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Note

A Note on Magnetic Properties of Volcanic Rocks Collected from King George Island, Antarctic Peninsula

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Abstract : The basic magnetic properties are reported for Eocene andesite and granitic andesite collected from the King Sejong Station and Marsh Runway at King George Island, South Shetland Islands, Antarctic Peninsula. Samples A (andesite), B (granitic andesite) and D (granitic andesite) carry stable component of natural remanent magnetization (NRM), but sample C (andesite) unstable NRM. These NRM stabilities are consistent with the domain structures estimated by the ratios of J_R/J_S and H_{RC}/H_C values. On the basis of their Curie temperature, we infer magnetite as the main magnetic carrier for samples A, B, and C and titanomagnetite for sample D. Our study reveals that samples A and B are suitable for paleomagnetic investigations, whereas sample D is not.

Key words : King George Island, natural remanent magnetization, AF demagnetization, thermomagnetic curve.

1. Introduction

Paleomagnetic studies of Antarctic Peninsula revealed S-shape bending of the southern peninsula since the Cretaceous according to Kellogg and Reynolds (1978) and Kellogg (1980). Watts (1982) reported a possibility that Antarctica moved as a single plate or rotated about the present south pole since the early Tertiary based on the evidences from paleomagnetism and K-Ar age studies using rocks collected from King George Island, South Shetland Islands, Antarctic Peninsula (Fig. 1). However, previous studies provided very little information on the fundamental magnetic characteristics, such as natural remanent magnetization (NRM) stability, determination of magnetic minerals and remagnetization etc. In particular, without the knowledge of remagnetization, one can say little about the paleomagnetic results. This study reports the magnetic properties of 4 igneous rocks collected from King George Island. The results may provide an assessment on reliability of the previous results and help us to determine precise paleomagnetic study that needs to be carried out in future.

Two block samples were collected by Y. Kim (Korea Ocean Research and Development Institute) in 1993 from King Sejong Station. They are andesite (sample A) and granitic andesite (sample B) without orientations, estimating intrusive ages as 50 Ma and 41-45 Ma respectively (Lee *et al.* 1996). The other 2 block samples C and D were collected with orientations by K. Kaminuma (NIPR) in 2000. Sample C is andesite collected from near Marsh Runway whose age is estimated to be 54.3±0.6 Ma (Watts 1982). Sample D is granitic andesite from King Sejong Station, whose age is estimated to be the same as that of the sample B based on the locality and rock type. From these block samples, the cylindrical samples of 2.5 cm in diameter with a length of 2.5 cm and small fragments were prepared for analysis of magnetic properties and microscopic observations.

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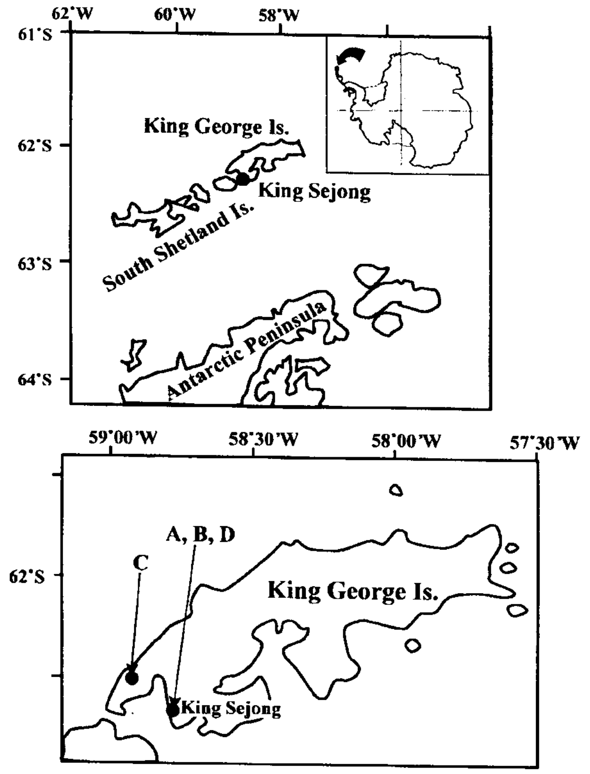

Fig. 1. The map near King George Island and the sampling sites of this study.

