of activity, the domes of horn-blende dacite, Mts. Sōma, Mizusawa-yama, Haruna-Fuji and Futatsu-dake, were erupted in the order just mentioned. It seems likely that tuff-breccia and pumice were erupted from a crater which was later filled up by the dome of Futatsu-dake. The pumice layer covers widely the eastern slope of the volcano, its eastern extension being found even beyond the Tone River. A geologic sketch map is shown in Fig. 2.

In October and November, 1952, a magnetic dip survey was carried out at Mt. Haruna by the writer with a miniature earth-inductor.[2] The purpose of the survey is to study the relation between geomagnetic anomaly and the reverse thermo-remanent magnetism of the pumice covering the eastern part of the volcano. The number of surveyed sites reached 25, while the error of each measurment was about 1 *minute* of arc. The observed values are shown in Table I and plotted in Fig. 3 with an altitude abscissa where the corrections for diurnal variations are made with reference to the magnetograms of the Abura-tsubo base-station which is about 150 *km* distant from Mt. Haruna. The normal value for this district is 49°50′.

1) S. TANEDA, *Mem. Fac. Sci. Kyūsyū Imp. Univ. D*, **1** (1941), 44.
2) T. RIKITAKE, *Bull. Earthq. Res. Inst.*, **29** (1951), 147.

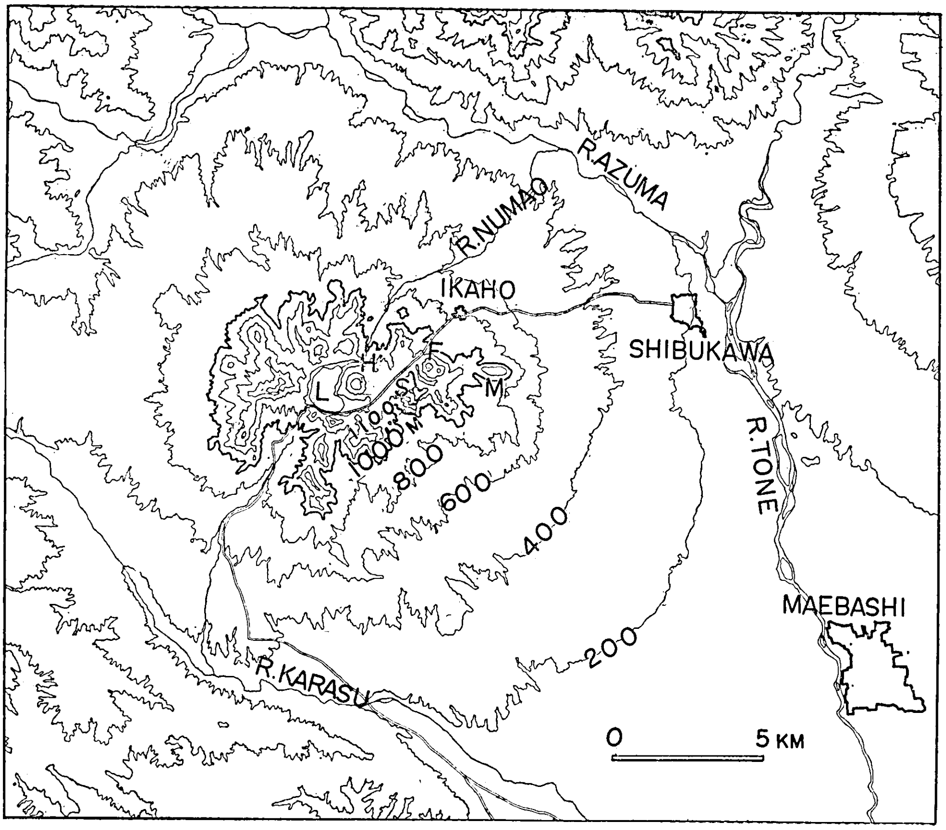

Fig. 1. Topographical map of Mt. Haruna.
H: Mt. Haruna-Fuji S: Mt. Sōma F: Mt. Futatsu-dake
M: Mt. Mizusawa L: the Haruna Lake.

