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ROCK MAGNETIC ANALYSIS FOR SAMPLES OF THE NAPIER COMPLEX IN THE MT. RIISER-LARSEN AREA, EAST ANTARCTICA

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Abstract: Samples collected at eight sites from granulites of the Archean Napier Complex and dolerite dikes intruding the complex in the Mt. Riiser-Larsen area, East Antarctica, were analyzed rock-magnetically in order to assess the stability of their natural remanent magnetizations (NRMs). Results of isothermal remanence acquisition experiments and hysteresis measurements indicate the presence of magnetite in the pseudo-single to multi domain size, which is consistent with N. ISHIKAWA and M. FUNAKI (Proc. NIPR Symp. Antarct. Geosci., **10**, 79, 1997). Stable magnetic components carried by fine-grained magnetites were isolated from some sites. Samples with such components may have a mixture of magnetites with different grain sizes although the effect of the mixing was not clearly observed. Heavily-deformed samples were found to be magnetically anisotropic, while magnetic fabrics of less-deformed samples indicate the possibility that the fabrics are of primary origin. The high-stability magnetic components from the less-deformed dolerite samples of one site with primary magnetic fabrics may be of primary remanence acquired in the emplacement of the dike at 0.8–1.0 Ga.

key words: the Napier Complex, Mt. Riiser-Larsen, rock magnetism, AMS, hysteresis parameters

1. Introduction

The Napier Complex in Enderby Land, East Antarctica, is expected to contain information on the early history of the Earth. Paleomagnetic information is useful for clarifying the distribution of continents and the geomagnetic situation in the early stage of the Earth's history. We collected paleomagnetic samples from the Mt. Riiser-Larsen area for these purposes on February 20–21, 1995. Preliminary paleomagnetic results have been reported by ISHIKAWA and FUNAKI (1997). Additional paleomagnetic and rock magnetic studies were carried out for those samples in order to assess the stability of their natural remanent magnetizations (NRMs).

2. Samples

We collected samples at eight sites in the western part of the Mt. Riiser-Larsen area on Amunsen Bay (Fig. 1); five sites of granulites of the Napier Complex (sites 1, 2, 3, 4 and 8) and three sites of dolerite dikes intruded the complex (sites 5, 6 and 7). Detailed geological work was later performed in the area by the geologic team of the

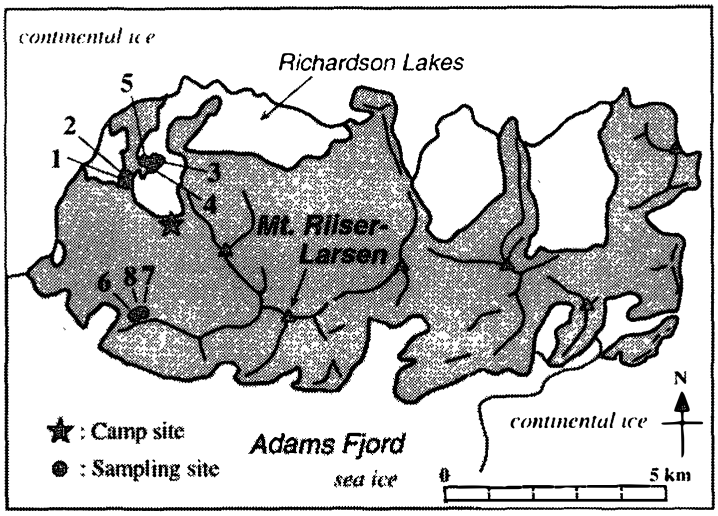

Fig. 1. Map showing sampling sites in the Mt. Riiser-Larsen area.

summer party of JARE-38. According to ISHIZUKA *et al.* (1997), sites 1, 2 and 5 are situated in a shear zone and sites 3 and 4 are in another shear zone. Microscopic observations revealed that granulite samples from sites 1, 2, 3 and 4 were subjected to mylonitization. Samples from sites 1, 2 and 3 show gray to black color, while those from site 4 are white. Principal minerals in samples from site 4 are plagioclase and quartz. The dolerite samples from the three sites (sites 5, 6 and 7) show igneous texture, but the samples from site 5 were subjected to stronger deformation than those from the other two sites. Granulite from site 8 consist mainly of plagioclase and quartz with garnet, and these grains are coarser (1–2 mm) than those from the other sites. The effect of deformation is less clear in the samples from site 8.

3. Paleomagnetic Data

We had previously presented paleomagnetic results on these rocks (ISHIKAWA and FUNAKI, 1997). However, we incorrectly calculated the *in-situ* directions of magnetic components. The corrected *in-situ* mean directions of the stable components are listed in Table 1, and the directions with α_{95} smaller than 30° are plotted in Fig. 2.

