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On the Anomalies of the Geomagnetic Field due to Mt. Kabuto, Hyôgo Prefecture, Japan

By

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Abstract

In this paper are given the results of measurements and their interpretations of the vertical and horizontal components of the geomagnetic field on and around Kabutoyama tholoide (andesite) situated in the northern part of Nishinomiya city, Hyôgo prefecture, Japan. The direction and intensity of magnetization of the mountain assumed from those of nine rock samples from different places at the mountain surface produce, by computation, vertical and horizontal magnetic fields which are nearly in good agreement with the observed.

Introduction

In the northern part of Nishinomiya city, Hyôgo prefecture, there exists a beautiful volcanic tholoide (assumed to be erupted in later Tertiary stage) in a perfectly helmet-like shape; the mountain name "Kabuto" means helmet. Rock facies composing the tholoide is rhombicpyroxene andesite1) or sanukitoid2) which is the principal rock constituting the Seto-uchi volcanic zone and have fairly strong remanent magnetism. Interpretation of magnetic anomalies due to such a body with known shape is, therefore, very simple. The calculation would be much more easy when intensity and direction of the volcanic rock can be measured, since the intensity of magnetization might be greater than that of the surrounding rocks, and a simple calculation is available. On the other hand, magnetic properties of rocks, such as the natural remanent magnetism, the susceptibility, Curie point and crystallographic structure of ferromagnetic minerals are determinable by using a series of equipments which have been built for the study on rock magnetism in Kyoto University.

Thus, comprehensive interpretations for the anomalies can be obtained as shown in the following sections.

(1) Magnetic anomalies at Mt. Kabuto.

For the purpose of obtaining magnetic anomalies due to the volcanic tholoide, the magnetic survey by means of vertical and horizontal Schmidt's type magnetometers has been carried out.

The area covered is about 1000 m × 900 m of which the center is that of the volcano and in which 69 stations of the measurements were taken. Fig. 1 and

Fig 2 show the distribution in the vertical and horizontal components of the anomalies, respectively. Corrections were made for the diurnal variations of geomagnetism and for the temperature variations of the instruments during measurements. For the determination of the temperature coefficients of the instruments which have been adjusted for the sake of the measurements at Mt. Kabuto, the following formula has been employed.

$$D - D_0 = \alpha(\theta-\theta_0)+\beta(D_A-D_{A0}) \qquad (1)$$

where $D - D_0$ = Observed value of the relative diurnal variation at a definite station, Mt. Kabuto (lat. =34°46′N, long. =135°20′E),
D_A-D_{A0} = Observed value of the relative diurnal variation at Aso Magnetic Observatory, Mt. Aso (an active volcano) (lat. =32°54′N, long. =131°O′E),
$\theta - \theta_0$ = Relative observed temperature of the instrument,
α = Temperature coefficient of the instrument,
β = Ratio of the amplitude of the diurnal variation at Mt. Kabuto divided by that of Mt. Aso,
o = The initial time of the observation, 9^h40^m, December 25, 1958.

Table I.

(A)

Time of observation	Relative temperature of vertical instrument $(\theta-\theta_0)$	$Z-Z_0$	Z_A-Z_{A0}
9^h43^m	0.0°C	0.0 gamma	0.0 gamma
10 00	2.0	−28.5	−10.0
10 34	6.0	−74.9	−14.9
11 01	6.5	−78.3	−19.8
11 31	7.0	−85.2	−20.7
12 01	6.8	−76.0	−21.6
12 30	7.3	−80.5	−19.2
13 02	8.9	−99.8	−17.9
13 31	8.9	−99.0	−14.9
14 01	7.6	−76.6	−11.9
14 31	6.7	−74.1	− 7.9
15 01	3.5	−31.3	− 4.0
15 30	2.4	−24.6	− 3.3

Remarks: Z = the observed value of vertical component of diurnal variation at Mt. Kabuto,
Z_A = the observed value of vertical component of diurnal variation at Aso Magnetic Observatory,
O = the initial time of observation.

(B)

Time of observation	Relative temperature of horizontal instrunent ($\theta-\theta_0$)	$H-H_0$	H_A-H_{A0}
9^h42^m	0.0°C	0.0 gamma	0.0 gamma
9 59	1.9	− 22.9	−1.8
10 33	6.4	− 82.4	−5.6
10 59	7.1	− 90.7	−9.1
11 29	7.4	− 96.1	−8.9
12 00	6.8	− 83.3	−8.8
12 28	7.0	− 89.0	−6.6
13 00	8.6	− 99.3	−4.4
13 29	9.4	−115.2	−3.0
13 59	8.3	−103.3	−1.6
14 29	7.7	− 85.1	0.8
14 59	3.8	− 48.8	3.2
15 29	2.5	− 19.1	6.9

Remarks: H = the observed value of horizontal component of diurnal variation at Mt. Kabuto,
H_A = the observed value of horizontal component of diurnal variation at Aso Magnetic Observatory,
O = the initial time of observation.

Assuming in the first approximation that the diurnal variations at Mt. Kabuto and those at Mt. Aso take place nearly at the same time, we adopt in the formula (1) the D_A and D_{A0} values at times 17 minutes (longitude difference) earlier than those at which the D and D_0 values are considered. Putting the observed values (shown in Table I) of D, θ and D_A during 6 hours (9^h40^m—15^h30^m, Dec. 25, 1958) into the formula (1), and have been determined by the method of the least squares, giving the following results.

