14. *The Distribution of Magnetic Dip in Ooshima (Oo-sima) Island and its Change that Accompanied the Eruption of Volcano Mihara, 1950.*

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1. Introduction.

After the minor eruption on Aug. 19, 1940, Volcano Mihara in Ooshima (Oo-sima) Island had been quiet for about ten years when a new activity took place in the morning of July 16, 1950. The eruption became greater day by day and the old crater pit was filled with new lava and ejecta. At the beginning of September the lava overflowed the central cone and flowed down the slope to the caldera. The activity continued up to Sept. 23, while the total amount of the lava which welled up during the period was estimated[1] to be about 3×10^7 *metric tons*.

Magnetic dip surveys over Ooshima Island were carried out by the writer in July and September, 1950, for the purpose of finding out the changes in geomagnetism expected to accompany such severe eruption.

We have hitherto coducted several geomagnetic investigations with respect to Ooshima Island. The earliest one was by S. Nakamura[2] who made a magnetic dip survey in the north-western part of the island with a dip-circle in the year 1928. However, the topography changed so greatly during the war that it was of great difficulty to find the old measuring stations. Hence, the writer gave up the attempt to compare the result of the present survey with that of Nakamura's. In 1936, R. Takahasi and T. Nagata[3] made a magnetic survey with a magnetometer of the Japanese Hydrographic Department pattern. They measured three components of the earth's magnetic field at 12 stations which were distributed almost equidistantly along the coast of Ooshima. And at three stations within the somma only the dip was measured. At several stations, the writer could identify the places on which the measurement was made with the aid of

1) R. TAKAHASI, and D. SHIMOZURU, Read at the Oct. Meeting of the Earthquake Research Institue, 1950.

2) S. NAKAMURA, *Zisin*, **6** (1934), 637.

3) R. TAKAHASI and T. NAGATA, *Bull. Earthq. Res. Inst.*, **15** (1937), 441.

the pegs, photographs and sketch-maps prepared by Takahasi and Nagata. After making allowances for the influence of general magnetic disturbance or secular change, some increases in magnetic dip was found out during the period 1936–1950, the increase generally amounting to several *minutes* of arc.

Soon after the beginning of the eruption, the writer made a survey throughout the island with a newly constructed earth-inductor. During the surveying period July 25–30, bombs and lapillis were being ejected from a crater which newly opened at the south-western corner of the old pit, while the bottom of the pit was being upheaved gradually. The number of stations amounted to as much as 36 in the survey. With these results, magnetic anomaly due to Volcano Mihara was studied, the mean intensity of magnetization being determined to be about 0.03 *emu*. The anomaly nearer the somma was so large that the maximum dip-angle amounted to as much as 56°.

The second survey was carried out during the period Sept. 22–26, while the eruption suddenly stopped in the night of Sept. 23. At that time, the lava had already overflowed the central cone and a new cinder cone was formed in the old crater. Comparing the results of the second survey with those of the first, we found that marked geomagnetic changes occurred during the period, the maximum change in dip being as much as 30 *minutes* of arc. At almost all stations, the magnetic dip-angle decreased, the decrease becoming larger as the station approached the crater.

Generally speaking, we have had hitherto a good many number of investigations concerning the relation between local geomagnetic changes and volcanic activities. Especially, at the time of Miyake-sima eruption, 1940, R. Takahasi[4], T. Minakami[5], T. Nagata[6] and Y. Kato[7] made geomagnetic studies with various instruments, confirming the existence of local magnetic changes. Since Ooshima Island like Miyake-sima Island is composed of basaltic rocks, we may well expect some anomalous changes in the earth's magnetic field to occur at the time of eruption.

2. The instrument.

An earth-inductor of small type which was newly designed and constructed by the writer[8] was used for the survey. The instrument was so

4) R. TAKAHASI and K. HIRANO, *Bull. Earthq. Res. Inst.*, **19** (1941), 82 and 373.
5) T. MINAKAMI, *Bull. Earthq. Res. Inst.*, **19** (1941), 356.
6) T. NAGATA, *Bull. Earthq. Res. Inst.*, **19** (1941), 335.
7) Y. KATO, *Proc. Imp. Acad. Japan*, **16** (1940), 440.
8) T. RIKITAKE, *Bull. Earthq. Res. Inst.*, **29** (1951), 147.

constructed as to be handy for transportation in the field and only 5–10 *minutes* are needed to carry out measurement at one station. The observation may be carried out by a single person. Some scenes of observation are, for example, shown in Photos. 1 and 2. The electromotive forces

Photo. 1.
Station No. 5. The Bench Mark on the central cone.

Photo. 2.
Station No. 24. Nomashi Village.

induced in the rotating coil are amplified with a special amplifier and are detected with a crystal receiver. According to the results of calibration, the accuracy of measurement amounts to 1 or 2 *minutes* of arc.

3. The results of the survey.

The results of the first and second surveys are shown in Table I together with the latitude, longitude and height above sea level of the stations. As some stations on the central cone were buried by the new lava, it was impossible to repeat the observation. Sketch-maps of the measuring points were illustrated in Figs. 1 for convenience of future measurement.

Fig. 1-1 Station No. 1
The fifth middle school.

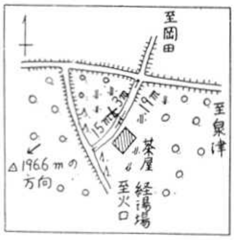

Fig. 1-2 Station No. 2
Sangome, Okada road.

Fig. 1-3 Station No. 3
Rokugome, Okada road.