The NRMs of samples generally consisted of two components: the low-stability (L) component removed in low demagnetization steps and the high-stability (H) component isolated in high steps (ISHIKAWA and FUNAKI, 1997). Samples from sites 1 and 2 yielded additional stable components in the intermediate demagnetization range, referred to as the intermediate-stability (I) component (ISHIKAWA and FUNAKI, 1997). The L component directions from all sites except site 1 show steep negative inclinations and form a cluster (Fig. 2). The *in-situ* directions of these L components are close to the expected direction of the geocentric axial dipole field in the Mt. Riiser-Larsen area. The L component is probably of viscous remanence (VRM) origin, produced in the recent geomagnetic field. The *in-situ* directions of the I component from site 2 and the H components from sites 3 and 4 are close to those of the L component (Fig. 2), implying overprints of this secondary component on NRMs of the three sites. The H compo-

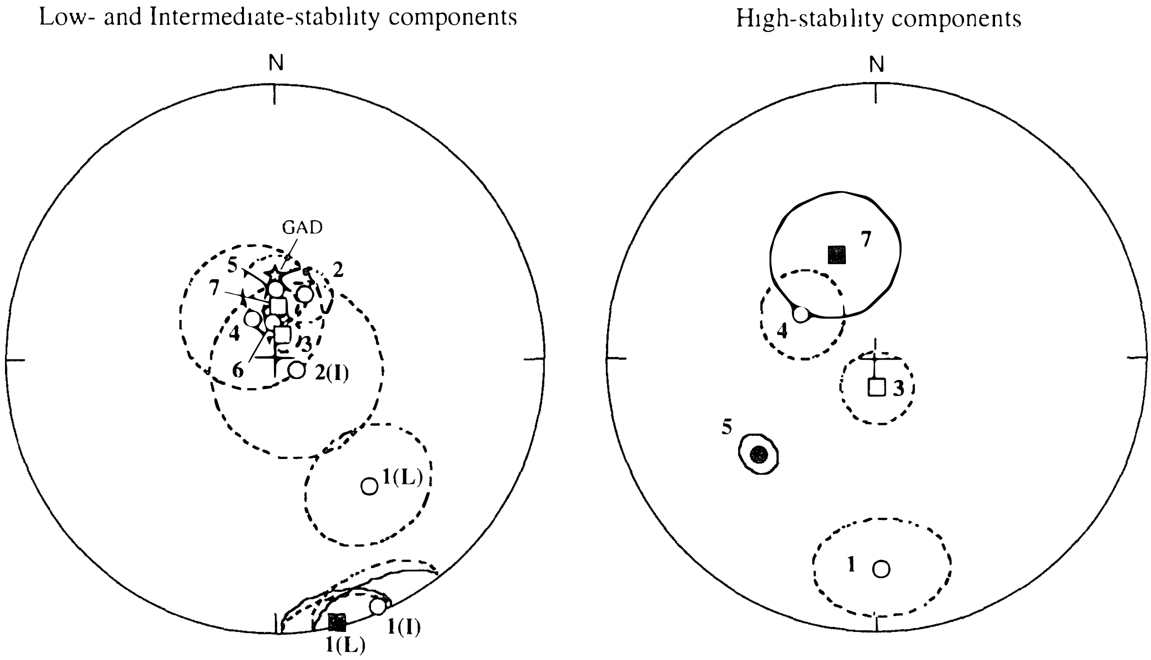

Fig. 2. Equal-area projections of site mean directions of stable magnetic components with α_{95} smaller than 30°. Circles and squares indicate components isolated by thermal and AF demagnetization, respectively. L, I and H are the low-, intermediate- and high-stability components, respectively. Solid (open) symbols are on the lower (upper) hemisphere. Ovals around the directions indicate 95% confidence limits. The star represents the geocentric axial dipole field direction (GAD) expected in the sampling area.

nents of dolerite sites (sites 5 and 7) show positive inclination in *in-situ* coordinates (Fig. 2). Samples from site 1 yielded the L, I and H components (Fig. 2). *In-situ* directions of these components are different from both the H component directions of dolerite dikes and the L component direction. ISHIKAWA and FUNAKI (1997) indicated that the H components of sites 1, 5 and 7 may be carried by fine-grained magnetites, and suggested the possibility that the H components of two dolerite sites (sites 5 and 7) may be of primary origin and that those of the granulite site (site 1) might have been acquired before the intrusion of the dolerites.

4. Rock Magnetic Analysis and Results

4.1. Hysteresis parameters

Hysteresis parameters were determined by the use of an Alternating Gradient Force Magnetometer (AGFM; Princeton Measurement Corporation, Model 2900-02) at Kyoto University. Values of coercive force (Hc), coercive force of remanence (Hcr), saturation magnetization (Ms) and saturation remanence (Mrs) were obtained through measurements of hysteresis loops, isothermal remanence (IRM) acquisition and DC demagnetizations of saturation IRM. Ten rock chips of 5 to 20 mg from each site were used for the experiments. Two specimens for each site were crushed and five rock chips were picked out from each crushed specimen. The maximum field was 1.0 T. Hyster-

Table 1. Paleomagnetic results from the Mt. Riiser-Larsen area.

