7. *Some Physical Properties of the Lavas of Volcanoes Asama and Mihara. II. Magnetic Susceptibility.*

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1. Introduction.

In his previous paper,[1] the writer gave the results of his experimental studies on the electric conductivity and the temperature effects of the lavas ejected from volcanoes Asama and Mihara. The results of these studies seem to be of help in interpreting the variations in earth-current,[2] which is closely related to the volcanic activities of these mountains. On the other hand, magnetic surveys and continuous observations of geomagnetic variations having been carried out recently on a number of active volcanoes, a knowledge of the magnetic properties of lava, lapilli, and ash ejected from a particular volcano becomes neccessary in making further studies of these variations. As mentioned frequently in the writer's paper,[3] Mts. Asama and Mihara being the most active volcanoes in Japan, a magnetic survey of the former is being made by T. Minakami,[4] and that of the latter by R. Takahasi and the writer.[5] The values of the magnetic susceptibility of the ejecta of these volcanoes and the remanent magnetism in them may be important in interpreting the results of the magnetic surveys. The magnetic properties of the rocks composing the volcanoes may also be related to the magnetic local variations accompanying the activity of these volcanoes.[6] In order to study the problems of the magnetic changes in connection with volcanic and seismic activities,[7] the importance of all these in geophysics is appreciated by many geophysicist, especially in Japan, so

1) T. NAGATA, *Bull. Earthq. Res. Inst.*, **15** (1937), 663.
2) T. MINAKAMI, *Bull. Earthq. Res. Inst.*, **13** (1935), 629.
3) T. NAGATA, *Bull. Earthq. Res. Inst.*, **16** (1939), 93.
4) T. MINAKAMI, *Bull. Earthq. Res. Inst.*, **16** (1938), 100.
5) R. TAKAHASI and T. NAGATA, *Bull. Earthq. Res. Inst.*, **15** (1937), 443.
6) T. NAGATA, *Zisin*, **10** (1938), 221. (in Japanese); T. MINAKAMI, *Zisin*, **11** (1939). (in Japanese).
7) Y. KATO, *Journ. Coll. Sci. Tôhoku Imp. Univ.*, **27**, (1938), 1.

that a knowledge of the magnetic properties of the earth's crust is indispensable. At present, we have a number of papers on the magnetism of igneous and sedimentary rocks, many comprehensive studies by J. G. Koenigsberger,[8] the fruitful results obtained by C. Maurain,[9] R. Chevallier,[10] É. Thellier[11] and their colleagues, works replete with suggestions by M. Matuyama[12] and by S. Nakamua,[13] and the recent interesting works of É. Thellier,[14] A. G. McNish,[15] Y. Kato,[16] and others. On the values of magnetic susceptibility, numerous data have been obtained, chiefly with the object of interpreting the results of magnetic prospectng.

The writer, however, presents here the results of his studies on the magnetic susceptibility of rocks ejected from Vocanoes Asama and Mihara, the results thus far being discussed as much as possible from the chemical and petrological points of view. He hopes that it will contribute to our knowledges of the magnetic properties of rocks, especially in connexion with the geomagnetic studies of these two volcanoes.

2. Instruments.

The instrument used in the present experiments for measuring the values of magnetic susceptibility in various external magnetic fields, was a modified Stschodro[17] type ballistic method instrument, a general view of which is shown in Fig. 1 (Plate 1). The details of the instrument are as follows;

The field coil is a cylindrical solenoid, 100 *cm* long and 7·0 *cm* in diameter, the magnetic field in the centre of the coil being 12·58 *Gauss* for a current of one *Ampere* through the solenoid.

The secondary coil is also a cylindrical solenoid, which is set coaxially with the primary coil (field coil), 14·8 *cm* long, 3·23 *cm*, and

8) J. G. KÖNIGSBERGER, *Beitr. Angew. Geophys.* **4** (1932) 385; **5** (1935), 193. *Terr. Mag.*, **34** (1927), 207; **35** (1930), 145. and others Resumé of his works was publisbed in *Terr. Mag.*, **43** (1938), 119~299.

9) CH. MAURAIN, *Journ. d. Phys.*, **5~10** (1901), 123; **4~1** (1920), 90.

10) R. CHEVALLIER, *C. R. Acad. Sci.*, **180** (1925), 1473; **144** (1932), 1468.

11) É. THELLIER, *C. R. Acad. Sci.*, **197** (1933), 232; 1399.

12) M. MATUYAMA, *Proc. Imp. Acad. Japan.* **5** (1932), 113.

13) S. NAKAMURA and S. KIKUCHI, *Proc. Phys. Math. Soc. Japan.* **6** (1929) 268.

14) É. THELLIER, *Ann. d. Phys. Globc.* **16** (1938), 156.

15) A. G. MCNISH and F. A. JOHNSON, *Terr. Mag.*, **43** (1938), 417.

16) Y. KATO, *Joum. Coll. Sci. Tôhoku Imp. Univ.*, **27** (1938), 93.

17) N. STSCHODRO, *Gerl. Beitr. Geophys.* **17** (1927), 148.

4·45 *cm* in inner and outer diameters, the number of total turns of the coil being 31200, the electric resistance of which is about 6·5 *kilo ohms.*

The sensitivity of the instrument depends on both the number of total turns of the secondary coil and the sensitivity of the ballistic galvanometer, and also on the resistance in the electric circuit. As shown in Fig. 2, a ballistic type galvanometer, 10^{-11} current sensitivity, was used in its aperiodic state. To prevent leakage of electric charge, all parts of the instrument were perfectly insulated, and the outer side of the insulating materials sufficiently shielded electrically in order to eliminate errors due to accumulation of electro-static charge.

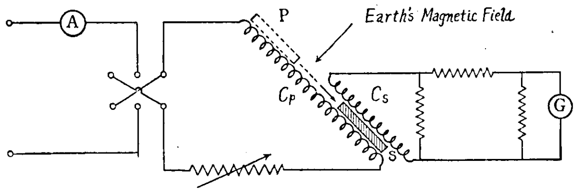

Fig. 2. Instrument for measuring magnetic susceptibility.
(Ballistic method.)
Cp: Primary coil (Field coil).
Cs: Secondery coil.
S: Specimen.

The sample to be examined slides down from the position P on the axis of the primary coil, by which a uniform magnetic field is produced, into the secondary coil within the short time of 0·5 *sec.*, whereupon the ballistic galvanometer deflects in proportion to the total electric charge induced in the secondary-coil circuit. The reverse operation for measurement consists in suddenly pulling up the sample, the galvanometer deflecting in the opposite direction to the first operation. The arithmetical mean values of these two deflection readings were adopted as the reading of one measurement, three or five measurements forming a set of observations. Thus magnetization J, or the apparent magnetic susceptibility κ of the specimen can be calculated, putting the observed values of the deflection θ in the formula,

$$\theta = Cs\kappa H = CsJ, \tag{1}$$

where κ, J, H, s, C are respectively the magnetic susceptibility and intensity of magnetization of the specimen, the intensity of the magnetic field, the area of cross section of the specimen, and a constant determined by the number of total turns of the secondary coil, the electric resistance in the secondary-coil circuit, and the characterisity of the galvanometer. Here, the intensity of the magnetic field in the secondary coil is given by

$$H_{ex}=\frac{2\pi nI}{10}\left(\frac{L_1}{\sqrt{L_1^2+\rho^2}}+\frac{L_2}{\sqrt{L_2^2+\rho^2}}\right)\text{ Gauss/Ampere}, \qquad (2)$$

where H_{ex}, n, I, L_1, L_2, and ρ are respectively the intensity of the external magnetic field supplied from the primary coil, the number of turns of the coil per one *cm*, intensity of the electric current, the lengths between the centre of the secondary coil and the two ends of the primary solenoid, and the radius of the coil. Since, in the present case, $L_1=72{\cdot}6$ cm, $L_2=27{\cdot}4$ cm, $\rho=3{\cdot}50$ cm, and $n=10{\cdot}05$,

$$H=12{\cdot}56\,I\ \text{(Gauss/Ampere)}. \qquad (2')$$

Although the value of C can be calculated theoretically, it can also be determined experimentally with the aid of the relation

$$C=4\pi C',\quad C'=\frac{\theta_0}{H_0 s_0}, \qquad (3)$$

where θ_0 and s_0 are respectively the deflection of the galvanometer when the external magnetic field H_0 is produced suddenly, and the effective cross section of the secondary-coil. Here, s_0 is given by

$$s_0=\frac{\pi}{3}(r_1^2+r_2^2+r_1r_2), \qquad (4)$$

where r_1 and r_2 are the inner and outer radii of the secondary coil. In the present instrument,

$$C'=27{\cdot}26\ \text{(mm/Gauss. cm)},\quad C=342{\cdot}4\ \text{(mm/Gauss. cm)},$$

provided the length of the optical lever of the galvanometer is taken as 105·0 *cm*. In order to eliminate the effects of the earth's magnetic field, two coaxial solenoids were so set that the axes of the solenoids were perpendicular to the direction of the earth's magnetic field; actually, the component of the earth's magnetic force in the direction of the axes is smaller than 0·005 *Gauss*. With the aid of this instrument it is possible to observe the hysteresis phenomenon in the magnetizing process of volcanic rocks.

Another instrument for measuring the magnetic susceptibility in an extremely small magnetic field was constructed. It was on the alternating magnetic field principle, in which the small induced voltage is magnified considerably with the aid of a "resistance-coupling" bulb amplifier. A general view of the instrument and its electric connexion is shown in Fig. 3 (Plate 2), and in Fig. 4. The details of the instrument are as follows;

The alternating electric current supply was from an ordinary A.C. source of 50 cycles or from a low frequency electric oscillator, the same

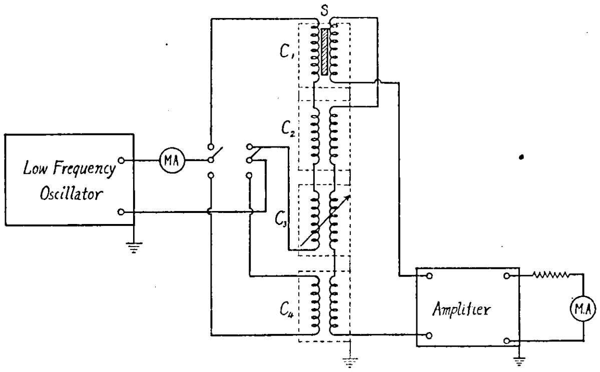

Fig. 4. Schematic representation of the instrument for measuring the magnetic susceptiblity of rocks, by means of the alternating magnetic-field method.

C_1: Induction coil.
C_2: Constant part of compensating coil.
C_3: Variable part of compensating coil.
C_4: Check-coil.
S: Speciemen.

apparatus as used in Iida's experiment.[18] In the case of the oscillator, the frequency of oscillation was kept at 50 cycles ($\pm 1\%$) throughout the experiment.

An induction coil and a compensating coil were constructed as similarly as possible in all their parts. Their primary coils were cylindrical solenoids 22·0 *cm* long, 4·5 *cm* in diameter, the intensity of the magnetic field in the centre of them being 12·50 *Gauss* per Ampere current through the coils. The secondary coils, 3·4 *cm* in their mean diameter, which was set coaxially with the primary coil, consisted of cylindrical solenoids of 9850 turns.

The check-coil, which was used for checking the sensitivity of the whole measuring system, was a mutual induction coil, the primary part of which was nearly the same as that of the induction coil, while the number of total turns of the secondary part, 2·88 *cm* in diameter, was exactly 80. In order to eliminate external electro-magnetic disturbances, all the coils just mentioned were perfectly shielded electrically.

18) K. IIDA, *Bull. Earthq. Res. Inst.* **17** (1939), 79.