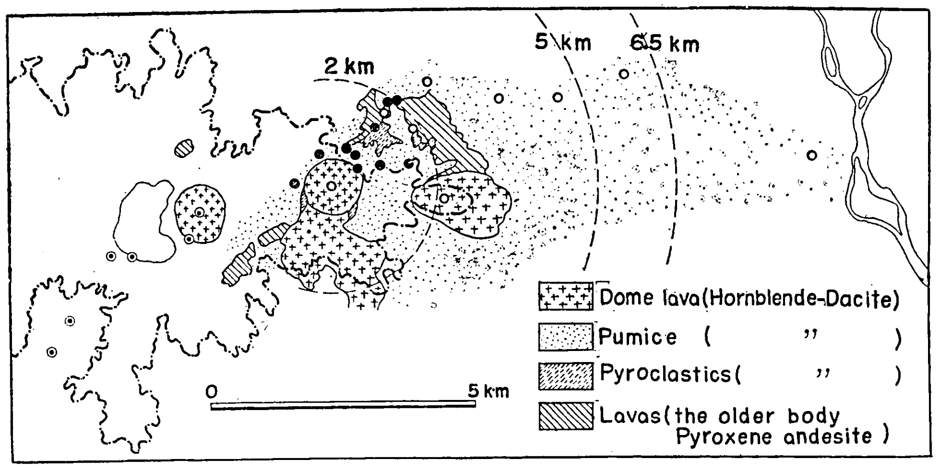

Fig. 2. Geologic sketch map of Mt. Haruna (after H. Kuno).

Table I.

The observed values of magnetic dip.

Time		Locality		Approximate Altitude	Dip
Oct. 29	$13^h 48^m$	榛名湖畔	Side of Lake Haruna	1100^m	49°32′
	14 22	榛名富士山麓	Foot of Mt. Haruna-Fuji	1120	49 02
	15 17	富士山頂三角点	Summit of Mt. Haruna-Fuji	1391	54 56
	16 36	ヤセオネ峠	Pass Yaseone	1179	50 48
	17 00	ケーブルと旧道との交叉点	Cross-point of cable-way and road	1060	50 34
	17 40	橋本ホテル前	Near Hotel Hashimoto	900	50 42
	18 02	天溪園玄関	Tenkeien	840	47 55
Oct. 30	08 24	伊香保神社上	Ikaho Shrine	510	51 10
	08 52	見晴台三角点	Summit of Miharashidai	976	51 42
	09 22	水沢山の麓	Foot of Mt. Mizusawa	1020	51 24
	09 45	水沢山と二ツ嶽の間の沢	Between Mts. Mizusawa and Futatsu-dake	1000	50 00
	10 16	二ツ嶽の麓	Foot of Mt. Futatsu-dake	1010	49 37
	10 36	わしの巣附近	Near Washinosu	960	49 55
	10 49	わしの巣	Washinosu	970	49 37
	12 34	伊香保ホテル附近	Near Hotel Ikaho	670	50 22
	13 13	大日向驛前	Ōhinata-station	560	50 13
	13 40	六本松	Ropponmatsu	460	49 56
	14 14	御蔭松	Okagenomatsu	390	49 50
	14 50	渋川驛前	Shibukawa-station	190	49 36
Nov. 8	06 28	スケート・リンク	Skating-rink	840	49 52
	10 02	水沢山三角点	Summit of Mt. Mizusawa	1194	54 02
	12 34	二ツ嶽頂上	Summit of Mt. Futatsu-dake	1342	56 01
	15 07	天神峠	Pass Tenzin	1121	50 30
	15 49	榛名神社	Haruna Shrine	870	48 45
	16 11	榛名山町	Harunasan Town	800	47 44

