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4. *Magnetic Survey on Hakone Volcano by Use of a Proton Magnetometer.*

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Summary

In connection with the seismic activity that occurred beneath the central cones of Hakone Volcano since the beginning of September, 1959, a magnetic survey with a proton magnetometer was carried out from Oct. 26 to 29, 1959.

It is made clear that the central area in the caldera can be divided magnetically into several areas. They are Kamiyama lavas, Komagatake lavas, Futagoyama lavas and the basalt lapilli and ash called Kanto ash. The differences in anomaly between these areas are obviously caused by the magnetization contrast of the formations. The intensity of magnetization of the central cone, Mt. Kamiyama, for example, seems unexpectedly large for an andesitic volcano, even though the topographic effect is taken into account.

Now that the distribution of the present magnetic field in the caldera has been obtained, repetition of a magnetic survey of this kind would elucidate the volcanic activity in relation to the change in the earth's magnetic field.

1. Introduction

A seismic activity with felt shocks of small magnitude started underneath the central cones of Hakone Volcano in the beginning of September, 1959. The activity lasted a few months. Seismographs installed by Prof. Minakami around the seismic area recorded a few hundred shocks every day during the most active period. In the hope of detecting changes in the earth's magnetic field, which might be accom-

*) Communicated by T. RIKITAKE.

panied by the activity, the writers undertook a magnetic work over the volcano.

It has been established that the magnetic method is very useful for studying volcanoes. Local magnetic anomalies that are closely related to the structure of volcanoes have been found on many volcanoes. The local anomalous changes in the earth's magnetic field as have been observed on Ooshima Island are even more important. Repeated magnetic surveys and continuous observations with variometers made there revealed geomagnetic changes which were likely caused by demagnetization and magnetization associated with rise and fall of the activities of Miharayama Volcano[1]. Since then, observation of changes in the geomagnetic field on volcanoes has been regarded as one of the most promising methods of foretelling the activity.

The first magnetic survey was carried out within the caldera surrounded by the old somma of Hakone Volcano with a portable proton magnetometer from Oct. 26 to Oct. 29. The magnetometer, all transistorized, was specially designed for field-use by the Research Group for Proton Magnetometer. The details of the magnetometer are reported elsewhere[2].

The portable proton magnetometer enables us to make absolute measurements of total geomagnetic force quite easily. A good many measurements can be performed in a short time. Preceding this survey, the writers calibrated the magnetometer at Aburatsubo station. According to the results of the comparison with the variometers, the instrumental error never exceeded 5 γ, which assured sufficient accuracy for the present survey.

In the northern part of Mt. Kamiyama, one of the central cones, there are engraved valleys with many sulphurous fumaroles, Oowakidani and Sôunzan valleys. In the latter there occurred a great landslide on July 26, 1953. It was reported[3] that the end of the slid area reached as far as 2 *km* from its source. As can be seen in Fig. 1, measuring points of this time are distributed, in the main, around Mt. Kamiyama, where the seismic activity was inferred to be most marked from the seismometric observations.

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1) For instance,
T. RIKITAKE and I. YOKOYAMA, *Jour. Geophys. Res.*, **60** (1955), 165.
I. YOKOYAMA, *Bull. Earthq. Res. Inst.*, **33** (1955), 251.
I. YOKOYAMA, *Bull. Earthq. Res. Inst.*, **35** (1957), 567.

2) The RESEARCH GROUP for PROTON MAGNETOMETER, *Bull. Earthq. Res. Inst.*, in press.

3) F. KISHINOUYE and J. OSSAKA, *Bull. Earthq. Res. Inst.*, **33** (1955), 153.

