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Investigation of Rock Magnetism in Aso Volcano

by

Nobukazu ITOH[1], Masahiro SAWADA[2], Teruaki YAMAMOTO[3] and Nobuaki SHIGENO[4]

[1]Global Environment and Marine Department
[2]Kakioka Magnetic Observatory
[3]Sapporo District Meteorological Observatory
[4]Seismological and Volcanological Department

Abstract

The magnetic properties of rock in the Mt. Aso volcano were investigated by collecting a total of 47 rock samples from three geological units that form an area near the Aso Nakadake crater: a Youngest pyroclastic cone; a Young volcanic edifice; and an Old volcanic edifice. This was done with the objective of gathering basic magnetic petrology data for the volcano. The results of this investigation were as follows.

(1) The remnant magnetization values of the samples collected near the Nakadake crater measured at room temperature ranged from the order of several A/m to several tens of A/m, suggesting that magnetically, the measured samples have basaltic properties. Further, the magnetization values tended to differ between the geological units and also vary from one rock type to another. We were also able to determine that rocks from the same outcrop do not necessarily present similar magnetization values.

(2) Changes in the remnant magnetization were studied by progressive thermal demagnetization, and the results suggest that samples from different geological units exhibit different trends in thermal demagnetization.

(3) We estimated the amount of induced magnetization by measuring the initial susceptibility, which was found to be about 1 A/m for the samples from the Nakadake crater. It was also found that the initial susceptibility of some of the samples changes at about 400°C. Furthermore, there tended to be a gradual increase in the initial susceptibility up to a certain temperature, above which the initial susceptibility changed rapidly.

1. Introduction

The Kakioka Magnetic Observatory (KMO) conducts geomagnetic total intensity observation near Nakadake, one of the peaks of Mt. Aso, an active volcano in Kyushu Island, Southwest Japan, and investigates and analyzes the thermal demagnetization phenomenon inside the volcano. The decrease of magnetic moment can be estimated from the magnetic total force observation. As the demagnetization is attributed to the temperature increase and the magnetic petrologic properties, understanding of the magnetic property is useful for estimation of the underground thermal condition. Tanaka (1993) reported that magnetic measurement of rocks serves as a crater's thermometer for temperatures below the Curie point.

In order to obtain the basic data on the magnetic properties of rocks of the Aso volcano, we took samples of the three geological units constituting the volcanic body near the Nakadake crater of Mt. Aso from 2003 to 2004 for investigation of magnetic petrology.