Table I. The

Nos. of station	Locality		Latitude	Longitude
1	大島第五中學校	The fifth middle school	34°46′.9 N	139°23′.8 E
2	岡田登山道三合目	Sangome, Okada road	46.5	23.8
3	同　六合目	Rokugome, Okada road	45.5	23.9
4	同　十合目	First somma	44.6	23.8
5	內輪山水準點	Central cone	43.7	23.9
6	內輪山上	Central cone	43.2	23.9
7	內輪山最高點	Central cone	43.5	24.2
8	內輪山上	Central cone	43.7	24.1
9	沙漠	Sabaku	43.9	23.2
10	自動車道路	High way	44.7	23.1
11	沙漠岡田口	Sabaku	43.9	23.8
12	公園口鳥居	Torii, Ooshima park	43.8	24.6
13	大島公園口	Ooshima park	44.2	25.0
14	動物園	Zoo	45.2	26.5
14′	ヒユツテ	Lodge	45.2	26.5
15	笠松展望台附近	Kasamatsu	46.3	25.7
16	泉津小學校	Senzu primary school	46.6	25.3
17	泉津小學校跡	Old Senzu primary school	46.7	25.1
18	泉津登山道附近	Senzu road	46.3	24.6
19	大島測候所	Ooshima meteorol. station	45.8	22.6
20	六踏園	Rokutoen	46.8	21.4
21	泉濱南端	Izumihama	45.8	21.4
22	元村小學校	Motomura primary school	44.8	21.9
23	元村小學校跡	Old Motomura primary school	45.0	21.6
24	野增村綠地	Nomashi village	43.8	21.5
25	千波崎附近	Senbazaki	41.9	22.2
26	間伏海岸	Mabushi	41.3	23.3
27	差木地小學校	Sashikiji primary school	40.9	25.0
28	波浮港小學校	Habuko primary school	41.2	26.5
29	波浮登山道	Habu road	41.7	25.6
30	白石山東方鞍部	First somma	43.2	24.6
31	沙漠中神社前	Shrine	43.4	23.4
32	沙漠野增口	Sabaku	43.8	23.2
33	野增口峠	First somma	43.8	22.9
34	椿茶屋元村口六合目	Tsubaki-chaya	44.3	22.7
35	三原茶屋元村口一合目	Mihara-chaya	44.5	22.2
36	內輪山上	Central cone	43.2	23.9

results of the surveys.

Height above sea level	Survey I		Survey II	
	Date	Dip	Date	Dip
80*m*	1950 04*h*51*m*	48° 43′.5	1950 13*h*41*m*	48° 42′.9
185	VII 25th 05 54	49 36 .5	IX 23rd 14 23	49 33 .2
370	07 05	48 30 .3	15 12	48 22 .1
560	09 35	51 33 .3	17 09	51 18 .6
660	10 49	56 26 .6	IX 25th 11 08	56 07 .0
700	12 35	53 39 .9	— —	— —
755	13 15	53 57 .0	IX 24th 16 56	53 34 .2
700	13 58	53 23 .1	— —	— —
530	14 50	48 34 .6	IX 24th 08 48	48 14 .2
440	15 50	53 00 .0	IX 23rd 17 46	52 40 .1
570	VII 26th 07 55	46 48 .9	IX 24th 15 24	46 35 .1
540	08 50	50 02 .4	13 22	49 50 .3
460	09 30	49 18 .6	— —	— —
100	13 30	48 34 .6	IX 23rd 09 10	48 24 .4
110	10 50	50 28 .1	09 36	50 18 .4
40	14 36	51 15 .5	10 28	51 07 .9
40	15 15	48 36 .9	11 00	48 37 .1
40	15 55	46 42 .5	11 36	46 42 .8
220	17 34	46 46 .4	— —	— —
180	VII 27th 10 27	48 13 .8	IX 22nd 18 15	48 10 .3
15	14 05	49 51 .8	16 49	49 46 .5
20	16 05	48 48 .4	15 47	48 44 .9
50	VII 28th 08 44	47 51 .7	IX 25th 16 45	47 42 .3
50	09 27	50 03 .3	17 16	50 00 .3
20	10 43	47 40 .3	IX 26th 08 50	47 28 .6
20	13 57	47 36 .3	12 10	47 30 .3
20	15 44	47 02 .3	13 43	46 59 .5
40	17 00	47 56 .8	15 12	47 57 .3
55	VII 29th 08 16	48 26 .5	18 12	48 22 .5
220	10 13	50 30 .4	17 17	50 30 .0
640	12 01	53 09 .9	IX 24th 12 05	52 49 .0
610	13 29	51 09 .3	10 26	50 42 .1
530	VII 30th 14 00	49 43 .5	10 03	49 26 .8
560	14 33	51 44 .4	09 16	51 27 .2
350	15 38	50 57 .5	IX 25th 14 57	50 43 .6
100	16 23	46 53 .8	15 21	46 43 .6
700	— —	— —	12 55	54 35 .8

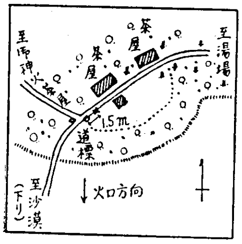

Fig. 1-4 Station No. 4
First somma.

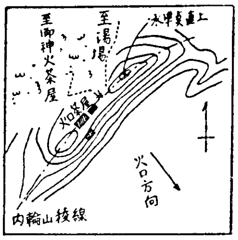

Fig. 1-5 Station No. 5
Central cone.

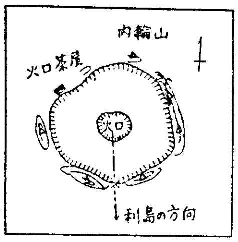

Fig. 1-6 Station No. 6
Central cone.

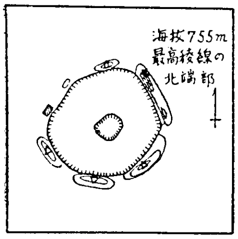

Fig. 1-7 Station No. 7
Central cone.

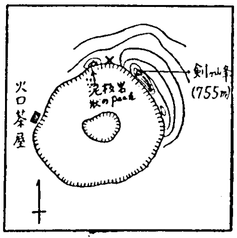

Fig. 1-8 Station No. 8
Central cone.

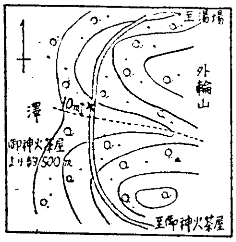

Fig. 1-9 Station No. 10
High way.

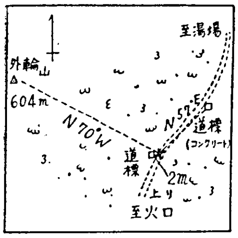

Fig. 1-10 Station No. 11
Sabaku.

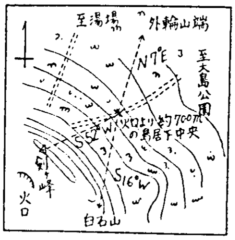

Fig. 1-11 Station No. 12
Torii, Ooshima park.

