10. *Magnetization of the Gabbro from Mt. Tsukuba with Special Relation to the Geomagnetic Anomalies**.

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1. Introduciton.

In August, 1951, a magnetic dip survey was carried out at Mt. Tsukuba by the Earthquake Research Institute with a miniature earth-inductor [1]. The number of surveyed sites reached 20, while the error of each measurment was about ±1 *minute* of arc. The observed values are shown in Table I and plotted in Fig. 2 with an altitude abscissa.

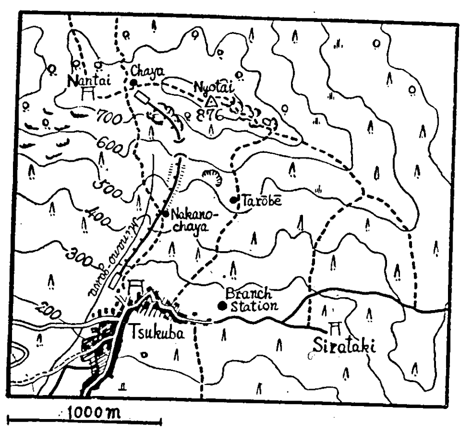


Fig. 1. Topographical map of Mt. Tsukuba.

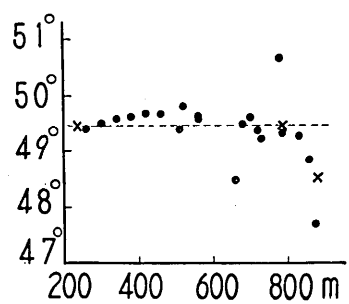


Fig. 2. The distribution of the dip at Mt. Tsukuba. The mark × denotes the values obtained by A. Tanakadate in Dec., 1906.

Looking at the general aspect of the distribution, one notices a conspicuous decrease in the dip-angle above the height of 500 *meters*. Taking into consideration the fact that the dip-angle usually increases with the increase in height on volcanoes, the geomagnetic anomaly found on Mt. Tsukuba, which is not a volcano, appears curious and interesting. As early as in Dec., 1906, A. Tanakadate suggested the unusual magnetization of the rocks near the summits of Mt. Tsukuba performing a survey with

* Communicated by T. RIKITAKE.

1) T. RIKITAKE, *Bull. Earthq. Res. Inst.*, **29** (1951), 147.

Table I.

The observed values of magnetic dip.

Time		Locality		Approximate Altitude	Dip
Aug. 8	10*h*02*m*	ケーブル斜面	slope of the cable way	300 *meters*	49°29.′3
	10 48	仲の茶屋	Naka-no-chaya	520	47.0
	11 32	トンネルと鞍部との中間	between the tunnel and the saddle-point	700	36.1
	11 59	鞍　部	saddle-point	790	20.7
	13 04	男體頂上	summit of Nantai	860	48 49.8
	13 44	女體頂上	summit of Nyotai	875	47 41.7
	14 34	辨慶茶屋	Benkei-chaya	660	48 28.5
	15 04	ハイキング・コース岐路	fork of the hiking-course	560	49 34.2
	15 54	白　瀧	Sirataki	260	24.3
Aug. 9	09 18	ケーブル斜面	slope of the cable-way	340	34.9
	09 32	〃	〃	380	36.9
	09 48	〃	〃	420	40.1
	10 00	〃	〃	460	39.8
	10 20	〃	〃	560	37.2
	10 54	〃	〃	680	28.8
	11 22	〃	〃	730	14.6
	13 32	女體への道	the way to Nyotai	830	16.4
	14 41	大黒岩	Daikoku-iwa	780	50 38.8
	15 01	出舟入舟	Debune-iribune	720	49 22.8
	16 40	太郎兵衛茶屋跡	site of Tarobē-chaya	510	23.6

a dip-circle. The values observed by him are also shown in Fig. 2 where the corrections for the secular variation are neglected because it is almost impossible to identify strictly the positions on which the observations were made. But these old measurements seem to agree with the results of our present survey.

From the standpoint of geology, Mt. Tsukuba is composed of various gabbroic rocks surrounded with granitic ones and the relation between them is not distinct because the outcrop has not been found about the boundary. According to H. Tsuya[2] who made a field survey at the time of the land-slide of July, 1938, the boundary is thought to coincide approximately with the contour line of 500 *meters*. Referring to these facts, samples of rocks were taken at eight localities from the

2) H. TSUYA, *Bull. Earthq. Res. Inst.*, **17** (1939), 517.

midway up to the top of the mountain in order to study the magnetization of the rocks which may furnish some clues to the interpretation of the geomagnetic anomaly.