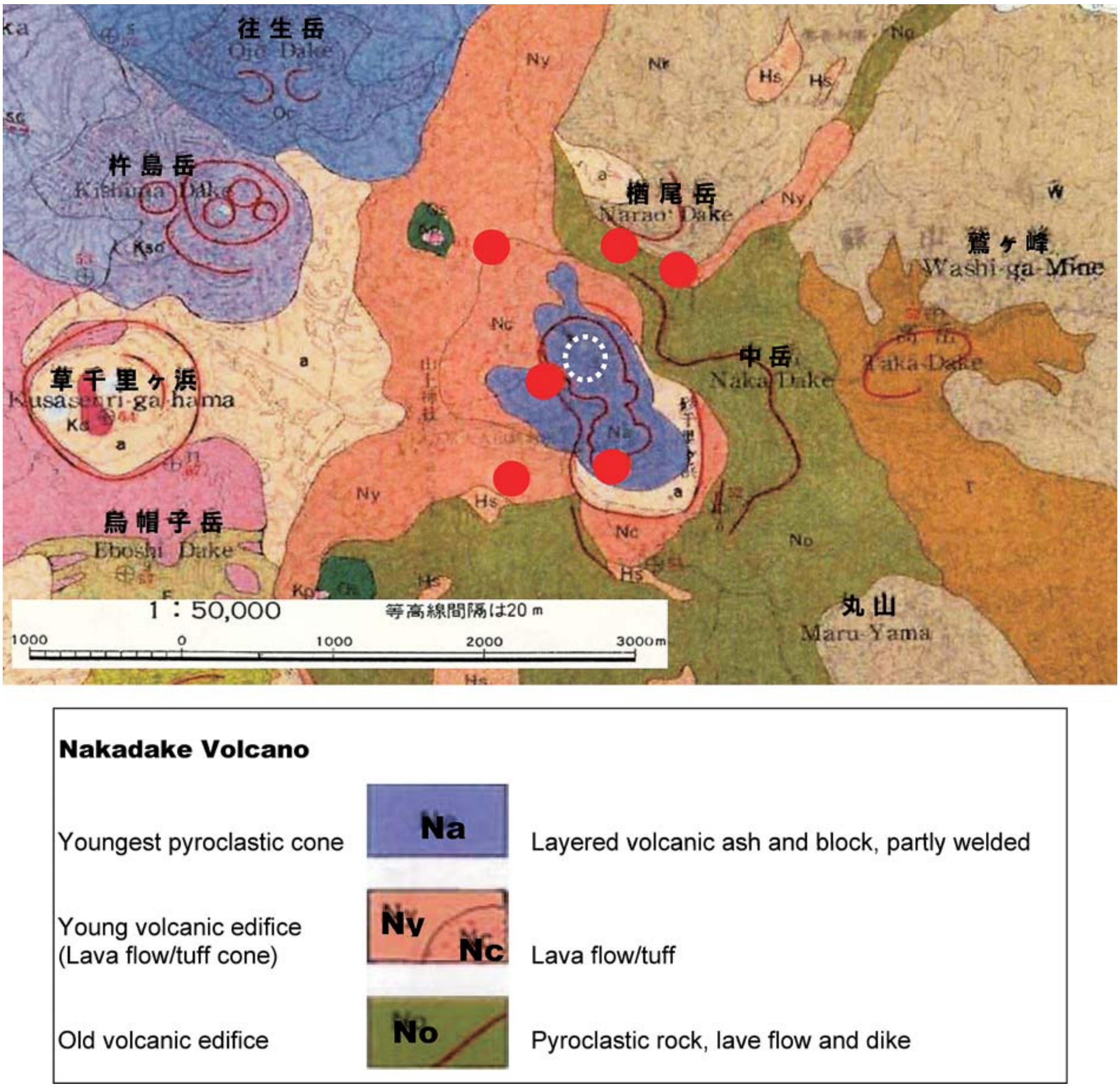


Fig. 1 Geology of Mt. Aso and sampling sites (red circle)
White broken line indicates the position of Nakadake's first crater
Source: Ono and Watanabe (1985)

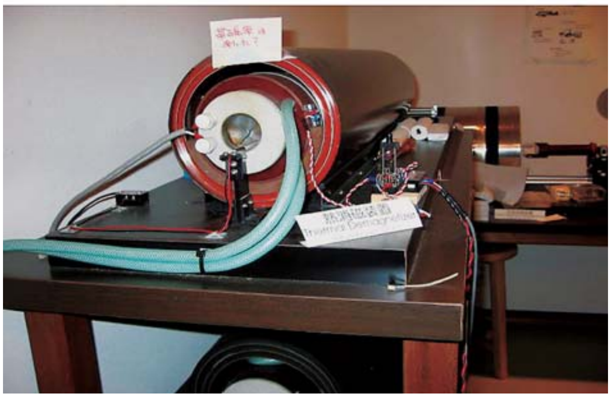
2. Rock Sampling

Mt. Aso has a composite volcanic edifice composed of several volcanoes. KMO observes geomagnetic total force of geomagnetism near the currently active Nakadake crater. The Nakadake crater consists of two kinds of lava flow of different eruption age and a pyroclastic rock formation deposited on the lava flows. In our investigation, samples were taken from these three geological units. Fig. 1 shows the geology near the Nakadake crater of Mt. Aso and the sampling sites in red circles.

Unweathered rock samples were taken with a rock hammer in blocks, with the size of about 20 cm. In addition, the samples were oriented by a clinometer to check whether or not the samples acquired secondary magnetization. About 10 samples were taken at each site. To prepare specimens, the samples were immobilized by plaster (left photo in Fig. 2) and hollowed out by a rock drill to take cylindrical cores with the diameter of 25 mm. The cylindrical samples were then cut into pieces with the height of 22 mm with a rock cutter to prepare the specimens for magnetic measurement (the specimen on the right in the right photo, Fig. 2). Cylindrical cores each measuring 7 mm in diameter were also taken out of the rock samples, and the cores were each cut

Fig. 2 Plaster-immobilized specimen (left photo) and trimmed specimens for measurement (right photo). The larger cylindrical specimen in the photo on the right is for measurement of magnetization, while the smaller for measurement of susceptibility.

(1) Spinner magnetometer (Schonstedt SSM-2A)



(2) Thermal demagnetizer (Natsuhara Co., Ltd. TSD-1)

Fig. 3 (1) Spinner magnetometer (Schonstedt SSM-2A) (top photo) and (2) thermal demagnetizer (Natsuhara Co., Ltd. TSD-1) (down photo)

into 15 mm high pieces, to prepare specimens for measurement of susceptibility (the specimen on the left in the right photo, Fig. 2).

3. Outline of Measurement

Magnetism and susceptibility were measured using the facilities of Sakurajima Volcano Research Center of the Disaster Prevention Research Institute, Kyoto University. The Center has a magnetic shield room, in which the static field of magnetism can be kept below 100 nT to shut out the magnetic noise that causes secondary remnant magnetization. Measurement was made in the shield room, and a spinner magnetometer (Schonstedt SSM-2A) was used for magnetic measurement (top photo, Fig. 3). The SSM-2A is capable of measuring magnetic moments from 10^{-3} to 10^{-8} Am^2. A thermal demagnetizer TSD-1 producted by Natsuhara Co., Ltd. was used (bottom photo, Fig. 3) for thermal demagnetization. This thermal demagnetizer is capable of simultaneously heating eight specimens up to 800°C. For details of the measuring facility and the equipment, refer to Miki (1995).

The purpose of the investigation is to measure the amount of remnant magnetism at room temperature and investigate the temperature dependency of remnant magnetization. The temperature dependency of initial susceptibility and the changes in susceptibility associated with temperature changes were also investigated.

The amount of remnant magnetization at room temperature was directly measured using the SSM-2A. Temperature dependency of remnant magnetization was measured by the following progressive thermal demagnetization. First, the specimens are heated up to the target temperature by the TSD-1, and kept in the target temperature for about 15 minutes to ensure complete thermal demagnetization inside the specimens at that temperature. Then, the specimens are cooled down to room temperature, and the amount of remnant magnetization at that temperature is measured using the SSM-2A. The temperature steps are 100°C, 200°C, 300°C, 350°C, 400°C, 450°C, 500°C, 520°C, 540°C, 550°C, 560°C, 580°C, and 600°C.