2. Magnetic properties

Stability of the natural remanent magnetization

The NRM stabilities of samples A, B, C, and D were examined by AF demagnetization up to 50 or 100 mT in steps of 5 mT. The demagnetization curves are shown in Fig. 2. The NRM intensity ($R = 4.40 \times 10^{-5}$ Am^2/kg) of sample A exhibited zigzag variation during demagnetization, but the directions were relatively stable. The NRM is decomposed into the soft and hard components with respect to 30 mT in the Zjiderveld projection (vector analysis of x, y, z components). The hard component may be acquired as thermal remanent magnetization (TRM) in the samples during cooling stage of the volcanism, while the soft one may represent secondary magnetization such as isothermal remanent magnetization (IRM) and/or viscous remanent magnetization (VRM). The NRM of sample B ($R=1.56 \times 10^{-4}$ Am^2/kg) appears to be more stable than that of sample A. A small amount of unstable NRM component was demagnetized by 20 mT, but the hard one survives up to 80 mT. Sample C ($R = 2.63 \times 10^{-4}$ Am^2/kg) exhibits very unstable NRM throughout the demagnetization steps to 50 mT. It is thought to consist of IRM and VRM. The NRM of sample D ($R = 3.24 \times 10^{-5}$ Am^2/kg) was stable to 50 mT. A small amount of the soft component was observed up to 10 mT.

Magnetic hysteresis properties and thermomagnetic curves

Magnetic properties of saturation magnetization (J_S), saturation remanent magnetization (J_R), coercive force (H_C) and remanent coercive force (H_{RC}) were obtained from the hysteresis loops at room temperature under the external magnetic field between −1.0 and 1.0 T. The data are summarized in Table 1 together with the ratios of J_R/J_S and H_{RC}/H_C values.

Thermomagnetic curve (Js-T curve) was obtained by a vibrating sample magnetometer under the vacuum condition of 10^{-3} Pa in the external steady magnetic field at 1.0 T. The 1st run cycles of these curves are shown in Fig. 3. The Js-T curves of samples A, B, and C showed almost reversible curves with a Curie point clearly defined at 580°C, suggesting that almost pure magnetite is the magnetic mineral. The curve of sample D, however, showed irreversible curve with a broad range of Curie point centered at 570°C in the heating curve and at about 550°C and 340°C in the cooling curve. The magnetization after heating decreased about 15% compared with the original intensity.

Microscopic observation

Small fragments were polished by diamond paste for microscopic observations. Dominant magnetic minerals in sample A were fine-grained magnetite of <20 μm in diameter (Fig. 4A). A small amount of large magnetite grains around 300 μm was also present. The fine-grained magnetite showed a homogeneous feature, but the larger grains were invaded by silicate veins and/or nodules of nonmagnetic iron oxide. Sample B included fine-grained magnetite of <20 μm along with larger opaque grains of 50-300 μm in diameter consisting of magnetite, ilmenite ($FeTiO_3$) and chalcopyrite ($CuFeS_2$) (Fig. 4B). Larger magnetite grains between 50 and 400 μm in diameter were the dominant magnetic minerals in the sample C (Fig. 4C). Fine-grained magnetite grains of <10 μm were present in the sample, but their amount was negligibly small. Sample D included only fine-grained magnetite of dominant size of about 10 μm in diameter (Fig. 4D). Throughout these 4 samples, no evidences of oxidation were observed in the magnetic minerals as the low temperature oxidation (formation of maghemite by