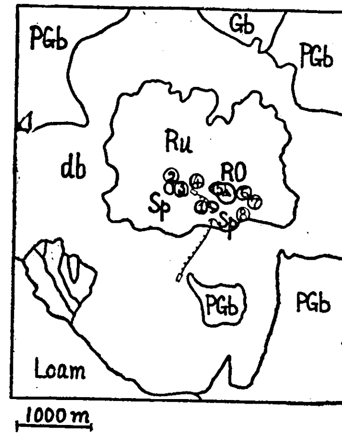


Fig. 3. Geological map of Mt. Tsukuba.

Legend

db : Detritus
Gb : Biotite-granite
PGb : Porphyritic biotite-granite
RO : Olivine-gabbro
Sp : Spessartite
Ru : Uralite-gabbro

2. Magnetization of the gabbro.

A 2-*cm* cube was cut from each oriented sample and its magnetization was measured with an induction-type magnetometer[3] which was lent for use by the Geophysical Institute of Tokyo University. It operates on the principle that the faint residual magnetism of a rock is sufficient to induce an alternating voltage in a signal pick-up coil when the specimen is rotated close to the coil. This voltage is electronically amplified to a usuable level. The errors in determinations of the direction

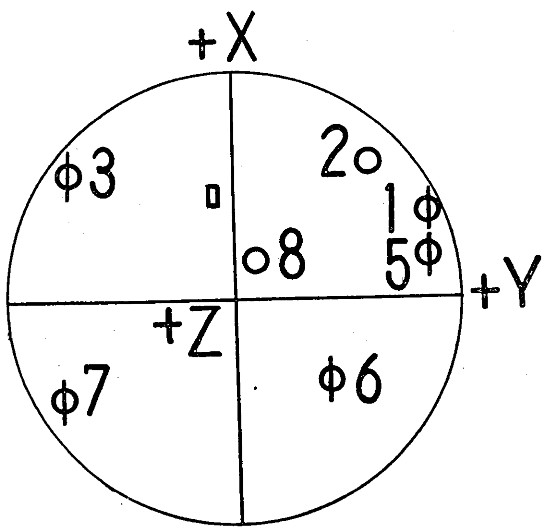
Table II.

Magnetization of the gabbro from Mt. Tsukuba.

Sample No.	Locality		Decli.	Dip.	Intensity in 10^{-4} *c.g.s.* per *cc*	Rock
1	トンネル上	above the tunnel	241°E	− 3°	12.0	Uralite-gabbro
2	男體頂上	summit of Nantai	46	11	6.3	Norite
3	立身石附近	near Rissin-seki	135	−10	34.0	Amphibolite (so-called spessartite)
4	五軒茶屋附近	near Gokenjaya			order of 10^{-6}	〃
5	女體頂上	summit of Nyotai	253	−12	7.4	Leucoratic part of olivine-gabbro
6	大黑岩	Daikoku-iwa	321	−40	120.0	Amphibolite (so-called spessartite)
7	出舟入舟	Debune-iribune	54	− 8	0.7	Leucocratic part of the uralite-gabbro
8	辨慶七戻	Benkei-nanamodori	25	65	18.0	〃

3) T. NAGATA, K. AKASI and T. RIKITAKE, *Bull. Earthq. Res. Inst.*, **21** (1943), 276.

and intensity of polarization of the samples are respectively $\pm 5°$ and about 5 per cent depending on the intensity of magnetization. The results are shown in Table II. In nomenclature of the rock specimens, the writer owes much to R. Morimoto. The directions are represented as points in the lower hemisphere of the Schmidt equal-area projection[4]



□: Earth's present field
○: North seeking magnetization
ф: South seeking magnetization

Fig. 4. Equal area plot of magnetization of rock samples.

(Fig. 4). The anomalously intense magnetization of sample No. 6 (Table II) seems to correspond to the large value of the dip-angle at Daikoku-iwa (780 *meters* altitude).