To monitor the specimens' chemical changes during temperature rise, initial susceptibility was measured immediately after every magnetic measurement. The susceptibility measuring device MS-2 manufactured by Bartington Instruments Ltd. was used for measurement of susceptibility. Temperature changes of susceptibility were also measured with the MS-2 for two specimens of each sample.

4. Measurement Results and Discussion

4.1 Remnant magnetization at room temperature

A total of 47 specimens sampled from the youngest pyroclastic cone (Na), young volcanic edifice (Ny) and old volcanic edifice (No) of Nakadake were measured. They include 18 samples from the youngest pyroclastic cone, 17 young volcanic edifice samples, and 12 old volcanic edifice samples. The measurement results at room temperature are shown in Fig. 4 and Tables 1 to 3.

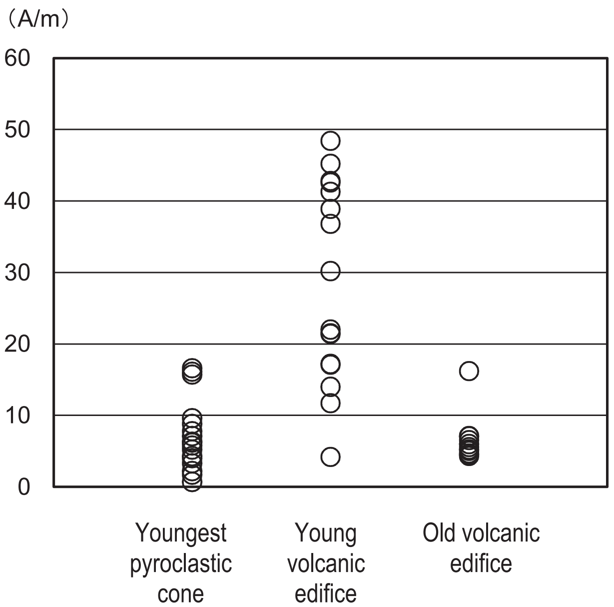


Fig. 4 Distribution of remnant magnetization (Nakadake youngest pyroclastic cone specimens, Nakadake young volcanic edifice specimens and Nakadake old volcanic edifice specimens)

The measurement results, as arranged by the geological unit, are 0.7 to 16.6 A/m for the samples from the youngest pyroclastic cone, 4.2 to 48.4 A/m for the young volcanic edifice samples, and 4.3 to 16.2 A/m for the old volcanic edifice samples (Fig. 4). The samples from the youngest pyroclastic cone of Nakadake and those from the old volcanic edifice are similar in the distribution of magnetization values. On the other hand, samples in the young volcanic edifice have a wider variation of magnetization than in the other geological unit, and their magnetization values are also larger than those of the other two.

Regarding the results of each individual specimen measured, even rocks taken from the same geological unit vary in remnant magnetization to some extent. Some probable causes are that the pores of some porous materials contained in the specimens are not counted in the volume calculation, the sizes of particles that constitute the rocks are different, and that magnetic minerals changed their properties. The samples from the pyroclastic rocks contain scoria, which are porous black ejecta made out of basic magma, and the specimens of the youngest pyroclastic cone (Na 3 and 4) have large remnant magnetization. The specimens of pyroclastic rock (Na 8 and 16), which contain gravel of a few millimeters in diameter, show values very different from the average. The remnant magnetization values of lava specimens vary greatly from one specimen to another, and it is difficult to interpret the variance of magnetization from the difference in particle size of the specimens. Probable factors that cause such dispersion of remnant magnetization include the differences in the type or content of magnetic minerals such as magnetite contained in specimens taken from each volcanic edifice. Some specimens show weathering, but the relationship between the degree of weathering and magnetization values could not be clarified.

In the past, measurement results reported by Ota (1963) state that the Aso Nakadake specimens gave about 10 A/m, and Yasuhara and Ota (1965) state that the specimens from various sites in the Aso volcano, namely Tawarayama, Sugaru, Saka-

Table 1 Results of remnant magnetization measurement of Nakadake youngest pyroclastic cone specimens

Specimen no.	Remnant magnetization [A/m]	Angle of declination [deg.]	Angle of inclination [deg.]	Characteristics of specimen
Na1	9.6	83.0	64.9	Pyroclastic rock
Na2	3.3	-20.6	25.8	
Na3	15.7			
Na4	16.6			
Na5	0.7			
Na6	0.7	11.9	39.2	
Na7	4.0	12.8	45.2	
Na8	16.1	-106.6	44.3	
Na9	8.8	3.6	50.6	
Na10	7.1	81.6	18.1	
Na11	4.3	12.8	43.2	
Na12	7.8	15.7	40.9	
Na13	6.3	-3.7	43.3	
Na14	2.2	-5.3	36.3	
Na15	5.8	-17.3	38.3	
Na16	1.7	9.3	40.9	
Na17	6.2	-131.0	76.7	
Na18	5.2			
Average	6.8	-3.8	43.4	
Standard deviation	5.0	57.8	14.4	
No. of measurement	18	14	14	

Table 2 Results of remnant magnetization measurement of Nakadake young volcanic edifice specimens