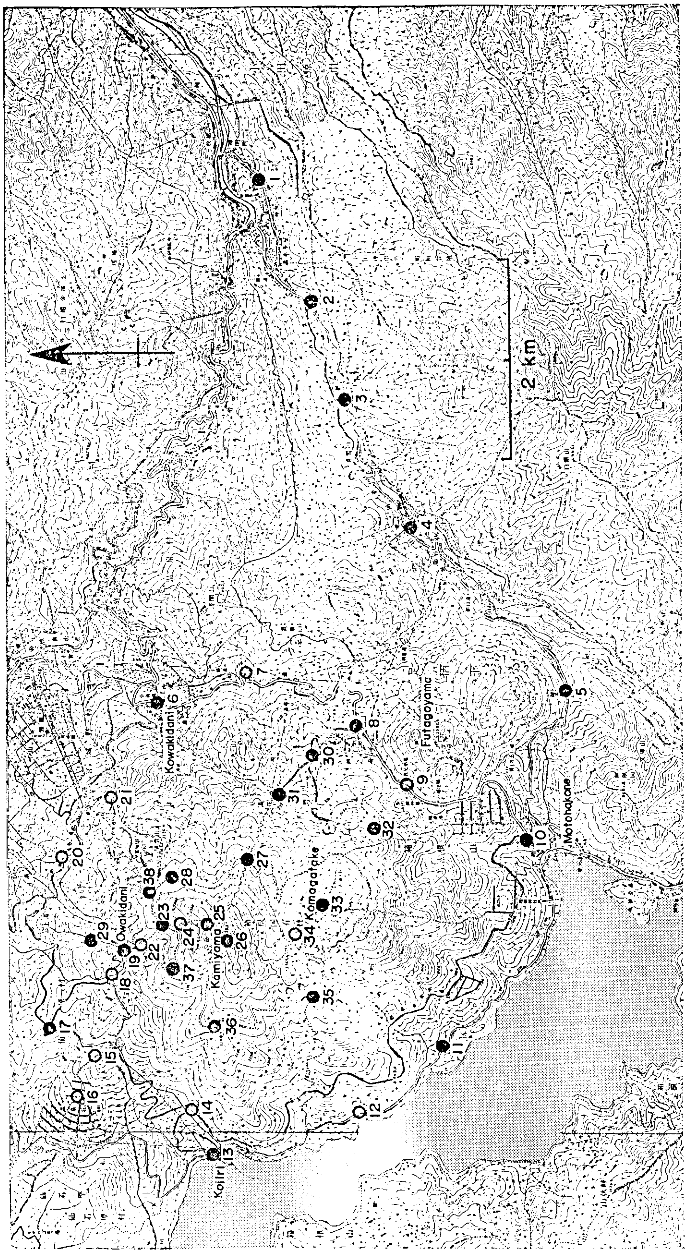


Fig. 1. Distribution of measuring points.
Full circles: Brass bars are buried as bench marks.
Hollow circles: Only wooden bars are buried.

2. Distribution of the total force intensity

Since three components of geomagnetic field or dip have been usually measured over volcanoes, no general representation of geomagnetic anomalies in the total force intensity has been obtained yet. In order to have an idea of the distribution of total force, we may study a somewhat idealized case in the following. When a circular cone with a radius of 5 *km* and a height of 0.8 *km*, which may well represent the mean topography of Ooshima Island, is uniformly magnetized in the direction of the geomagnetic field, the magnetic field caused by the natural remanent magnetization of rocks has been calculated by Rikitake[4]. As the results were expressed in the way of the distributions of three geomagnetic components, the writers have calculated the distribution of the total force intensity from them. Fig. 2 shows this result when the intensity of magnetization is taken to be unity and the normal dip at the cone is assumed to be 48°. It is noticeable that the maximum anomaly of the total force intensity is found at a point slightly south of the summit and that the regions of small anomaly appear on the east-west line, which results in the depression of the iso-anomaly lines towards the summit on that line.

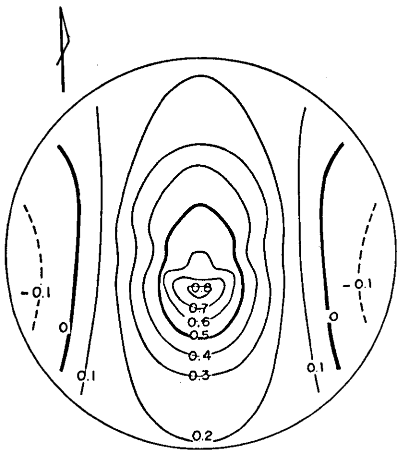


Fig. 2. The total force intensity of the magnetic field on the surface of the cone, when $J=1$ *e.m.u./cc.* (unit in gauss).

3. Results of the survey

The results of the survey are shown in Table 1 together with the height above sea level of the measuring points. Surroundings of the stations are sketched for the future measurements in Fig. 8. Corrections for the diurnal variations in the magnetic field have been made by adopting Aburatsubo station as the standard one, where the normal value of the total force intensity is taken to be 45707 γ, the value at 0^h00^m(J.S.T.) on Oct. 30, 1959. Thus corrected values are also shown

4) T. RIKITAKE, *Bull. Earthq. Res. Inst.*, **29** (1951), 161.

Table 1. The results of the survey.

