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THE MAGNETIC ANISOTROPY OF GNEISSIC ROCKS FROM THE SKARVSNES AREA, EAST ANTARCTICA

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Abstract: The relationship between magnetic anisotropy and natural remanent magnetization (NRM) was investigated in the gneissic rocks collected from Skarvsnes, Lützow-Holm Bay, East Antarctica. About 60% of the samples show clear gneissosity, but 40% of the samples have less clear gneissosity. The samples with gneissic fabric show magnetic anisotropy. The maximum value of H_C and I_R, and the minimum values of χ_{diff} coincide with the lineation within a foliation plane. During thermal demagnetization of the samples having stable NRM's, the NRM declinations are gradually shifted toward the direction of lineation, and they are stabilized in a plane, within the rock, having well developed foliation. The anisotropy tendency is more clearly observed by using the H_C and I_R values than χ_{diff} values. Two kinds of virtual geomagnetic pole (VGP) positions are identified from the Skarvsnes area. The former is consistent (latitude 11.2°S, longitude 16.0°E) with the previous results reported from the Lützow-Holm Bay area, and the latter (latitude 2.5°S, longitude 63.2°E) reflects the magnetic anisotropy resulting from the lineation.

1. Introduction

We report preliminary results for the natural remanent magnetization (NRM) characteristics, and magnetic anisotropy obtained from the hysteresis properties using gneissic rocks from the Skarvsnes area (latitude (Lat.) = 69.5°S, longitude (Lon.) = 39.6°E) on the east coast of Lützow-Holm Bay, Queen Maud Land, East Antarctica (Fig. 1).

In this area, various kind of gneissic rocks are exposed, such as garnet-biotite gneiss, hornblende gneiss, pyroxene gneiss and metabasite (ISHIKAWA *et al.*, 1977). The Skarvsnes area is situated in the granulite facies terrain of the Lützow-Holm Complex, which is geologically characterized by the progressive metamorphism of medium pressure type (HIROI *et al.*, 1987; SHIRAISHI *et al.*, 1987). The peak metamorphic condition is estimated to be 810°±20°C in temperature and about 7 kb (7×10^8 Pa) in pressure (HIROI *et al.*, 1987).

The Lützow-Holm Complex has been deformed at least twice (HIROI *et al.*,

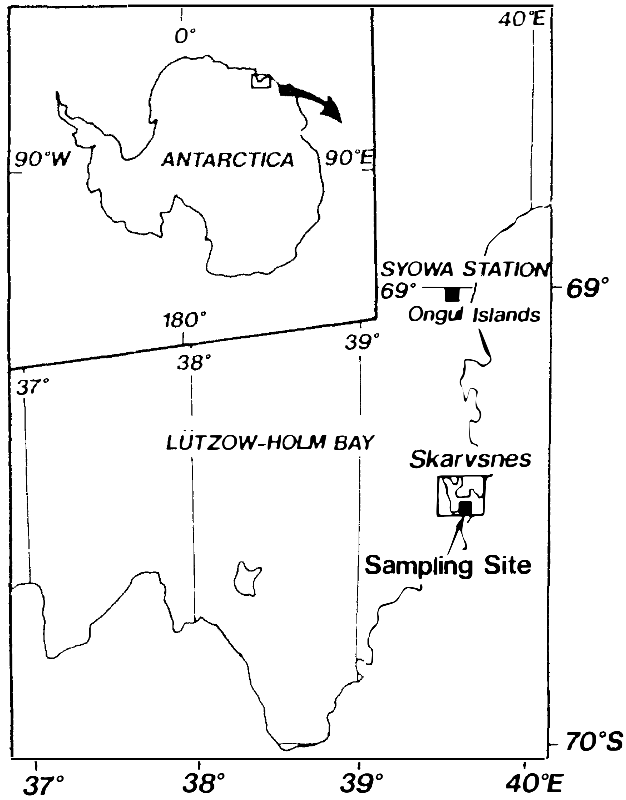

Fig. 1. The location of Skarvsnes, Antarctica.

1987), and the age of the latest regional metamorphism with associated folding was estimated to be about 500 Ma (SHIRAISHI *et al.*, 1992). The geochronological ages of the gneissic rocks from the Skarvsnes area were obtained as 510±30 Ma (Rb-Sr; NICOLAYSEN *et al.*, 1961), 458±10 Ma (Rb-Sr isochron; MAEGOYA *et al.*, 1968), 1100 Ma (Rb-Sr isochron; MAEGOYA *et al.*, 1968), 1300 Ma (Rb-Sr isochron; SHIBATA *et al.*, 1986) and 1900 Ma (Pb-Pb isochron; SHIRAHATA, 1983). Ages around 500 Ma may indicate the most recent thermal event in the Skarvsnes area.