$\alpha_z=9.3\pm0.7\gamma/{}_{\circ}\mathrm{C}$, $\beta_z=1.1\pm0.1$ (for vertical),

$\alpha_h=11.6\pm0.8\gamma/°\mathrm{C}$, $\beta_h=1.0\pm0.1$ (for horizontal),

where the annexed errors are the probable errors. Thus, the adjusted values of β_z and β_h suggest that the amplitudes of diurnal variations of the vertical and the horizontal components of the geomagnetic field at Mt. Kabuto and Mt. Aso are practically the same.

As can be seen in Fig. 1 and Fig. 2, the positive anomalies (vertical and horizontal) appear at southern slope and the negative at the northern slope of the tholoide. Although the negative minimum of -500γ (Fig. 2) at the north-west slope attracts our attention, it can hardly be regarded as of importance because of a single observation point. If we disregard this negative minimum, the straight lines connecting the positive maxima (both the vertical

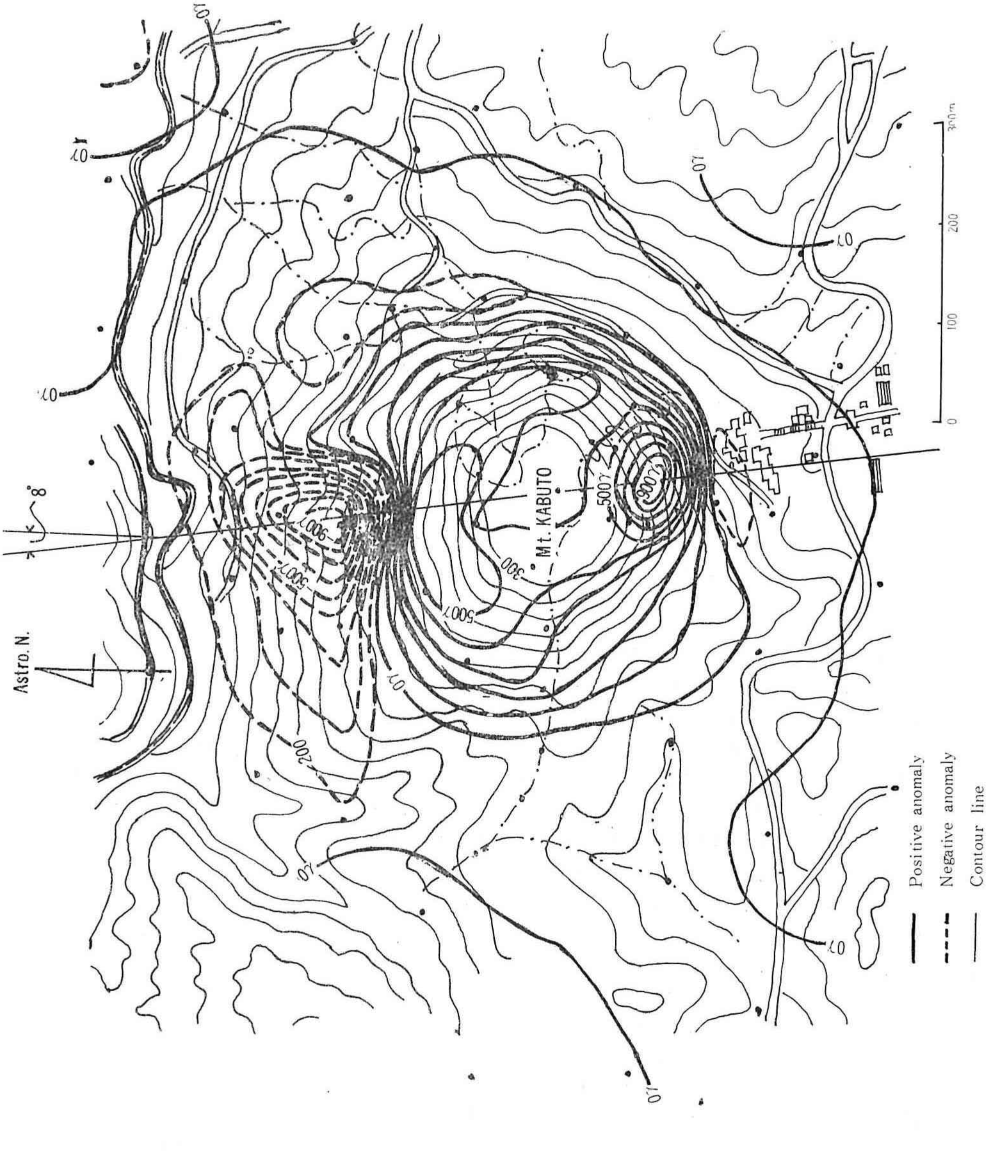

Fig. 1. Distribution of the anomaly in the vertical component in gamma.