Site No.	Demag. level	Comp	n/N	*In-situ* direction		α_{95} (°)	k	VGP (South pole)	
				Dec. (°)	Inc. (°)			Lat. (°S)	Lon. (°E)
1	AF 2–8	L	9/10	166.5	1.2	12.2	18.7	−23.2	36.0
	AF 8–20	H	9/10	192.3	−2.9	31.8	3.6		
	TH 80–200	L	6/7	143.3	−40.3	18.5	14.1	3.9	17.2
	TH 200–500	I	6/7	157.1	−2.2	14.8	21.4	−20.2	26.2
	TH 530–580	H	5/7	178.2	−23.3	17.5	28.7	−11.1	48.9
2	TH 80–200	L	6/8	26.0	−69.0	8.2	68.2	70.9	−74.7
	TH 200–500	I	4/8	120.3	−82.3	26.5	13.0	56.6	26.5
	TH 500–560	H	5/8	267.3	−8.7	41.7	4.3		
3	AF 2–10	L	10/10	20.7	−82.2	5.2	88.3	79.6	19.4
	AF 10–20	H	7/10	176.0	−81.3	11.1	30.7	49.8	48.9
4	TH 80–400	L	5/9	329.5	−75.9	21.7	13.3	76.8	141.3
	TH 400–540	H	3/9	301.2	−63.9	12.9	92.3	53.1	145.5
5	TH 80–240	L	8/10	0.3	−69.4	10.2	30.2	76.3	−128.6
	TH 400–570	H	9/10	231.3	43.0	5.8	80.9	−37.7	114.1
6	TH 80–320	L	5/10	355.9	−79.2	4.7	263.3	87.2	82.1
	TH 360–520	H	5/10	274.8	−28.2	35.7	5.6		
7	AF 2–10	L	9/12	5.7	−74.2	5.5	87.4	83.2	−104.8
	AF 20–60	H	6/12	338.8	56.0	19.2	13.1	−14.6	−146.8
Low-stability component									
mean (sites 2, 3, 4, 5, 6 and 7)				3.8	−75.7	6.1	123.1	86.3	−104.3
								(A_{95}=10.6°, K=40.8)	

Notes: Demag. level: levels of thermal (TH) and alternating field (AF) demagnetizations included in least-square line fitting (°C for TH and mT for AF). Comp: stable magnetic components isolated. L, I and H represent the low-, intermediate- and high-stability components, respectively. n/N: the number of specimens used in calculation (n) and subjected to demagnetization (N). Dec. and Inc.: declinations and inclinations of site mean directions in *in-situ* coordinates, respectively. α_{95} and A_{95}: the radius of the 95% confidence limit for site mean directions and a mean pole, respectively, k and K: precision parameters. VGP: virtual geomagnetic pole positions (south poles) calculated from *in-situ* site mean directions with α_{95} smaller than 30°.

esis data were slope-corrected to eliminate both paramagnetic and diamagnetic effects by subtracting the constant slope in the high field above 0.7 T from the values in the data.

Results of IRM acquisition experiments are shown in Fig. 3. The IRMs were saturated at 300 to 400 mT, indicating the presence of magnetite as a principal magnetic mineral. Hysteresis experiments indicated that the rock chips shows both ferrimagnetic and paramagnetic properties. Slope-corrected loops generally showed ordinary ferrimagnetic shapes (Fig. 4A). However, the slope-corrected loops of chips with large paramagnetic signal influence were anomalous (Fig. 4B). The reason for the anomalous shape was unknown. The anomalous loops were obtained from one chips from site 1, six from site 4 and eight from site 8. Hysteresis parameters were not determined from these chips. The slope-corrected loops of two chips from site 8 appeared to be of "wasp-waisted" shape (Fig. 4C). This shape indicates a bimodal