Generally, gneissic rocks have well developed layered fabric and the NRM direction appears to be influenced by the orientation of the associated magnetic mineral fabric. Anisotropy of magnetic susceptibility (AMS) has generally been used for identification of the magnetic fabric, but STEPHENSON *et al.* (1986) indicate, for example, that the single domain (SD) uniaxial prolate grains of magnetite had a zero susceptibility along the easy axis of magnetization, and an AMS did not agree with the anisotropy of an isothermal remanent magnetization (IRM). However, there dose not appear to be such clarity about the relationship between the NRM direction and the magnetic anisotropy for gneissic rocks. Therefore, to elucidate the relationship between the NRM and obvious magnetic anisotropy, we evaluate magnetic susceptibility (differential susceptibility (χ_{diff}): gradient of the magnetic hysteresis loop at the abscissa after the saturation of magnetization), saturation isothermal remanent magnetization (SIRM) and coercive force (H_C) (all of which are obtained from the magnetic hysteresis loops).

2. Description of Samples and Measurements

A total of 136 oriented samples of gneissic rocks such as pyroxene gneiss, biotite gneiss, garnet biotite gneiss and other gneisses, were collected at 10 sites (site A-site J) around Mt. Suribati, southern part of Skarvsnes (Lat. = 69°30′, Lon. = 39°39′) as located in Fig. 1. The drilled one inch core samples were cut into one inch long

Table 1. The characteristics of samples from Skarvsnes.

Site	Sample name	Rock	N	Gneissosity
A	921- 939	Garnet-biotite gneiss	14	○
		Garnet gneiss	5	×
B	940- 955	Garnet-hornblende gneiss	5	△
		Garnet-biotite gneiss	6	△
		Garnet gneiss	5	○
C	956- 962	Pyroxene gneiss	4	○
		Hornblende gneiss	3	×
D	963- 976	Pyroxene gneiss	10	△
E	977- 980	Biotite gneiss	4	×
F	981- 984	Metabasite	4	×
G	985- 990	Biotite gneiss	6	○
H	991- 998	Garnet-biotite gneiss	6	○
I	999-1014	Garnet gneiss	6	△
		Garnet-biotite gneiss	10	○
J	1015-1060	Pyroxene gneiss	20	×
		Garnet gneiss	26	○

Gneissosity ; ○ : well developed lineation and foliation, △ : poorly and no developed foliation, × : no developed foliation.

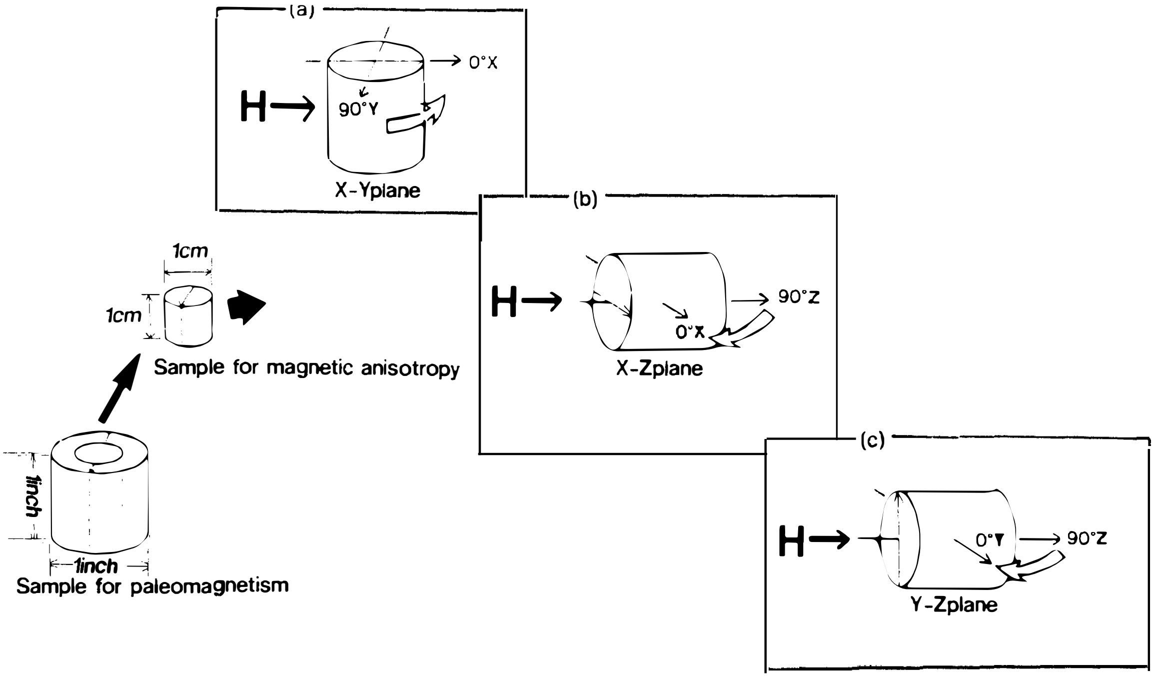

Fig. 2. The method of measuring magnetic anisotropy by a VSM.

cylinders for analysis. Clear gneissosity was recognized in 73 samples, but it was less clear in 58 samples. The character of the gneissosity in rock types from each sampling site, is indicated in Table 1.