The amplifier was designed as a low frequency voltage amplifier, the magnifying ratio for a frequency of 50 cycles in its stable condition being about 11000. The amplifier too was perfectly shielded against electro-magnetic disturbances. As the electric resistance between the grid and filament in the first bulb of the amplifier was large (about $2\,K\Omega$), it may be safe to assume that the induced voltage in the secondary circuit of the measuring system had a very small load, negligible in the case of approximate calculations. Hence, if v_1 and v_2 denote the induced voltage in the induction and compensating coils respectively, we get

$$\left.\begin{aligned} v_1 &= -\frac{4\pi n N_1}{10} s_1 C_1 \omega I_0 \cos\omega t - \frac{16\pi^2 N_1 n}{10} s_0 C_1 \omega \kappa I_0 \cos\omega t, \\ v_2 &= +\frac{4\pi n N_2}{10} s_2 C_2 \omega I_0 \cos\omega t, \end{aligned}\right\} \tag{5}$$

and

$$V = v_1 + v_2\ , \tag{6}$$

where

$N_1,\ N_2$ = Number of total turns of the secondary solenoids of the induction and compensating coils.

$C_1,\ C_2$ = Constants depending only on the geometrical shape of the solenoids.

$n,$ = Number of turns per cm in the primary coils.

$s_1,\ s_2$ = Areas of cross section of the secondary coils.

s_0 = Area of cross section of specimen.

I_0 = Peak intensity of electric current through the primary coils.

ω = Frequency of alternating current.

As N_2 was adjusted to

$$N_2 = \frac{s_1 C_1}{s_2 C_2} \tag{7}$$

that is, $V=0$, when $\kappa=0$, we get

$$V = -\frac{16\pi^2 N_1}{10} \omega s_0 C_1 x I_0 \cos\omega t. \tag{8}$$

The total induced voltage (V) is put into the amplifier, the voltage of output V_0 then becoming

$$V_0 = K \cdot V, \tag{9}$$

where K is the magnifying constant of the amplifier, whereas the induced voltage in the secondary part of the check-coil is

$$V_c = -\frac{4\pi n N_c}{10} s_c C \omega I_c \cos \omega t\,, \tag{10}$$

and, if V_c is put into the amplifier, the out-put voltage is given by

$$V_{0,\,c} = K \cdot V_c. \tag{11}$$

Hence, if we adjust the intensity of the electric current I_c to

$$V_{0,\,c} = V_0,$$

then

$$I_c = 4\pi \frac{N_1 C_1 s_0}{N_c C s_c} I_0 \kappa. \tag{12}$$

In the present calculations, we may take $C_1 = C \fallingdotseq 1$ and

$$\frac{4\pi n I_0}{10} = H_0,$$

provided we neglect a small error of the order of 0·1 percent. From these conditions, we get

$$I_c = \frac{4\pi N_1 s_0}{N_c s_c} I_0 \kappa = \frac{10 N_1 s_0}{n N_c s_c} J_0,$$

where J_0 is the intensity of magnetization of the specimen.

Since, in the present instrument, $N_1 = 9850$, $N_c = 80$, $S_c = 6{\cdot}52\ \mathrm{cm}^2$, and $n = 10{\cdot}05$, we get

$$I_c = 112{\cdot}6 \frac{s_0}{s_c} J_0 = 18{\cdot}81 s_0 J_0. \tag{13}$$

By representing the above mentioned relation in terms of the effective values of the alternating current, namely, $\bar{I} = \overline{I_0 \cos \omega t} = \frac{I_0}{\sqrt{2}}$, etc., we get

$$\left. \begin{aligned} X &= 4{\cdot}218 \frac{\bar{I}_c}{\bar{I} s_0} \times 10^{-3}, \quad \bar{H} = 12{\cdot}61 \bar{I}, \\ J &= 5{\cdot}316 \frac{\bar{I}_c}{s_0}. \end{aligned} \right\} \tag{14}$$

By means of these formulae, we obtain the values of the intensity of magnetization or the magnetic susceptibility from the observed values of $\overline{I}_c$ and $\overline{I}$.

3. The specimens.

The samples to be measured were pulverized, the mean diameter of the small grains ranging between 0·1 *mm* and 0·2 *mm*. Since the mean diameter of the ferromagnetic minerals, magnetite, pyrrhotite, ilmenite, hematite, etc., contained in these rocks was usually smaller than those of the particles, judging from the microscopic observations of these samples, the crystal construction of these minerals may probably be intact. A cylindrical tube of bakelite, 16·1 *cm* in length and 1·90 *cm* in diameter, was filled with these particles. The magnitude of the demagnetizing factor at the centre of the tube was 0·250, whereas if the cylindrical tube was replaced by a rotational ellipsoid of suitable dimensions, the factor was 0·318. The intensity of the effective magnetizing field H can therefore be taken equal to that of the external field H_{ex}, provided we neglect an error of the order of 0·1 percent, for the magnetic susceptibility of the rocks examined in the present study were smaller than 3×10^{-3} C. G. S. The number of samples examined in the present study was sixteen, of which ten were the ejecta of Asama and the remainder those of Mihara. The six samples of Asama ejecta were the same as those already studied petrologically by H. Tsuya,[19] who calssified these six rocks as follows.

No. 1 Kurohu-yama lava (Locality. Southern foot of Mt. Kurohu, somma of Mt. Asama), Olivine-bearing two-pyroxene-andesite.

No. 2 Yunotaira lava (An older lava of Maekakeyama crater), Olivine-bearing two-pyroxene-andesite.

No. 3 Tenmei lava (Lava flow, Onino-osidasi), Olivine-bearing hypersthene-augite-andesite.

No. 4 One of the bread-crust bombs ejected in Sept. 1929. Olivine-bearing hypersthene-augite-andesite.

No. 5 Mugen-no-tani obsidian (Lava of Mugen volcano) Hornblende-two-pyroxene-andesite.

No. 6 Ko-asama-yama lava (Ko-asama lava dome), Hornblende-two-pyroxene-andesite.

19) H. TSUYA, *Bull. Earthq. Res. Inst.* 9 (1936), 575.

According to Tsuya, the chemical composition of these rocks are as shown in Table. I.

Table I. Bulk compostions of the Asama rocks.

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
SiO_2	58·39	59 67	62·37	60·24	72·01	69·93
Al_2O_3	17·89	16.83	15·90	16·43	14·37	14·12
Fe_2O_3	2·45	1·44	1·14	1·54	0·73	2·45
FeO	5·33	5·51	4·79	5·26	1·81	0·45
MgO	3·30	3·92	3·43	3·92	0·57	0·58
CaO	7·23	7·21	6·13	7·07	2·56	2·42
Na_2O	3·04	2·81	3·20	3·00	4·35	4·04
K_2O	0·71	1·00	1·49	1·16	2·39	2·25
H_2O+	0·36	0·28	0·30	0·17	0·26	2·00
H_2O-	0·12	0·13	0·12	0·06	0 08	0·97
TiO_2	0·71	0·70	0·66	0·70	0·41	0·38
P_2O_5	0·15	0·14	0·13	0·13	0·07	tr.
MnO	0·14	0·12	0·11	0·11	0·08	0·09
Total	99·82	99·76	99·77	99·79	99·69	99.68
Norms Q	15·20	15·92	17·84	15·98	30·39	31·77
Or	4·45	6·12	8·90	6·68	13·91	13·36
Ab	25·69	23·59	27·26	25·17	36·70	24·08
An	32·82	30·22	24·48	28·09	12·79	11·96
C	1·83	3·87	4·12	5·02	—	0·71
Hy	14·19	15·89	13·63	14·66	3·65	1·24
Mt	3·49	2·08	1·62	2·31	1·16	0·23
Hm	—	—	—	—	—	2·24
Ap	0·31	0·31	0·31	0·31	—	tr.
Il	1·37	1·37	1·21	1·37	0·61	0·76

The data obtained by microscopic observation will be shown later. The four other samples, which were ejected in the recent activity of Volcano Asama, are

No. 7 Volcanic lapilli ejected May 28, 1935,

No. 8 Volcanic ash ejected May 22, 1935, No. 9 Volcanic ash ejected May 20, 1935,

No. 10 Volcanic bomb ejected June 6, 1938.

The chemical composition of these rocks should almost be similar to the central-cone ejecta, i.e. samples No. 3 and No. 4. The samples from Volcano Mihara are those collected and studied geochemically by I. Iwasaki,[20] the petrographic characters of which were also studied by him and H. Kuno, and by H. Tsuya,[21] according to whom they are

No. 11 Old lava of Oosima (locality. sea-cliff immediately west of Okata, at the northern end of Oosima Island.)
Hypersthene-bearing olivine-basalt,

No. 12 Old lava of Oosima (same locality as No. 11.)
Aphyric basalt,

No. 13 Somma lava of Oosima (southwestern part of the ring-wall of the somma.)
Hypersthene-bearing olivine-basalt,

No. 14 An'ei lava ejected 1778 (northern foot of Volcano Mihara.)
Hypersthene-bearing basalt,

No. 15 Meizi-Taisyo lava ejected during the active period of 1911～1914 (northwestern part of the floor of the old summit-crater of Volcano Mihara.)
Basalt (Miharaite of S. Tsuboi.[22]).

The chemical composition of these five rocks are shown in Table II.

The other sample (No. 16) is a fragment[23] that was ejected on Aug. 11, 1938, in a minor activity of the volcano. This rock, microscopically, is almost holohyaline, it being impossible to see even the microlites of magnetite, although the chemical composition of this rock ought not to differ much from that of Miharaite (No. 15.)

20) I. Iwasaki, *Journ. Chem. Soc. Japan.* **56** (1935), 1511. (in Japanese).
21) H. Tsuya, *Bull. Earthq. Res. Inst.* **15** (1937), 296.
22) S. Tsuboi, *Journ. Coll. Sci. Tokyo Imp. Univ.*, **43** (1920), Part 6.
23) T. Nagata, *Bull. Earthq. Res. Inst.*, **16** (1938), 714.

Table II. Bulk compositions of the Mihara rocks.

	No. 11	No. 12	No. 13	No. 14	No. 15
SiO_2	48·02	51·25	51·23	52·45	52·53
Al_2O_3	20·48	14·73	15·24	13·48	15·25
Fe_2O_3	2·13	3·82	4·18	4·60	2·69
FeO	7·05	10·22	8·99	10·02	10·57
MgO	5·79	5·47	4·85	4·78	4·54
CaO	14·14	11·73	11·14	10·23	10·76
Na_2O	1·28	1·85	2·19	1·99	1·89
K_2O	0·30	0·26	0·54	0·52	0·43
H_2O_+	n.d.	n.d.	n.d.	n.d.	n.d.
TiO_2	0·78	0·81	0·83	1·39	0·74
P_2C_5	0·01	0·13	0·03	0·33	0·41
MnO	0·26	0 28	0·33	0·31	0·24
BaO	0·01	0·01	0·03	0·03	0·02
S	0·11	0·14	0·10	0·18	0·08
Total	100·363	100·708	99·68	100·319	100·157
Norms Q	0·24	5·41	5·35	9·61	7·87
Or	1·67	1·67	3·34	3·34	2·78
Ab	11·01	15·73	18·35	16·78	15·73
An	49·23	30·88	30·04	26·15	31·99
Wo	8·71	11·03	10·57	9·41	7·78
En	14·46	13·65	12·01	11·95	11·34
Fs	10·42	14·77	12·01	12·80	16·36
Mt	3·01	5·56	6·02	6·71	3·91
Il	1·52	1·52	1·52	2·58	1·37
Ap	tr.	0·33	tr.	0·65	0·99

4. Results of observations.

(1) Susceptibility.

With the ballistic instrument in a stationary magnetic field, the hysteresis phenomenon and the susceptibility of the samples were observed. Since the magnetizing coil could not produce a stationary field larger than 20 Gauss, the results with hysteresis phenomenon ranging from -20 to $+20$ Gauss alone will be reported here. The observed results are shown in Table III, and plotted in Fig. 5 (a)$\sim$(o). The variations in apparent magnetic susceptibility in the initial magnetizing process are shown in Table IV and Fig. 6.

Observations of the hysteresis phenomenon of two samples, namely, No. 6 and No. 16, however, are omitted, because the susceptibility of

Table III (a).