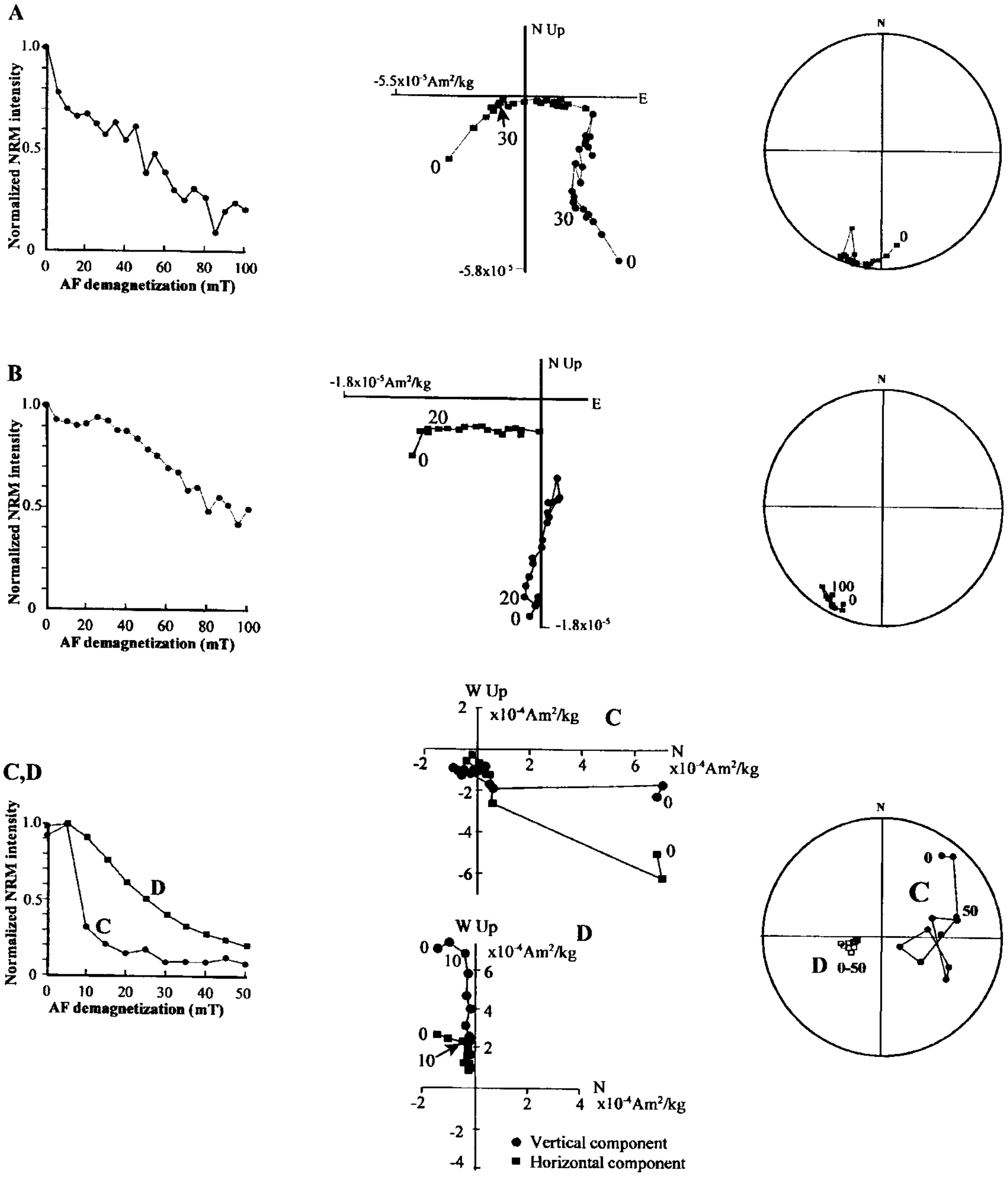

Fig. 2. AF demagnetization curves of the natural remanent magnetization. left: intensity change, center: Zjiderveld projection, right: directional change.

Table 1. Magnetic hysteresis properties.

Sample	J_S Am²/kg	J_R Am²/kg	H_C mT	H_{RC} mT	J_R/J_S	H_{RC}/H_C
A	0.41	0.019	5.6	28.3	0.046	5.05
B	0.34	0.016	6.6	21.1	0.047	3.20
C	30.67	0.97	4.1	17.7	0.032	4.32
D	2.11	0.168	8.2	25.2	0.080	3.07