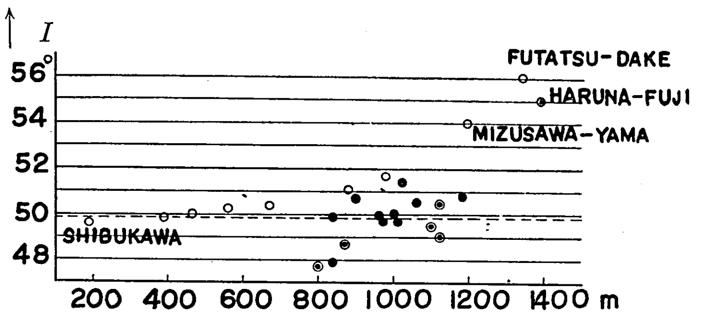

Fig. 3. Distribution of magnetic dip.

Looking at the general aspect of the distribution, the dip values observed in the region east of Mt. Haruna-Fuji (shown by double circles in Fig. 3) seem to form different series from those in the region to the west of it. Here the discussion will be confined to the eastern region where the geology is well known. Taking into consideration the fact that the dip-angle usually increases with the increase in height on an ordinary volcano, the low values observed at the foot of Mt. Futatsu-dake (shown by black circles in Fig. 3) look very anomalous.

2. The magnetization of the pumices.

After T. Rikitake's method,[3] it is possible to calculate the intensity of magnetization J of a uniformly magnetized circular cone if the shape of the cone and the dip anomaly on the central axis due to the cone are known. Corresponding to dip anomaly ΔI, if ΔI is small and the cone is magnetized in a direction in xz-plane with inclination θ, the following relation is obtained

$$\begin{aligned} f(\Delta I) &= \{\tan(I_0+\Delta I)-\tan I_0\}/\tan I_0 \\ &= \Delta Z/Z_0 - \Delta X/X_0 \\ &= \pi J G(2\sin\theta/Z_0+\cos\theta/X_0)\ , \end{aligned}$$

where I_0, Z_0 and X_0 denote respectively the normal value of I, Z and X there and G is theoretically determined depending on the shape of the cone. Applying this relation to the cases of Mts. Haruna-Fuji and Futatsu-dake, the specific intensities of magnetizations of the rocks composing the mountain-bodies are surmised as shown in Table II.

The results of the observation in the region east of Mt. Futatsu-dake are shown in Fig. 4 with the altitude from the bottom plane of Mt. Haruna as abscissa, where a mean profile curve of the mountain

Table II.
Dip anomaly and magnetization.

	G	I	ΔI	J
Mt. Haruna-Fuji	1.08	49°02′	5°54′	1.1×10^{-2} *emu*
Mt. Futatsu-dake	2.10	49 37	6 24	$5\ \ \times10^{-3}$

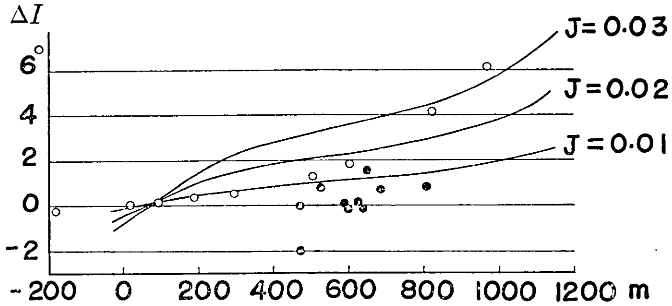

Fig. 4. Distribution of dip-anomaly.

3) T. RIKITAKE, *Bull. Earthq. Res. Inst.*, **30** (1952), 71.

is determined after T. Terada's method.[4] As already studied by T. Rikitake,[5] the distribution of the components of the magnetic field over a circular cone due to the magnetization of this cone are obtainable if the intensity of magnetization and the shape of the cone are known. On the assumption that Mt. Haruna is a circular cone with the radius 8 *km* at the bottom and the height 1270 *m* and uniformly magnetized northward with inclination 49°50′ (the normal dip-angle in this district), the increase in the dip-anomaly along the eastward slope of the mountain is obtained for each respective magnetization as shown in Fig. 4. Comparing the calculated anomaly with the observed one, we may presume that the mean intensity of magnetization amounts to about 0.01 *emu*. Taking into account the values obtained from both Mts. Haruna-Fuji and Futatsu-dake, the figure seems to be reasonable. As mentioned before, one noticed the conspicuous lower values deviating from this curve at the foot of Mt. Futatsu-dake, where hornblende dacite pumice covers the slope for a thickness more than 10 *meters*.