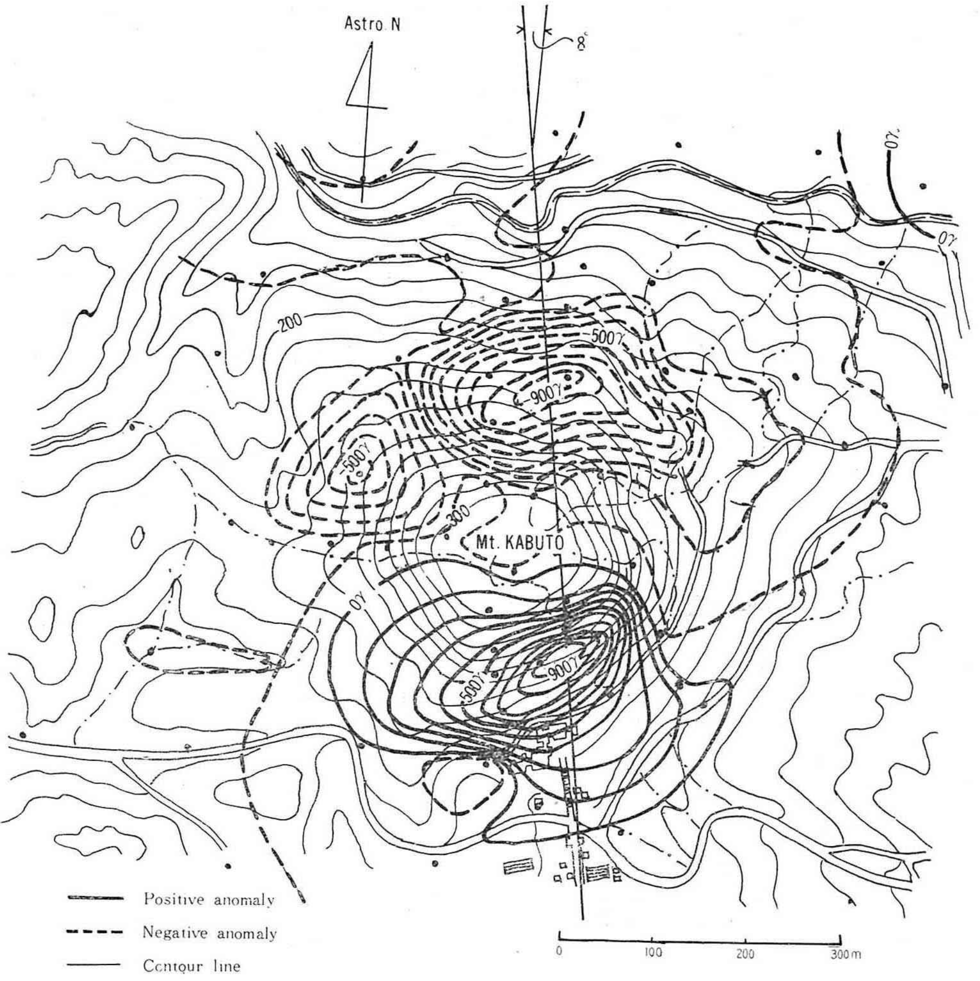

Fig. 2. Distribution of the anomaly in the horizontal component in gamma.

and horizontal anomalies) to the negative minima appear to have westward deviations of about 7°～8° from the geographical meridian. From the present geomagnetic declination 6.2° W calculated at Mt. Kabuto in the epoch of 1958[3] and by being added by the observation errors, it is plausible that the magnetization of the rock composing the tholoide is in the direction of the present geomagnetic field.

(2) Experimental determination of magnetization of rock samples composing Mt. Kabuto.

It is generally accepted that rocks in the geomagnetic field possess permanent or remanent magnetism[4][5] which was acquired in the direction of the ambient geomagnetic field at the time of solidification of the rocks; this may be, as generally taken for granted, different from that of the present. Beside the remanent magnetism, the rocks possess induced magnetism due to the present geomagnetic field. Generally speaking, the induced magnetism is much weaker than the remanent.

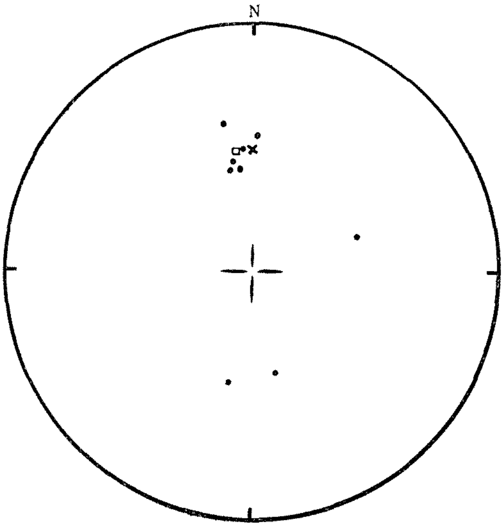

Fig. 3. Direction of remanent magnetizations plotted on Schmidt's equal area projection,

× : The direction of the present geomagnetic field.
□ : The mean value of the direction of magnetizations of samples obtained by disregarding the 3 samples of large deviations.

Hence, the next thing to do is to experimentally determine directions and intensities of remanent magnetization of rock samples taken from the tholoide. The determinations were done by making use of an astatic magnetometer with sensitlvities of $0.5\times10^{-4}-2.0\times10^{-6}$ Oe./s.d.. Sampling sites were chosen at two places lying on the above-mentioned straight line connecting the position of the maximum vertical component anomaly and that of minimum, one being situated at the northern side of the maximum anomaly, and the other the southern side of the minimum. Five samples were taken from the former site and four from the latter, separation of sampling points being from 50 to 100 cm along the mountain slope.