No.	Locality		Height above sea level	Date	Total force intensity	Corrected total force intensity*)
1	湯本幼稚園	Yumoto Kindergarten	120m	Oct. 26th 14h51m	46000.7γ	46034.7γ
2	須雲園バンガロー	Sugumoen	165	15 20	45131.7	45165.3
3	初花荘	Hatuhana-sô	255	15 46	45648.4	45688.8
4	発電所上	Electric powerhouse	335	16 09	46418.7	46470.2
5	甘酒茶屋	Amazake-tyaya	700	16 40	45552.1	45594.1
6	翠松園ホール前(小涌園)	Suisyô-en Hall	595	Oct. 27th 10 25	45939.6	45984.1
7	恵明学園	Keimei-gakuen	670	10 45	46846.2	46878.1
8	芦ノ湯	Asinoyu	870	11 11	46782.8	46818.9
9	曾我兄弟の墓	Graves of the Sogas	870	11 27	45627.2	45662.6
10	元箱根	Motohakone	805	11 56	46317.7	46358.1
11	元箱根キャンプ場	Wood for camping	740	13 28	46313.0	46341.0
12	九頭竜明神	Kutôryû-myôzin	735	13 42	47045.8	47076.2
13	湖尻	Koziri	725	14 01	46073.5	46108.8
14	自動車専用道路入口	Gate to the toll road	780	14 20	46266.1	46306.9
15	姥子	Ubako	875	14 57	46437.5	46437.2
16	上温泉荘バス停留所前	Kami-Onsen-sô	840	15 12	46223.8	46252.7
17	大涌谷下十字路	Oowakidani T-shape joint	930	15 31	47142.1	47164.9
18	大涌谷下	Wayside of the toll road to Oowakidani	1010	15 45	47074.0	47100.3
19	大涌谷登山口	Oowakidani	1045	15 58	46498.6	46528.9
20	上湯—強羅間	Side of the toll road between Kaminoyu and Sôunzan	800	16 27	46630.1	46658.4
21	早雲山見晴台下	Sôunzan	750	16 45	46639.5	46684.1
22	大涌谷登山道	Above fumaroles of Oowakidani	1080	Oct. 28th 9 15	46484.5	46504.2
23	神山—早雲山別れ道	Cross-way of northern flank of Mt. Kamiyama	1180	9 59	46256.7	46281.0
24	神山登山道	Wayside to Kamiyama	1245	10 32	47825.6	47851.3
25	冠ヶ岳下	At the foot of Kanmuri-ga-take	1350	11 10	47315.9	47338.6
26	神山頂上三角点	Summit of Mt. Kamiyama	1438	11 44	47539.0	47552.1
27	湯ノ花沢下り口	Cross-way of eastern flank of Mt. Kamiyama	1140	13 35	46702.9	46703.6
28	早雲山別れ道	Fork point	1205	14 19	46893.1	46895.1
29	大涌谷—上湯間	Wayside at the north of Oowakidani	980	15 46	47149.1	47152.2
30	湯ノ花沢ケーブル岐点	Fork point at Yunohanazawa	910	Oct. 29th 9 15	47485.0	47504.4
31	湯ノ花沢駐車場	Yunohanazawa	925	9 37	46047.6	46068.8
32	駒ヶ岳ケーブル(登り口)	At the foot of Komagatake	1025	9 53	46132.2	46154.7
33	駒ヶ岳頂上	Summit of Komagatake	1360	10 37	46578.4	46595.2
34	駒ヶ岳北西山麓	North-western flank of Mt. Komagatake	1230	11 42	46190.9	46215.3
35	坊ヶ沢下り口	Fork point above Bôgasawa	1190	12 15	46707.6	46724.8
36	神山西北西麓	On the western flank of Mt. Kamiyama	1195	13 44	46686.5	46695.2
37	冠ヶ岳麓	North-western slope of Mt. Kanmuri-ga-take	1190	14 27	46569.0	46577.7
38	早雲山上方	Wayside above Sôunzan	1230	15 28	47489.7	47502.2

*) Corrected values for the diurnal variation.