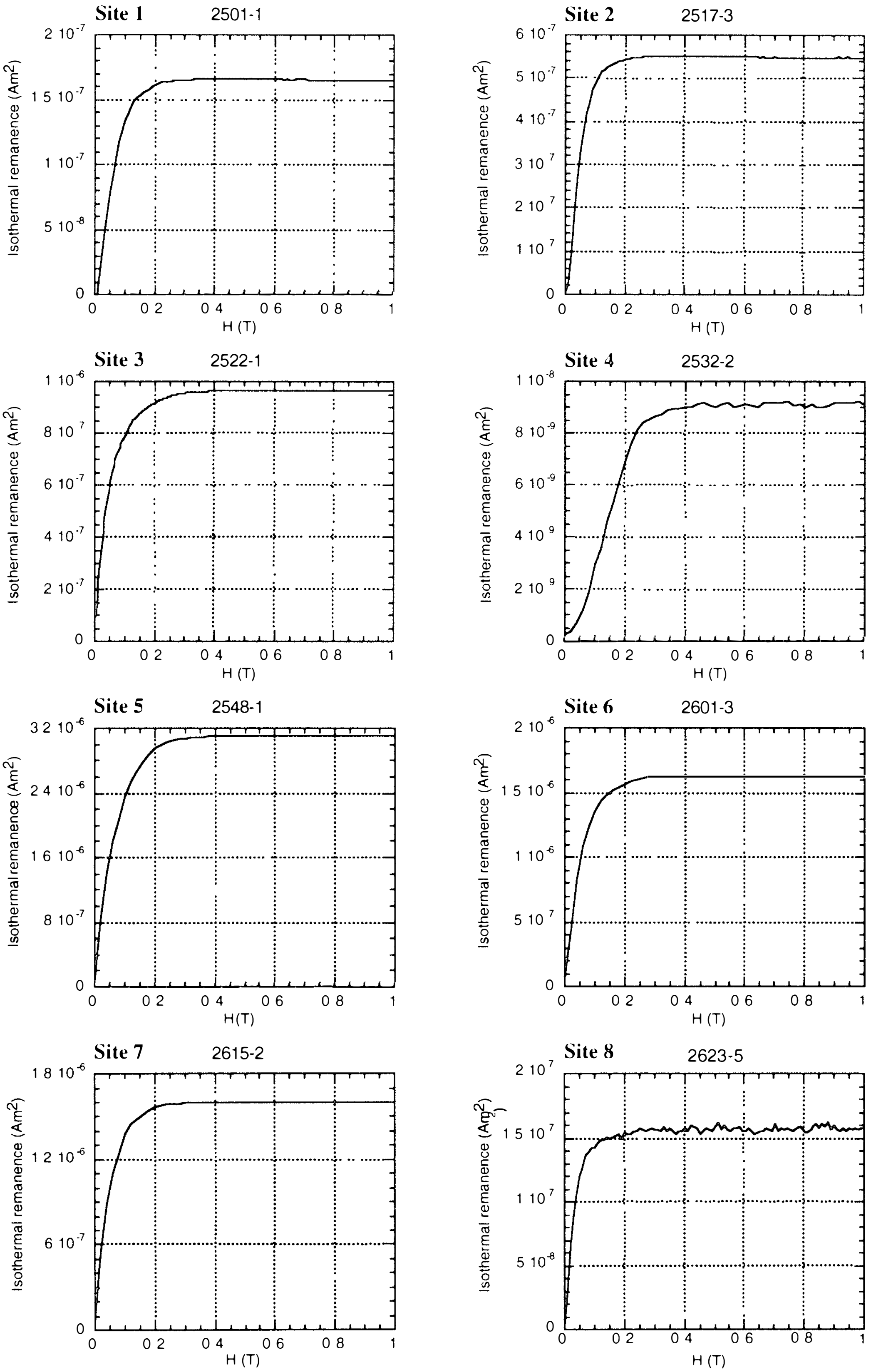

Fig. 3. Results of isothermal remanence acquisition experiments.

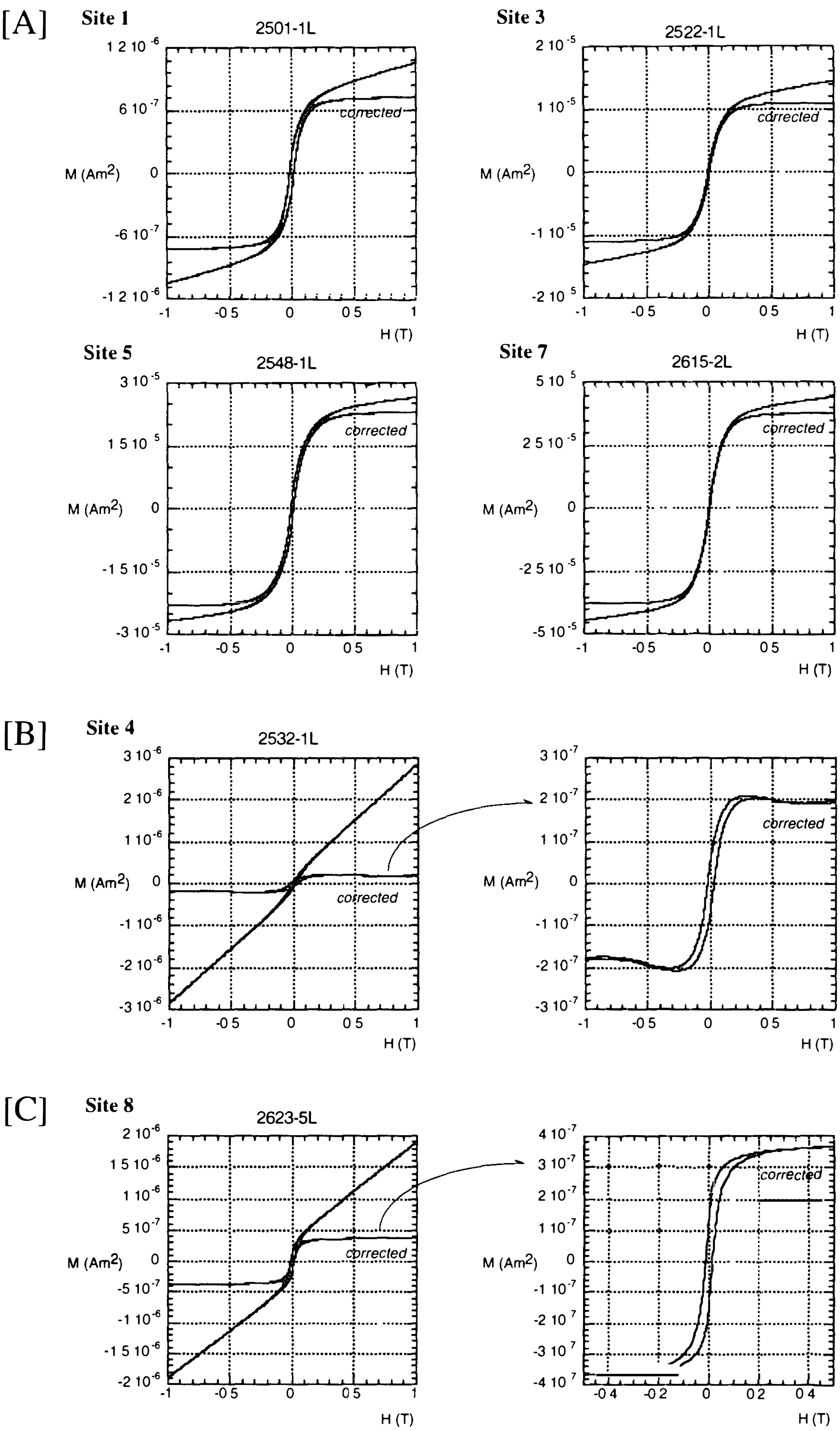

Fig. 4. Typical results of hysteresis loops. Slope-corrected hysteresis data (corrected) are also shown.