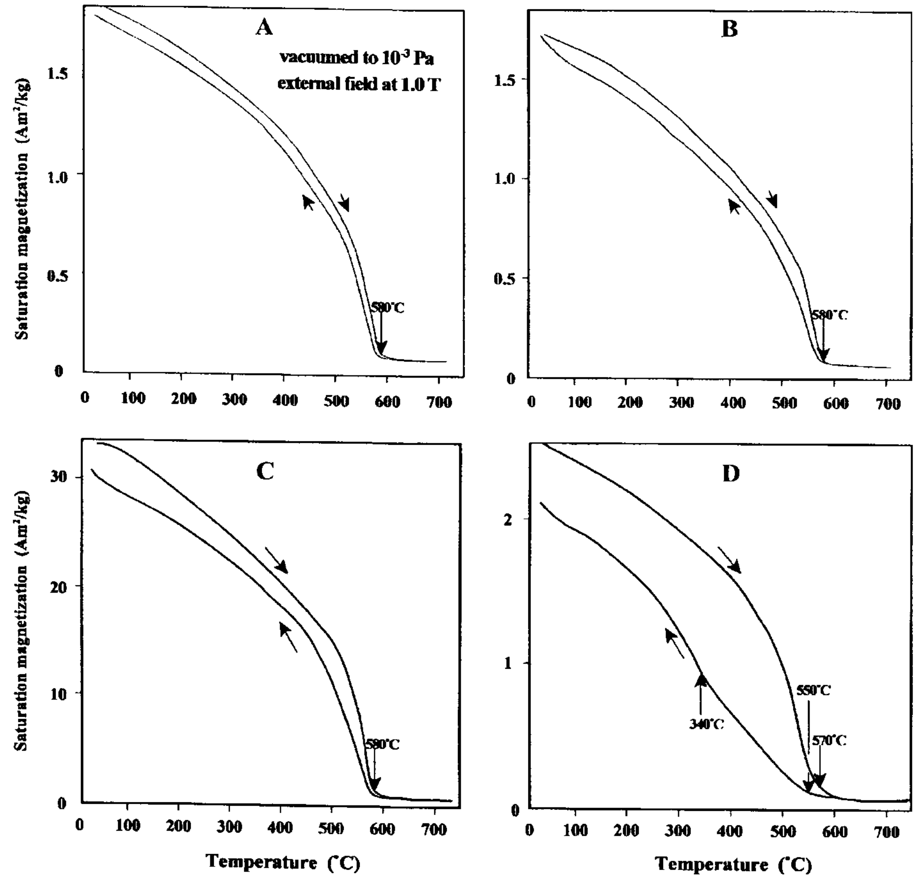

Fig. 3. Thermomagnetic curves under 1.0 T of steady magnetic field in the vacuumed condition to 10^{-3} Pa.

weathering product) and the high temperature oxidation (formation of ilmenite lamellae).

3. Discussion

Magnetic minerals determined by their Curie point appear to be magnetite for samples A, B, and C and titanomagnetite for sample D. The ratios of J_R/J_S and H_{RC}/H_C are reflected in the domain structure (Day *et al.* 1977), in the case of magnetite-ulvospinel series minerals. Based on these ratios in Table 1, the values fall within multi-domain (MD) area for samples A and C and the pseudosingle-domain (PSD) one for samples B and D. The magnetic grains of single-domain (SD) and PSD can be considered as having stable NRM, but these of MD can take only unstable NRM. The critical size of the domain structure of magnetite is in the range of 0.025-0.08 μm for the SD, 0.08-20 μm PSD and >20 μm for MD, as summarized by Dunlop and Özdemir (1997). Since the observed dominant magnetic grains were <20 μm of samples A, B and D and 50-400 μm of sample C, the domain state of the former and the latter samples can be classified as PSD and MD respectively. However, there is some inconsistency between the observed grain size and domain state for sample A; PSD is derived from the observed size, while MD is estimated from the hysteresis data. This discrepancy may be explained by the volume 300 μm and small grains (<20 μm). The ratios of J_R/J_S and H_{RC}/H_C, therefore, may reflect the characteristics of the larger grains than those of smaller grains in the case of sample A. The stabilities of NRM against AF demagnetization appear to diminish from samples D, B, and A to C. This tendency is consistent with the stability predicted on the basis of observed grain size under the microscope.

The magnetic minerals in these 4 samples seem to be fresh as shown from the absence of maghemite (γ-phase) under the microscopic observation. The Js-T curves of samples A, B and C are almost reversible, while that of sample D is irreversible. The former 3 samples are stable against heating, but the latter one is unstable. It appears