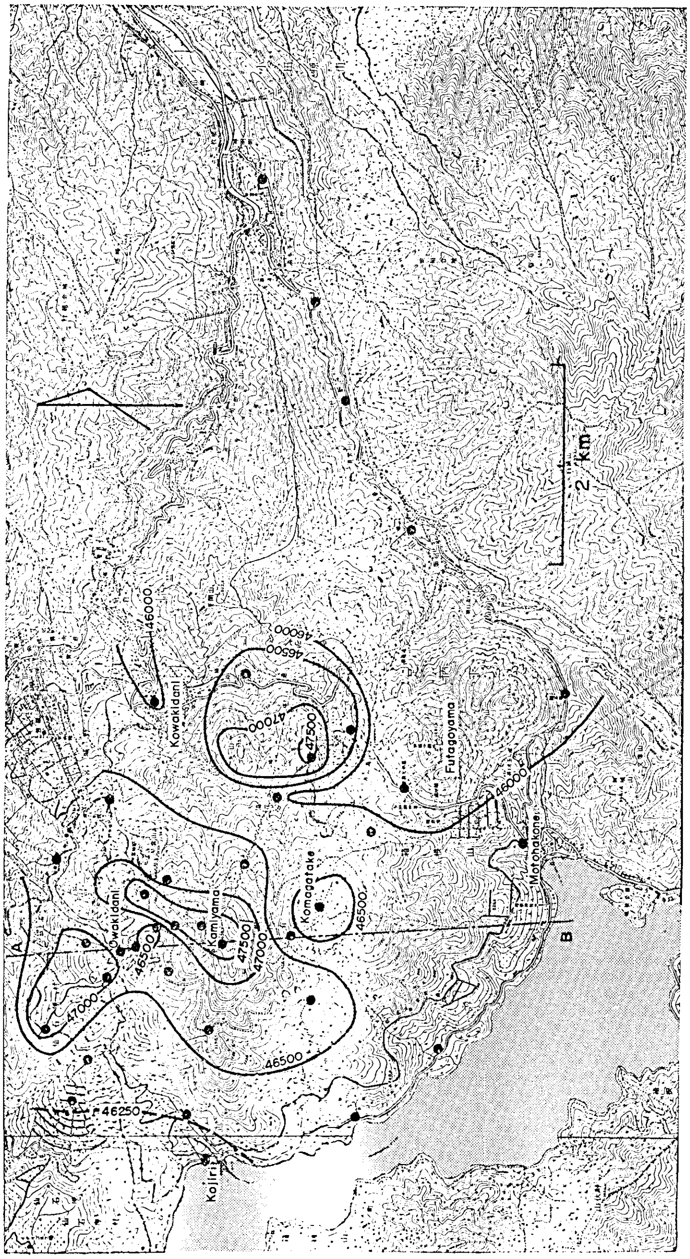


Fig. 3. Distribution of the total force intensity.
(Unit in gammas)

in Table 1. On the basis of these data, isodynamic lines are drawn as can be seen in Fig. 3.

The normal values of the total force intensity in the neighbourhood of Hakone Volcano is obtained to be 46040 γ from the magnetic chart for 1950.0. Therefore the area surveyed this time has anomalies more than 500 γ as a whole. Besides this large scale anomaly, local anomalies of narrow extent are remarkable. We can see, from Fig. 3, several foci of large intensity are scattered within the caldera corresponding to the distribution of central cones. The region around Mt. Kamiyama is specified by a large anomaly of the total force intensity, while anomalies

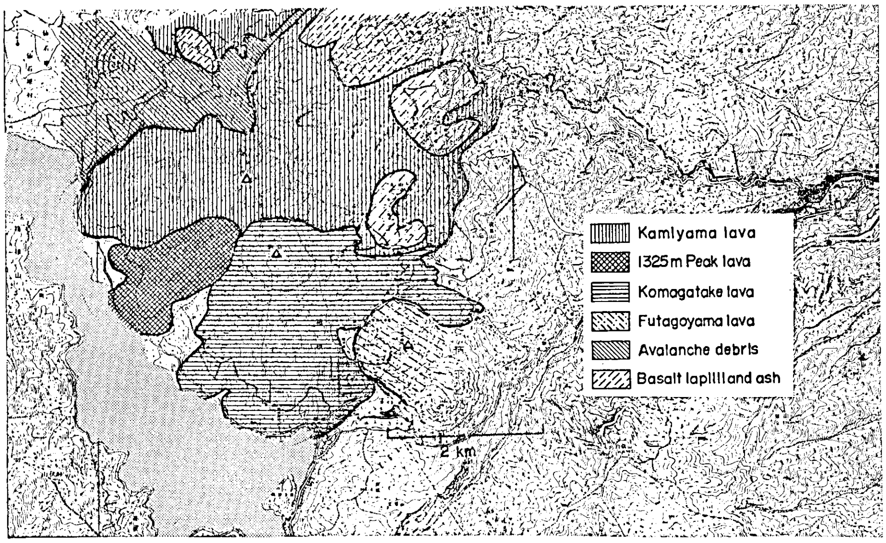


Fig. 4. The geological map in the central parts of the caldera. (After H. Kuno)

in the vicinity of Mt. Futagoyama seem rather small. Measurements on Mt. Komagatake have shown that the cone is magnetized with an intermediate intensity between Mt. Kamiyama's and Mt. Futagoyama's. In these territories bounded by central cones, there exist a few patches of great intensity that seem to have no apparent correspondence to the topography. This suggests that the magnetic field on the ground is more seriously affected by the magnetic properties of materials near the surface of the earth than by the togography. A geological chart[5] that is shown in Fig. 4 will ascertain it more clearly. The above stated anomaly characterized by every central cone can be illustrated by the difference in the magnetization of lavas mainly composed of andesite that

5) H. KUNO, *Explanetory Text Geol. Map in Japan, Atami* (1952).

flowed out from these cones. Although the distribution of the patches of great intensity does not seem to depend on the topography, it may be understood from Fig. 4 that these extraordinarily anomalous regions are formed by sedimentation of basalt lapilli and ash from Huzi Volcano.