The results of the determination are shown in Table II and Fig. 3. The errors annexed to the five mean values in the table are their mean errors; the mean values have been obtained by employing the intensity of remanent magnetization as weight. The mean values obtained for declination and inclination by disregarding the three data having large deviations, NW 7.0° and 49.3°N, are in good agreement with those of the present geomagnetic field, NW 6.2° and 48.6°N at Mt. Kabuto. In Table II are shown that the mean values of the intensity of remanent magnetization are (a) 0.48×10^{-3}. (b) 0.50×10^{-3} CGS emu/gr and those of the induced magnetization (a) 0.051×10^{-3}, (b) 0.053×10^{-3}, CGS emu/gr. The latter intensities are only 10 % of the former. This suggests that in the tholoide, which were assumed to be uniformly equal to the above obtained mean values of intensity of remanent magnetization for the case(b), the effect of the induced magnetization may be approximately neglected.

Tabele II. Magnetic properties of the rocks sampled from Mt. Kabuto.

No. of specimen		Intensity of remanent magnetization (J_r : CGS emu/gr)	Intensity of induced magnetization (J_i : CGS emu/gr)	Intensity of saturated magnetization (J_s : CGS emu/gr)	Direction of magnetization	
					Declination*	Inclination
1		0.56×10^{-3}	0.060×10^{-3}	5.9×10^{-1}	NE 2°	43°N
2		0.58×10^{-3}	0.059×10^{-3}	5.6×10^{-1}	NW 12°	55°N
3		0.43×10^{-3}	$0.052\times10_{-}{}^{3}$	3.5×10^{-1}	NW 7°	55°N
4		0.76×10^{-3}	0.062×10^{-3}	3.9×10^{-1}	NW 10°	52°N
5		0.31×10^{-3}	0.041×10^{-3}	2.2×10^{-1}	NW 11°	38°N
6		0.27×10^{-3}	0.040×10^{-3}	4.5×10^{-1}	NE 72°	53°N
7		0.37×10^{-3}	0.042×10^{-3}	3.6×10^{-1}	NW 4°	48°N
8		0.62×10^{-3}	0.055×10^{-3}	3.9×10^{-1}	NE 168°	55°S
9		0.45×10^{-3}	0.048×10^{-3}	4.8×10^{-1}	NW 168°	52°S
** Mean	a	$(0.48\pm0.13)\times10^{-3}$	$(0.051\pm0.07)\times10^{-3}$	$(4.4\pm0.9)\times10^{-1}$	NE 3.8° ±29.3°	72.8° ±14.0°N
	b	$(0.50\pm0.13)\times10^{-3}$	$(0.053\pm0.07)\times10^{-3}$	$(4.1\pm0.8)\times10^{-1}$	NW 7.0° ±2.1°	49.3° ± 2.8°N

* Referred to the magnetic north

** Mean: Intensity of remanent magnetization is emloyed as weight.
a: The overall mean.
b: The mean disregarding large deviations of Nos. 6,8 and 9.

On the other hand, thermo-magnetic analysis of the rocks has been made and the temperature dependency of saturation magnetization and Curie points of the rocks were examined in the laboratory, and those results are shown in Fig. 4 and Table II. From the results of these thermomagnetic analyses and also from X-ray analysis of the ferromagnetic minerals extracted, it has been presumed that the titano-magnetites may contribute to the ferromagnetism of Kabutoyama andesite. Regarding the poly-phased magnetic minerals as can be recognized in Js-T curves (as shown in Fig. 4), it can be understood in such

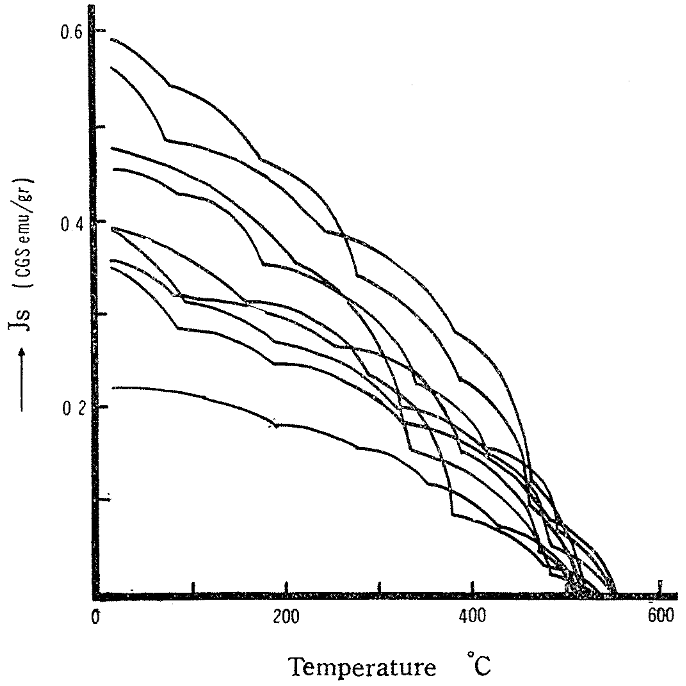

Fig. 4. Temperature dependency of saturation magnetization of the nine rock samples of which the magnetization were determined.

that they might have been exsolved from originally a single phased titanomagnetite to the descending of temperature, predicted by N. Kawai and others (Fig. 5), the oxidation of the original magnetite might have occurred at later stage of consolidation. The result in Fig. 6, which shows the relation between the frequencies of Curie points and the temperature of those of the ferromagnetic minerals contained in the rocks sampled, may suggest that the abovementioned presumption may likely be plausible.