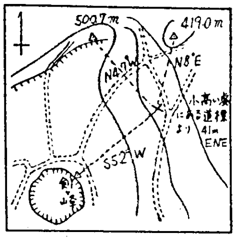

Fig. 1-12 Station No. 13
Ooshima park.

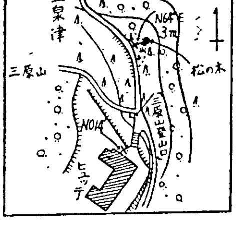

Fig. 1-13 Station
No. 14 Zoo.

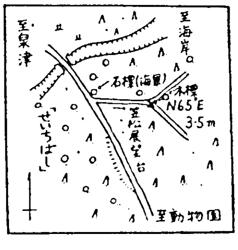

Fig. 1-14 Station
No. 15 Kasamatsu.

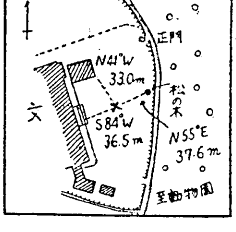

Fig. 1-15 Station No. 16
Senzu primary school.

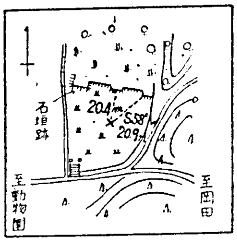

Fig. 1-16 Station No. 17 Old Senzu primary school.

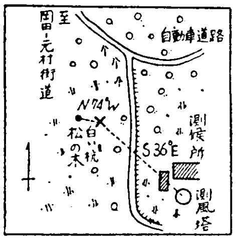

Fig. 1-17 Station No. 19 Ooshima meteorol. station.

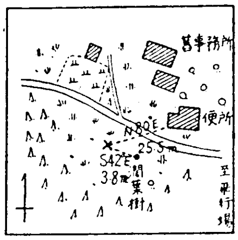

Fig. 1-18 Station No. 20 Rokutoen.

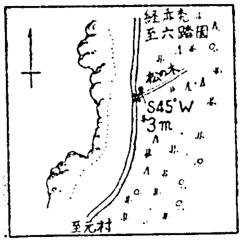

Fig. 1-19 Station No. 21 Izumihama.

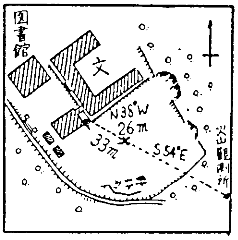

Fig. 1-20 Station No. 22 Motomura primary school.

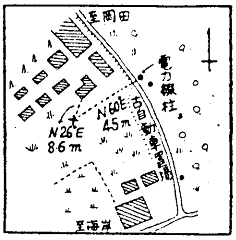

Fig. 1-21 Station No. 23 Old Motomura primary school.

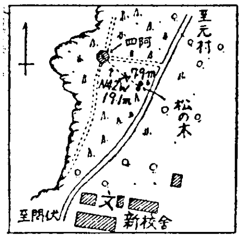

Fig. 1-22 Station No. 24 Nomashi village.

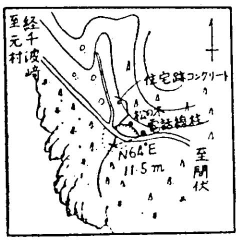

Fig. 1-23 Station No. 25 Senbazaki.

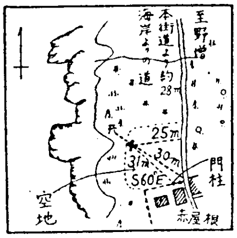

Fig. 1-24 Station No. 26 Mabushi.

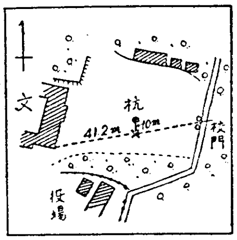

Fig. 1-25 Station No. 27 Sashikiji primary school.

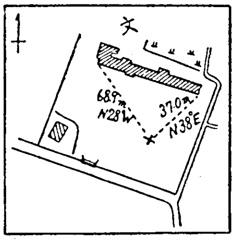

Fig. 1-26 Station No. 28 Habuko primary school.

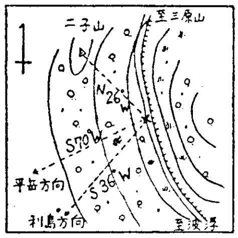

Fig. 1-27 Station No. 29 Habu road.

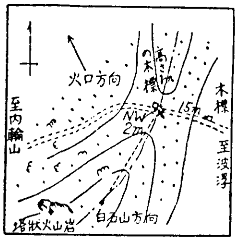

Fig. 1-28 Station No. 30 First somma.

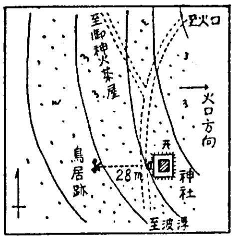

Fig. 1-29 Station No. 31 Shrine.

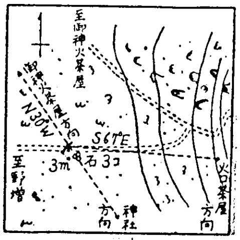

Fig. 1-30 Station No. 32 Sabaku.

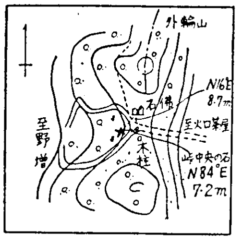

Fig. 1-31 Station No. 33 First somma.

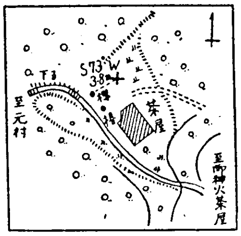

Fig. 1-32 Station No. 34 Tsubaki-chaya.

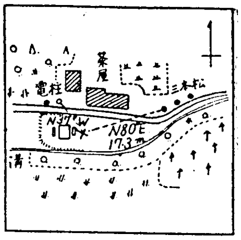

Fig. 1-33 Station No. 35 Mihara-chaya.