H Gauss	$J\times10^3$					
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
0	0·00	0·00	0·00	0·00	0·00	0·00
1·26	+ 2·60±0·04	+ 1·39±0·03	—	—	—	—
1·88	+ 3·83±0·06	—	+ 1·50±0·05	+ 2·42±0·05	+ 0·67±0·03	0·16±0·01
2·51	+ 5·23±0·03	+ 2·65±0·03	—	—	—	—
3·77	+ 7·81±0·03	+ 3·71±0·05	+ 3·05±0·07	+ 5·56±0·15	+ 1·34±0·02	0·34±0·02
6·28	+13·41±0·10	+ 6·19±0·03	+ 5·09±0·09	+ 8·85±0·17	+ 1·99±0·04	+ 0·57±0·02
8·79	+18·92±0·03	+ 8·69±0·05	+ 7·22±0·05	+12·85±0·14	+ 2·78±0·03	+ 0·79±0·02
11·30	+24·51±0·10	+11·38±0·05	+ 9·45±0·13	+16·40±0·25	+ 3·53±0·02	+ 1·00±0·06
13·82	+30·11±0·09	+13·78±0·06	+11·96±0·15	+20·38±0·13	+ 4·53±0·07	+ 1·20±0·04
16·33	+36·23±0·20	+16·48±0·14	+14·11±0·14	+25·12±0·05	+ 5·25±0·13	+ 1·49±0·03
18·84	+41·80±0·02	+19·01±0·06	+16·16±0·04	+29·74±0·09	+ 6·20±0·04	1·70±0·05
16·33	+36·44±0·02	+16·64±0·03	+14·11±0·04	+25·43±0·21	+ 5·39±0·12	
13·82	+30·95±0·03	+14·41±0·03	+12·25±0·04	+21·77±0·22	+ 4·66±0·02	
11·30	+25·77±0·17	+12·04±0·03	+10·32±0·04	+18·36±0·14	+ 3·74±0·02	
8·79	+20·52±0·02	+ 9·37±0·11	+ 8·29±0·04	+14·90±0·05	+ 3·01±0·12	
6·28	+15·06±0·03	+ 6·98±0·09	+ 6·11±0·09	+10·63±0·05	+ 2·18±0·02	
3·77	+ 9·70±0·02	+ 4·38±0·06	+ 4·00±0·04	+ 7·24±0·13	+ 1·47±0·04	
2·51	+ 6·78±0·02	—	—	+ 5·48±0·09	—	
1·88	—	—	+ 2·40±0·09	—	+ 0·88±0·03	
1·26	+ 4·09±0·09	+ 1·90±0·11	—	+ 3·68±0·05	—	
0	+ 1·49±0·03	+ 0·46±0·08	+ 0·89±0·04	+ 1·58±0·05	+ 0·28±0·06	
− 1·26	− 1·31±0·03	− 0·78±0·05	—	− 0·27±0·09	—	
− 1·88	—	—	− 0·74±0·08	—	− 0·31±0·02	
− 2·51	− 4·15±0·02	—	—	− 1·94±0·05	—	
− 3·77	− 7·14±0·14	− 3·35±0·09	− 2·42±0·05	− 4·19±0·09	− 0·91±0·09	
− 6·28	−12·95±0·03	− 5·88±0·03	− 4·69±0·12	− 7·79±0·13	− 1·57±0·04	
− 8·79	−18·47±0·06	− 8·48±0·09	− 6·87±0·05	−12·13±0·16	− 2·47±0·02	
−11·30	−24·20±0·03	−11·03±0·09	− 9·05±0·05	−15·48±0·05	− 3·43±0·02	
−13·82	−29·92±0·02	−13·64±0·09	−11·50±0·04	−19·51±0·13	− 4·22±0·03	
−16·33	−35·66±0·12	−15·93±0·09	−13·67±0·05	−23·59±0·17	− 4·94±0·02	
−18·84	−41·43±0·02	−18·52±0·09	−15·88±0·11	−29·32±0·13	− 5·99±0·02	
−16·33	−36·41±0·03	−16·72±0·14	−14·01±0·05	−25·01±0·11	− 5·13±0·02	
−13·82	−31·05±0·07	−14·27±0·13	−12·04±0·05	−21·80±0·10	− 4·36±0·02	
−11·30	−25·83±0·14	−11·98±0·09	−10·16±0·05	−18·04±0·07	− 3·57±0·02	
− 8·79	−20·50±0·07	− 9·32±0·11	− 8·03±0·05	−14·11±0·12	− 2·96±0·02	
− 6·28	−15·11±0·02	− 6·90±0·09	− 5·96±0·10	−10·71±0·05	− 2·13±0·02	
− 3·79	− 9·61±0·02	− 4·42±0·11	− 3·82±0·05	− 6·92±0·05	− 1·44±0·03	
− 2·51	− 6·77±0·02	—	—	—	—	

(to be continued.)

Table III (a). (*continued.*)

H Gauss	$J\times10^3$					
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
− 1·88	—	—	− 2·29±0·05	− 3.95±0·06	− 0·88±0·03	
− 1·26	− 4·07±0·03	− 1·79±0·03	—	—	—	
0	− 1·47±0·04	− 0·51±0·06	− 0·84±0·05	− 1·53±0·06	− 0·03±0·03	
+ 1·26	+ 1·42±0·06	+ 0·79±0·03	—	—	—	
+ 1·58	—	—	+ 0·79±0·04	+ 1·39±0·06	+ 0·34±0·04	
+ 2·51	+ 4·31±0·02	—	—	—	—	
+ 3·79	+ 7·16±0·03	+ 3·35±0·13	+ 2·48±0·05	+ 3·90±0·05	+ 0·96±0·02	
+ 6·28	+12·85±0·03	+ 6·00±0·16	+ 4·74±0·75	+ 8·34±0·09	+ 1·75±0·07	
+ 8·79	+18·51±0·06	+ 8·72±0·09	+ 6·98±0·74	+12·09±0·11	+ 2·60±0·04	
+11·30	+24·18±0·04	+11·25±0·03	+ 9·05±0·14	+16·01±0·04	+ 3·50±0·10	
+13·82	+29·84±0·08	+13·78±0·14	+11·50±0·07	+19·75±0·17	+ 4·25±0·02	
+16·33	+35·69±0·03	+16·43±0·05	+13·79±0·07	+23·78±0·18	+ 5·04±0·07	
+18·84	+41·20±0·13	+18·96±0·11	+15·88±0·11	+28·31±0·09	+ 6·05±0·02	

Table III (b).

H Gauss	$J\times10^3$				
	No. 11	No. 12	No. 13	No. 14	No. 15
0	0·00	0·00	− 0·06±0·02	− 0·07±0·04	− 0·02±0·02
+ 0·63	—	+ 0·35±0·03	+ 1·83±0·04	+ 1·62±0·02	+ 1·06±0·04
+ 1·26	+ 0·80±0·03	+ 0·72±0·03	+ 3·79±0·04	+ 3·33±0·02	+ 2·24±0·02
+ 2·51	+ 1·63±0·02	+ 1·60±0·04	+ 7·83±0·03	+ 7·29±0·02	+ 4·81±0·04
+ 3·77	+ 2·42±0·02	+ 2·48±0·04	+12·08±0·06	+11·66±0·08	+ 7·60±0·06
+ 5·02	+ 3·19±0·07	+ 3·61±0·05	+16·46±0·06	+16·51±0·06	+10·61±0·03
+ 6·28	+ 4·00±0·04	+ 4·58±0·06	+20·70±0·03	+21·37±0·03	+13·52±0·06
+ 7·54	+ 4·86±0·02	+ 5·75±0·06	+25·05±0·02	+26·24±0·04	+16·58±0·07
+ 8·79	+ 5·67±0·03	+ 6·96±0·04	+29·61±0·03	+31·36±0·07	+19·67±0·03
+11.30	+ 7·31±0·07	+ 9·26±0·06	+38·93±0·03	+42·05±0·02	+26·04±0·02
+13·82	+ 9·01±0·02	+ 6·08±0·04	+48·17±0·02	+52·86±0·02	+32·60±0·03
+16·33	+10·66±0·03	+14·59±0·07	+57·56±0·06	+64·05±0·02	+93·47±0·04
+18·84	+12·38±0·02	+17·55±0·06	+67·07±0·04	+75·58±0·06	+46·30±0·02
+16·33	+10·97±0·02	+15·99±0·06	+60·08±0·09	+69·34±0·06	+41·95±0·02
+13·82	+ 9·42±0·07	+14·14±0·06	+52·24±0·09	+61·26±0·03	+36·75±0·06
+11·30	+ 7·85±0·02	+12·13±0·04	+44·08±0·07	+52·72±0·02	+31·39±0·02
+ 8·79	+ 6·21±0·02	+10·00±0·07	+36·08±0·04	+43·64±0·04	+25·77±0·02
+ 6·28	+ 4·65±0·02	+ 7·76±0·07	+27·88±0·06	+34·42±0·09	+20·17±0·04
+ 3·77	+ 2·97±0·02	+ 5·62±0·04	+19·18±0·02	+24·51±0·07	+14·29±0·02

(*to be continued.*)

Table III (b). (*continued.*)

H Gauss	$J\times10^3$				
	No. 11	No. 12	No. 13	No. 14	No. 15
+ 2·51	+ 2·18±0·02	+ 4·39±0·05	+14·86±0·02	+19·54±0·02	+ 4·39±0·05
+ 1·26	+ 1·42±0·02	+ 3·22±0·05	+10·48±0.02	+14·61±0·02	+ 3·22±0·05
0	+ 0·64±0·02	+ 1·99±0·04	+ 6·03±0·03	+ 9·48±0·02	+ 1·99±0·04
− 1·26	− 0·24±0·02	+ 0·68±0·05	+ 1·68±0·04	+ 4·46±0·04	+ 0·68±0·05
− 2·51	− 1·06±0·02	− 0·53±0·04	− 2·80±0·02	− 0·43±0·06	− 0·53±0·04
− 3·77	− 1·96±0·02	− 1·56±0·06	− 7·14±0·02	− 5·49±0·02	− 1·56±0·06
− 6·28	− 3·69±0·04	− 3·65±0·10	−16·56±0·06	−16·09±0·06	− 3·65±0·10
− 8·79	− 5·33±0·06	− 5·95±0·06	−25·78±0·02	−26·90±0·04	− 5·95±0·06
−11·30	− 7·06±0·03	− 8·35±0·04	−35·33±0·03	−37·85±0·03	− 8·35±0·04
−13·82	− 8·78±0·02	−11·08±0·04	−44·91±0·07	−48·98±0·07	−11·08±0·04
−16·33	−10·38±0·02	−13·94±0·05	−54·83±0·02	−60·89±0·04	−13·94±0·05
−18·84	−12·28±0·06	−16·97±0·04	−64·86±0·04	−72·51±0·07	−16·97±0·04
−16·33	−10·74±0·02	−15·37±0·04	−57·32±0·02	−65·58±0·08	−15·37±0·04
−13·82	− 9·14±0·02	−13·61±0·15	−49·46±0·02	−57·87±0·08	−13·61±0·15
−11·30	− 7·52±0·03	−11·47±0·04	−41·87±0·03	−49·44±0·03	−11·47±0·04
− 8·79	− 5·95±0·02	− 9·52±0·04	−33·68±0·17	−40·35±0·09	−23·71±0 02
− 6·28	− 4·36±0·02	− 7·16±0·04	−25·29±0·10	−31·05±0·03	−18·11±0·02
− 3·77	− 2·76±0·02	− 4·78±0·03	−16·61±0·04	−21·27±0·03	−12·15±0·03
− 2·51	− 1·94±0·02	− 3·67±0·04	−12·33±0·06	−16·38±0·03	− 9·19±0·02
− 1·26	− 1·15±0·02	− 2·78±0·07	− 8·06±0·06	−11·43±0·03	− 6·11±0·04
0	− 0·34±0·04	− 1·31±0·04	− 3·68±0·02	− 6·37±0·06	− 3·04±0·03
+ 1·26	+ 0·49±0·04	− 0·10±0·03	+ 0·74±0·02	− 1·39±0·03	0·00±0·03
+ 2·51	+ 1·32±0·04	+ 1·17±0·04	+ 5·08±0·06	+ 3·52±0·02	+ 2·99±0·03
+ 3·77	+ 2·13±0·04	+ 2·15±0·04	+ 9·15±0·02	+ 8·67±0·04	+ 6·03±0·02
+ 6·28	+ 3·83±0·02	+ 4·35±0·04	+18·80±0·07	+19·03±0·06	+12·29±0·02
+ 8·79	+ 5·51±0·03	+ 6·79±0·04	+27·71±0·03	+29·32±0·08	+18·49±0·03
+11·30	+ 7·13±0·02	+ 9·17±0·06	+36·82±0·07	+39·99±0·04	+24·72±0·03
+13·82	+ 8·81±0·03	+11·74±0·12	+46·04±0·02	+50·34±0·08	+31·19±0·06
+16·23	+10·49±0·02	+14·59±0·04	+55·24±0·03	+61·51±0·08	+37·60±0·03
+18·84	+12·23±0·03	+17·26±0·04	+64·65±0·03	+72·48±0·02	+44·17±0·06

Table III (c).