Specimen no.	Remnant magnetization [A/m]	Angle of declination [deg.]	Angle of inclination [deg.]	Characteristics of specimen
Ny1	22.0	-10.3	36.8	Lava
Ny2	45.2	3.1	60.3	Lava
Ny3	48.4	-53.7	42.7	Lava
Ny4	42.6	-22.5	17.1	Lava
Ny5	38.9	-16.3	37.8	Lava
Ny6	4.2			Pyroclastic rock
Ny7	41.3	-2.0	51.1	Lava
Ny8	11.7	6.3	43.7	Lava
Ny9	42.8	18.5	56.7	Lava
Ny10	42.8	16.3	58.2	Lava
Ny11	17.2	-17.8	51.7	Lava
Ny12	14.0	-27.9	-40.3	Lava
Ny13	21.4	18.5	47.4	Lava
Ny14	36.8	-13.5	50.2	Lava
Ny15	30.2	-1.7	59.0	Lava
Ny16	21.5	2.0	40.8	Lava
Ny17	17.1			Lava
Average	29.3	-6.7	40.9	
Standard deviation	13.9	19.6	25.1	
No. of measurement	17	15	15	

Table 3 Results of remnant magnetization measurement of Nakadake old volcanic edifice specimens

Specimen no.	Remnant magnetization [A/m]	Angle of declination [deg.]	Angle of inclination [deg.]	Characteristics of specimen
No1	4.7	-40.4	53.4	Lava
No2	7.1	-7.2	45.4	Lava
No3	5.2	3.3	37.8	Lava
No4	16.2	2.7	30.2	Lava
No5	7.1	3.9	43.9	Lava
No6	6.5	-6.1	30.6	Lava
No7	4.3	20.9	47.1	Pyroclastic rock
No8	6.0	9.9	67.2	Pyroclastic rock
No9	5.6	11.7	40.8	Lava
No10	4.5	-3.1	56.6	Lava
No11	4.5	-4.6	55.5	Lava
No12	5.0	159.0	23.2	Lava
Average	6.4	12.5	44.3	
Standard deviation	3.2	48.5	12.7	
No. of measurement	12	12	12	

Values in Table 1 to 3 are obtained by dividing the measured magnetic moment (Unit: Am^2) by the volume of the cylindrical specimen (Unit: m^3). Declination and inclination were calculated from the X, Y and Z components of the measured magnetic moment. Specimens with blank declination or inclination cells indicate boulder stone. A "+" with declination indicates east, while a "+" with inclination indicates down.

nashi, Yomineyama, Nekodake, Eboshidake, Tochinoki, Kishima and Ojodake, gave about 1 A/m. Tanaka (1993) measured remnant magnetization of lava and scoria and reported that the magnetization values of lava and scoria specimens are 2×10^{-2} emu/g (equivalent to 50 A/m if the density is 2.5 g/cm^3) and 2×10^{-3} emu/g (equivalent to 4 A/m if the density is 2.0 g/cm^3), respectively.

In conclusion, it was found that the measured specimens gave magnetization values close to those of general basalt (10 A/m and above), magnetization values show different tendencies for each geological unit, and rocks from the same geological unit do not necessarily share the same magnetization values.

4.2 Changes in remnant magnetization by progressive thermal demagnetization

Progressive thermal demagnetization was conducted for the 47 specimens mentioned above. The measurement results are shown in Figs. 5 to 7 and Tables 4 to 6. The ratio to the remnant magnetization values at room temperature is plotted on the vertical axis. Most of the specimens lost magnetism before the temperature reached 600°C.

The youngest pyroclastic cone specimens were demagnetized almost linearly from 100°C to 600°C on average. For the young volcanic edifice specimens, almost none of them were demagnetized, except a few, until 200 to 300°C, but thereafter rapid demagnetization occurred. The old volcanic edifice specimens showed a pattern between the demagnetization curves of the other two volcanic edifices. These results indicate that the specimens of different geological units show different tendencies of thermal demagnetization.

4.3 hanges in initial susceptibility associated with progressive thermal demagnetization

Susceptibility is defined as the degree of magnetization of a material when put in a magnetic field and is expressed as magnetization divided by the intensity of magnetic field applied. Measurement of susceptibility is effective for monitoring changes in magnetic minerals. To monitor changes of magnetic minerals by progressive thermal demagnetization, the initial susceptibility was measured for each temperature (they were measured after they had been cooled down to room temperature). Figures 8 to 10 show the measurement results. The initial susceptibility of some lava specimens showed changes as the temperature rose to around 400°C. This is probably because the existing magnetic minerals were changed or metamorphosed into different minerals. But X-ray diffraction analysis was not conducted in our investigation and did not clarify how the magnetic minerals changed or metamorphosed.

The amount of induced magnetization was estimated based on the measured initial susceptibility. Since the susceptibility of rock at room temperature is approximately 0.01 to 0.05, the induced magnetization was estimated to be 1 to 5% of the average magnetic field near Mt. Aso (about 47,000 nT), which is about 0.4 to 1.9 A/m.