4. The local magnetic anomaly in Ooshima Island.

As shown in Table I, the dip-angle varies from place to place within a range of 46°−56°. Generally speaking, it increases with the increase in height of the station as was often the case in other volcanoes, such as, for example, Mt. Sakura-jima[9], Mt. Kusatsu-shirane[10], Mt. Asama[11] and Miyake-sima Island[5].

According to the magnetic chart[12] for 1950.0, the normal geomagnetic dip θ_n amounts to 47° 50′ in the vicinity of Ooshima Island. The anomly in dip-angle $\Delta\theta = \theta - \theta_n$ was calculated. The distribution of the anomaly is shown in Fig. 2. It is noticeable that the isanomaly lines are fairly parallel to the topographical contour lines. It is also remarkable that the anomaly is comparatively small in the interior of the first and second somma, notwithstanding the high altitudes of the stations above sea level. The relation between the dip-anomaly and the altitudes above sea level is

9) H. TSUYA and T. MINAKAMI, *Bull. Earthq. Res. Inst.*, **18** (1940), 335.
10) T. MINAKAMI, *Bull. Earthq. Res. Inst.*, **16** (1938), 117.
11) T. MINAKAMI, *Bull. Earthq. Res. Inst.*, **16** (1938), 100; **18** (1940), 178.
12) Published by the Geographical Survey Institute.

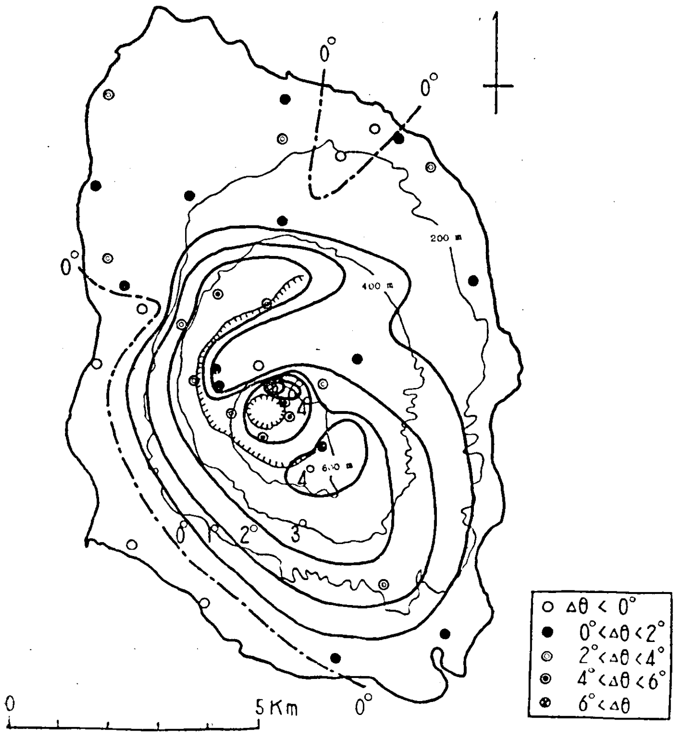

Fig. 2 The distribution of dip-anomaly in Ooshima Island.

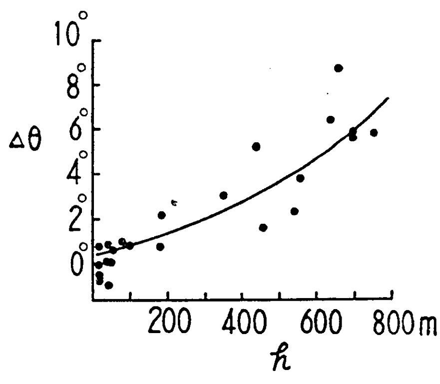

Fig. 3 The relation between dip-anomaly and height above sea level.

graphically shown in Fig. 3. The general tendency to increase as the height increases is expressed by the curve in the figure, the curve being obtained as a quadratic expression of which the coefficients are determined by means of the least square method.

According to the investigations carried out up to now, it was confirmed that the magnetic anomalies in the vicinity of volcanoes could be interpreted as due to both induced magnetization and natural remanent magnetization of the rocks composing volcanoes, the direction of magnetization coinciding roughly with that of the earth's magnetic field in ordinary cases.

The writer will calculate here the magnetization of a circular cone by which the mean topography of Ooshima Island may be well expressed. Superposing the potential of circular discs, the gravitational potential of a circular cone having the radius a_0 at the bottom and the height h is obtained as follows;

$$V = 2\pi k^2 \rho \int_z^h a dz_1 \int_0^\infty \frac{1}{\alpha} e^{-\alpha(z_1 - z)} J_0(\alpha r) J_1(\alpha a) d\alpha$$
$$+ 2\pi k^2 \rho \int_0^z a dz_1 \int_0^\infty \frac{1}{\alpha} e^{-\alpha(z - z_1)} J_0(\alpha r) J_1(\alpha a) d\alpha, \qquad (1)$$

where k^2 and ρ denote respectively the gravitational constant and the density. a is the radius at the height $z = z_1$. When the cone is uniformly magnetized in a direction with inclination θ in xz -plane, the magnetic field caused by the magnetization is calculated from Poisson's relation as follows;

$$\left.\begin{aligned} \Delta X &= J\left\{\cos\theta\left(\frac{F}{r}\cos 2\phi - G\cos^2\phi\right) - H\sin\theta\cos\phi\right\}, \\ \Delta Y &= J\left\{\cos\theta\sin 2\phi\left(\frac{F}{r} - \frac{G}{2}\right) - H\sin\theta\sin\phi\right\}, \\ \Delta Z &= J\{H\cos\theta\cos\phi + G\sin\theta\}, \end{aligned}\right\} \qquad (2)$$

where

$$\left.\begin{aligned} F &= 2a_0\rho^{-\frac{1}{2}} \int_0^{h/a_0} \alpha^{1/2}\left(\frac{2-\kappa^2}{\kappa}K - \frac{2}{\kappa}E\right) d\zeta_1, \\ G &= \rho^{-\frac{1}{2}} \int_0^{h/a_0} \kappa^2 \alpha^{-1/2}\left\{K + \frac{\kappa^2\alpha/\rho - (2-\kappa^2)}{2(1-\kappa^2)}E\right\} d\zeta_1, \\ H &= \rho^{-\frac{3}{2}} \int_0^{h/a_0} \kappa\alpha^{-1/2}(\zeta - \zeta_1)\left\{-K + \frac{2-\kappa^2}{2(1-\kappa^2)}E\right\} d\zeta_1, \\ \kappa^2 &= 4\alpha\rho/\{(\alpha+\rho)^2 + (\zeta - \zeta_1)^2\}, \\ a/a_0 &= \alpha, \quad r/a_0 = \rho, \quad z_1/a_0 = \zeta_1, \quad z/a_0 = \zeta. \end{aligned}\right\} \quad \ldots\ldots (3)$$

K and E denote complete elliptic integrals, while J denotes the intensity of magnetization. The origin of the cylindrical coordinate r, ϕ, and z is taken at the centre of the base plane of the cone.