Taking into account the fact that Mt. Tsukuba stands at the edge of Kwanto-plain, we may surmize that the summits have been struck by lightnings and the rocks there have locally magnetized very abnormally against the earth's magnetic field. Therefore, samples No. 2 (the summit of Nantai), No. 6 (Daikoku-iwa) and No. 7 (Debune-iribune) do not necessarily agree with the general aspect of magnetization of the mountain-body. Moreover, we cannot assert that the gabbroic rocks of Mt. Tsukuba have not been influenced by any thermal action of the surrounding granitic rocks. Geological age of the granitic rocks, host rock of the gabbro, is post-Permo-Carboniferous and perhaps, pre-

4) J. W. GRAHAM, *Journ. Geophys. Res.*, **54** (1949), 162.

Miocene. Thus it is rather difficult to touch on the Palaeomagnetism directly from the above data. Though it will be of great interest to study the Palaeomagnetism of such an old geological age, a good number of samples will be needed for that purpose, so the discussion concerning the subject will be made after we measure the magnetization of much more samples from Mt. Tsukuba.

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

For studying the distribution of the magnetic dip-angle at Mt. Tsukuba, we have luckily a slope in approximately the NS-direction where formerly the rails of cable-way were laid. The results of the observations along this slope are shown in Fig. 5. The normal value for this district (49°25.′0) is decided from the values at the Branch Station of Earthquake Research Institute at Tsukuba village and the Kakioka Magnetic Observatory. Though observations were impossible to carry out because of a tunnel at about 600 *meters* altitude, a decrease above the height of 500 *meters* is remarkable as already mentioned.

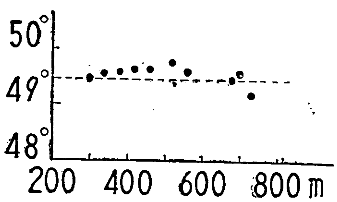


Fig. 5. The distribution of the dip along the slope of the disused cable-way.

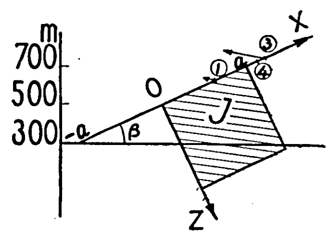


Fig. 6. The schematic model of the slope of the disused cable-way.

In order to interpret the anomaly, we assume a two-dimensional model as shown in Fig. 6. The slope of the disused cable-way is represented schematically cut by the plane in NS-direction. Reflecting the geological knowledge, the contact plane of gabbro and granite is assumed to be situated at 500 *meters* altitude and to be perpendicular to the slope. And the depth of the block of gabbro is assumed to be half of the length of the slope for conveniences' sake. To decide the direction of magnetization J, the writer referred to those of sample No. 1, 3 and 4 which are regarded to be on the NS-direction plane and to keep clear of lightnings effects. Thus the block of gabbroic rocks is assumed to be uniformly magnetized (its intensity J) upwards about 7° contrariwise to the present geomagnetic field.

The magnetic potential due to the uniform magnetization of the said mass is given by

$$\phi=2J_z\int_0^a\int_0^b\frac{z-\zeta}{(x-\xi)^2+(z-\zeta)^2}d\xi d\zeta+2J_x\int_0^a\int_0^b\frac{x-\xi}{(x-\xi)^2+(z-\zeta)^2}d\xi d\zeta. \quad (1)$$

where J_x and J_z denote the components of the magnetization respectively in X and Z-direction.

The first term of the righthand side of (1) becomes

$$\begin{aligned}\phi_1&=2J_z\int_0^a\int_0^b\frac{z-\zeta}{(x-\xi)^2+(z-\zeta)^2}d\xi d\zeta\\&=-2J_z\int_0^b(z-\zeta)d\xi\int_x^{x-a}\frac{d\xi'}{\xi'^2+(z-\zeta)^2}\\&=2J_z\int_0^b\left(\cot^{-1}\frac{z-\zeta}{x}-\cot^{-1}\frac{z-\zeta}{x-a}\right)d\zeta\\&=2J_z\Big[(z-b)\left(\tan^{-1}\frac{x-a}{z-b}-\tan^{-1}\frac{x}{z-b}\right)-z\left(\tan^{-1}\frac{x-a}{z}-\tan^{-1}\frac{x}{z}\right)\\&\quad+\frac{x}{2}\log\frac{\{(x-a)^2+(z-b)^2\}(x^2+z^2)}{\{(x-a)^2+z^2\}\{x^2+(z-b)^2\}}-\frac{a}{2}\log\frac{(x-a)^2+(z-b)^2}{(x-a)^2+z^2}\Big]. \quad (2)\end{aligned}$$