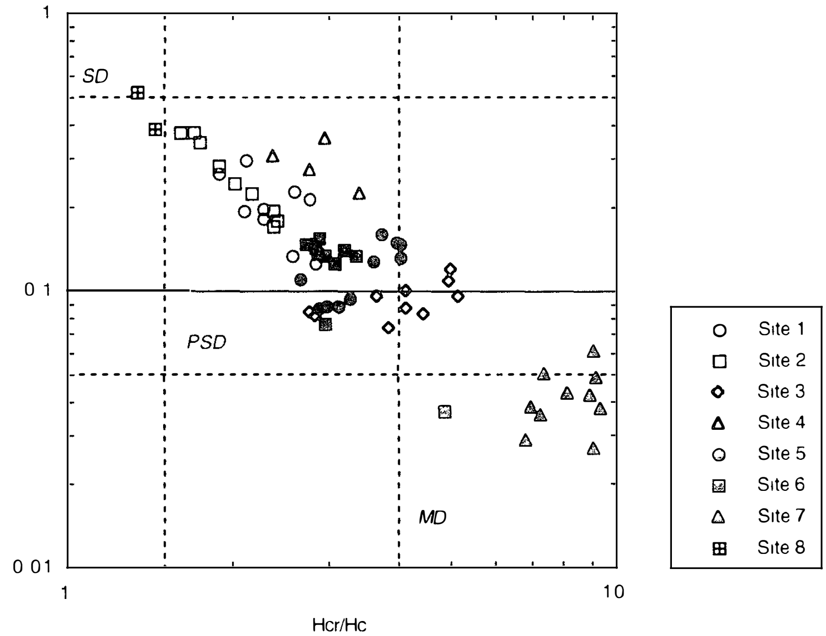

Fig. 5. A logarithmic plot of hysteresis parameters. Single domain (SD), pseudo-single domain (PSD) and multidomain (MD) fields (after DAY et al., 1977).

coercivity distribution of magnetic minerals (PARRY, 1980, 1982; JACKSON, 1990, JACKSON *et al*, 1993; CHANNELL and MCCABE, 1994); coercivity contrasts araise from mixtures of grain size of a single magnetic mineral or from a combination of magnetic minerals with large different coercivities. The values of Mrs/Ms and Hcr/Hc at all sites except sites 7 and 8 lie in the pseudo-single domain (PSD) field (Fig. 5) according to the criteria of DAY *et al.* (1977). The hysteresis ratios of site 7 lie in the multi domain (MD) field, while those of site 8 in the region lie in and around the single domain (SD) field.

4.2. *Anisotropy of magnetic susceptibility*

Anisotropy of magnetic susceptibility (AMS) was measured with a KLY-3S susceptibility meter (AGICO Inc.) at Kyoto University. Five to ten specimens of paleomagnetic standard size for each site were subjected to the measurements, including specimens after demagnetization by the alternating field (AF) method. The anisotropy degree (Pj) and shape parameter (T) of a susceptibility ellipsoid (JELINEK, 1981) were calculated.

Initial mean mass susceptibilities of specimens from sites 1, 2 and 4 ranged from 10^{-8} to 10^{-6} m^3/kg and those from site 8 were on the order of 10^{-7} m^3/kg. Specimens from sites 3, 5, 6 and 7 had mass susceptibilities of 10^{-6} to 10^{-5} m^3/kg, which correspond to volume susceptibilities of 10^{-3} to 10^{-2} SI, if the volume of each specimen is assumed to be that of the standard paleomagnetic specimen (11.1 cc). The susceptibility values indicate that main carriers of AMS are ferrimagnetic minerals for sites 3, 5, 6 and 7, and those of AMS of the other sites are both ferrimagnetic and paramagnetic minerals (TARLING and HROUDA, 1993).

Anisotropy parameters and directions of magnetic fabrics are plotted in Figs. 6 and

7, respectively. Almost all specimens from sites 4, 7 and 8 showed low Pj values (< 1.1), while the Pj values from the other sites were higher than 1.1 (Fig. 6). The T values appeared to become higher, that is, the oblateness of magnetic fabrics increased, as the Pj values increased. The oblate magnetic fabrics were more remarkable in specimens from sites 3 and 6. Magnetic fabrics of all sites except site 4 yielded a cluster