Taking $a_0 = 5$ km, $h = 0.8$ km and the inclination of the cone to be $9°$ as the mean topography of Ooshima Island, the integrals in (3) are numerically calculated. The distribution of the components of the magnetic field over the surface of the cone is obtained as shown in Figs. 4 in which

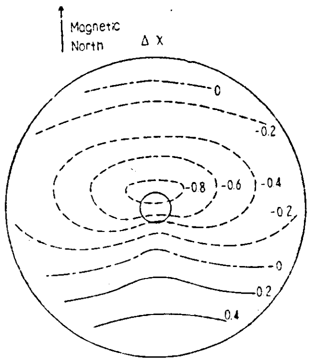

Fig. 4a The magnetic north component of the magnetic field on the surface of the cone.

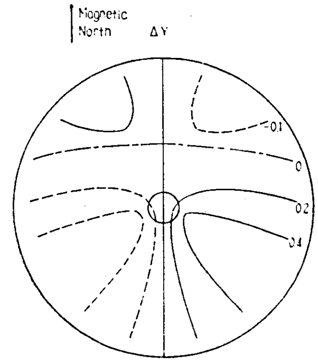

Fig. 4b The magnetic west component of the magnetic field on the surface of the cone.

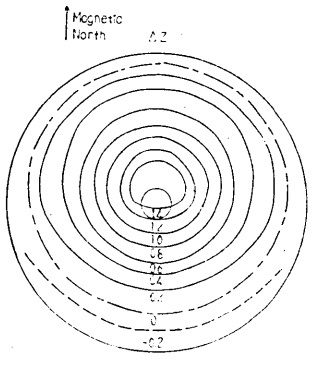

Fig. 4c The vertical component of the magnetic field on the surface of the cone.

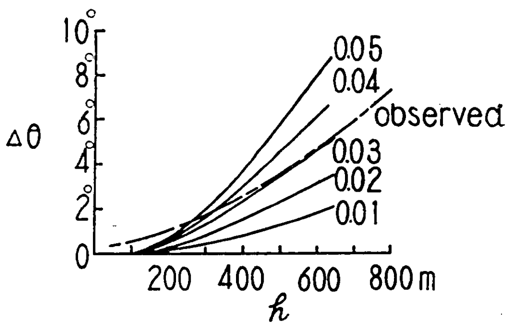

Fig. 5 Changes in the calculated and observed dip-anomaly with the height above sea level.

the intensity of magnetization is taken to be unity and θ is assumed to be 48°. As seen in the figures, the magnetic anomaly shows a particular form, the mode of distribution being approximately the same with those observed at various volcanoes. From the calculated ΔX and ΔZ, the anomaly in magnetic dip is also estimated, where the normal value for the horizontal intesity is assumed to be 0.306 *Gauss* from the chart. The increase in the dip-anomaly averaged through the whole azimuth is obtained for each respective magnetization as shown in Fig. 5. Comparing the calculated anomaly with the observed one, we may presume that the mean intensity of magnetization amounts to about 0.03 *emu*. Taking into account the magnetic properties of the rocks composing Vocano Mihara[13], the value thus obtained seems to be reasonable. Hence, the magnetic anomaly in Ooshima Island may be attributed to the magnetization of the rocks composing the volcano as was the case in other volcanoes which were already investigated.

5. Changes in magnetic dip during the period from 1936 to 1950.

The writer could identify eight stations on which the observation were made by Takahasi and Nagata[3] in 1936. The stations are Zoo, Senzu, Rokutoen, Motomura, Nomashi, Mabushi, Sashikiji and Habu. Among these stations, Rokutoen and Motomura underwent great changes in their circumstances, thus making it rather difficult to identify the stations.

In order to eliminate general secular changes, magnetic disturbance and daily variation that may be considered to be almost the same within a region of a few hundred *kilometers*, Kakioka Magnetic Observatory (latitude: 36° 14′ N, longitude: 140° 11′ E) is taken as the standard point. θ denotes the observed dip-angle at a station in Ooshima Island and θ_k that at Kakioka exactly at the same time. Then, making $\theta_{1950}-\theta_{1936}$ and $\theta_{k,1950}-\theta_{k,1936}$, we obtain

$$\delta\theta = (\theta_{1950} - \theta_{1936}) - (\theta_{k,1950} - \theta_{k,1936})\,.$$

$\delta\theta$ thus obtained may be regarded as the local change in magnetic dip from which the influences of general magnetic disturbances had been eliminated. The method considered here is the same with that already studied by Nagata[14] in connexion with the comparison of the results of magnetic surveys before and after the Niisima Earthquake, 1936.

In Table II, $\theta_{1950}-\theta_{1936}$, $\theta_{k,1950}-\theta_{k,1936}$ and $\delta\theta$ are given for the respective stations. The distribution of $\delta\theta$ is also shown in Fig. 6. Except Rokutoen

13) T. NAGATA, *Bull. Earthq. Res. Inst.*, **21** (1943), 1.
14) T. NAGATA, *Bull. Earthq. Res. Inst.*, **15** (1937), 497.

Table II. Changes in magnetic dip during the period from 1936 to 1950.