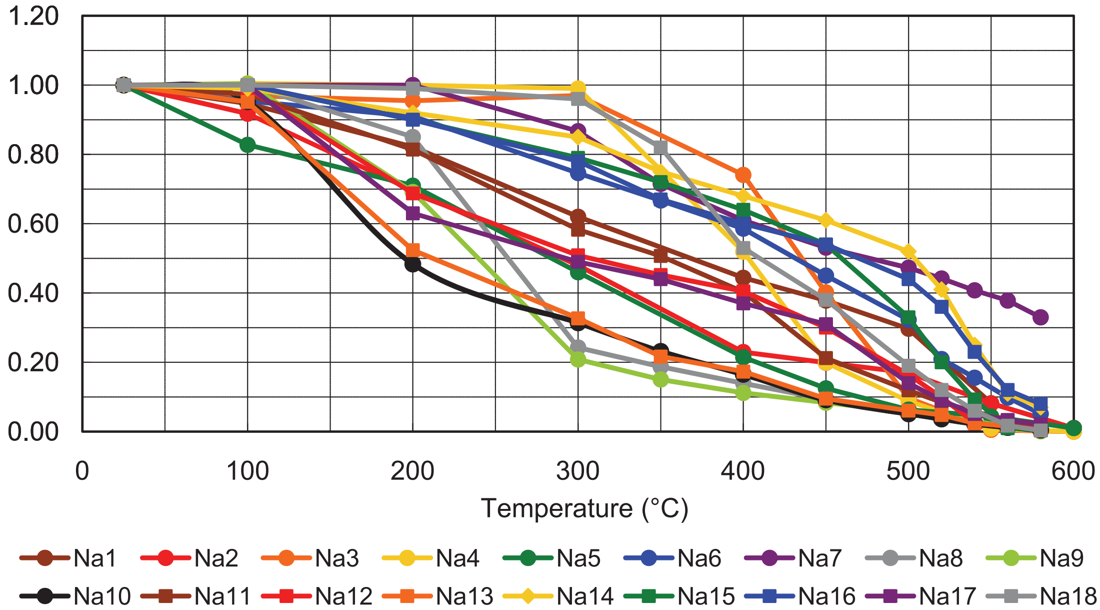


Fig. 5 Results of progressive thermal demagnetization of Nakadake youngest pyroclastic cone specimens

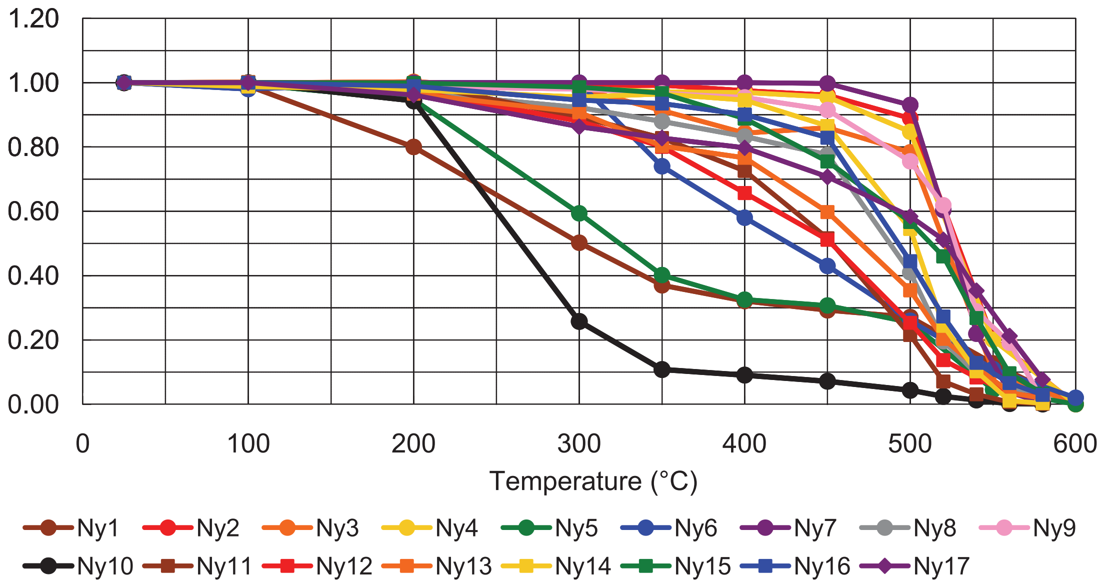


Fig. 6 Results of progressive thermal demagnetization of Nakadake young volcanic edifice specimens

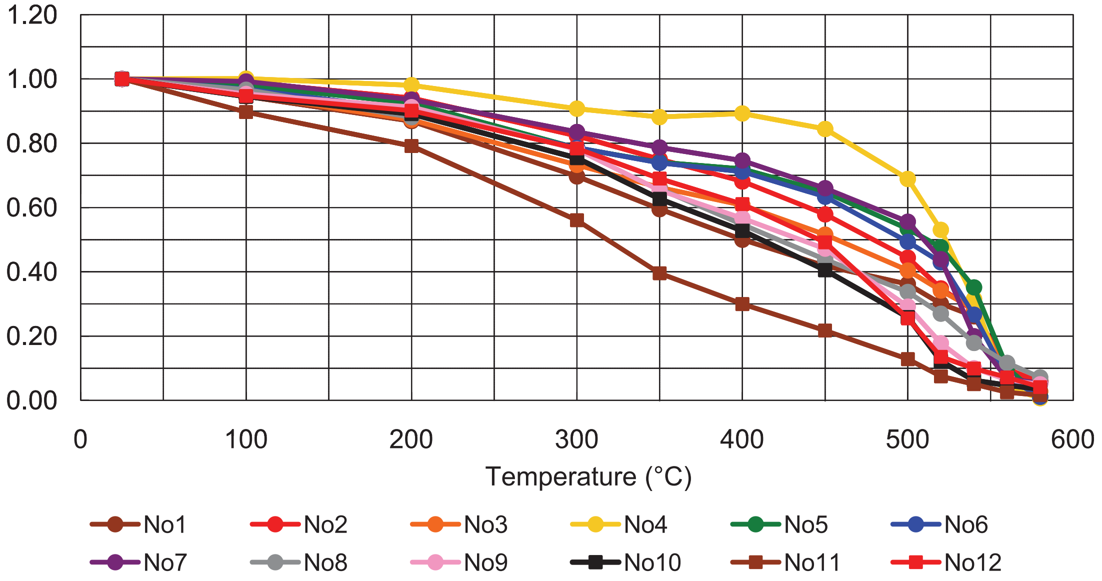


Fig. 7 Results of progressive thermal demagnetization of Nakadake old volcanic edifice specimens