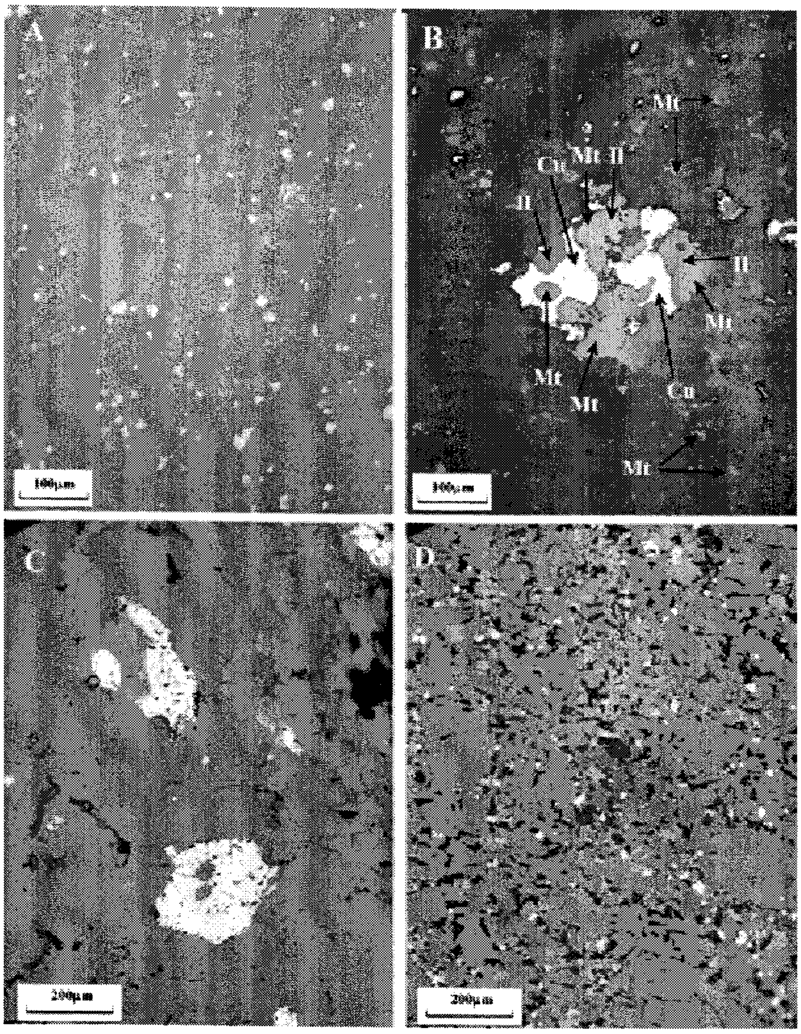

Fig. 4. Grain-size of opaque minerals taken under the reflected light microscope. Mt: magnetite (Fe_3O_4), Il: ilmenite ($FeTiO_3$), Cu: chalcopyrite ($CuFeS_2$).

Table 2. Magnetic properties and opaque minerals observed by the microscope.

Sample	NRM	NRM	T_c	T_c^*	Js-t	Opaque minerals	Size
A	4.40×10^{-5}	stable	580	580	rev	Fe_3O_4, iron oxide	<20, 300
B	1.56×10^{-4}	stable	580	580	rev	Fe_3O_4, $FeTiO_3$, $CuFeS_2$	20, 50-300
C	3.24×10^{-5}	unstable	580	580	rev	Fe_3O_4	50-400
D	2.63×10^{-4}	stable	570	550, 340	irrev	Fe_3O_4	10
unit	Am^2/kg			°C			μm

T_C and T_C^*: Curie point in the heating curve and cooling curve, respectively.
rev: reversible thermomagnetic curve.
irrev: irreversible thermomagnetic curve.

that the magnetic minerals at 570°C in sample D may have decomposed into two kinds of titanomagnetite having the Curie point of about 550°C and 340°C. Furthermore, on the basis of this decomposition, we

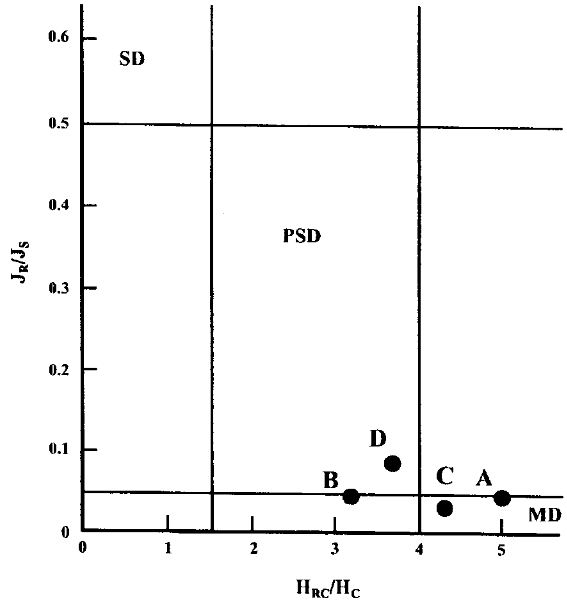

Fig. 5. Magnetic domain states estimated by hysteresis properties (Day *et al.* 1977). SD: single-domain, PSD: pseudosingle-domain, MD: multi-domain.

estimate the respective ulvospinel (Fe_2TiO_4) ratios in titanomagnetite after heating may be about 7% and 40% (Akimoto 1962). In summary, sample B appears to provide the most reliable NRM among the 4 samples. Sample D cannot be used to estimate paleointensity by Thellier & Thellier (1959) method due to thermal unstability.

Global paleointensity data collected from rock samples around the world are currently being used to constrain the geomagnetic field intensity when rocks were magnetized during geological time to better understand evolution of the geomagnetic field of the earth. However, the data are poor in the southern hemisphere, especially the Antarctic region. The study of paleointensity using volcanic rocks in King George Island may help scientist to establish the paleointensity during the last several ten million years. The magnetic unstability during heating of sample D suggests that it is not suitable for paleointensity study by Thellier & Thellier method, even though the NRM is the most stable.

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