No. of station	$\theta_{1950}-\theta_{1936}$	$\theta_{k,1950}-\theta_{k,1936}$		$\delta\theta$
14	-2′.6	-6′.8		4′.2
17	3 .1	-6 .2		9 .8
	1 .9	-6 .9		8 .8
	1 .9	-5 .8		7 .7
			mean	8 .8
20	2° 05 .4	-7 .1		2° 12 .5
	2 04 .4	-7 .9		2 12 .3
			mean	2 12 .4
23	-32 .9	-6 .8		-26 .1
	-33 .5	-6 .9		-26 .1
	-32 .0	-6 .3		-25 .7
	-33 .0	-7 .3		-24 .7
			mean	-26 .0
24	-4 .3	-8 .6		4 .3
26	-3 .0	-9 .7		6 .7
	-2 .9	-9 .6		6 .7
	-1 .7	-9 .1		7 .4
			mean	6 .9
27	-2 .0	-7 .5		5 .5
	-2 .8	-7 .4		4 .6
			mean	5 .1
28	1 .5	-8 .1		9 .6
	2 .1	-8 .0		10 .1
	0 .9	-8 .3		9 .2
			mean	9 .6

and Motomura, dip-angle increased slightly at all stations during the period from 1936 to 1950. As already mentioned, the identification of the points of the stations at Rokutoen and Motomura is not so easy. Since both stations are situated on old lava-flows with intense magnetization, the gradient in the earth's magnetic field is thought to be appreciable there. Hence, the chages in dip-angle at these stations are not reliable. After all, it may be said that local changes in magnetic dip of the order of several *minutes* of arc had occurred during the period though the detailed distribution of them is not clear.

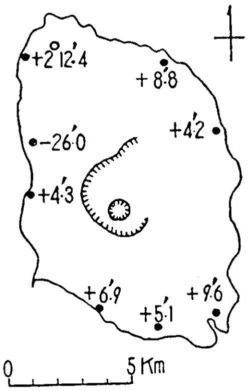

Fig. 6 The distribution of changes in magnetic dip during the period 1936-1950.

Table III. Changes in magnetic dip during the period from July to September, 1950.

Nos. of station	$\theta_{II} - \theta_{I}$	$\theta_{k,II} - \theta_{k,I}$	$\delta\theta$
1	-0′.6	0′.3	-0′.9
2	-3 .3	0 .8	-4 .1
3	-8 .2	0 .7	-8 .9
4	-14 .7	0 .8	-15 .5
5	-19 .6	-1 .0	-18 .6
6	—	—	—
7	-22 .8	-2 .7	-20 .1
8	—	—	—
9	-20 .4	-1 .8	-18 .6
10	-19 .9	-2 .6	-17 .3
11	-13 .8	-0 .6	-13 .2
12	-12 .1	-0 .2	-11 .9
13	—	—	—
14	-10 .2	-0 .2	-10 .0
14′	-9 .7	-0 .2	-9 .5
15	-7 .6	0 .0	-7 .6
16	0 .2	0 .2	0 .0
17	0 .3	0 .1	0 .2
18	—	—	—
19	-3 .1	2 .4	-5 .5
20	-5 .3	1 .6	-6 .9
21	-3 .5	1 .3	-4 .8
22	-9 .1	1 .9	-11 .3
23	-3 .0	2 .9	-5 .9
24	-11 .7	2 .1	-13 .8
25	-6 .0	1 .2	-7 .2
26	-2 .8	1 .3	-4 .1
27	0 .5	1 .4	-0 .9
28	-4 .0	1 .8	-5 .8
29	-0 .4	1 .7	-2 .1
30	-20 .9	4 .0	-24 .9
31	-27 .2	3 .1	-30 .3
32	-16 .7	2 .6	-19 .3
33	-17 .2	2 .5	-19 .7
34	-13 .9	1 .6	-15 .5
35	-10 .2	1 .8	-12 .0
36	—	—	—

6. Changes in magnetic dip that accompanied the eruption, 1950.

The survey I was carried out at the early period of the present activity of Volcano Mihara, while the survey II was made just at the final stage. After correcting general magnetic disturbances as in the previous section, changes in magnetic dip during the period I–II are obtained as shown in Table III. Their distribution is also shown in Fig. 7. As seen in the figure,

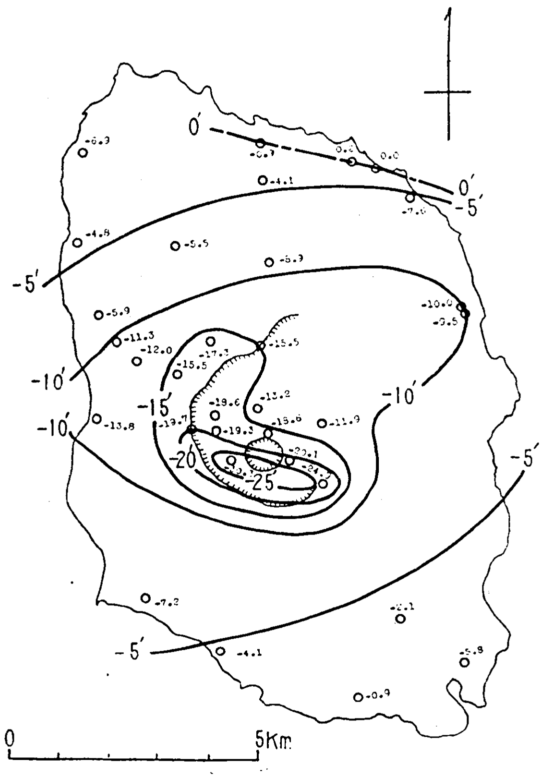

Fig. 7 The distribution of changes in magnetic dip associated with the eruption.

we find remarkable decrease in dip-angle all over the island except the northern extremity of the island. The amount of decrease becomes larger as the stations approach the central area of the island, the largest decrease amounting to as much as 30 *minutes* of arc at the station No. 31.

7. Discussions on the local anomalous changes in geomagenetism that accompanied the eruption.

In the case of Miyake-sima eruption of 1940, Takahasi and Hirano[4] concluded that the changes in the vertical intensity of the earth's magnetic field during the early period of the eruption may be explained by assuming that a spherical region with a radius of 3 *km* just under the centre of the island lost its magnetic property. As the mode of the changes obtained here seems very similar to that of the Miyake-sima eruption, the writer analyzed the distribution of geomagnetic changes from a similar standpoint as follows.