Table 4 Results of progressive thermal demagnetization of Nakadake youngest pyroclastic cone specimens (ratio to the amount of room temperature magnetization)

Temp	Na1	Na2	Na3	Na4	Na5	Na6	Na7	Na8	Na9	Na10	Na11	Na12	Na13	Na14	Na15	Na16	Na17	Na18
25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
100	0.95	0.92	0.97	1.00	0.83	0.95	1.00	1.00	1.00	0.95	0.97	0.99	0.95	0.99	1.00	1.00	1.00	1.00
200	0.82	0.70	0.95	1.00	0.71	0.91	1.00	0.85	0.69	0.48	0.81	0.69	0.52	0.92	0.90	0.90	0.63	0.99
300	0.62	0.48	0.97	0.99	0.46	0.75	0.87	0.24	0.21	0.31	0.58	0.51	0.33	0.85	0.79	0.78	0.49	0.96
350						0.67	0.71	0.19	0.15	0.23	0.51	0.45	0.22	0.75	0.72	0.67	0.44	0.82
400	0.44	0.23	0.74	0.52	0.21	0.59	0.61	0.14	0.11	0.16	0.40	0.40	0.17	0.68	0.64	0.60	0.37	0.53
450	0.38	0.20	0.40	0.20	0.12	0.45	0.53	0.09	0.08	0.09	0.21	0.30	0.09	0.61	0.54	0.54	0.31	0.38
500	0.30	0.17	0.10	0.09	0.06	0.32	0.47	0.05	0.06	0.05	0.12	0.16	0.06	0.52	0.33	0.44	0.14	0.19
520						0.21	0.44	0.04	0.04	0.04	0.08	0.10	0.05	0.41	0.20	0.36	0.09	0.12
540						0.16	0.41	0.03	0.03	0.02	0.06	0.02	0.02	0.25	0.09	0.23	0.05	0.06
550	0.08	0.08	0.01	0.01	0.04													
560						0.10	0.38	0.01	0.01	0.01	0.03	0.01	0.02	0.11	0.01	0.12	0.03	0.02
580						0.05	0.33	0.00	0.00	0.00	0.00	0.01	0.00	0.07	0.01	0.08	0.02	0.00

Table 5 Results of progressive thermal demagnetization of Nakadake young volcanic edifice specimens (ratio to the amount of room temperature magnetization)

Temp	Ny1	Ny2	Ny3	Ny4	Ny5	Ny6	Ny7	Ny8	Ny9	Ny10	Ny11	Ny12	Ny13	Ny14	Ny15	Ny16	Ny17
25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
100	0.99	0.99	1.00	1.00	1.00	0.98	1.00	1.00	0.99	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00
200	0.80	0.99	1.00	0.99	0.95	1.00	1.00	0.97	0.99	0.94	1.00	0.97	0.97	0.98	1.00	0.99	0.96
300	0.50	0.99	0.98	0.98	0.59	1.00	1.00	0.92	0.98	0.26	0.89	0.88	0.91	0.96	0.99	0.95	0.86
350	0.37	0.99	0.91	0.97	0.40	0.74	1.00	0.88	0.97	0.11	0.83	0.80	0.80	0.96	0.97	0.93	0.83
400	0.32	0.98	0.84	0.97	0.33	0.58	1.00	0.83	0.95	0.09	0.73	0.66	0.77	0.95	0.89	0.90	0.80
450	0.29	0.96	0.86	0.96	0.31	0.43	1.00	0.78	0.92	0.07	0.52	0.51	0.60	0.87	0.76	0.83	0.71
500	0.27	0.89	0.78	0.85	0.25	0.26	0.93	0.41	0.76	0.04	0.22	0.25	0.35	0.55	0.57	0.44	0.58
520							0.60	0.20	0.62	0.02	0.07	0.14	0.20	0.24	0.46	0.27	0.51
540							0.22	0.09	0.29	0.01	0.03	0.08	0.12	0.10	0.27	0.13	0.35
550	0.13	0.20	0.10	0.20	0.05	0.11											
560							0.04	0.05	0.19	0.00	0.01	0.03	0.04	0.01	0.10	0.07	0.21
580							0.00	0.02	0.01	0.00	0.00	0.02	0.02	0.00	0.03	0.03	0.08
600	0.00	0.00	0.00	0.00	0.00	0.02											

Table 6 Results of progressive thermal demagnetization of Nakadake old volcanic edifice specimens (ratio to the amount of room temperature magnetization)