4. Magnetization of Mt. Kamiyama

In this section, the anomalous distribution of magnetic field around Mt. Kamiyama, which is the largest among the central cones, will be studied in detail. We see that the total force intensity increases in

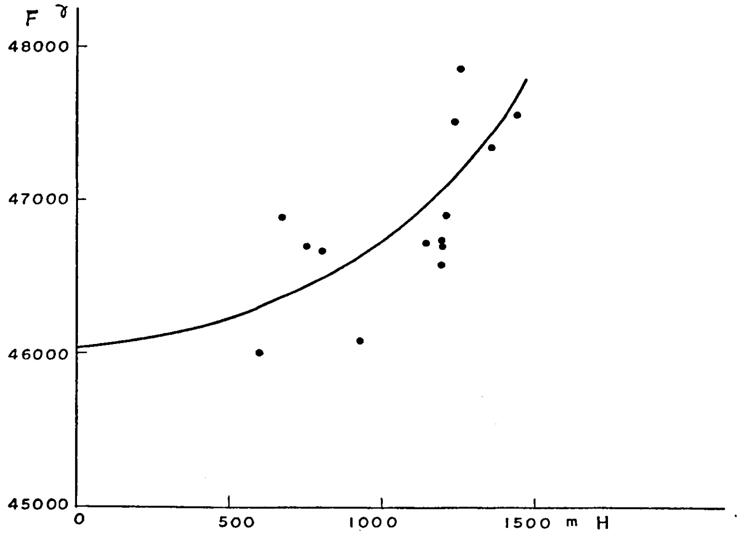


Fig. 5. Changes in the total force intensity with the altitude on Mt. Kamiyama.

general as the height above sea level increases. Fig. 5 shows how the magnetic field increases with the height.

It is also of interest to note that there exists an area of remarkably small anomaly in the north-western part of Mt. Kamiyama, whose topography shows as if the slope were engraved away just along the small anomalous region. The cross section along this valley is shown in Fig. 6. After Kuno[5], an explosion occurred in this part and the pyrocrastics due to this destruction were scattered widely over the north-western area of Mt. Kamiyama. The results of our magnetic survey seem to support the statement, because firstly it should be natural to consider that the small anomaly in that particular region may be caused by the defect of magnetized materials which should have composed an ideal circular cone and secondly by the weakening effect of the magnetization due to the random orientation of magnetization of pyrocrastics. If the cone retained its complete form, judging from the present magnetic field, the distribution of total force intensity would be quite alike as that in Fig. 2.

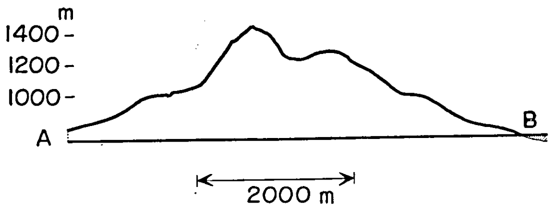


Fig. 6. Profile of Mt. Kamiyama along the line A–B in Fig. 3.

When the 700 *m* height above the sea level, which is the approximate height at the bottom of the caldera, is taken to be the base plane of Mt. Kamiyama, it may be allowed to approximate itself by a simple cone of 740 *m* in height and with a radius of 3 *km*. Assuming the values on the foot of the mountain to be 46000 γ, the anomaly of total force intensity on the top amounts to about 1500 γ. This anomaly is much larger than that of Mt. Asama, which is also an andesitic volcano as Mt. Kamiyama is. The anomaly related to Mt. Asama, however, amounts to a few hundred gammas at most[6].

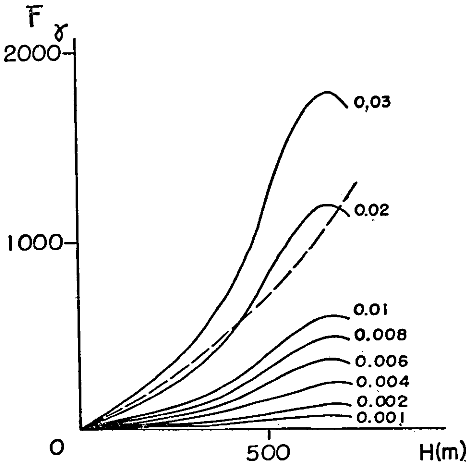


Fig. 7. The mean dependence of the total force intensity on the height, when a circular cone is uniformly magnetized. The intensity of magnetization J (in the unit of *e.m.u.*) is taken as a parameter. The broken line curve is obtained from measurements on Mt. Kamiyama.