In the first place, the method devised by the writer[15] by which the position, intensity and direction of an underground magnetic dipole can be determined from the anomalies on the earth's surface was applied. The values of $\delta\theta$ at intersection points of a series of parallel lines which are drawn on the map at 1.5 *km* interval are read off. Using these values, the partial derivatives f_{00}, $\partial f_{00}/\partial x$, $\partial f_{00}/\partial y, \ldots,$ $\partial^3 f_{00}/\partial x \partial y^2$, $\partial^3 f_{00}/\partial y^3$ are calculated by means of least square, where f is given by

$$f(\delta\theta) = \{\tan(\theta_n + \delta_0) - \tan\theta_n\}/\tan\theta_n \quad \ldots\ldots\ldots\ldots (4)$$

and where θ_n denotes the normal dip. Thus the coefficients of spherical harmonic expansion of magnetic potential on a sphere of radius a are obtained by solving certain simultaneous equations. Then adjusting a so as to minimize the square sum of the second degree coefficients, the depth of the magnetic centre is determined to be 5.5 *km*, while the position is also obtained as shown on the map of Fig. 8 with a circle.

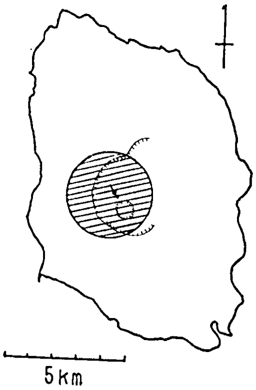

Fig. 8 The direction and position of the magnetic dipole by which the changes in geomagnetism are approximately explained. Hatched area shows the horizontal cross-section of the demagnetized region, where the original intensity of magnetization was assumed to be 0.03 *emu*, the eccentricity being introduced by the second degree term in the spherical harmonic expansion of the magnetic potential.

The obtained quantities are tabulated in Table IV. In order to compare the changes with those of the Miyake-sima erup-

15) T. RIKITAKE, *Journ. Geomagn. Geoelectr.*, **2** (1950), 20 and 25.

Table IV.

The coefficients of spherical harmonic expansions and various quantities related to the determined magnetic dipoles.

		Ooshima	Miyake-sima
Coefficients	a_1^0	-337 γ	-300 γ
	a_1^1	130	140
	b_1^1	117	125
	a_2^0	128	107
	a_2^1	45	-47
	b_2^1	-40	-42
	a_2^2	11	-6
	b_2^2	-8	-3
Depth of centre		5.5 *km*	2.9 *km*
Azimuth of north seeking end		S42°E	S42°E
Dip of dipole		-63°	-58°
Magnetic moment		6.3×10^{14} *emu*	8.6×10^{13} *emu*

tion, a similar analysis is made with respect to Takahasi-Hirano's data, the results being also shown in Table IV.

The coefficients are given by the next expansion of magnetic potential on a sphere of radius a' which is the same with the depth of the dipole,

$$W = a'\sum_n\sum_m P_n^m(a_n^m \cos m\phi + b_n^m \sin m\phi), \quad \ldots\ldots\ldots\ldots (5)$$

where the direction $\phi = 0$ is taken to the north.

Taking into account the direction of the magnetic dipole thus determined, the greatest part of the changes in geomagnetism obtained here is explained as the loss of magnetization in a roughly spherical region of which the centre is situated at a depth of about 5 *km*, the said depth as shown in Table IV, having been determined to be nearly 3 *km* in the case of the Miyake-sima eruption.

In the next place, some discussions on the intensity of magnetization and the shape of the mass by which the anomalous change may be caused will be made. As fully studied by Nagata[13] in the study of uniformity of natural remanent magnetization of rocks, the magnetic potential due to the magnetization of a mass of complex arbitrary form may be deduced from the gravitational potential as obtained by replacing the mass distribution by certain surface distribution, provided the shape does not deviate markedly from the sphere.

Let the surface of the mass be expressed by

$$l(\theta, \phi) = \sum_{n=0}^{\infty}\sum_{m=0}^{n} P_n^m (p_n^m \cos m\phi + q_n^m \sin m\phi), \qquad (6)$$

where l denotes the distance of the surface from the apparent centre. When we take a as the radius of the mean sphere, the difference $l-a=d$ becomes

$$d(l, \phi) = \sum_{n=1}^{\infty}\sum_{m=0}^{n} P_n^m (p_n^m \cos m\phi + q_n^m \sin m\phi). \qquad (7)$$

Since d/a is assumed to be small, the contribution of the mass distribution to the gravitational potential is almost the same with that of surface mass σ which is distributed on the sphere of radius a, where

$$\sigma(\theta, \phi) = a\rho/3 + \rho d(\theta, \phi), \qquad (8)$$

and where ρ denotes the density.

The gravitational potential in the external space due to such surface distribution is readily given by

$$V = -\sum_{n=0}^{\infty}\sum_{m=0}^{n} (a/r)^{n+1} P_n^m (u_n^m \cos m\phi + v_n^m \sin m\phi), \qquad (9)$$

where, by use of (7), (8) and (9), the coefficients are determined from potential-theory as follows;

$$u_0^0 = \frac{4\pi k^2 \rho a}{3}, \quad u_n^m = \frac{4\pi k^2 \rho n}{2n+1} p_n^m, \quad v_n^m = \frac{4\pi k^2 \rho n}{2n+1} q_n^m. \qquad (10)$$

On the other hand, the magnetic potential due to uniform magnetization of the said mass is obtained from the well-known Poisson's relation. When the direction of the magnetization is taken in xz -plane with an angle ω from the vertical axis, the magnetic potential is given by

$$W = \frac{J}{k^2\rho}\left\{\sin\omega\left(\sin\theta\cos\phi\frac{\partial}{\partial r} + \frac{1}{r}\cos\theta\cos\phi\frac{\partial}{\partial\theta} - \frac{\sin\phi}{r\sin\theta}\frac{\partial}{\partial\phi}\right)\right.$$
$$\left. + \cos\omega\left(\cos\theta\frac{\partial}{\partial r} - \frac{\sin\theta}{r}\frac{\partial}{\partial\theta}\right)\right\} V. \qquad (11)$$