Temp	No1	No2	No3	No4	No5	No6	No7	No8	No9	No10	No11	No12
25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
100	0.95	0.99	0.95	1.00	0.98	0.97	0.99	0.97	0.95	0.95	0.90	0.95
200	0.87	0.94	0.87	0.98	0.93	0.90	0.94	0.88	0.91	0.89	0.79	0.90
300	0.70	0.82	0.73	0.91	0.79	0.79	0.83		0.78	0.75	0.56	0.78
350	0.60	0.75	0.66	0.88	0.74	0.74	0.79	0.66	0.65	0.63	0.40	0.69
400	0.50	0.68	0.61	0.89	0.72	0.71	0.75	0.55	0.57	0.53	0.30	0.61
450	0.42	0.58	0.52	0.84	0.65	0.63	0.66	0.44	0.47	0.41	0.22	0.49
500	0.36	0.44	0.40	0.69	0.53	0.49	0.56	0.34	0.29	0.26	0.13	0.26
520	0.30	0.35	0.34	0.53	0.48	0.43	0.44	0.27	0.18	0.12	0.07	0.14
540	0.26	0.28	0.28	0.32	0.35	0.27	0.20	0.18	0.10	0.06	0.05	0.10
560	0.09	0.10	0.08	0.04	0.10	0.07	0.07	0.12	0.06	0.05	0.03	0.07
580	0.06	0.06	0.03	0.01	0.01	0.01	0.05	0.07	0.05	0.04	0.02	0.04

4.4 Changes in susceptibility associated with temperature changes

Changes in susceptibility of two pyroclastic rock specimens (Na 4-2: the youngest pyroclastic cone specimens and Ny 6-2: new volcanic edifice specimens) were measured as the temperature was changed. The rocks were measured while in a heated state. Figure 11 shows the measurement results. The path with large susceptibility corresponds to the chage in a temperature rise, while that with small susceptibility in a temperature decrease. The measurement results indicate that great changes in susceptibility occur at temperatures at which thermal demagnetization suddenly starts. The path difference between going up and down is presumed to depend on the effect of changes in the magnetic minerals.

5. Conclusion

A total of 47 samples were taken from the three geological units that constitute the main part of the Nakadake crater of Mt. Aso from 2003 to 2004 for a survey of rock magnetism in order to obtain basic data on the magnetic properties of the rock of the Aso volcano. The results revealed that the remnant magnetization values of the specimens from near the Nakadake crater (a few A/m to a few tens A/m) are close to those of general basalt (10 A/m and above), that remnant magnetization values or their temperature dependency vary by geological unit, and that even specimens from the same geological unit show different properties. The initial susceptibility of some lava specimens changed as the temperature exceeded 400°C, which suggests changes in the

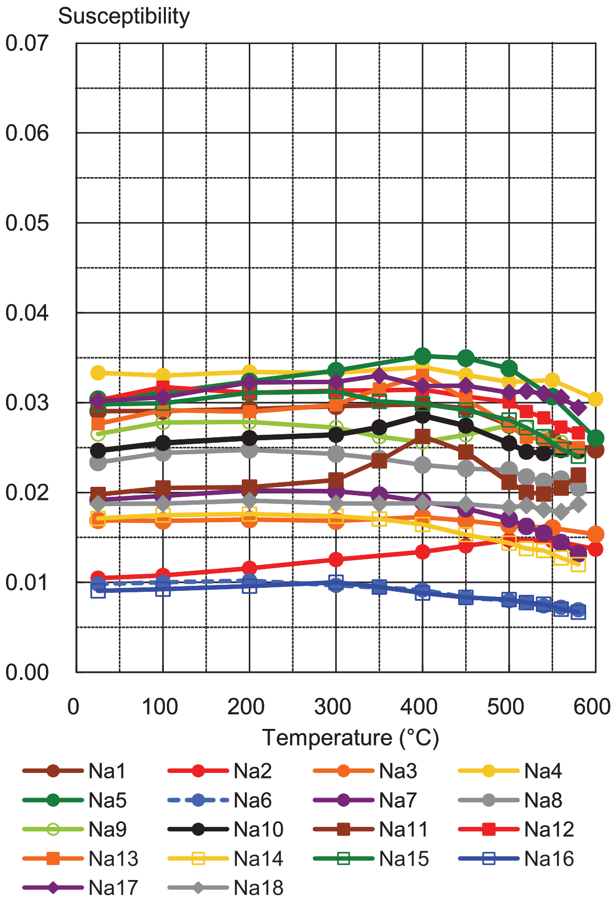


Fig. 8 Changes in initial susceptibility associated with temperature changes (Na 1 to 18: Nakadake youngest pyroclastic cone specimens)

magnetic minerals themselves.

As a future task to tackle, it seems necessary to review the changes or metamorphosis of minerals by heat with an appropriate method such as X-ray powder diffraction. Lava specimens show large differences in remnant magnetization values. The probable factors that could cause such dispersion are the differences in the types or