If the mountain shape were regarded as the same as in the case of Fig. 2, where the altitude and radius are 800 *m* and 5 *km* respectively, the mean dependence of total force intensity upon the height would be shown as in Fig. 7, taking the intensity of magnetization J as a parameter. The result obtained by this survey is shown together by a broken line in Fig. 7. We cannot apply the results of the calculation to the case of Mt. Kamiyama as it is, because the mountain shape used in the calculation does not

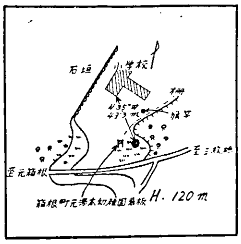
6) T. MINAKAMI, *Bull. Earthq. Res. Inst.*, **18** (1940), 178.

agree with that of Mt. Kamiyama. If the calculation with regard to the mountain of the same shape as Mt. Kamiyama is carried out, the anomaly will become more marked than that in Fig. 7. Therefore it may be said from Fig. 7 that the magnetization of Mt. Kamiyama will never exceed $J=0.02$ *e.m.u./cc*. On the other hand if $J=0.001$ *e.m.u./cc*[7] as is usual with the andesitic rocks, the anomaly at the top does not attain even to a hundred gammas. Even if the correction for the topography is taken into consideration, it seems unlikely that the anomaly reaches such a high value as one thousand gammas, as far as $J=0.001$ *e.m.u./cc* is assumed. It might be said that the magnetization of Mt. Kamiyama is unexpectedly strong for an andesitic volcano.

In order to find geomagnetic changes that might be accompanied by the seismic activity of Hakone Volcano, it is of necessity to repeat the magnetic measurements over Hakone Volcano and to compare the results with that of the survey this time.

Acknowledgments

We express our hearty thanks to Dr. T. Rikitake, under whose direction the present survey was conducted, for his valuable advice and support. We are also grateful for his kind help to Prof. T. Minakami who gave us facilities in performing the measurements. The writers thank the staffs of Kanagawa Prefectural Office and the members of Odawara Branch Office of the Public Work Section, Kanagawa Prefecture, for their cooperation.



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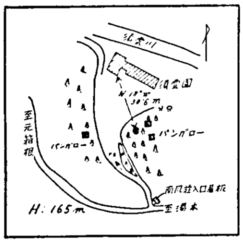

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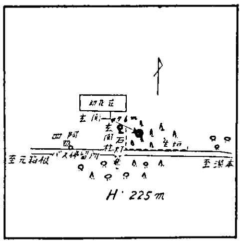
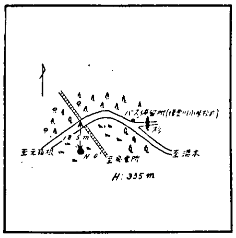


Fig. 8-3. Station No. 3.

7) T. NAGATA, S. AKIMOTO, S. UYEDA, Y. SHIMIZU, M. OZIMA and K. KOBAYASHI, *Phil. Mag. Suppl., Adv. Phys.*, **6** (1957), 225.



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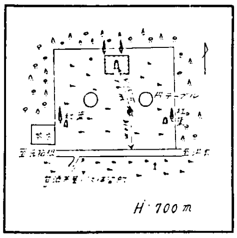

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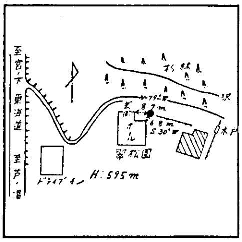

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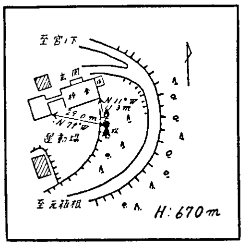

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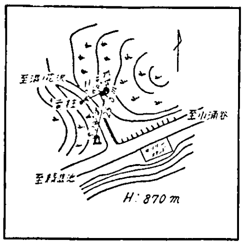

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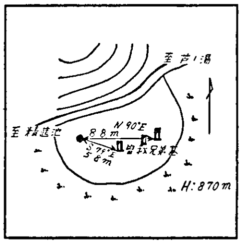

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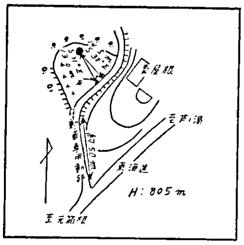

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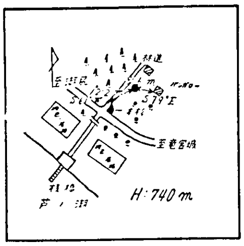

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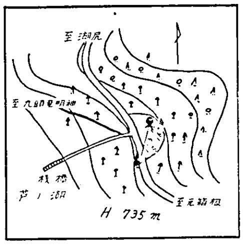