From (11), W is calculated up to degree 2 as follows;

$$W = \frac{J}{k^2\rho}\Big[(a/r)^2(u_0^0 \cos\omega P_1^0 + u_0^0 \sin\omega P_1^1 \cos\phi)$$
$$+(a/r)^3\{(2u_1^0 \cos\omega - u_1^1 \sin\omega)P_2^0$$
$$+\sqrt{3}(\overline{u'_1 \cos\omega + u_1^0 \sin\omega \cos\phi} + v_1^1 \cos\omega \sin\phi)P_2^1$$
$$+\sqrt{3}(u_1^1 \sin\omega \cos 2\phi + v_1^1 \sin\omega \sin 2\phi)P_2^2\}\Big]. \quad \ldots\ldots\ldots\ldots(12)$$

Equating the corresponding terms in (5) and (12) at $r = a'$, we get certain simultaneous equations from which u_0^0, u_1^0, u_1^1 and v_1^1 are solved. It must be noticed here that the direction of the magnetization is taken in xz -plane, hence the coefficients given in Table IV should be transformed to a suitable coordinate in the actual application of the above-mentioned method. After applying the method to the geomagnetic changes in Ooshima Island, we obtain

$$u_0^0 = 0.00380\frac{k^2\rho a'}{J}\Big(\frac{a'}{a}\Big)^2, \qquad u_1^0 = -0.00063\frac{k^2\rho a'}{J}\Big(\frac{a'}{a}\Big)^3,$$
$$u_1^1 = -0.00037\frac{k^2\rho a'}{J}\Big(\frac{a'}{a}\Big)^3, \qquad v_1^1 = 0.00040\frac{k^2\rho a'}{J}\Big(\frac{a'}{a}\Big)^3. \qquad (13)$$

Taking into account the relation (10), we have

$$J = 0.00380 \times \frac{3}{4\pi}(a'/a)^3,\ p_1^0 = -0.165\,a,\ p_1^1 = -0.097\,a,\ q_1^1 = 0.104\,a. \quad \ldots\ldots(14)$$

If we adopt 0.03 *emu* as the intensity of magnetzation as obtained in section 4, the radius of the mean sphere a amounts to 1.7 *km*. For the lowest possible value 0.01 *emu* of the mean intensity of magnetization for volcanoes of basaltic rocks, we also obtain a=2.5 *km*. Hence the changes in magnetic dip in Ooshima Island seems to be caused mainly by the demagnetization of a roughly spherical region of which the centre is situated at a depth of about 5 *km* and the mean radius about 2 *km*.

The unevenness of the surface can be further estimated from (14). The horizontal cross-section at the centre thus obtained is shown in Fig. 8. Although the unevenness of higher order is neglected, it will be recognised that the shape of the mass does not materially differ from the sphere.

As clarified in the foregoing pages, the changes in the earth's magnetic field that accompanied the eruption of Volcano Mihara are explained as the apparent magnetization of an underground spherical region, the centre of the mean sphere being situated at a depth of several *kilometers* just beneath the centre of the island. The deviation of the shape of the region from the sphere seems to be comparatively small as shown, for example, in Fig. 8. Since the direction of magnetization is roughly opposite to that of the earth's magnetic field, we may presume that the said region lost its magnetic property owing to the rise in temperature associated with the eruption. Taking a probable value as the intensity of magnetization, the radius of the region is estimated to be about a few *kilometers*. Thus it may be presumed that the temperature in a roughly spherical region having a radius of a few *kilometers* becomes higher than the Curie-point of rocks in connexion with the volcanic activity.

8. Summary and conclusion.

Comparing the results of the first and second surveys over Ooshima Island, marked changes in the earth's magnetic field were found out during the period from beginning to end of the eruption of Volcano Mihara, 1950. The magnetic dip-angle decreased all over the island. The largest value of the decrease amounted to as much as 30 *minutes* of arc. Applying the method devised by the writer for finding out the position, intensity and direction of an underground magnetic dipole directly from the distribution on the earth's surface, it was found that the changes obtained here may be almost explained as due to a dipole situated just beneath the centre of the island at a depth of 5.5 *km*, the direction being approximately opposite to the earth's magnetic field. Taking into account the intensity of magnetization of rocks composing the volcano, the generation of the dipole may be attributed to the demagnetization of a roughly spherical region having a radius of a few *kilometers*, while the demagnetization seems to be due to the rise in temperature in the said region associated with the eruption. It is of interest that the general mode of the change closely resembles that observed in the case of Volcano Miyake-sima where the rocks composing the volcano is also basalt.

Comparison with the survey carried out in 1936 was also made. However, no marked changes were to be found. The writer also studied the local anomaly in magnetic dip from which the mean intensity of magnetization was estimated to be about 0.03 *emu*.

In the course of the study, the writer was encouraged by his senior colleagues. The writer wishes to express his hearty thanks to Professor H. Tsuya, Professor R. Takahasi, Professor T. Hagiwara, Professor T.

Minakami, and Dr. T. Nagata for their helpful advices. To Dr. S. Imamiti and Mr. M. Hirayama of the Kakioka Magnetic Observatory who placed magnetic data at the writer's disposal, the writer's cordial thanks are also due. The writer also wishes to express his appreciations to Mr. K. Kasahara, Mr. S. Saito, and Miss Y. Hishiyama who assisted the writer in the field-measurement. The study was done with the financial aid of the research grant from the Deparment of Education, and the writer wishes to express his cordial thanks for the grant received.

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14. 伊豆大島における地磁氣伏角分布と三原山噴火に伴うその變化

地震研究所　力 武 常 次

1950年7月の三原山噴火に際して，地震研究所製小型磁氣感應儀を用いて，2回にわたり地磁氣伏角測定を實施した．伏角の分布は，從來多くの火山についてしらべられたように著しい異常を示して，最小 46°，最大 56° にわたつている．この異常より山体の平均帶磁の强さとして 0.03 *emu* がえられた．1936年の高橋，永田兩博士の測量と比較して，いちじるしい變化は見出されなかつたが，島全体にわたり伏角が數分程度增加していることになつた．

噴火の初期と末期の比較から，最大 30′ に達するいちじるしい伏角の減少が見出された．この變化は 1940年三宅島噴火の際の地磁氣變化によく似ていて，解析の結果，島の中心部の地下 5.5 *km* のところに中心をもつ，半徑約 2 *km* の近似的に球形の部分が，その帶磁を失つたと考えれば解釋出來ることになつた．すなわち，上記の部分が火山活動に伴つてキューリ點以上の高温になつたとすればよいことになる．