The force components of X and Z-direction due to the magnetic potential ϕ_1 become respectively

$$\begin{aligned}X_1&=-\frac{\partial\phi_1}{\partial x}\\&=J_z\log\frac{\{(x-a)^2+z^2\}\{x^2+(z-b)^2\}}{(x^2+z^2)\{(x-a)^2+(z-b)^2\}}. \quad \ldots\ldots\ldots\ldots(3)\end{aligned}$$

$$\begin{aligned}Z_1&=-\frac{\partial\phi_1}{\partial z}\\&=2J_z\left(\tan^{-1}\frac{x}{z-b}-\tan^{-1}\frac{x-a}{z-b}+\tan^{-1}\frac{x-a}{z}-\tan^{-1}\frac{x}{z}\right). \quad \ldots\ldots\ldots(4)\end{aligned}$$

Similarly, we have

$$\begin{aligned}\phi_2&=2J_x\int_0^a\int_0^b\frac{x-\xi}{(x-\xi)^2+(z-\zeta)^2}d\xi d\zeta\\&=2J_x\Big[(x-a)\left(\tan^{-1}\frac{z-b}{x-a}-\tan^{-1}\frac{z}{x-a}\right)-x\left(\tan^{-1}\frac{z-b}{x}-\tan^{-1}\frac{z}{x}\right)\end{aligned}$$

$$+\frac{z}{2}\log\frac{\{(z-b)^2+(x-a)^2\}(x^2+z^2)}{\{z-b)^2+x^2\}\{z^2+(x-a)^2\}}-\frac{b}{2}\log\frac{(z-b)^2+(x-a)^2}{(z-b)^2+x^2}\Big]..(5)$$

$$X_2=2J_x\left(\tan^{-1}\frac{z-b}{x}-\tan^{-1}\frac{z-b}{x-a}+\tan^{-1}\frac{z}{x-a}-\tan^{-1}\frac{z}{x}\right).........(6)$$

$$Z_2=J_x\log\frac{\{(x-a)^2+z^2\}\{x^2+(z-b)^2\}}{(x^2+z^2)\{(x-a)^2+(z-b)^2\}}\ ....(7)$$

Taking $a=b$ and neglecting z compared to a and b, we get

$$X_1=J_z\log\frac{\left\{\left(\frac{x}{a}-1\right)^2+\left(\frac{z}{a}\right)^2\right\}\left\{\left(\frac{x}{a}\right)^2+1\right\}}{\left\{\left(\frac{x}{a}\right)^2+\left(\frac{z}{a}\right)^2\right\}\left\{\left(\frac{x}{a}-1\right)^2+1\right\}}.....................(8)$$

$$Z_1=2J_z\left\{\tan^{-1}\frac{-x}{a}-\tan^{-1}\left(1-\frac{x}{a}\right)+\tan^{-1}\left(\frac{\frac{x}{a}-1}{\frac{z}{a}}\right)-\tan^{-1}\frac{x}{z}\right\}....(9)$$

$$X_2=2J_x\left\{\cot^{-1}\frac{-x}{a}-\cot^{-1}\left(1-\frac{x}{a}\right)+\cot^{-1}\left(\frac{\frac{x}{a}-1}{\frac{z}{a}}\right)-\cot^{-1}\frac{x}{z}\right\}.....(10)$$

$$Z_2=J_x\log\frac{\left\{\left(\frac{x}{a}-1\right)^2+\left(\frac{z}{a}\right)^2\right\}\left\{\left(\frac{x}{a}\right)^2+1\right\}}{\left\{\left(\frac{x}{a}\right)^2+\left(\frac{z}{a}\right)^2\right\}\left\{\left(\frac{x}{a}-1\right)^2+1\right.}....................(11)$$

and

$$J_x=-J\cos\alpha\,,\qquad J_z=-J\sin\alpha.$$

where α denotes the direction of the magnetization J measuring from the slope. The magnetic field caused by the magnetization is obtained as follows;

$$\Delta H=(X_1+X_2)\cos\beta+(Z_1+Z_2)\sin\beta.\ ....(12)$$

$$\Delta Z=-(X_1+X_2)\sin\beta+(Z_1+Z_2)\cos\beta.\ ....(13)$$

where β denotes the inclination of the slope to the level. Now, we consider the following function

$$f(\Delta I)=\frac{\tan(I_0+\Delta I)-\tan I_0}{\tan I_0} \doteqdot \frac{\Delta Z}{Z_0}-\frac{\Delta H}{H_0}. \quad \ldots\ldots\ldots\ldots\ldots (14)$$