(3) Analysis of the magnetic anomalies.

In order to analyse the magnetic anomalies observed, the first approximation is employed, and so the anomalous body is assumed a uniformly magnetized sphere,7) whose intensity of the magnetization, radius and density are respectively 0.50×10^{-3} CGS emu/gr, 200 m and 2.8 gr/cm^3. It may be proved that the field at outside points due to a spherical distribution of magnetic charge is the same as that due to a single charge concentrated at the center of the sphere. Hence, the magnetic field at an external point is the same as that produced by a dipole of magnetic moment,

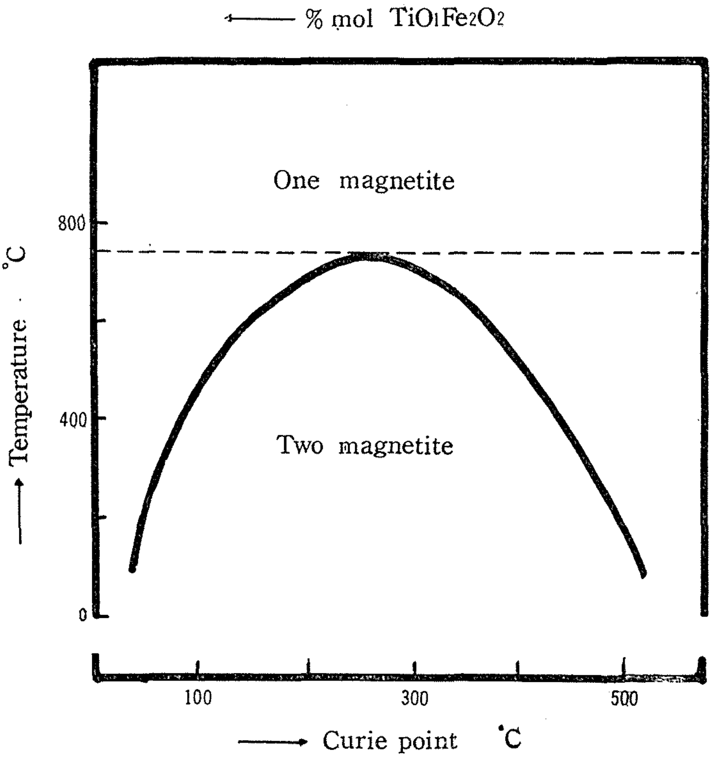

Fig. 5. Solvus phase diagram in titano-magnetite series (after N. Kawai, 1954).

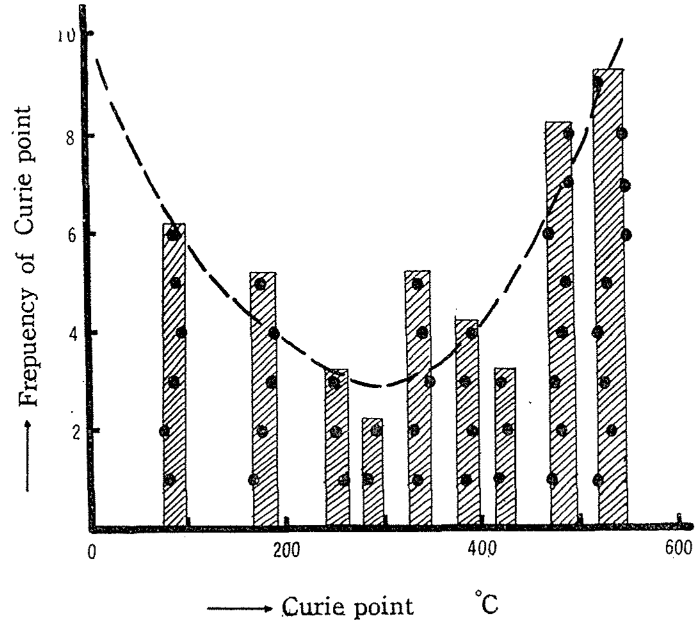

Fig. 6. Relation between Curie points of nine samples and its frequencies.

$$M=\frac{4}{3}\pi R^3 J\,, \qquad (2)$$

where R is the radius of the assumed sphere and J the intensity of magnetization per unit volume of the rock composing the sphere.

Putting the values obtained in the above into the formula (2), the following values are gotten,

$$\begin{aligned} M &= 43.3\times10^9 \quad \text{CGS emu/gr}\,, \\ M_x &= 28.4\times10^9 \quad \text{CGS emu/gr}\,, \\ M_z &= 32.7\times10^9 \quad \text{CGS emu/gr}\,, \end{aligned} \qquad (3)$$

where M_x is the horizontal component and M_z the vertical one of the magnetic moment of the sphere when NW 7.0° and 49.3°N are employed as the declination and inclination respectively, which obtained in the previous section. While, the vertical (dZ) and horizontal component (dH) of the magnetic anomaly at a given station above the magnetized body can be expressed by some elementary calculations as follows,

$$\begin{aligned} dZ &= -\frac{3M_x xz}{r^5}-\frac{M_z x^2}{r^5}+\frac{2M_z z^2}{r^6} \\ dH &= \frac{2M_x x^2}{r^5}-\frac{M_x z^2}{r^5}-\frac{3M_z xz}{r^5}\,, \quad r^2=x^2+z^2\,, \end{aligned} \qquad (4)$$

where z, x and r are the vertical distance from the position of the station measured to the center of the sphere, the distance along the magnetic meridian and the distance from the station to the center of the sphere, respectively. The results calculated along the magnetic meridian according to the formulae (3) and (4) are shown in Fig. 7.