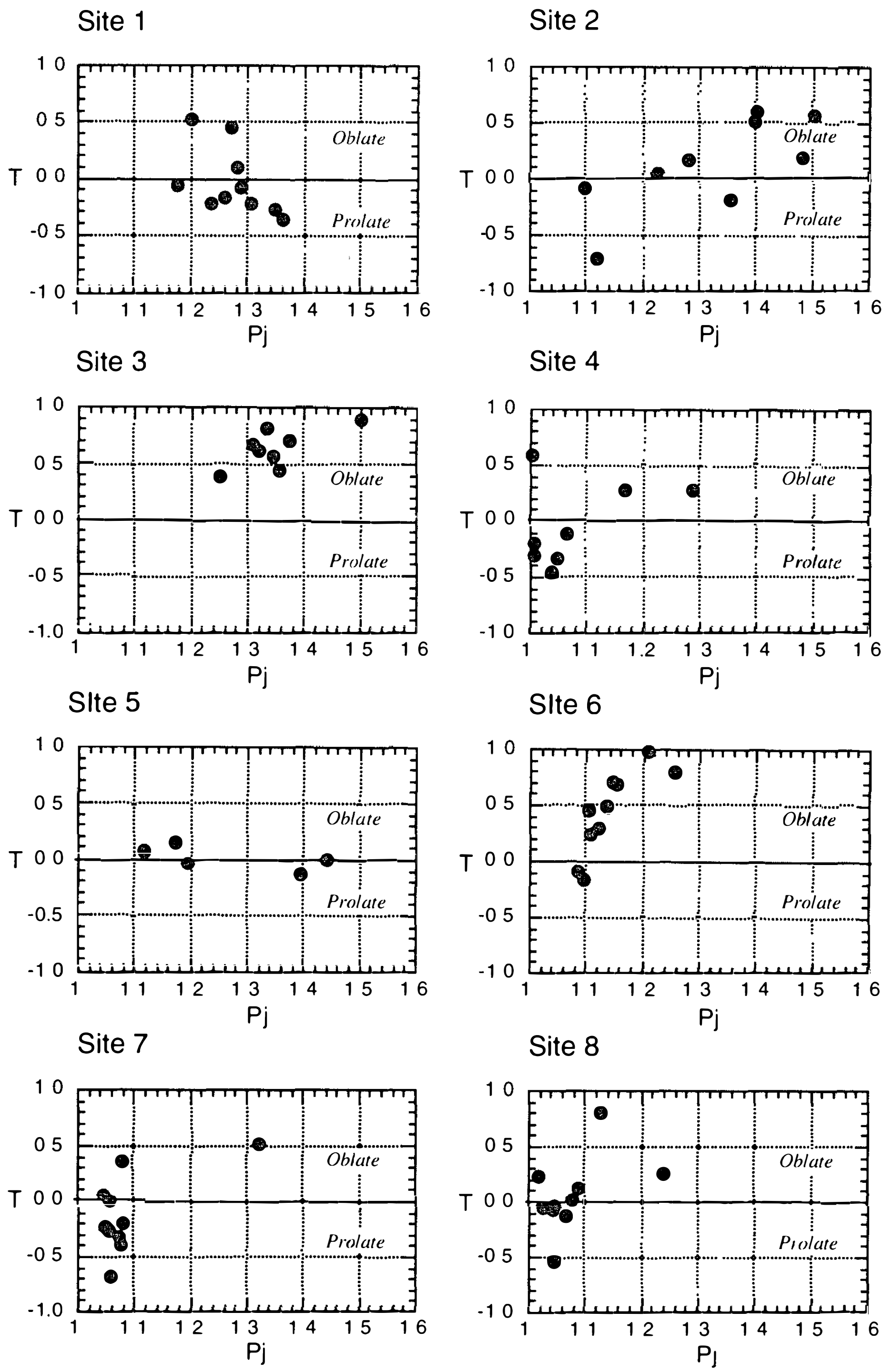

Fig. 6. Plots of the magnitude of the shape parameter, T, against the anisotropy degree, Pj.