Table III.
Chemical composition (HK 51070801 b).

Fe_2O_3	FeO	TiO_2	MnO	V_2O_3
53.15	31.93	6.82	0.69	0.49%

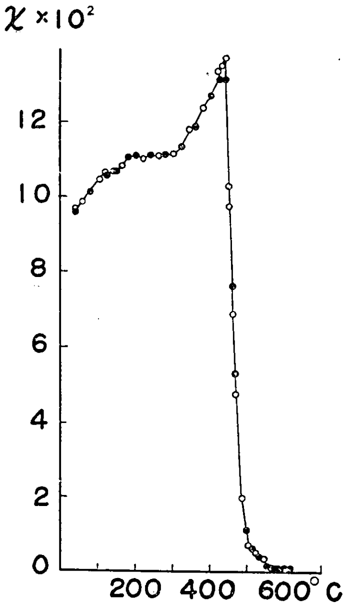

Fig. 5.
○ cooling ● heating.
(After T. Nagata, S. Uyeda and S. Akimoto)

As regards the pumice, T. Nagata, S. Uyeda and S. Akimoto[6] studied magnetic characteristics in detail. Referring to their studies, the general description of the rock samples is as follows. The result of chemical analysis of magnetite separated from the pumice is given in Table III and their intensity of natural remanent magnetism is 4.3×10^{-3} *emu* in average and the direction is almost opposite to that of the present geomagnetic field. The change of magnetic susceptibility of the ferromagnetic mineral in a weak magnetic field with temperature is illustrated in Fig 5. Its singularity is a stepwise

4) T. TERADA, *Bull. Earthq. Res. Inst.*, **7** (1929), 207.
5) T. RIKITAKE, *Bull. Earthq. Res. Inst.*, **29** (1951), 170.
6) T. NAGATA, S. UYEDA and S. AKIMOTO, *Journ. Geomag. Geoelectr.*, **4** (1952), 22.

change, having apparently two Curie points i. e. 540°C and about 280°C. The thermo-remanent magnetizations (T. R. M. s) produced by cooling down the rock sample to the room temperature (10°C) from various temperatures from 200°C to 600°C in a magnetic field of 0.5 *Oe* are shown in Fig. 6. As shown in this figure, the direction of T. R. M. thus produced are opposite to that of applied magnetic field (Reverse T. R. M.). In the ordinary rock samples, T. R. M. is always "positive" i. e. the direction of T. R. M. is parallel to that of applied magnetic field. In the case of the pumice from Mt. Haruna, however, T. R. M. s produced by cooling from a temperature above 300°C in a magnetic field of 0.5 *Oe* are always Reverse T. R. M. Seeing Fig. 6, we are convinced of the existence of the phenomenon of self-reversal of thermo-remanent magnetism of the pumice notwithstanding the positive values obtained for the mountain-body of Mt. Futatsu-dake as stated above.

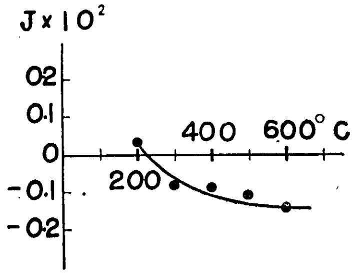

Fig. 6.
(After T. Nagata, S. Uyeda and S. Akimoto)

3. Interpretation of the anomalous distribution of magnetic dip-angle.

Taking into account both the anomalous distribution of dip-angle at the foot of Mt. Futatsu-dake and the above-mentioned phenomenon of self-reversal of thermo-remanent magnetism of the pumices, there seems to be a causal relation between them. Next it comes into question whether the ejected pumice from Mt. Futatsu-dake cools