However, in the observed results (Fig. 8), we can find that both the vertical and horizontal component of the magnetic anomalies at the top of the tholoide are remarkably smaller than the values to be expected with the spherical model. Hence, the present writer has assumed this to be due to the intense decomposition of the rocks at the top, because the decomposition of the cropping out rocks might have diminished the ferromagnetic minerals therein, and so rendered the ferromagnetism of the rocks to decrease. In order to approximate the calculation further to the observed values, was assumed the following model which is shown in Fig. 9 where the dotted sphere represent the eroded part of the andesite possessing Jr whose intensity decreases to 2/5 of the uneroded andesite. Thus, the calculated anomalies across the tholoide become closer to the observed anomalies as shown in Fig. 9, 10 and Table III.

However, the present writer cannot overlook that there still remain considerable differences between the two, which may probably suggest that the model is still too simple to represent the subsurface structure.

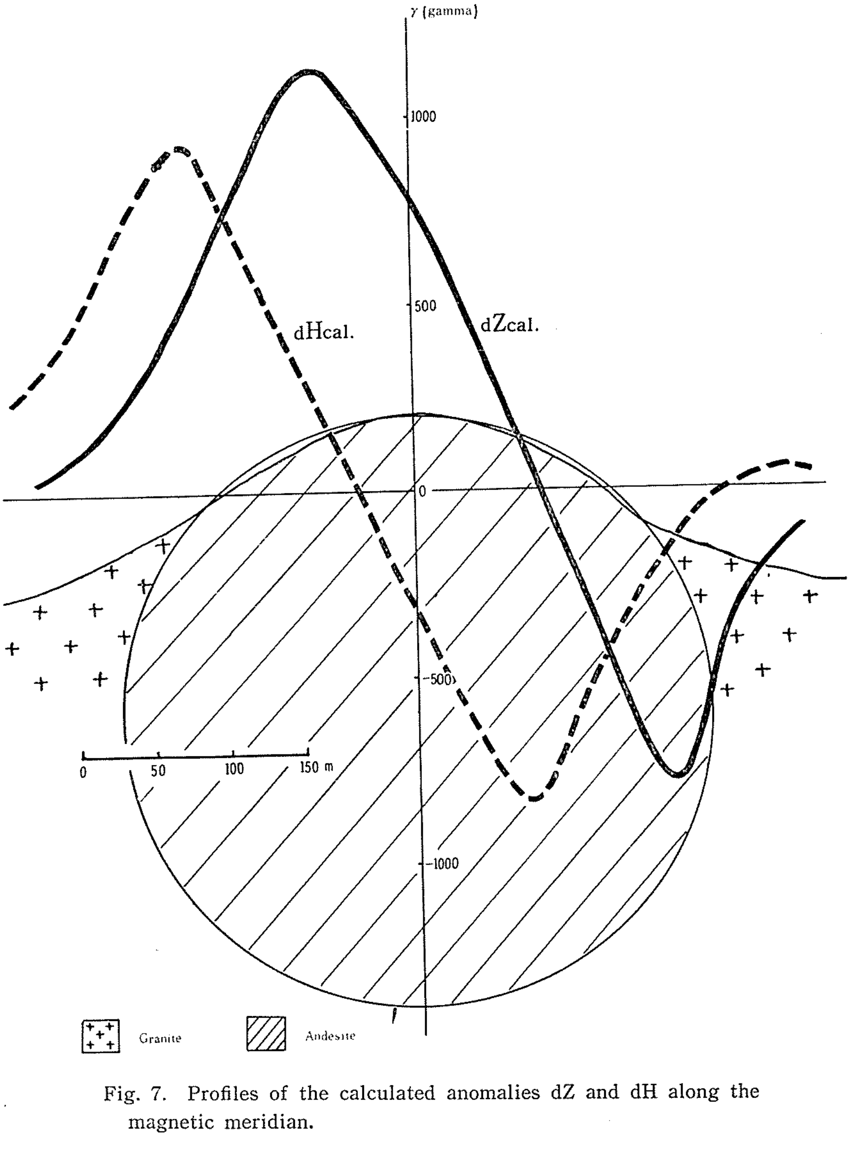

Fig. 7. Profiles of the calculated anomalies dZ and dH along the magnetic meridian.