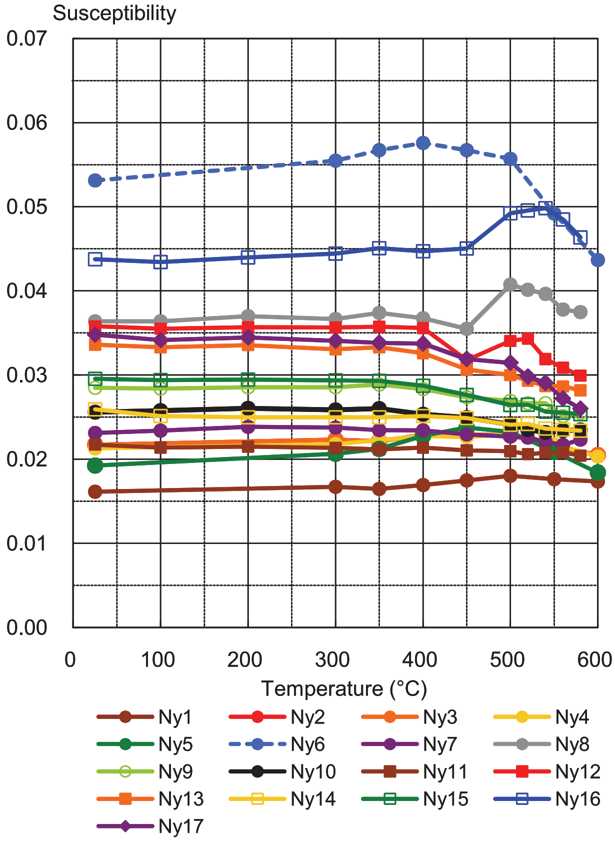


Fig. 9 Changes in initial susceptibility associated with temperature changes (Ny 1 to 17: Nakadake young volcanic edifice specimens)

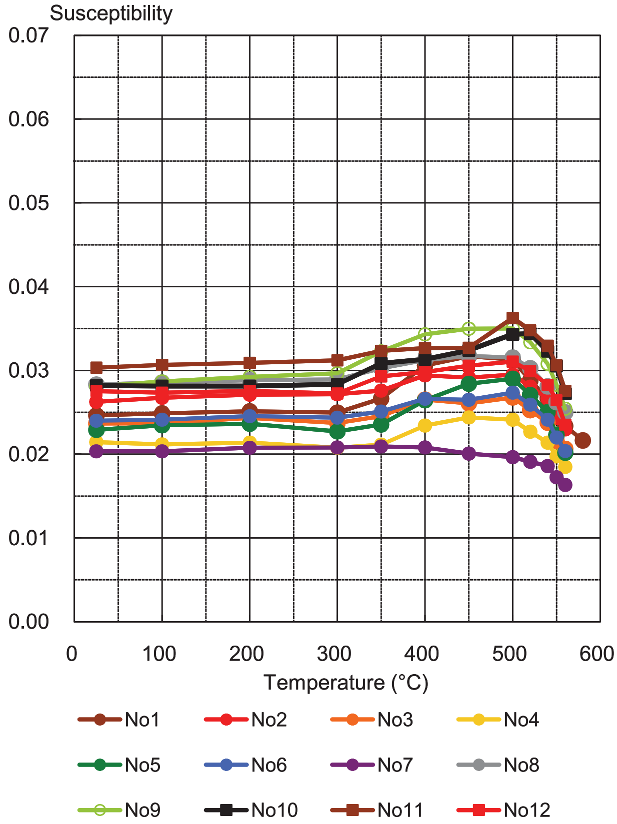
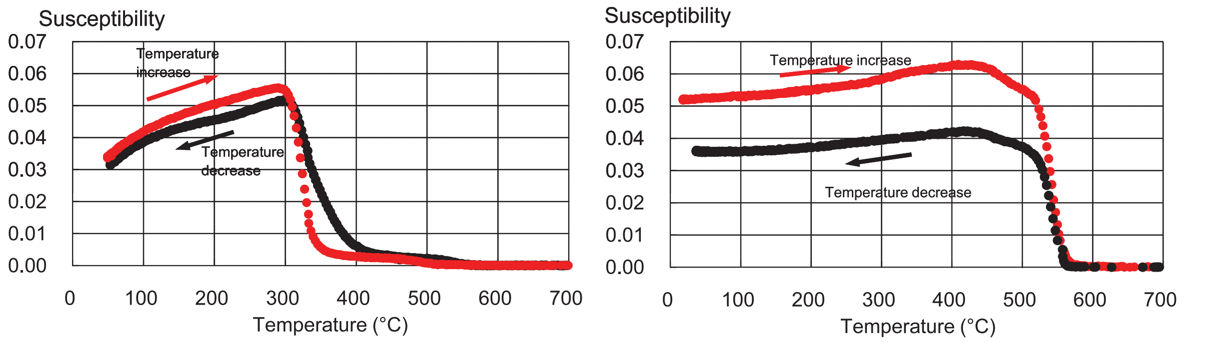


Fig. 10 Changes in initial susceptibility associated with temperature changes (No 1 to 12: Nakadake old volcanic edifice specimens)



(Na 4-2: Pyroclastic rock (Nakadake youngest pyroclastic cone specimen))

(Ny 6-2: Pyroclastic rock (Nakadake young volcanic edifice specimen))

Fig. 11 Changes in initial susceptibility associated with temperature changes (Na 4-2: Nakadake youngest pyroclastic cone specimens [left]; and Ny 6-2: Pyroclastic rock (Nakadake young volcanic edifice specimens) [right])

contents of magnetic minerals contained in the specimens by the volcanic edifice. It is also necessary to conduct surveys on aspects other than rock magnetism.

Other research institutes have conducted aerial magnetic observation for the purpose of estimating the magnetic structure of the volcanic edifice (Tanaka et al. 2001, Utsugi et al. 2003, and Utsugi et al 2006). It seems clear that it will be necessary to continue to analyze and store data for estimations of the complex magnetic structure and so that the details of the thermal state of the inside of a volcano can be inferred.

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