H Gauss	$J\times10^3$				
	No. 7	No. 8	No. 9	No. 10	No. 16
0	0·00	0·00	0·00	0·00	0·00
+ 1·26	—	—	—	+ 0·96±0·04	—

(*to be continued.*)

Table III (c). (*continued.*)

H Gauss	$J\times10^3$				
	No. 7	No. 8	No. 9	No. 10	No. 16
+ 1·88	+ 1·57±0·04	+ 1·60±0·03	+ 1·55±0·03	—	+ 0·27±0·02
+ 2·51	—	—	—	+ 2·14±0·04	—
+ 3·77	+ 3·19±0·07	+ 3·24±0·10	+ 3·33±0·06	+ 3·42±0·02	+ 0·47±0·04
+ 6·28	+ 5·43±0·02	+ 5·38±0·04	+ 5·28±0·03	+ 6·15±0·08	+ 0·84±0·05
+ 8·79	+ 7·86±0·06	+ 7·65±0·03	+ 7·79±0·03	+ 8·73±0·02	+ 1·18±0·05
+11·30	+ 9·94±0·10	+ 9·91±0·03	+10·00±0·03	+11·67±0·06	+ 1·48±0·03
+13·82	+12·67±0·23	+12·62±0·07	+12·41±0·07	+14·54±0·02	+ 1·78±0·04
+16.33	+14·76±0·06	+14·76±0·06	+14·88±0·03	+17·43±0·04	+ 2·14±0·05
+18·84	+17·79±0·14	+17·58±0·10	+17·23±0·03	+20·31±0·04	+ 2·42±0·07
+16·33	+15·84±0·15	+15·38±0·03	+15·21±0·08	+18·25±0·02	
+13·82	+13·87±0·11	+13·36±0·03	+13·41±0·14	+15·79±0·02	
+11·30	+11·88±0·10	+11·05±0·08	+11·13±0·14	+13·32±0·06	
+ 8·79	+ 9·51±0·16	+ 8·75±0·03	+ 8·83±0·06	+10·76±0·03	
+ 6·28	+ 7·14±0·21	+ 6·59±0·10	+ 6·57±0·11	+ 8·11±0·04	
+ 3·77	+ 4·69±0·13	+ 4·33±0·03	+ 4·30±0·04	+ 5·48±0·02	
+ 2·51	—	—	—	+ 4·07±0·03	
+ 1·88	+ 2·94±0·03	+ 2·65±0·04	+ 2·55±0·04	—	
+ 1·26	—	—	—	+ 2·75±0·02	
0	+ 1·16±0·03	+ 0·95±0·03	+ 0·95±0·03	+ 1·44±0·03	
− 1·26	—	—	—	− 0·10±0·03	
− 1·88	− 0·74±0·03	− 0·82±0·07	− 0·65±0·06	—	
− 2·51	—	—	—	− 1·31±0·02	
− 3·77	− 2·68±0·03	− 2·57±0·03	− 2·45±0·04	− 2·70±0·02	
− 6·28	− 4·76±0·04	− 4·79±0·02	− 4·81±0·06	− 5·61±0·02	
− 8·79	− 7·14±0·14	− 7·39±0·06	− 7·34±0·04	− 8·32±0·02	
−11·30	− 9·82±0·08	− 9·84±0·03	− 9·68±0·03	−11·33±0·03	
−13·82	−12·65±0·16	−12·31±0·03	−12·24±0·04	−14·21±0·02	
−16·32	−15·35±0·07	−14·85±0·06	−14·83±0·03	−17·20±0·03	
−18·84	−17·66±0·10	−17·23±0·19	−17·02±0·04	−20·03±0·03	
−16·32	−16·07±0·10	−15·52±0·06	−15·17±0·03	−18·06±0·06	
−13 82	−13·82±0·09	−13·49±0·13	−13·01±0·06	−15·60±0·02	
−11·30	−11·69±0·10	−11·05±0·08	−11·00±0·04	−13·08±0·03	
− 8·79	− 9·35±0·12	− 8·93±0·06	− 8·81±0·03	−10·43±0·04	
− 6·28	− 6·93±0·03	− 6·66±0·03	− 6·64±0·03	− 7·98±0·07	
− 3·79	− 4·65±0·03	− 4·33±0·03	− 4·38±0·03	− 5·23±0·06	
− 2·51	—	—	—	− 3·89±0·04	
− 1·88	− 2·86±0·06	− 2·63±0·03	− 2·55±0·06	—	
− 1·26	—	—	—	− 2·65±0·06	

(*to be continued.*)

Table III (c). (*continued.*)

H Gauss	$J\times10^3$				
	No. 7	No. 8	No. 9	No. 10	No. 16
0	− 1·11±0·08	− 0·91±0·03	− 0·91±0·06	− 1·24±0·03	
+ 1·26	—	—	—	− 0·21±0·03	
+ 1·88	+ 0·74±0·04	+ 0·85±0·09	+ 0·72±0·03	—	
+ 2·51	—	—	—	+ 1·51±0·04	
+ 3·77	+ 2·65±0·04	+ 2·66±0·03	+ 2·52±0·03	+ 2·85±0·06	
+ 6·28	+ 5·08±0·03	+ 5·05±0·09	+ 4·96±0·06	+ 5·87±0·07	
+ 8·79	+ 7·54±0·04	+ 7·50±0·04	+ 7·52±0·03	+ 8·58±0·02	
+11·30	+10·01±0·01	+ 9·75±0·10	+ 9·79±0·03	+11·36±0·06	
+13·81	+12·65±0·62	+12·43±0·06	+12·34±0·08	+14·80±0·06	
+16·33	+15·14±0·04	+14·78±0·03	+14·86±0·04	+17·20±0·03	
+18·84	+17·97±0·07	+17·38±0·04	+17·08±0·04	+20·05±0·06	

these rocks were so small that accurate measurement could not be made with the apparatus at our command.

While the specific susceptibilities in weak fields obtained with the aid of the alternating field method, are also shown in Table V and plotted in Fig. 7, the minimum and maximum values and the value at the earth's magnetic field (0·45 Gauss) of the specific susceptibility

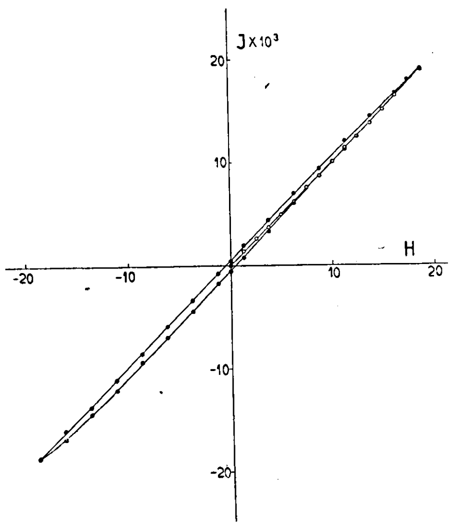

Fig. 5 (a).
Magnetization curve.
No. 1. Kurohu-yama lava, Asama.

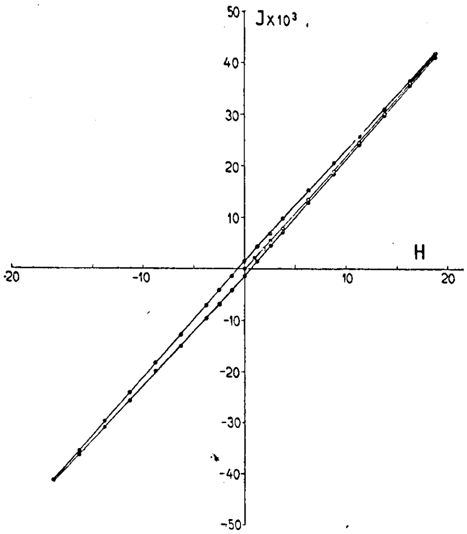

Fig. 5 (b).
No. 2. Yuno-taira lava, Asama.

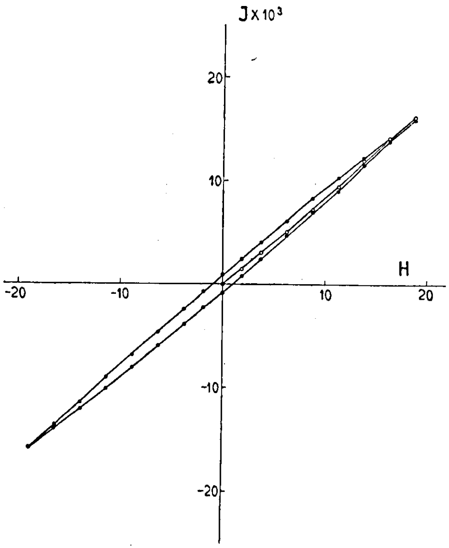

Fig. 5 (c).
No. 3. Temmei lava, Asama.

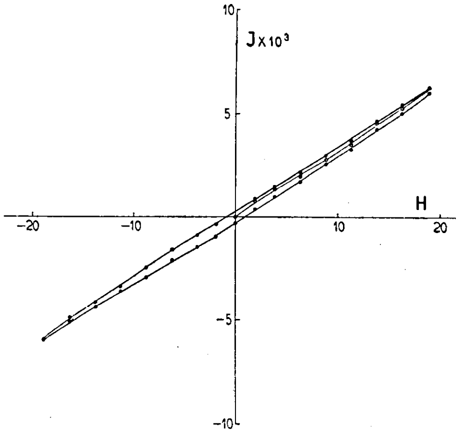

Fig. 5 (e).
No. 5. Mugen-no-tani obsidian, Asama.

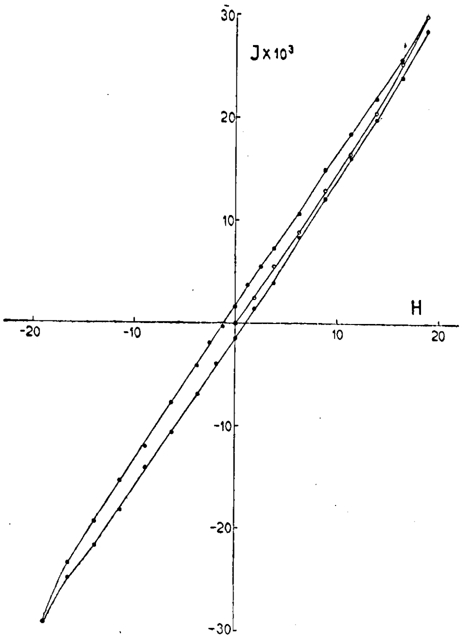

Fig. 5 (d).
No. 4. Bread-crust bomb ejected in Sept. 1929. Asama.