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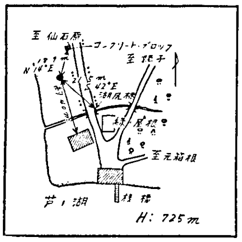

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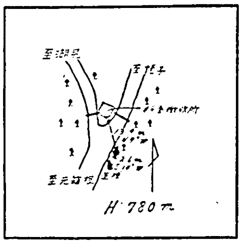

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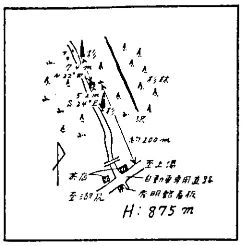

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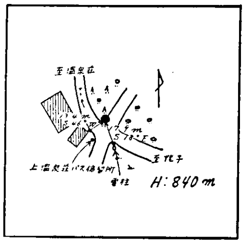

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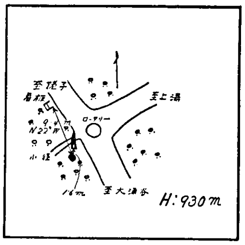

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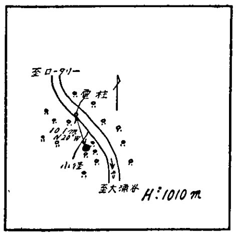

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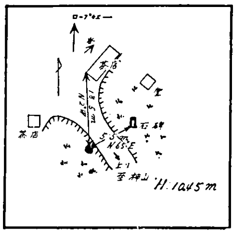

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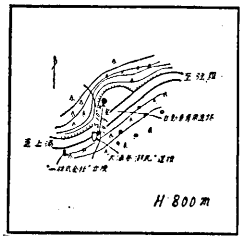

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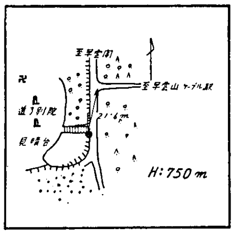

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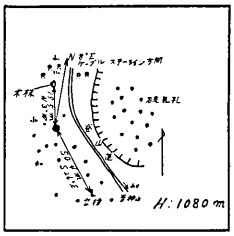

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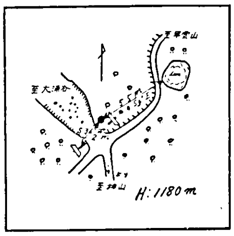

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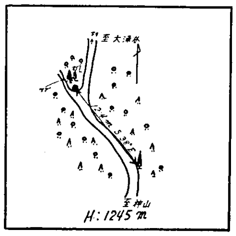


Fig. 8-24. Station No. 24.

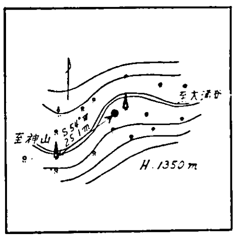


Fig. 8-25. Station No. 25.

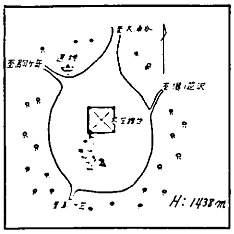


Fig. 8-26. Station No. 26.

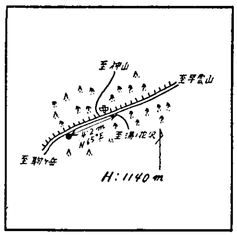


Fig. 8-27. Station No. 27.

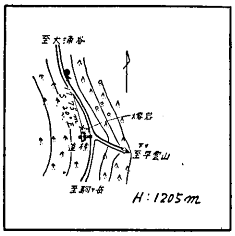
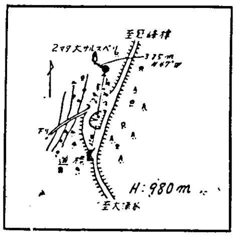


Fig. 8–28. Station No. 28.



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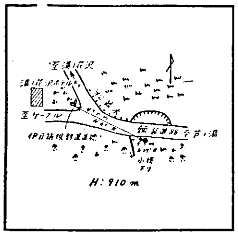

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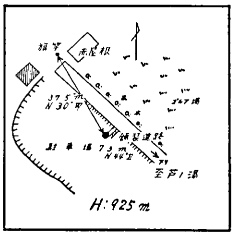

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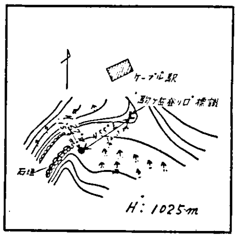

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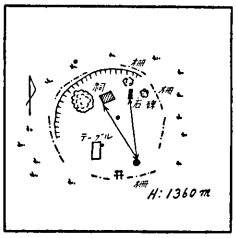

Fig. 8–33. Station No. 33.