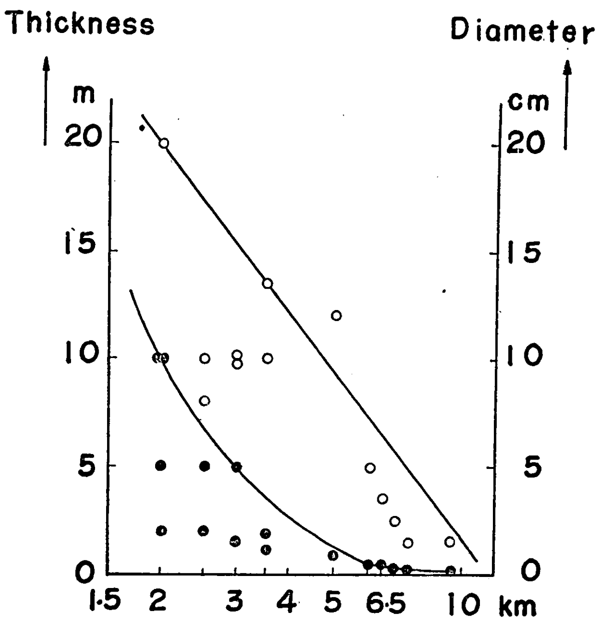

Fig. 7.
● Thickness of pumice layer
○ Mean diameter of pumice particle.

down below Curie point before landing in the present position.

The variations in the thickness of the pumice layer with the distance from Mt. Futatsu-dake is shown in Fig. 7, where the thickness is probably underestimated since the pumice layer cannot be seen in its original state. The distribution of the mean diameter of the five largest particles of each outcrop of the pumice layer gives mean diameters at distances of 2 *km*, 5 *km* and 6.5 *km* of 20 *cm*, 10 *cm* and 5 *cm* respectively (see Fig. 7). According to T. Minakami's investigation[7] made on Mt. Asama, as soon as the vertical velocity of the small fragments shot upward by the explosion diminishes at a certain height after about 120 *sec* for instance, the column is diffused in all directions assuming a cauliflower shape. At the same time, the smoke drifts with the wind, the larger fragments falling more rapidly on the lee side of the mountain. Therefore, the pumices from Mt. Futatsu-dake are thought to be distributed on the lee side of the volcano following the prevailing wind direction of the upper atomosphere.

Taking the origin of the co-ordinate at the maximum height to which the pumice was ejected from the crater, the equations of its motion are given by

$$\ddot{x}-\lambda(v_0-\dot{x})^2=0\ ,$$
$$\ddot{z}+\lambda\dot{z}-g=0\ ,$$

where the x axis is taken in the direction of the wind and the z axis downward and

$$\lambda=\frac{3k\rho'}{4\rho d}\ ,$$

and ρ', ρ, d and k denote the mean density of air, bulk density of pumice, diameter of pumice and coefficient of resistance respectively. The initial conditions are

$$t=0: \qquad x=z=0\ ,$$
$$\dot{x}=\dot{z}=0\ .$$

Solving one of the above equations, we have

$$x=v_0 t-\frac{1}{\lambda}\log(\lambda v_0 t+1)\ .$$

Here k is taken to be 1.35 after Minakami and v_0 is assumed to be 30 *m/sec* as a rather high value. Then, the time of flight is calculated with the aid of the relation between the diameters of the pumice particles and the distance to which they were sent, the results being shown in Table IV.

7) T. MINAKAMI, *Bull. Earthq. Res. Inst.*, **20** (1942), 93.