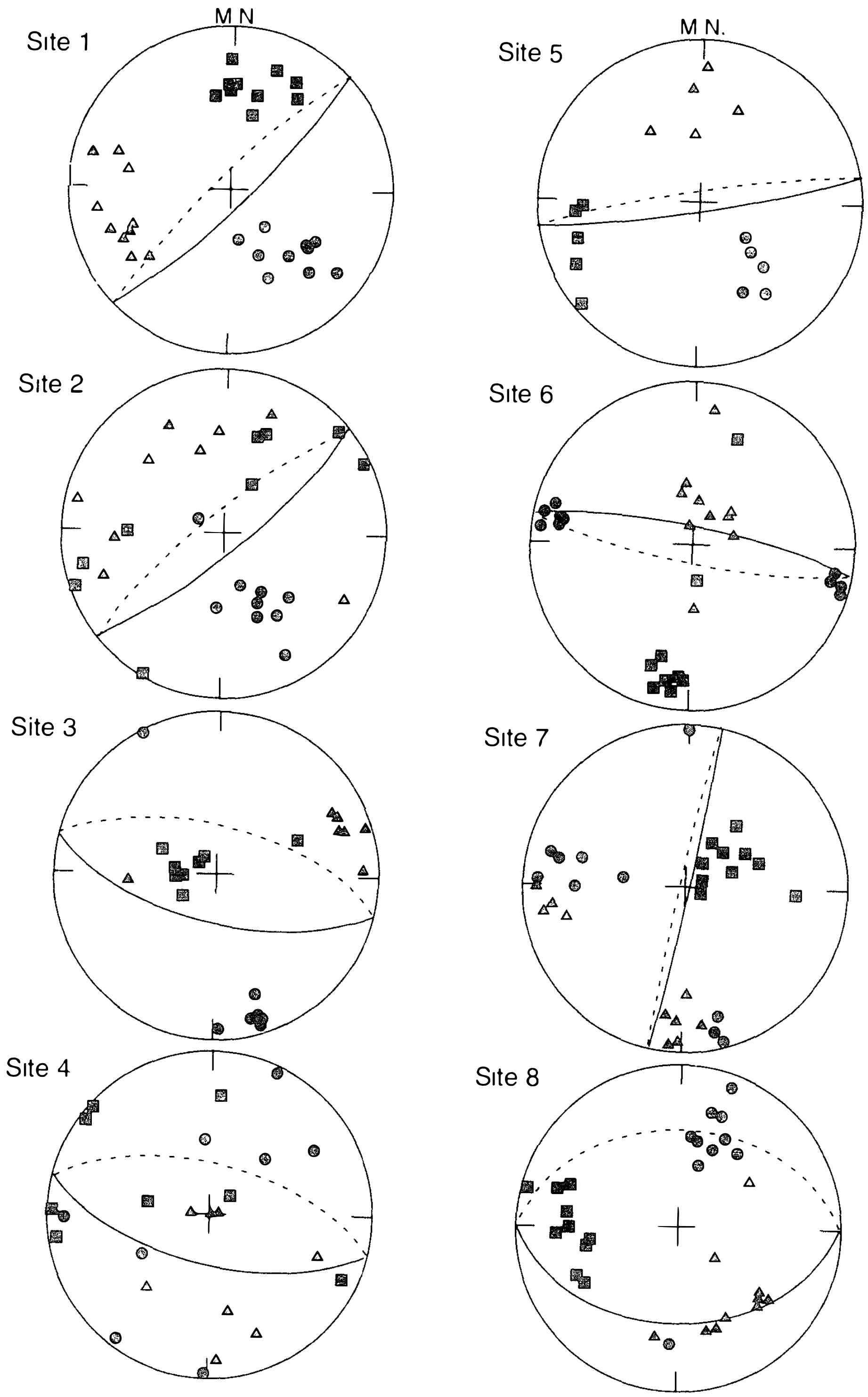

Fig. 7. Equal-area plots of directions of the principal susceptibility axes of magnetic fabrics. The directions of the maximum (K1), intermediate (K2) and minimum (K3) principal axes are plotted as squares, triangles and circles, respectively. Solid symbols are on the lower hemisphere. Great circles indicate planes of petrographical foliations of granulite contact planes of dolerite dikes. M.N. denotes the magnetic north. The magnetic declination (55.5° W) in the sampling area is not taken into account in this figure.

of the minimum susceptibility (K3) axes (Fig. 7). Directions of the maximum (K1) and intermediate (K2) susceptibility axes from sites 1, 5 and 7 were also grouped, while the K1 and K2 directions of sites 2, 3, 6 and 8 appeared to show girdle-like distribution. The K3 directions of sites 1 and 2 located in the same shear zone were consistent. The magnetic foliations of the two sites were inclined against the petrographical foliations. The petrographical foliation of site 3 was different from those of sites 1 and 2, and the magnetic foliation of site 3 was also different. The magnetic foliation of site 3 intersected the petrographical foliation. On the other hand, the magnetic foliation of site 8 was approximately parallel to the petrographical foliation. One of the general characteristics in magnetic fabrics from dike rocks is that the K3 axis is normal to the contact plane (*e.g.*, MacDonald and Ellwood, 1987). Such a feature was recognized in the magnetic fabrics from site 7 (dolerite dike); the K3 directions of six specimens from site 7 were approximately normal to the contact plane. The remaining four specimens yielded K2 axes normal to the contact plane and K3 axes parallel to the contact plane. Magnetic foliations of the other dolerite dikes (sites 5 and 6) intersected their contact planes. The orientation of the magnetic fabrics of site 5 was rather similar to those of sites 1 and 2.

5. Discussion and Conclusions

Ishikawa and Funaki (1997) showed the existence of magnetite in samples from the Mt. Riiser-Larsen area based on the results of demagnetization experiments of natural remanent magnetizations (NRMs) and strong-field thermomagnetic experiments. The IRM acquisition experiment results in this study are consistent with Ishikawa and Funaki (1997). The NRMs were characterized by a median demagnetization field (MDF) lower than 10 mT (Ishikawa and Funaki, 1997). The low MDF implies a large contribution of magnetites of large grain size to the NRMs. The fact that the values of hysteresis ratios are distributed in the PSD and MD fields probably supports the above implication. However, samples from site 7, from which the values of hysteresis ratios lie in the MD field, yielded stable magnetic components isolated at high alternating filed (AF) demagnetization steps above 20 mT. The carrier of the stable component with high coercivity is considered magnetite of fine grain size, which is not consistent with the hysteresis measurement results. Mixtures of magnetites with different grain sizes, for example, the mixture of SD and MD magnetites or PSD and MD magnetites, have the possibility that the values of the hysteresis ratios lie in the MD field (*e.g.*, Parry, 1980, 1982). The high Hcr/Hc values of site 7 may imply a bimodal coercivity distribution in magnetite. The MDFs of samples from site 8 were lower than 5 mT (Ishikawa and Funaki, 1997), implying that large grains of magnetite are NRM carriers. Although the values of the hysteresis ratios of the two chips from site 8 are plotted in the SD field, the "wasp-waisted" hysteresis loops of the chips may indicate mixing of MD magnetites and smaller ones.

Mylonitization is observed in granulite samples from sites 1, 2, 3 and 4. Goldstein (1980) indicated that samples from mylonite zones had higher values of anisotropy degree than non-mylonitized samples and yielded more oblate magnetic fabrics. Such features are observed in samples from sites 1, 2 and 3. Goldstein