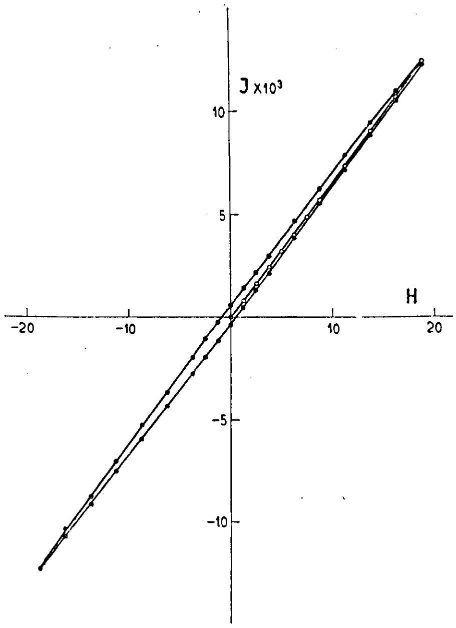

Fig. 5 (f).
No. 11. Old lava of Oosima I.

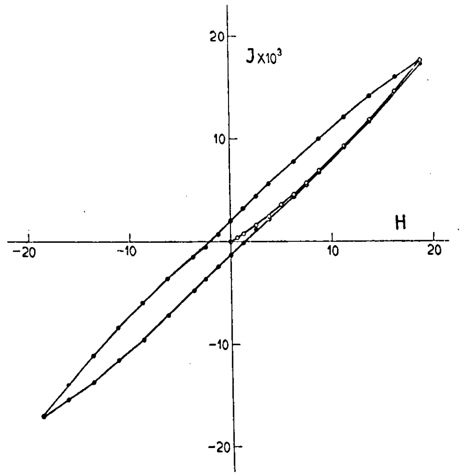

Fig. 5 (g).
No. 12. Old-lava of Oosima. II

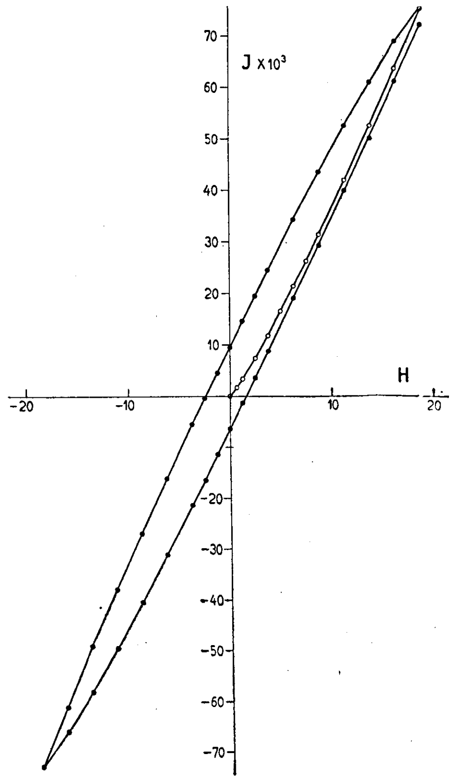

Fig. 5 (i).
No. 14. An'ei lava, Oosima.

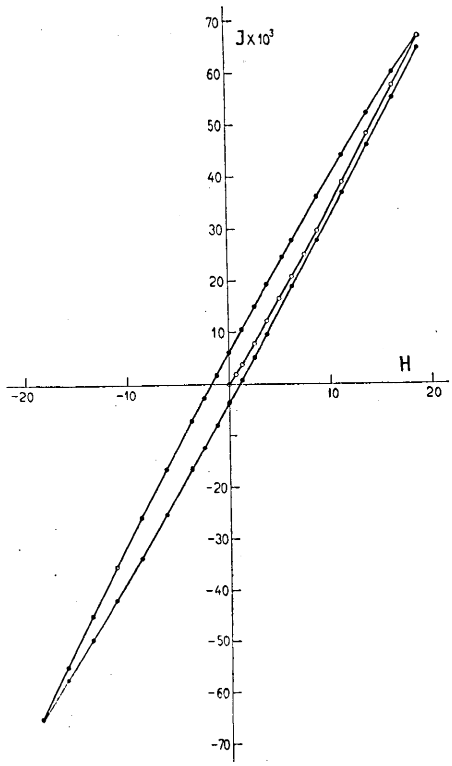

Fig. 5 (h).
No. 13. Somma lava of Oosima.

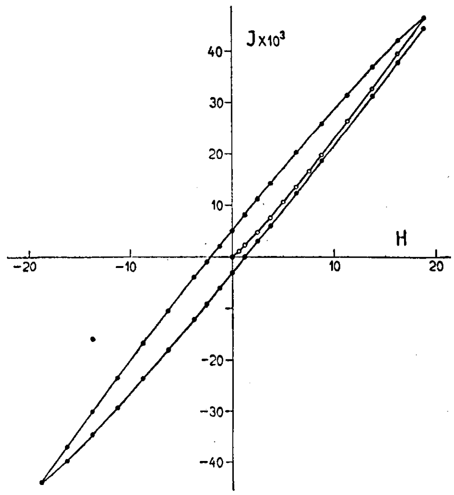

Fig. 5 (j).
No. 15. Meizi-Taisyo lava, Oosima.

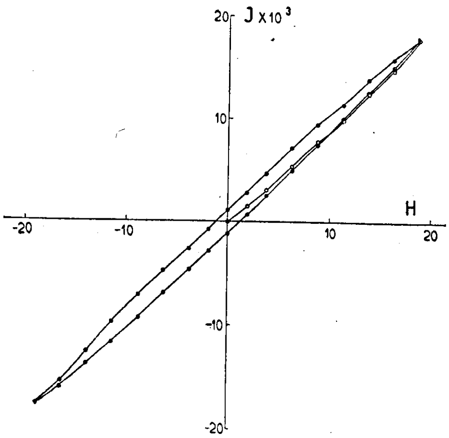

Fig. 5 (k).
No. 7. Lapilli (ejected, May 28, 1935), Asama.

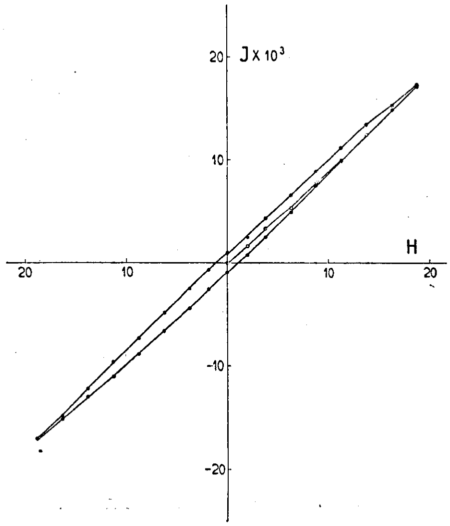

Fig. 5 (m).
No. 9. Ash (ejected, May 22, 1935), Asama.

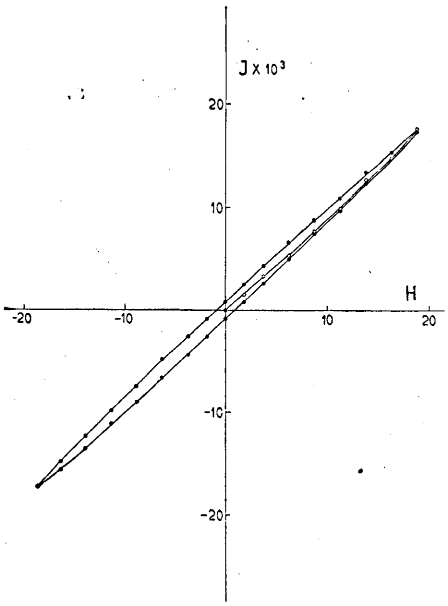

Fig. 5 (l).
No. 8. Ash (ejected, May 20, 1935), Asama.

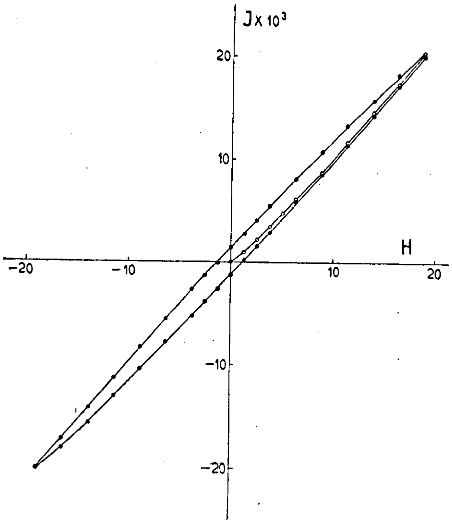

Fig. 5 (n).
No. 10. Bomb (ejected, June 6, 1938), Asama.

of each sample are given in Table VI, where the amounts of Fe_2O_3, FeO, and TiO_2, and of the norms of magnetite and ilmenite are also shown once more.

Generally speaking, the more the amount of magnetite or of Fe_2O_3, the larger the specific susceptibility. Assuming that susceptibility χ

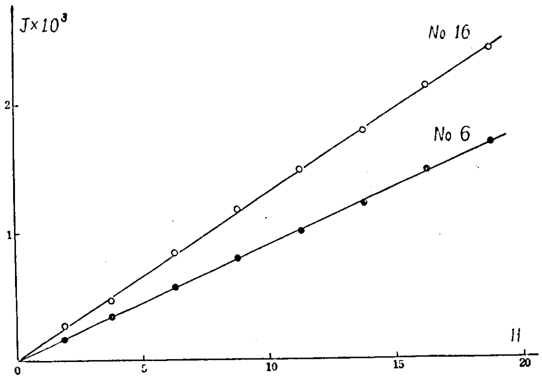

Fig. 5 (o).
Magnetization curves.
No. 6. Ko-Asama lava, Asama.
No. 16. Fragment, (ejected, Aug. 11. 1438), Oosima.

is proportinal to the normative amount of magnetite C_{Mt}, it is possible to establish the relation

$$\chi_{H=0\cdot45} = (2\cdot6 \pm 0\cdot7) \times 10^{-2} C_{Mt}, \qquad (1)$$

as shown in Fig. 8. Sample No. 12, however, deviates widely from this relation, while in the others it holds within an error of 25 per-cent, whence it follows that the amounts of ferromagnetic minerals

Table IV (a). Specific susceptibilities of the Asama rocks.

H Gauss	J×10³					
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
1·89	1·18	0·57	0·58	0·84	0·169	0·064
3·77	1·21	0·57	0·59	0·88	0·182	0·068
6·28	1·24	0·57	0·59	0·92	0·176	0·070
8·79	1·25	0·58	0·60	0·95	0·176	0·070
11·30	1·26	0·59	0·61	0·95	0·175	0·069
13·82	1·27	0·58	0·63	0·97	0·183	0·068
16·33	1·28	0·59	0·64	1·00	0·183	0·070
18·84	1·29	0·59	0·63	1·03	0·184	0·071

Table IV (b). Specific susceptibilities of the Mihara rocks.

H Gauss	$\chi \times 10^3$				
	No. 11	No. 12	No. 13	No. 14	No. 15
0·63	—	0·33	1·80	1·42	0·96
1·26	0·40	0·34	1·86	1·46	1·101
2·51	0·40	0·38	1·92	1·60	1·11
3·77	0·40	0·39	1·97	1·72	1·14
5·02	0·39	0·42	2·02	1·81	1·19
6·28	0·39	0·43	2·03	1·88	1·21
7·54	0·40	0·45	2·05	1·92	1·24
8·79	0·40	0·47	2·08	1·97	1·26
11·30	0·40	0·49	2·12	2·05	1·30
13·82	0·40	0·51	2·15	2·11	1·34
16·33	0·40	0·53	2·17	2·16	1·37
18·84	0·41	0·56	2·19	2·21	1·39

Table IV (c). Specific susceptibilities of the new ejecta of Volcanoes Asama and Mihara.