Thus the total time of flight obtained for pumice particles of diameter of 20 *cm*, 10 *cm* and 5 *cm* become roughly 200 *sec*, 300 *sec* and 400 *sec* respectively in rather an overestimate. Concerning the heat conduction of the pumice particle, it is assumed for brevity that the particle is a sphere with radius a and it flies through air of which the temperature is constant, i.e. θ_0. The equations of heat conduction are given by

Table IV.

d	x	t
20 *cm*	2000 *m*	80 *sec*
10	5000	175
5	6500	220

d: diameter of pumice particle (observed)
x: horizontal distance from Mt. Futatsu-dake (observed)
t: time of flight from the maximum height (calculated).

$$\frac{\partial(r\theta)}{\partial t}=\kappa\frac{\partial^2(r\theta)}{\partial r^2}\,,$$

$$\theta=\theta_1 \quad \text{when} \quad t=0\,,$$

$$\frac{\partial\theta}{\partial r}+h(\theta-\theta_0)=0 \quad \text{when} \quad r=a\,,$$

where h is an experimental constant depending upon what is called the surface conductivity of the sphere. In solving these equations, let $r(\theta-\theta_0)=u$, then a particular solution is given by

$$u=e^{-\kappa\frac{\mu_s^2}{a^2}t}\sin\frac{\mu_s}{a}r\,,$$

where μ_s is a value of μ which is a root of the next transcendental equation:

$$\mu\cos\mu+(ah-1)\sin\mu=0\,.$$

The general solution is given by

$$u=\sum_{s=1}^{\infty}A_s e^{-\kappa\frac{\mu_s^2}{a^2}t}\sin\frac{\mu_s}{a}r\,.$$

Using the initial condition $r(\theta_1-\theta_0)=\sum_{s=1}^{\infty}A_s\sin\frac{\mu_s}{a}r$, we have

$$A_s=\frac{2}{a}\frac{\mu_s^2+(ah-1)^2}{\mu_s^2+ah(ah-1)}\times\frac{a^3h(\theta_1-\theta_0)}{\mu_s^2}\times\sin\mu_s\,.$$

Therefore
$$\theta-\theta_0=\frac{2a^2h(\theta_1-\theta_0)}{r}\sum_{s=1}^{\infty}\frac{\mu_s^2+(ah-1)^2}{\mu_s^2\{\mu_s^2+ah(ah-1)\}}e^{-\kappa\frac{\mu_s^2}{a^2}t}$$
$$\times\sin\mu_s\times\sin\frac{\mu_s}{a}r\,.$$

At the centre of the sphere, we have

$$\theta-\theta_0=2ah(\theta_1-\theta_0)\sum_{s=1}^{\infty}\frac{\mu_s^2+(ah-1)^2}{\mu_s^2\{\mu_s^2+ah(ah-1)\}}e^{-\kappa\frac{\mu_s^2}{a^2}t}$$
$$\times\sin\mu_s\times\mu_s\ .$$

For the particle of the pumice concerned here, various constants are taken as follows :

K:	thermal conductivity	0.44×10^{-3} *cal/cm. sec.* °*C*
$\kappa=K/C\rho$:	diffusivity (C:	specific heat, ρ: density)
		3.1×10^{-3} *cm²/sec*
α:	emissivity	1.1×10^{-2} *cal/cm². sec.* °*C*
$h=\alpha/K$		25/*cm*

Taking $\theta_0=50°C$ and $\theta_1=1000°C$ for simplicity's sake, the changes in temperature numerically calculated at the centre of the pumice particle of various diameter are shown in Fig. 8 respectively. As seen in the figure, the particles of 20 *cm* and 10 *cm* diameter are considered to cool down below Curie point (about 300°C) certainly after landing in