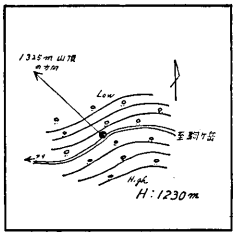

Fig. 8–34. Station No. 34.

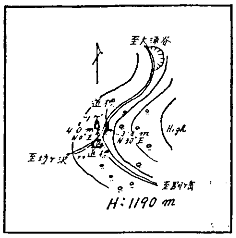

Fig. 8–35. Station No. 35.

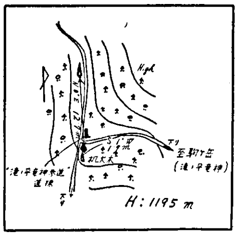

Fig. 8–36. Station No. 36.

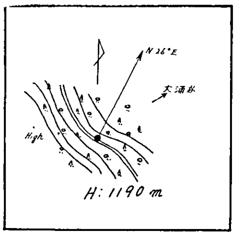

Fig. 8–37. Station No. 37.

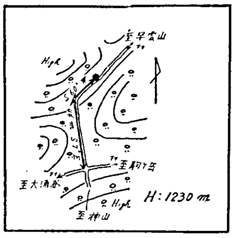

Fig. 8–38. Station No. 38.

4. プロトン磁力計による箱根火山の磁気測量

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1959 年，9 月上旬以来，箱根火山中央火口丘の神山周辺に，有感地震を伴う地震活動が活潑となつた．水上教授によつてカルデラ内の数カ所に設置された地震計は，活動最盛期には，連日 200～300ヶの地震を記録し，活動開始以来 3ヶ月後に至つても，まだその終熄を見ていない．筆者等は，火山活動に伴つて期待される地磁気変化を検出しようと，箱根火山カルデラ内で，10 月 26 日から 29 日までの 4 日間プロトン磁力計を用いて，第 1 回目の磁気測量を行なつた．

火山地域では，火山の構造に関連して，磁気異常が観察される．大島三原山における地磁気偏角の連続観測より，現在では，火山活動と地磁気の変化との間に密接な関係のあることが推定されている．磁気測量を繰り返せば，箱根火山においても，同様のことが期待されるわけである．

使用したプロトン磁力計は，文部省科学試験研究費研究班の試作になるもので，従来の観測所固定用のものを，トランジスターを用いて小型化し，携帯に便利にしたものである．測定は全磁力だけに限られるが，携帯用プロトン磁力計の出現により，地磁気絶対測定が著しく容易になり，短時間内に数多くの測点で測定することが可能になつた．器械の精度については，測量に先立つて，油壺において地磁気変化計の記録と比較し，5γ 以上の誤差はないことが確認された．

測定の結果は，第 1 表，第 3 図に示されている．測定時の地磁気日変化量は，油壺観測所を基準にとつて補正した．火山構造に従がい，最低 45165.3γ から最高 47851.3γ におよぶ全磁力の地域的変動が見出される．また，図から明らかなように，カルデラの中央部は，大きく数ケの異常地域に分けることができる．すなわち，神山周辺の大きな磁気異常によつて特徴附けられる部分，双子山の小さな全磁力によつて特徴附けられる部分，その間の駒ケ岳を中心とする部分，これら中央火口丘によつて区画された領域内に，不規則に分布する，きわめて大きな全磁力を示す斑点状の地域，が存在する．これらの異常は，この地域の地下構造物質の違いにもとずくものであることが，地質図より明瞭に読みとれる．中央火口丘によつて特徴附けられる異常地域は，それぞれの火口より流出した熔岩の帯磁の差によつて形成されたものであるし，斑点状に分布する地域の大きな磁気異常は，富士火山礫および火山灰の帯磁によるものと推定される．

700 m の水準面を基盤として，この地域の磁気異常をみると，神山の如きは，700 m の高さで 1500 γ もの異常を示している．この異常は，神山と同じような安山岩質の火山である浅間山で得られた値の数倍にも達する．地形の影響を考慮しても，神山の帯磁の強さは異常に大きいと考えられる．

第 1 回目の測量結果は，概略以上の通りである．今回のような測量を繰り返すことによつて，箱根火山においても，活動の消長に伴う磁気変化が明らかになるものと期待される．

今回の測量に当つて，終始，適切な指導と支持を頂いた，力武博士に感謝するとともに，種々の便宜を計らい，折にふれて助言を与えられた，水上教授に深く謝意を表わす次第である．なお，現地での測量に際しては，神奈川県庁ならびに小田原土木出張所の諸氏の御好意，御尽力に負うところがきわめて多いことを附記して，関係各位に御礼を申し上げたい．