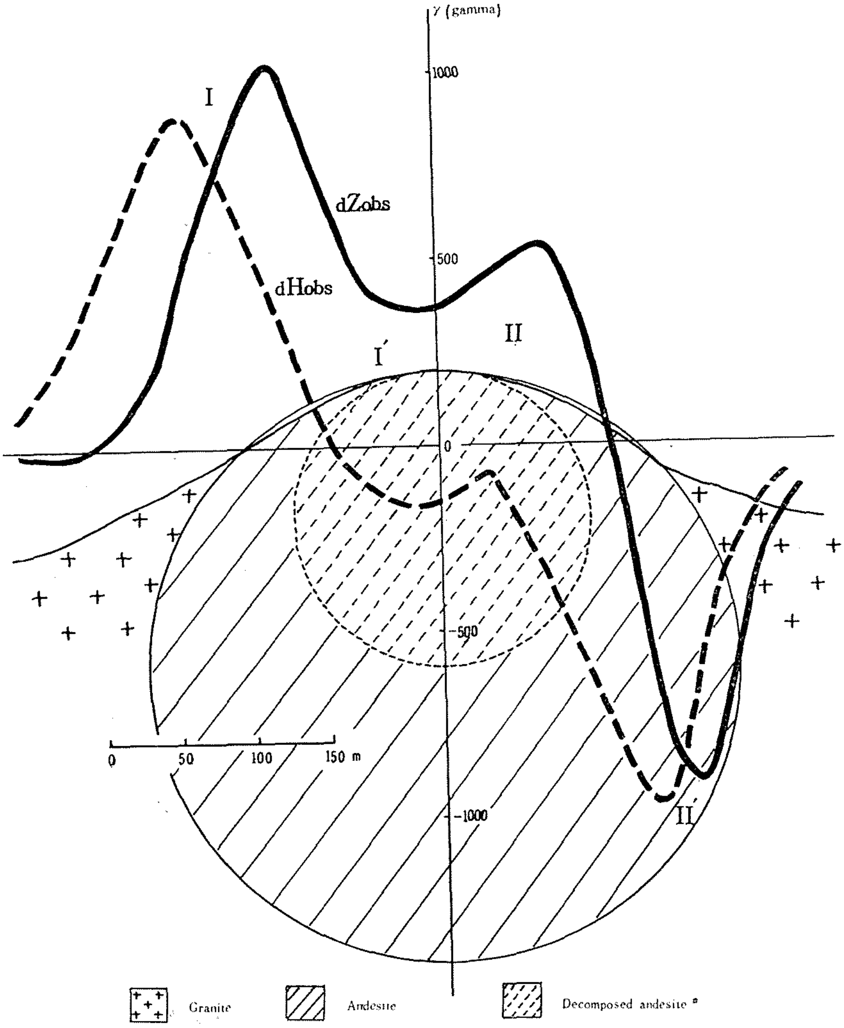

Fig. 8. Profiles of the observed anomalies dZ and dH along the lines connecting the positions of extreme values of dZ and dH respectively.

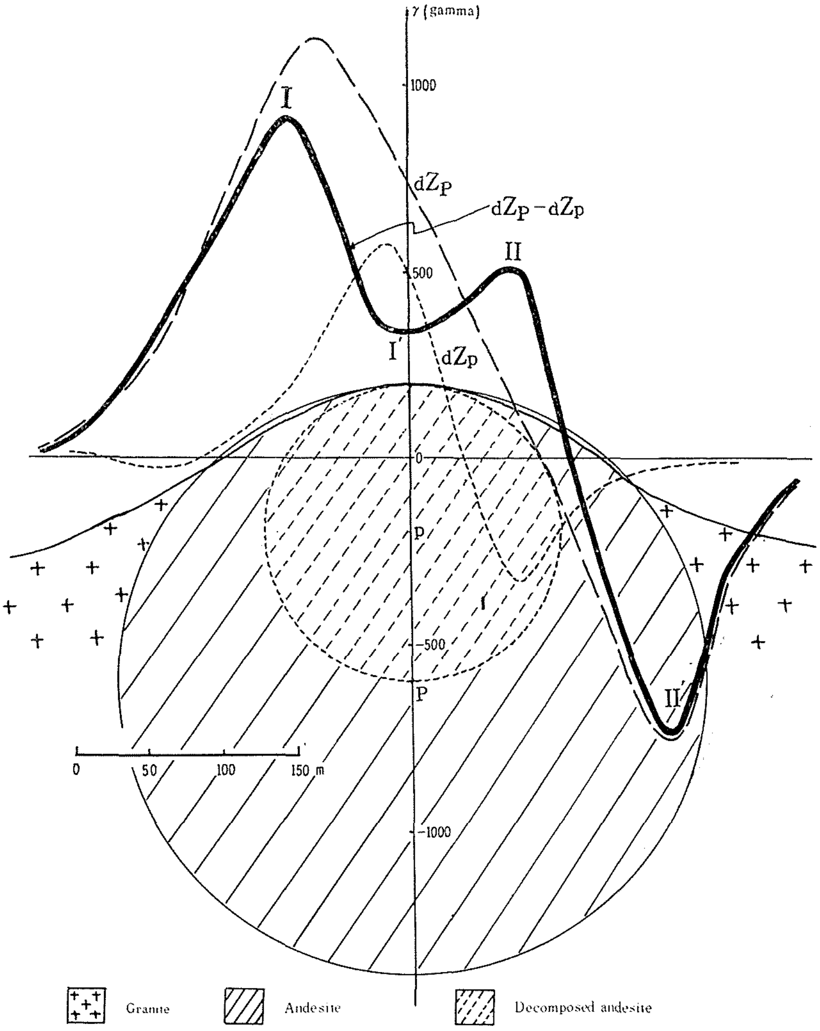

Fig. 9. Profiles of the calculated vertical anomaly under assumption of modified model at the top of tholoide, whose radius is 100 m and intensity of magnetization 3/5 of the uneroded part, where dZ_P shows the anomaly due to large sphere P, dZ_p the anomaly due to small sphere p, and (dZ_P-dZ_p) the resultant.