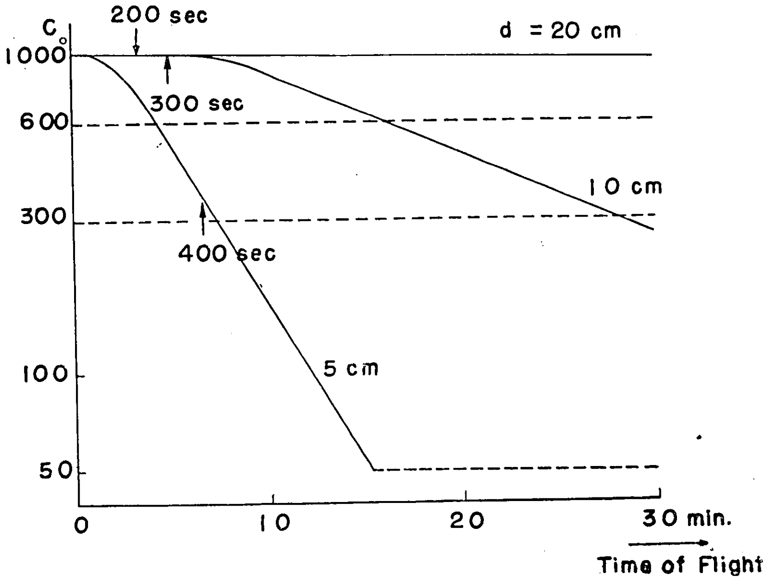

Fig. 8. The changes in temperature at the centre of the pumice particle.

the present position. Therefore they are to be magnetized opposite to the applied geomagnetic field at that time unless they have been moved. Anomalous distribution of dip-angle about the basin covered with the pumice layer between Mts. Futatsu-dake and Mizusawa-yama seems to be due to the reversal of thermo-remanent magnetism of the pumice there.

In order to fathom the depth of the pumice layer so as to show the anomalies, we assume a magnetized disk with the same diameter as that of the basin. At a point on the central axis of the disk with radius R and depth d, the magnetic anomaly is given by

$$\Delta Z = \frac{\gamma}{G\sigma}\frac{\partial^2 U}{\partial z^2} = 2\pi d\gamma \frac{R^2}{(z^2+R^2)^{3/2}} ,$$

where γ, G, σ and U denote the vertical component of the magnetization, gravitational constant, density and gravitational potential respectively. Taking $R \gg z$

$$\Delta Z = 2\pi d\gamma \frac{1}{R} .$$

Thus we have

$$\Delta I = \sin I_0 \times \cos I_0 \times \frac{\Delta Z}{Z} = \sin I_0 \times \cos I_0 \times \frac{2\pi d\gamma}{RZ} .$$

Approximately taking $R=500\ m$, $\gamma=-10^{-2}\ emu$, $I_0=49°50'$ and $\Delta I=-1°$, the depth d amounts to about 100 *meters*. This value seems to be reasonable.

4. Conclusion.

The causal relation between the anomalous distribution of the magnetic dip at Mt. Haruna and the magnetic characteristics of the pumice which covers the slope of the mountain has thus been made clear.

In concluding, the writer wishes to express his sincere thanks to Dr. Rikitake for his helpful guidance. To Prof. T. Minakami, Prof. T. Nagata, Mr. S. Akimoto and Mr. S. Uyeda for their helpful advices, the writer's cordial thanks are due. The writer's sincere thanks are also due to Dr. H. Kuno for geological informations of the volcano. This study was conducted under the financial aid of the grant from the Department of Education. The writer is grateful to the authorities of the Department.

3. 榛名山の地磁気異常とその浮石の逆熱残留磁気との関係

地震研究所　横　山　　泉

1952年10月，11月にわたり，小型地磁気感応儀を用いて，榛名山の地磁気伏角を測定した。その目的は，既に，地球物理学教室の永田研究室により発見されたところの榛名山一帯に分布する浮石の逆熱残留磁気と，地磁気異常との関連を調べることである。二ッ嶽と水沢山との間の，浮石層に厚く蔽われていると思われる地域一帯に於ては，伏角分布の異常が明かに認められる。この異常は，二ッ嶽より噴出された浮石の逆帯磁に因るものであることが略々結論された。然るに，榛名富士，二ッ嶽を夫々独立した円錐と見做して，その山体の帯磁を求めると，正常な帯磁を得た。榛名山全体に就ても同じである。即ち噴出された浮石は逆熱残留磁気的であるが，これを噴出した山体は正常に帯磁しているという事が明かになった。