H Gauss	$J \times 10^3$				
	No. 7	No. 8	No. 9	No. 10	No. 16
1·26	—	—	—	0·48	—
1·88	0·50	0·52	0·50	—	0·112
2·51	—	—	—	0·54	—
3·77	0·50	0·53	0·51	0·57	0·112
5·02	—	—	—	0·60	—
6·28	0·51	0·53	0·53	0·61	0·114
7·84	—	—	—	0·61	—
8·79	0·53	0·54	0·55	0·63	0·115
11·30	0·52	0·54	0·56	0·65	0·112
13·82	0·54	0·56	0·56	0·66	0·112
16·33	0·54	0·56	0·57	0·67	0·114
18·84	0·56	0·57	0·59	0·68	0·115

namely, magnetite and ilmenite, in norms, which are calculated from the data of chemical composition, do not exactly agree with the amounts of ferromagnetic minerals that are actually contained in the

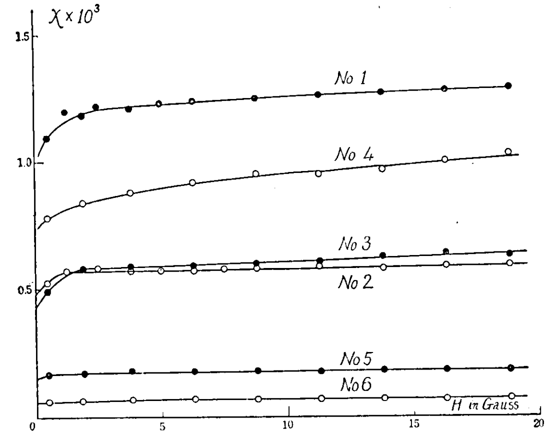

Fig. 6 (a).

Specific susceptibility of Asama lava.

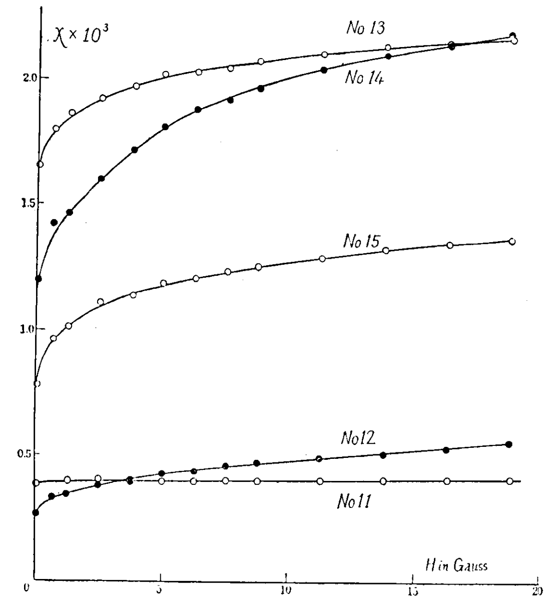

Fig. 6 (b).

Specific susceptibility of Mihara lava.

rocks, i. e. the modes of magnetite, pyrrhotite, ilmenite, hematite, "titanomagnetite," etc. Notwithstanding these circumstances, it may be said that, in many cases, the amount of magnetite as calculated from the chemical compositions, can be taken as a measure of the value of the magnetic susceptibility of rocks, provided we do not concern ourselves with their exact values.

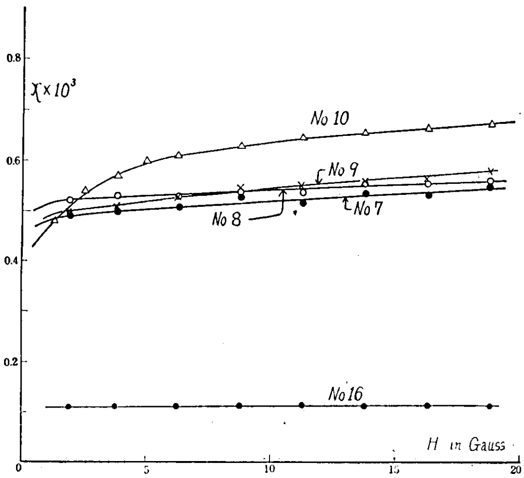

Fig. 6 (c).
Specific susceptibility of new ejecta of Asama.

Table V. Specific susceptibilities of the Asama and Mihara rocks at weak magnetic field.

H Gauss	$\chi \times 10^3$										
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 11	No. 12	No. 13	No. 14	No. 15
0·06	0·94	0·48	0·44	—	0·15	—	0·38	0·26	1·65	1·10	0·78
0·13	0·95	0·49	0·46	0·72	0·16	0·058	0·38	0·26	1·65	1·14	0·83
0·19	1·01	0·50	0·47	0·76	0·16	—	—	0·26	1·70	1·21	0·86
0·25	1·10	0·50	0·46	0·75	0·15	0·057	0·39	0·26	1·71	1·22	0·88
0·31	1·05	0·50	0·46	0·77	0·15	0·060	—	0·27	1·73	1·27	0·91
0·38	1·06	0·51	0·47	0·74	0·16	0·060	0·40	0·28	1·75	1·25	0·89
0·44	1·05	0·52	0·49	0·78	0·16	0·061	0·40	0·28	1·76	1·35	0·90
0·50	1·09	0·52	0·49	0·78	0·17	0·061	0·41	0·29	1·83	1·36	0·91
0·57	1·11	0·54	0·51	0·78	0·17	0·060	—	0·29	1·84	1·35	0·90
0·63	1·11	0·55	0·52	0·80	0·17	0·062	0·40	0·30	1·85	1·37	0·92
0·69	—	0·56	0·54	0·81	0·17	0·062	—	0·31	—	—	—
0·75	1·11	0·55	0·55	0·82	0·18	0·064	0·40	0·33	1·85	1·38	0·92
0·88	1·11	—	—	—	—	—	—	—	1·85	1·39	0·94
1·01	1·13	—	—	—	—	—	0·41	—	1·89	1·42	0·92
1·26	1·16	—	—	—	—	—	0·40	—	—	1·43	0·98

The deviations in the values of the susceptibility from the standard value given by eq. (1) will now be discussed. From the results shown in Fig. 6, we get the relation

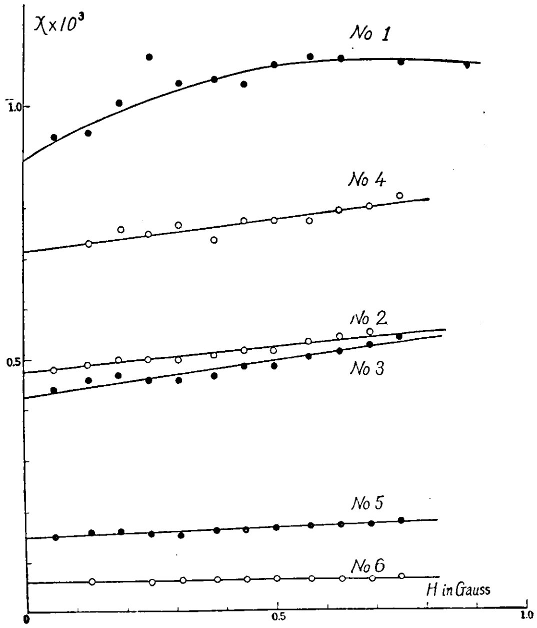

Fig. 7 (a).
Specific susceptibility of Asama lava in a weak magnetic field.

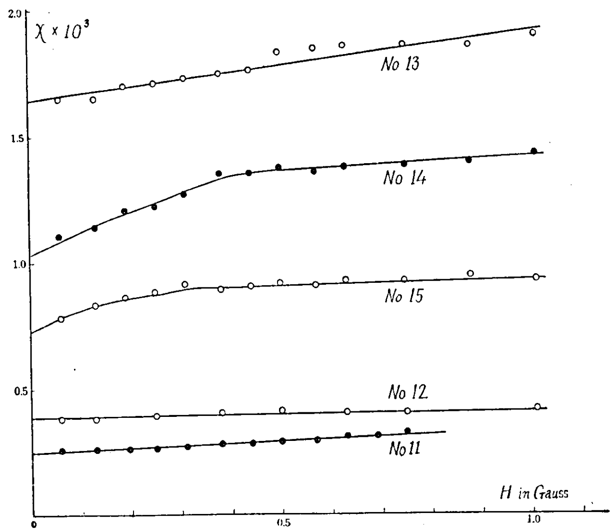

Fig. 7 (b).
Specific susceptibility of Mihara lava in a weak magnetic field.

Table VI.

No of Samples	$\chi_{min.}$	$\chi_{max.}$	$\chi_{0.45}$	Fe_2O_3	FeO	TiO_2	Mt	Il
1	0.94×10^{-3}	1.29×10^{-3}	1.05×10^{-3}	2.45%	5.33%	0.71%	3.49%	1.37%
2	0.48	0.59	0.52	1.44	5.51	0.70	2.08	1.37
3	0.44	0.63	0.49	1.14	4.79	0.66	1.62	1.21
4	0.71	1.03	0.78	1.54	5.26	0.70	2.31	1.37
5	0.15	0.184	0.16	0.73	1.81	0.41	1.16	0.61
6	0.058	0.071	0.061	2.45	0.45	0.38	0.23	0.76
11	0.38	0.41	0.40	2.13	7.05	0.78	3.01	1.52
12	0.26	0.56	0.28	3.82	10.22	0.81	5.56	1.52
13	1.65	2.19	1.76	4.18	8.99	0.83	6.02	1.52
14	1.10	2.21	1.35	4.80	10.02	1.39	6.71	2.58
15	0.78	1.39	0.90	2.69	10.57	0.74	3.91	1.37

$$\chi_{H=0.45} \leqq 3.40\times10^{-2} C_{Mt} ,$$

or

$$\frac{K_{H=0.45}}{\rho} \leqq 3.40\times10^{-2}\frac{\rho_0}{\rho}\, p \qquad (2)$$

where p, ρ, and ρ_0 are respectively the volume percentages of magnetite in rocks, the densities of the rocks and magnetite. Putting $\rho_0=5.2$,[24] we get

$$K_{H=0.45} \leqq 0.177p \qquad (3)$$

As may be expected from our present studies, eq (3) gives the largest susceptibility. On the other hand, it is possible to calculate theoretically the magnitude of the macroscopic susceptibility of rocks containing many microcrystals of ferromagnetic minerals uniformly distributed in nonmagnetic substances, as shown in the following examples.

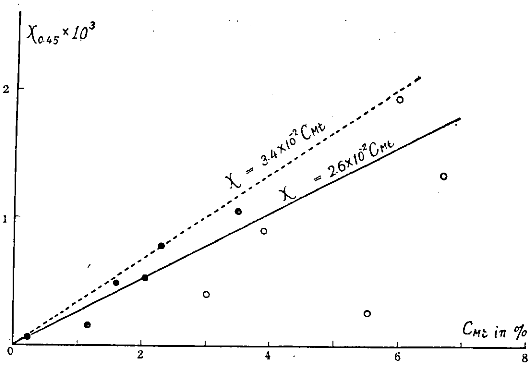

Fig. 8. Relation between specific susceptibility in the earth magnetic field and amount of magnetite in norm.

With the aid of the analogy in an electro static-problem, we assume that the effective magnetic field $\mathfrak{H}_e$ in a cavity in a magnetic medium,

24) The density of magnetite is 5.2 ± 0.2, even when it contains a small percentage of impurities.

the susceptibility of which is K, is given by

$$\mathfrak{H}_e=\mathfrak{H}+\nu\mathfrak{J}, \quad \mathfrak{J}=K\mathfrak{H} \tag{3}$$

where $\mathfrak{J}$ and ν are the intensities of magnetization of the medium, the demagnetizing factor depending only on the geometrical shape of the cavity. If the cavity is a sphere, then $\nu=4\pi/3$, as is well known from the theory of electric polarization.