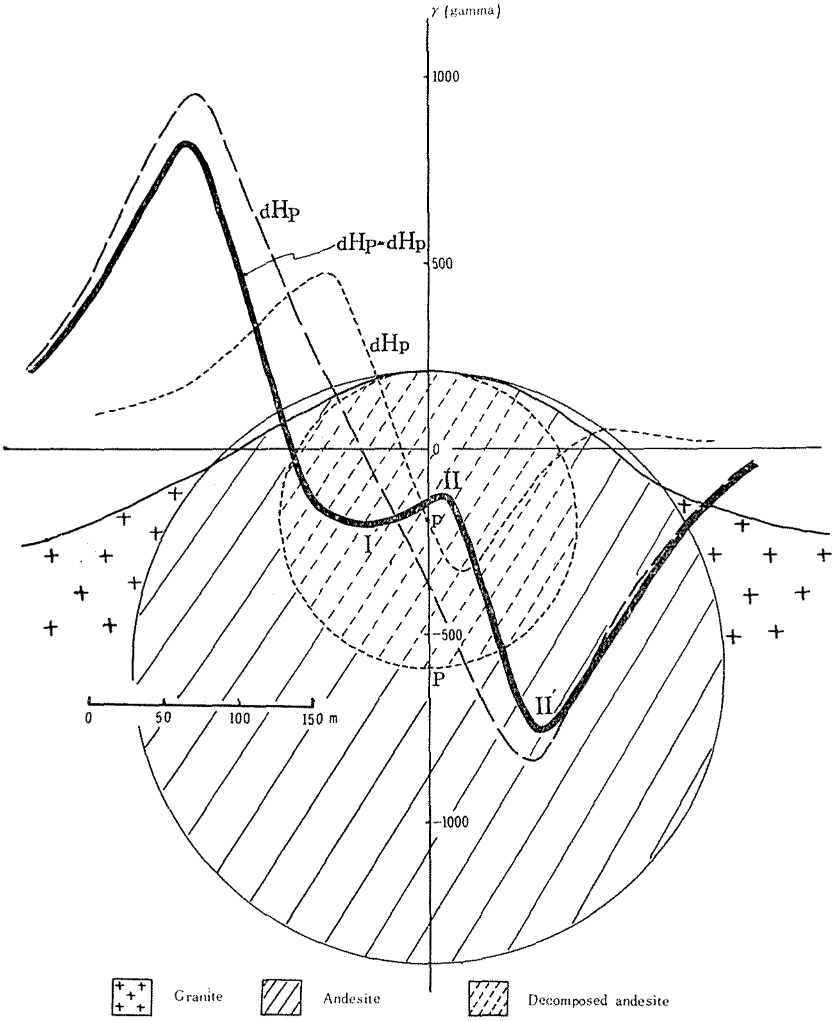

Fig. 10. Profiles of the calculated horizontal anomaly under assumption of modified model at the top of tholoide, whose radius is 100 m and intensity of magnetization 3/5 of the uneroded part, where dH$_P$ shows the anomaly due to large sphere P, dHp the anomaly due to small sphere p, and (dH$_P$-dHp) the resultant.

Table III. Maximum and minimum intensities of magnetic anomalies and its positions of the observed values and the calculated.

		Observed value				Calculated value			
		Vertical		Horizontal		Vertical		Horizontal	
		Intensity	Position	Intensity	Position	Intensity	Position	Intensity	Position
Max.	I	1030γ	−110m	890γ	−170m	920γ	−82m	830γ	−160 m
	II	540	70	− 70	32	510	70	−120	10
Min.	I	360	− 12	−170	− 17	330	− 5	−200	− 38
	II	−890	170	−950	140	−750	175	−760	75

Remarks: Position shows where the max. and min. intensities of magnetic anomalies apear along the magnetic meridian, and also the horizontal distance from the center of sphere. Positive distance in horizontally measured from the center of sphere to the right, and negative one to the left.

In conclusion, the following facts may be summarized.

(1) The positive and negative values of the magnetic anomalies due to Mt. Kabuto, both in the vertical and in the horizontal component, are about ±900 gammer, and its direction of magnetization is approximately in that of the present geomagnetic field.

(2) The mean direction of magnetization of the rocks composing the tholoide is found to be NW 7.0° in declination and 49.3° N in inclination with intensity of 0.50×10^{-3} CGS emn/gr in the remanent magnetization and of 1.7×10^{-4} in the susceptibility.

(3) According to the thermo-magnetic and X-ray analysis it has been presumed that the titano-magnetites which have various Curie points may contribute to the ferromagnetism of Kabutoyama andesite.

(4) For the purpose of approximating the calculation to the observed results, when the spherical model were assumed instead of the tholoide, fairly good approximations have been gotten by assuming the spherical part eroded at the top, whose intensity of magnetization decreased.

Acknowledgement

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