(1980) also indicated that the magnetic foliation of mylonite was parallel to the mylonite foliation. However, the magnetic foliations of sites 1, 2 and 3 are not parallel to the petrographical foliations observed in the field. The directional relationship between magnetic fabrics and internal petrographical structures of the samples has to be assessed through microscopic observations. Magnetic fabrics of site 4 yield low magnitude of anisotropy degree and no directional trend. The hysteresis loops of site 4 indicate a small ferrimagnetic contribution. The AMS of site 4 may be dominated mainly by paramagnetic minerals, probably plagioclases. Plagioclases in samples from site 4 may have no remarkable directional trend. The values of mean susceptibility indicate that the AMS of sites 1 and 2 is affected by both ferrimagnetic and paramagnetic minerals as well as site 4. The AMS of the two sites, however, is possibly controlled mainly by ferrimagnetic minerals (magnetites) because the existence of ferrimagnetic minerals was suggested clearly by the hysteresis results. Granulites at site 8 show no significant deformation. The magnetic fabrics, of which magnetic foliation is parallel to the petrographical foliation, may be primary fabrics associated with granulite formation. Among magnetic fabrics from dolerite dikes, the fabrics from site 7 may also be primary because K3 axes normal to the contact plane are obtained. The fabrics with K2 axes normal to the contact plane are possibly caused by interchange of K2 and K3 axes because the magnitude of fabrics is low. Samples from site 5 show intensive shearing, and the K3 directions of site 5 are consistent with those of sites 1 and 2. It is thus implied that the dolerite dike at site 5 as well as granulites of sites 1 and 2 had been subjected to a deformation event. The magnetic fabrics of site 6 are not a general feature of dike rocks. If the magnetic fabrics of sites 7 and 8 are primary, the anomalous fabrics may be attributed not to any regional tectonic event around sites 6, 7 and 8, but to internal structure (*e.g.*, magma flow) of the dike at site 6.

The H components from sites 1, 5 and 7 are free from the influence of a viscous remanence imparted in the recent geomagnetic field. ISHIKAWA and FUNAKI (1997) suggested the possibility that the H components of the two dolerite sites (sites 5 and 7) are primary remanences and that those of the granulite site (site 1) had been acquired before the emplacement of the dolerites. Samples from sites 1 and 5 show intensive deformation and are magnetically anisotropic. It is thus suggested that the component directions from sites 1 and 5 may be affected by deformation and/or the magnetic anisotropy observed in those samples. The samples from site 7, which are less deformed, are less anisotropic magnetically and probably show primary magnetic fabrics. The H component from site 7 may be of primary origin although the presence of SD magnetites as the carrier of the component is not indicated clearly by the rock-magnetic experiments in this work. TAKIGAMI *et al.* (1998) obtained ages of about 0.8 to 1.0 Ga with the ^{40}Ar-^{39}Ar geochronological method from samples from site 7. The virtual geomagnetic pole (VGP) of the component is not close to the apparent polar wander path (APWP) for East Gondwanaland between about 0.5 and 1.0 Ga (POWELL *et al.*, 1993; GRUNOW, 1995; Fig. 8). It is possible that continental fragments of East Gondwanaland were distributed in a different frame at the emplacement of the dike. However, there are only three poles before 700 Ma in East Gondwanaland: two poles of 730 Ma from India and Australia and one pole of 1.0 Ga from Australia (POWELL *et al.*, 1993). In order to assess this possibility, it is indispensable to obtain more

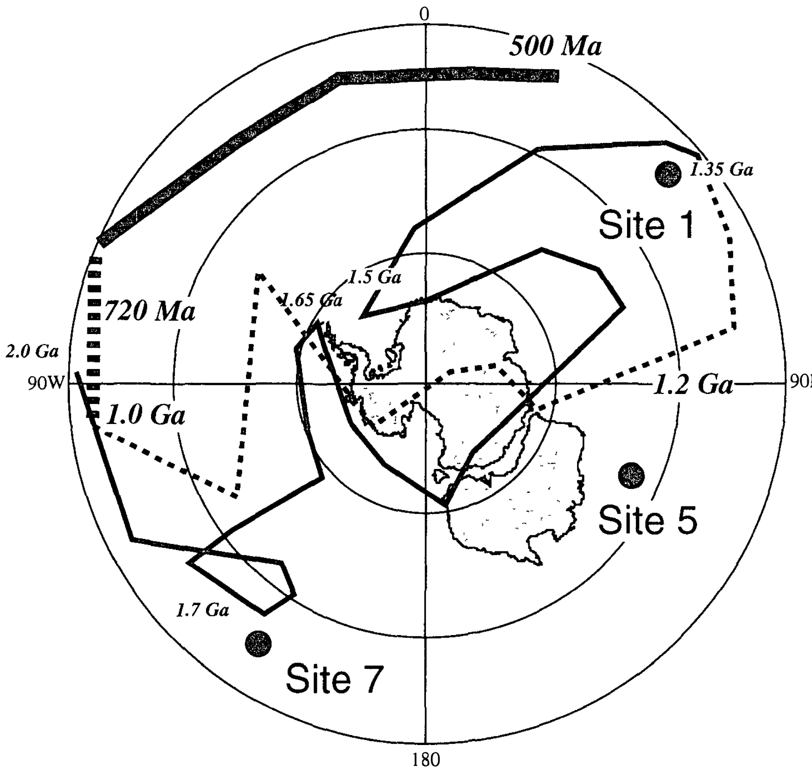

Fig. 8. Equal-area projection of VGP positions for the high-stability components from sites 1, 5 and 7. South poles are plotted. Solid and open symbols are on the lower (northern) and upper (southern) hemispheres, respectively. The thick line is the APWP for East Gondwanaland between about 0.5 and 1.0 Ga (POWELL et al., 1993; GRUNOW, 1995). The thin line is the APWP for Australia between 1.0 and 2.0 Ga (IDNURM and GIDDINGS, 1988; TANAKA and IDNURM, 1994; IDNURM et al., 1995). These APWPs are converted to paths in the East Gondwanaland reference frame using the parameters of POWELL et al. (1988) and shown in present-day Antarctica coordinates. Solid (broken) segments of the paths are on the southern (northern) hemisphere.

paleomagnetic poles from dike rocks in the Mt. Riiser-Larsen area as well as other fragments of East Gondwanaland.

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