If $\mathfrak{H}_i$, $\mathfrak{J}_i$, K_0, and λ denote respectively the effective magnetic fields, the intensity of magnetization, the magnetic susceptibility, and the demagnetizing factor of the small ferromagnetic minerals, we get

$$\mathfrak{H}_i=\mathfrak{H}_e-\lambda\mathfrak{J}_i, \quad \mathfrak{J}_i=K_0\mathfrak{H}_i. \tag{4}$$

Assuming that the volume content of the ferromagnetic mineral is p, i.e.

$$\mathfrak{J}=p\mathfrak{J}_i \tag{5}$$

we get from eqs. (1) and (2)

$$K=\frac{pK_0}{1+(\lambda-\nu p)K_0}. \tag{6}$$

This relation is nearly the same as that obtained by R. Chevallier,[25] while the special case, where $\nu=\lambda$ in eq. (6), agrees with Ollendorff's formula,[26] which was fully discussed by J. G. Koenigsberger[27] in many actual examples, and in the more special case in which $\nu=0$ and $\lambda=4\pi/3$, as given by Y. Kato.[28]

Comparing eq. (6) with eq. (3), we take the equation

$$K=\frac{pK_0}{1+\lambda K_0} \tag{7}$$

as an empirical formula for the maximum value of the macroscopic susceptibility of the rocks that contain many small phenocrysts of magnetite, assuming that $p\nu\simeq\frac{4\pi}{3}p\leqslant\lambda$ and K_0 is not large compared with unity. Then substituting the numerical values in eq. (3) into eq. (7), we obtain

$$K_a=\frac{K}{p}=\frac{K_0}{1+\lambda K_0}=0{\cdot}177\,, \tag{8}$$

where K_a was defined as the "apparent susceptibility of a ferromagnetic

25) R. CHEVALLER, *C. R. Acad. Sci.*, **194** (1932), 1468.
26) F. OLLENDORFF, *Archiv. f. Elec. Tech.*, **25** (1931), 436.
27) J. G. KOENIGSBERGER, *Beitr. Angew. Geophys.*, **4** (1932), 385.
28) Y. KATO, *Jour. Coll. Sci. Tohoku Imp. Univ.*, **27** (1938), 97.

mineral." Taking 2·8–3·4 for the value of λ in eq. (8), for magnetite, 0·25 mm mean diameter, which was determined by Koenigsberger[29] experimentally, we get

$$K_0 = 0{\cdot}35 \sim 0{\cdot}44.$$

These values of K_a and K_0 seem to be somewhat smaller than those of pure magnetite, the K_a and K_0 of which are 0·20∼0·28 and 1·3∼5·0 respectively. We may conclude, therefore, that the magnetite in the volcanic rocks of Mts. Asama and Mihara contain more or less TiO_2, Fe_2O_3, and FeO as a solid solution, or as "titanomagnetite" or "maghematite" containing Fe_2O_3 in the crystal lattices of magnetite, seeing that the susceptibility of these minerals are smaller than that of pure magnetite.

Table VII. The Values of apparent susceptibilities of magnetites in the Asama and Mihara rocks.

No. of samples	$K_a = K/p$	No. of samples	$K_a = K/p$
1	0·156	11	0·069
2	0·130	12	0·026
3	0·157	13	0·152
4	0·157	14	0·104
5	0·072	15	0·119
6	0·138		

In Table VII, the magnitude of K_a of each sample is given, while these values are plotted in Fig. 9 as functions of ratios Fe_2O_3 : FeO : TiO_3 in the numbers of molecules, in which we can see a regularity in the correlation between the value of K_a and the ratios Fe_2O_3 : FeO : TiO_2. A quantitative description of this relation, however, will be attempted after we get a large number of these data.

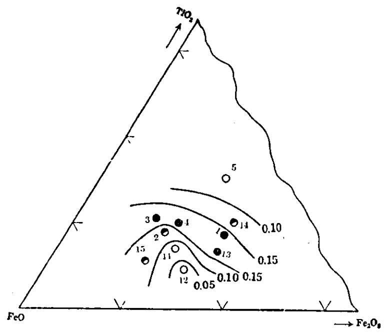

Fig. 9. Relation between apparent susceptibility of ferromagnetic minerals. K_a and Fe_2O_3: FeO: TiO_2 ratios in the rocks.

From microscopic observations, H. Tsuya[30] determined volumetrically the quantities of phenocrysts in the rocks of Asama. According to him, the volume percentage of magnetite

29) J. G. KÖNIGSBERGER, *loc. cit.*
30) H. TSUYA, *loc. cit.*

present as phenocrysts in these rocks are as those given in Table VIII, where the mean diameters of magnetite[31] are also shown. Here, the

Table VIII.

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Vol. percentage of phenocrysts of magnetites	1·13%	0·61	0·68	0·64	0·56	0·56
Size of magnetites	0·08～ 0·10 mm	0·08～ 0·30 mm	0·10～ 0·15 mm	0·08～ 0·10 mm	0·05～ 0·10 mm 0·02× 0·05 mm	0·02× 0·05 mm

amounts of magnetite in samples Nos. 1, 2, 3, and 4 are those of phenocrysts, the magnetite contained in the groundmass being omitted, while the values of Nos. 5 and 6 are almost the total amounts of magnetite in the rocks. The sizes of the magnetite in the rocks of Mihara are generally very small, namely, 0·02 mm or less, in mean diameter.

As is well known, the size and shape of ferromagnetic minerals are closely related to the magnitude of K_a, in eq. (6). Generally speaking, the larger the size of the minerals, the larger the magnitude of K_a. This tendency can also be seen in our results; that is, the K_a of samples Nos. 1, 2, 3, and 4, which containing phenocrysts of magnetite, about 0·10～0·15 mm in mean diameter, is larger than the mean value of K_a of all the samples, while the K_a of the others, namely, magnetite that are smaller than 0·05 mm, are usually smaller than the mean value, although it seems that in sample No. 13 this relation does not hold.

(2) Remanent magnetization and increase of susceptibility accompanying increase in the external magnetic field in the initial magnetizing process.

In Table IX and Fig. 4, is shown the increase in apparent magnetic susceptibility accompanying the increase in intensity of the external magnetic field. A conspicuous change in the specific susceptibility will be seen, for example, in the case of sample No. 14 (Mihara, An'ei lava flow), the χ of which at 18·84 Gauss is about twice that at 0·06 Gauss, while the χ of No. 11 (Mihara, Old lava I) changes but little, only 8 percent, in the range of from 0·1 to 18·84 Gauss. In order to show

31) The writer alone is responsible for the values of the mean diameters of micro-magnetites.

the increase quantitatively, we take a quantity given by $(\chi_{18 \cdot 8}-\chi_{1 \cdot 3})/\chi_{18 \cdot 8} \equiv R_{\chi}$ as a measure of the rate of increase in specific susceptibility, where $\chi_{18 \cdot 8}$ is the maximum value of χ for each sample in the range of magnetic field used in the present experiment, while $\chi_{1 \cdot 3}$ is a value almost the same as the minimum, the numerical value of which is reliable to within an error of one percent. The actual values of R_{χ} are given in Table IX.

The hysteresis curves shown in Fig. 3 are not complete, as they are hysteresis loops only in the region of a magnetic field of from -20 to $+20$ Gausses, where the magnetization in the rocks is not yet saturated. They are, however, also characteristic curves as a measure of the "hardness" in the magnetization of natural rocks. The intensity of the remanent magnetization[32] J_r, which was obtained when H was reduced from 18·84 Gauss to zero, the ratio $J_r/J_{1 \cdot 3}$, and the coersive force[32] H_c are also given in Table IX. It may be expected that the value of $J_r/J_{1 \cdot 3}$ would be closely related to the quantity R_{χ}. Actually, there is a linear relation between these two quantities, as shown in Fig. 10, from the results shown in which we get, approximately,

$$J_r/J_{1 \cdot 3}=0{\cdot}65+6{\cdot}2R_{\chi} \quad \text{for Mihara,}$$

$$J_r/J_{1 \cdot 3}=0{\cdot}36+4.0R_{\chi} \quad \text{for Asama.}$$

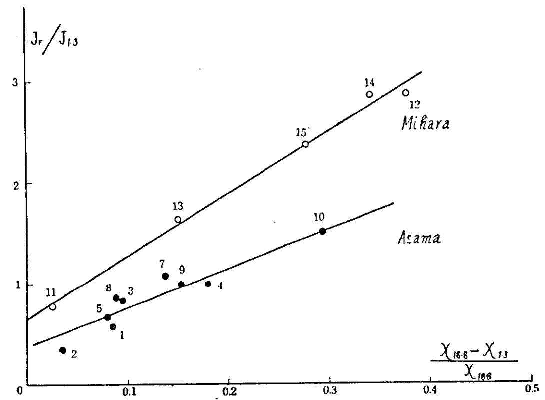

Fig. 10. Relation between intensity of remanent magnetization and rate of increase of specific susceptibility in the initial magnetizing process.

It is an interesting fact that the numerical values of the correlation factors in the two volcanoes differ,[33] although there is a linear relation between the $J_r/J_{1 \cdot 3}$ and the R_{χ} of the ejecta of one volcano, which fact may point to the existence of a magnetic property common to rocks that have differentiated from

32) "Remanent magnetization" and "coersive force" in this paper are defined, at present, respectively, as the quantities in the present incomplete hysteresis loops corresponding to the intensity of the remanent magnetization and coersive force in the usual perfect hysteresis curves.

33) In the case of the ejecta of Mt. Huzi (8 samples) we obtained

$$J_r/J_{1 \cdot 3}=0{\cdot}18+7{\cdot}3R_{\chi}.$$

This also differs from those in the cases of Asama and Mihara.

one magma, although the cause of this phenomenon is not yet clear at present.

Table IX. Remanent magnetization.

No. of samples	J_r	J_r/J_{13}	H_c	R_χ
1	$1{\cdot}49\times10^{-3}$	0·58	0·67 Gauss	0·086
2	0·46	0·36	0·46	0·035
3	0·89	0·87	1·04	0·095
4	1·58	0·98	1·07	0·180
5	0·28	0·68	0·90	0·082
7	1·16	1·09	1·14	0·127
8	0·95	0·89	1·01	0·088
9	0·95	0·98	1·12	0·152
10	1·44	1·51	1·35	0·295
11	0·64	0·80	0·92	0·026
12	1·99	2.76	1·97	0·381
13	6·08	1·60	1·73	0·152
14	9·48	2·85	2·43	0·340
15	5·13	2·29	2·15	0·277

In order to see the relation between J_r/J_{13} and the chemical composition of the ferromagnetic substances in the rocks, if any, we plotted the values of J_r/J_{13} against the ratios $Fe_2O_3:FeO:TiO_2$ in the numbers of molecules, as shown in Fig. 11, where a regularity is seen in the correlation between these two quantities. Further quantitative discussions of this diagram, however, will be deferred until we are in possession of more data on the magnetic properties of volcanic rocks.

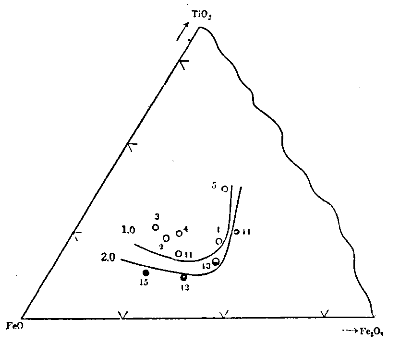

Fig. 11. Relation between remanent magnetizatoin and $Fe_2O_3:FeO:TiO_2$ ratios.

The rate of increase in susceptibility, or the value of $J_r/J_{1\cdot3}$, is related not only to the material composing the ferromagnetic minerals in rocks, but also to the shapes of these microcrystals. The result of microscopic observation now to be mentioned is an interesting phenomenon related to this problem. The micro-crystals of magnetite in sample Nos. 11 and 13, which are mostly $0{\cdot}005\sim0{\cdot}02\,mm^3$, are scattered in the groundmass, while those in Nos. 12, 14, and 15 are connected with one another, five to twenty of them forming the shape of a chain or of a dendritic branch, although the size of the individual crystals is nearly the same as that in No. 11 or 13. On the other hand, the values of R_χ of the former two are clearly smaller than those of the latter three. In the rocks of Asama, (although microscopic observations of Nos. 7, 8, 9, and 10 are lacking at present,), the micro-crystals or phenocrysts of magnetite are scattered and separated from one another, the values of R_χ being also smaller than those of Nos. 12, 14, and 15. It is, however, not clear whether or not the apparent shape of the magnetite and the chemical composition are independent of each other. When we have the quantities of the other paramaters of the magnetic properties of the natural rocks, i. e. the intensity of the true remanent magnetization, the true coersive force, the temperature at Curie-points, the thermo-remanent magnetization, the natural remanent magnetization, and the data of the chemical and mineralogical observations of the ferromagnetic minerals in these rocks, the measurements of which are now being carried out, it is hoped that we shall have a better and more complete view of these phenomena of the magnetic properties of volcanic rocks.