For simplicity's sake, we take

$$Z_0 = H_0 = 0.3\,\Gamma$$

and taking $\alpha=32°$ and $\beta=25°$, the function $f(\Delta I)$ becomes

$$f=\frac{J}{0.3}\left[0.29\log\frac{\left\{\left(\frac{x}{a}-1\right)^2+\left(\frac{z}{a}\right)^2\right\}\left\{\left(\frac{x}{a}\right)^2+1\right\}}{\left\{\left(\frac{x}{a}-1\right)^2+1\right\}\left\{\left(\frac{x}{a}\right)^2+\left(\frac{z}{a}\right)^2\right\}}\right.$$

$$+2.26\left\{\tan^{-1}\frac{\frac{z}{a}}{1-\frac{x}{a}}-\tan^{-1}\frac{1}{1-\frac{x}{a}}+\tan^{-1}\frac{a}{x}-\tan^{-1}\frac{z}{x}\right\}$$

$$\left.-0.52\left\{\cot^{-1}\frac{\frac{z}{a}}{1-\frac{x}{a}}-\cot^{-1}\frac{1}{1-\frac{x}{a}}+\cot^{-1}\frac{a}{x}-\cot^{-1}\frac{z}{x}\right\}\right]. \quad (15)$$

in the end. Their numerical values for $a=1\,km$, $z=-1\,m$ and $x=-1\sim$

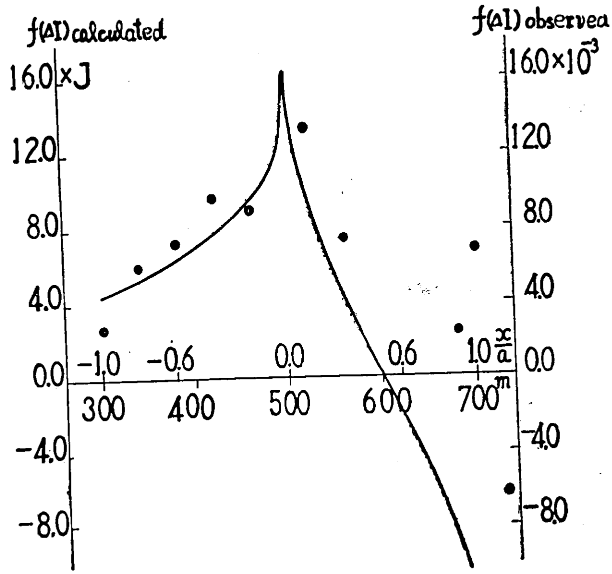


Fig. 7. The calculated curve (full line) and the observed values for $f(\Delta I)$.

+1 *km* are represented in Fig. 7. As seen in the figure, the decrease at about 500 meters altitude seems to be explained roughly, and the curve theoretically obtained covers approximately the points plotted as the results of the observations if J is assumed to be of the order of 10^{-3} *c.g.s.* per *cc.*

4. Conclusion.

The anomalous distribution of the magnetic dip at Mt. Tsukuba seems to be interpreted roughly with assumptions reasonable from the view-points of geology and geophysics. The discussion concerning the Palaeomagnetism at Mt. Tsukuba will be made after we measure the magnetization of a number of rocks.

In the end, the writer wishes to express his sincere appreciation to Dr. T. Rikitake for his helpful advices. The induction-type magnetometer became available through the courtesy of the Geophysical Institute of Tokyo University and the writer's hearty thanks are especially due to Dr. T. Nagata. The writer owes the geological knowledge about Mt. Tsukuba to Prof. H. Tsuya, Prof. T. Ichimura, and Ass. Prof. R. Morimoto, to whom the writer's cordial thanks are also due.

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10. 筑波山斑糲岩の帯磁と地磁氣異常

地震研究所　横　山　泉

1951 年 8 月，小型地磁氣感應儀を用いて筑波山の地磁氣伏角測定が實施された．その高度分布を調べると，大體 500 m を境として伏角が減少するという著しい異常を示す．これを説明する鍵として，8 ケの岩石試料を採取して來て，その帯磁の强さと方向とを電磁誘導型磁力計で測定した．その結果および地質學的資料を參考として妥當と思われる模型を考え，それによる伏角異常を求めると，上記觀測結果を定性的にも定量的にも大體説明出來るようである．筑波山斑糲岩を古地磁氣學的に論ずることは，岩石試料の數が少ないので，より多くの試料の採取および測定をまつて行う豫定である．