5. Magnetic anomalies and the susceptibility of the rocks.

In his previous paper,[34] the writer reported the regularity in the distribution of the geomagnetic declinations around the craters of Volcanöes Asama and Mihara. From the results of his study, the distributions of declination δ on the ridge of the central cone around the crater were given by

$$\tan\delta = 0{\cdot}031\sin\varphi + 0{\cdot}043\sin 2\varphi \qquad K_A = 0{\cdot}013 \qquad \text{for Mihara,}$$

$$\tan\delta = 0{\cdot}015\sin\varphi + 0{\cdot}017\sin 2\varphi \qquad K_M = 0{\cdot}055 \qquad \text{for Asama,}$$

where φ and K are respectively the azimuthal angle measured clockwise from the magnetic North and the mean value of the apparent magnetic susceptibility of the rocks of the central cone. If we assume that the density of the rocks is, roughly, 2·50, their apparent specific susceptibility will be

$$\chi_M = 5{\cdot}2\times 20^{-3}, \quad \chi_A = 2{\cdot}2\times 10^{-3}.$$

On the other hand, the mean values of the specific susceptibility

34) T. NAGATA, *Bull. Earthq. Res. Inst.*, **16** (1938), 288.

of the central cone ejecta obtained in the present study are $1{\cdot}15\times10^{-3}$[35] and $0{\cdot}77\times10^{-3}$ for the cases of Mihara and Asama respectively. These values are very small compared with those that were expected from the results of magnetic surveys, although it is clear that the values of χ of Asama are smaller than those of Mihara in both experiment and survey, whence it may be that the difference is due to the existence of thermo-remanent magnetization in the rocks composing the central cones of these volcanoes. The values of the natural remanent magnetization of a few samples of central cone ejecta of Mihara seems to warrant this expectation; that is, the mean value of the intensity of the remanent magnetization, which was estimated roughly by means of the usual magnetometer method, is about 2×10^{-2}, while the direction of magnetization coincides with the magnetic North within an error of 10 degrees. The results of more accurate measurement of the remanent magnetization will be reported in the near future.

6. Summary and conclusion.

In the present report, the writer gives only the actual data of magnetic susceptibility of the rocks ejected from Volcanoes Asama and Mihara. This work is a part of the studies on the physical properties of the lava of these two volcanoes, as well as a preliminary study of the magnetic properties of Japanese igneous rocks.

The following facts have been established;

(1) Roughly speaking, the specific susceptibility of rocks is proportional to the amount of magnetite (in norm) in them.

(2) The degree of susceptibility may depend on the chemical composition of the rocks, as well as on the size of the ferromagnetic minerals in them.

(3) The value of susceptibility increases with increase in intensity of the external magnetic field. The rate of increase seems to depend not only on the chemical composition of the rocks, but also on the shape of the ferromagnetic microlites in them.

(4) The intensity of the remanent magnetization is closely related to the rate of change of susceptibility in various magnetic fields. The correlation factor between them seems to be a characteristic quantity of the group of rocks that have differentiated from a common magma.

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35) The mean value of χ at 0·45 Gauss of six samples of the central cone ejecta of Mihara, two of which are Nos. 14, and 15, only the susceptibility in a weak magnetic field of the remaining four weak samples having been measured for the purpose of ascertaining the values of χ.

Since the results given in the present paper are not sufficiently accurate, further quantitative results from a larger number of samples will be reported in the near future. On the other hand, the intensity of remanent magnetization, thermo-remanent magnetization, natural residual magnetization, coercive-force and temperatures of the Curie-point are all significant quantities in the "magnetic analysis" of natural rocks, while the petrographical, mineralogical, and the chemical characters of the rocks and ferromagnetic minerals contained in them are no less important. The results of measurements of these quantities, a part of which is already completed, will be discussed in a forthcoming paper.

In conclusion, the writer wishes to express his cordial thanks to Dr. H. Tsuya, who kindly allowed the writer the use of his samples and the petrographic data obtained by him, as well as for his many valuable advices and suggestions in the course of the present study. The writer's hearty thanks are also due to Dr. I. Iwasaki for his kindness in placing his samples at the writer's disposal, to Dr. H. Kuno for his valuable advices and suggestions from the petrographical point of view, and to Prof. K. Sezawa Dr. C. Tsuboi and Dr. R. Takahasi for their interest and encouragement throughout the present study.

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7. 淺間及三原火山熔岩の物理的性質

II. 帶磁率

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淺間及三原兩火山の代表的岩石の電磁氣的性質に關する實驗的研究の第 2 報告である．本報告では地球磁場の強さ (約 0·45 Gauss) に於ける比帶磁率，及び −20 Gauss から +20 Gauss に至る磁場の強さの範圍での磁氣履歷現象に就いて測定した結果を論ずる．

測定裝置の一つは Stschodro 型の定磁場內彈動測定法の感度を高めたものであつて，此の裝置によつて 10^{-4} 以上の帶磁の強さを 2×10^{-5} の精度で測定し得る．今一つの裝置は交番磁場を用ひて，二次線輪內の誘導電壓を增幅器で擴大する方式であつて 10^{-7} 以上の帶磁の強さを測定し得る．測定した岩石は，淺間山の安山岩 4 種，石英安山岩 2 種，三原山の玄武岩 5 種であつて，之等の岩石は旣に津屋博士，岩崎博士によつて，岩石學的性質や化學成分が充分に知られてゐるものである．其の他に兩火山の最近の噴出物 5 種の測定を行つた．

測定の結果に就いては，次の諸事實が注目される．

(1) 比帶磁率は大體に於いて，その岩石內に含有される磁鐵鑛の量に比例するが，岩石の化學成分から計算した Norm に於ける磁鐵鑛の分量から期待される値より一般に小さい．之は勿論 Norm に於ける磁鐵鑛の分量が Mode のそれと一致しない事や，磁鐵鑛が純粹の狀態で存在する

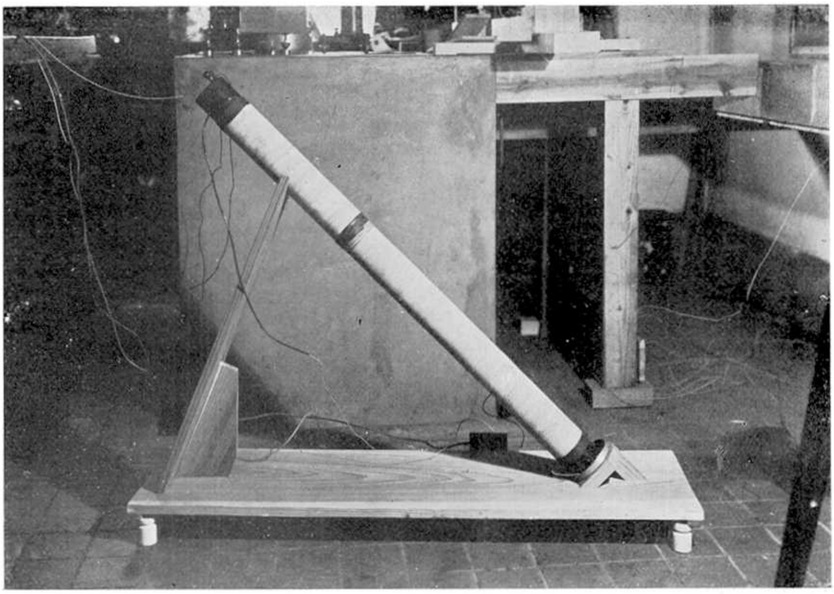

Fig. 1. Apparatus for measuring magnetic susceptibilities of rooks. (Ballistic method in stationary magnetic field.)

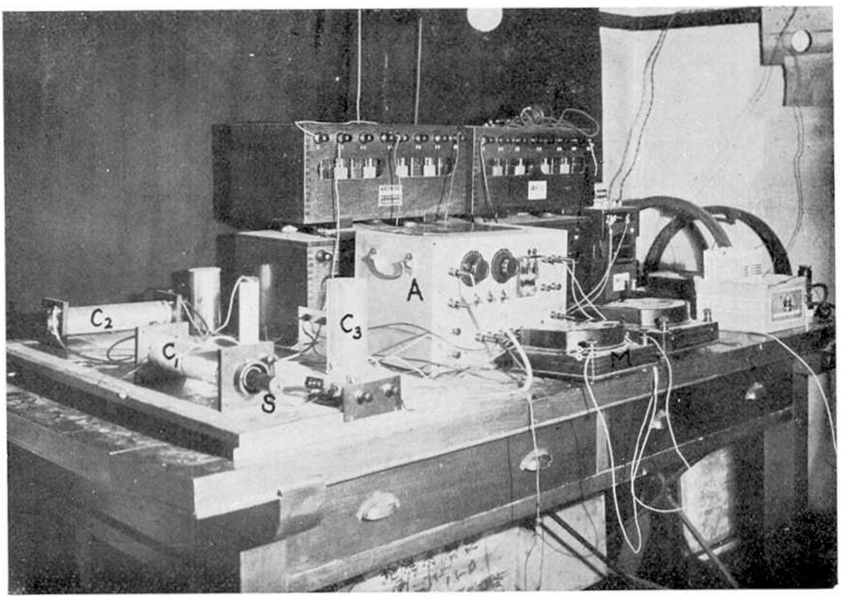

Fig. 3. Apparatus for measuring magnetic susceptibilities of rocks at weak field.

事が少い事等に因るさ思はれるが，我々の場合にも，磁鐵鑛粒の“見かけの帶磁率” K_a さ岩石中の Fe_2O_3 : FeO : TiO_2 の比さの間には一定の關係が在る樣に見える．

(2) K_a の大きさには粒の大きさや形もかなり影響する樣である．即ち粒が小さい程 K_a が小さいさいふ傾向か見られる．

(3) 弱磁場（20 Gauss 以下）に於いても比率磁率が磁場の强さの增加さ共に著しく增加する岩石がある．此の變化が著しい程殘留磁氣の强さが大きいのは當然の事であるが，殘留磁氣さ初期帶磁率さの比 (J_r/K) さ帶磁率の變化度さは，三原山及び淺間山の岩石に於いて，それぞれ異つた直線的關係を有する．この事實は兩火山の岩石が，それぞれ異つた特性を有する事を示す樣に思はれる．

(4) 殘留磁氣の强さは磁鐵鑛粒の不純度による他，粒子の形が少からず影響してゐるさ考へられる．卽ち J_r/K さ岩石內の Fe_2O_3 : FeO : TiO_2 の比さの間にはやはり一定の關係があるが，同時に，Nos. 12, 14, 15 の3種の岩石に於ける如く微小磁鐵鑛が數個乃至10數個連結して鎖狀又は樹枝狀を爲してゐる場合には，其の他の岩石に於ける如く磁鐵鑛粒が個々分散してゐる場合に比し J_r/K の値が大きいさいふ事實がある．但し，この現象さ，化學成分さが獨立の現象であるか，又は相關連した現象であるかは現在は分らない．

(5) 磁氣測量の結果に對する吟味の一例さして，三原及淺間火山の火口周邊に於ける磁氣異常の分布から期待される兩中央火口丘の岩石の見かけの帶磁率さ，實驗測定から得られた結果さ對比して見るさ，後者が前者より著しく小さく約 1/3 である．此の事實は岩石中の自然殘留磁氣の强さが相當に大きい事を示してゐる．

この報告に於ける材料のみでは，以上の諸事實に就いての定量的議論には不充分である．近い將來に於いて，更に多くの岩石に就いて，磁氣履歷現象，溫度效果，熱殘留磁氣，自然殘留磁氣等の岩石の“磁氣分析”の結果さ，岩石及び造岩强磁性鑛物の岩石，鑛物學的並びに化學的觀測結果さを對比して更に詳しい報告を爲す豫定である．