The NRM's before and after AF and thermal demagnetizations were measured using a 3-axis cryogenic magnetometer. The magnetic hysteresis loops were measured at room temperature using cylindrical core samples of 1 cm in both diameter and length. The magnetic hysteresis loops were determined by cycling between -0.8 T and $+0.8$ T, from which I_R, H_C and χ_{diff} values were obtained. In order to estimate spatial variations of the magnetic properties, the hysteresis loops were measured at every 15° in the x-y, y-z and z-x planes of the sample (Fig. 2).

3. NRM Characteristics

A survey of the NRM stability to AF and thermal demagnetizations was completed for select samples in order to determine the demagnetization characteristics. The AF demagnetization was carried out, stepwise at every 5 mT up to 50 mT, and the thermal demagnetization in 50°C steps up to 630°C. The typical Zijderveld projection for one sample which carries a stable NRM component is shown in Fig. 3a. During thermal demagnetization, the soft component was removed from the NRM (2.58×10^{-5} Am^2/kg) below 230°C. On the basis of these results, the optimum field and temperature for the magnetic cleaning were assumed to be 25 mT and 230°C, respectively.

The samples showing stable NRM's against AF demagnetization and the NRM directions after thermal demagnetization at 280°C are shown in Fig. 4. The direc-

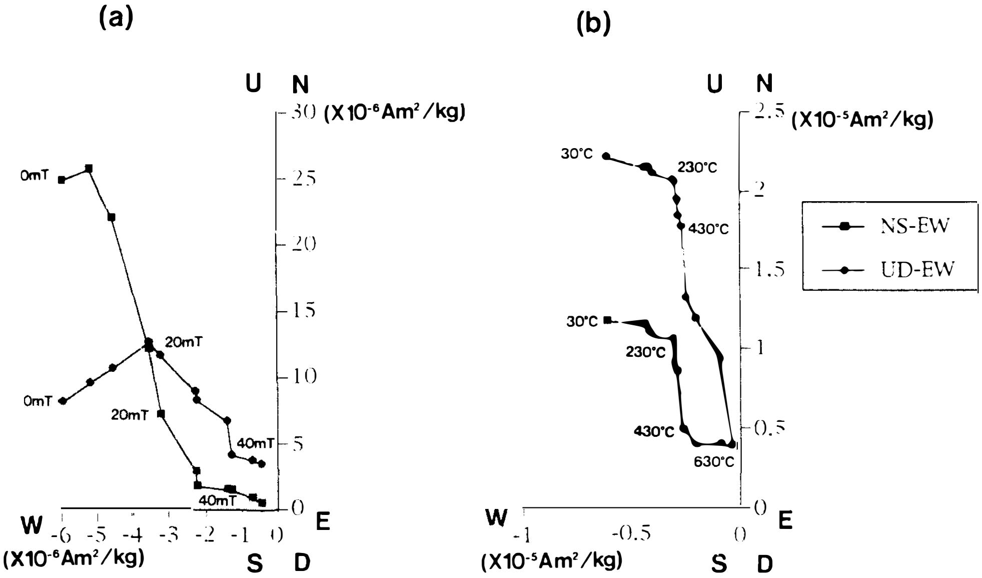

Fig. 3. Zijderveld graphs of AF and thermal demagnetization of NRM of the gneissic rocks from Skarvsnes. E: East, W: West, N: North, S: South, U: Up, D: Down
(a) AF demagnetization (0–50 mT).
(b) Thermal demagnetization (30°C–630°C).

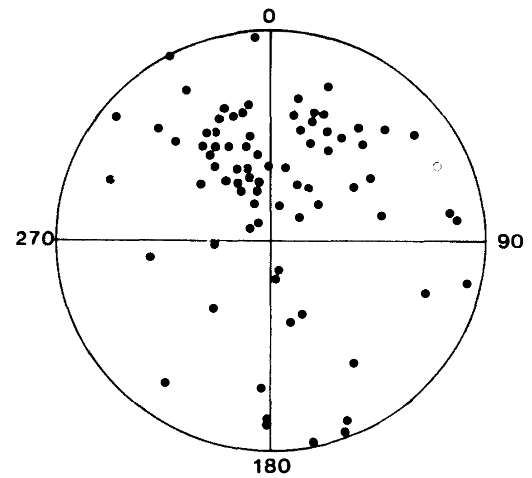

Fig. 4. All NRM directions which have stable NRM against AF demagnetization (after thermal demagnetization: 330°C or 280°C).

tions of the stable NRM's are scattered. The dispersion of the directions of the stable component of the NRM seems to correlate with the gneissosity of the samples.

Samples were divided into two groups based on the extent to which the NRM directions move toward the lineation within the foliation planes, *i.e.*, group (ab) and (c). Group (ab) NRM directions move slightly toward lineation within a foliation plane of the rocks, and group (c) NRM's exhibit drastic excursions. Observationally, the samples without foliation or with poorly-developed foliation were found to belong to group (ab) and those with well-developed foliation to group (c).

Figure 5 shows three examples of group (c). The solid/open circles show downward/upward NRM directions, and solid/dotted arrows denote upward/downward directions of the lineation within the foliation plane. The directions of the original NRM after AF (25 mT) demagnetization and after thermal (180°C, 280°C

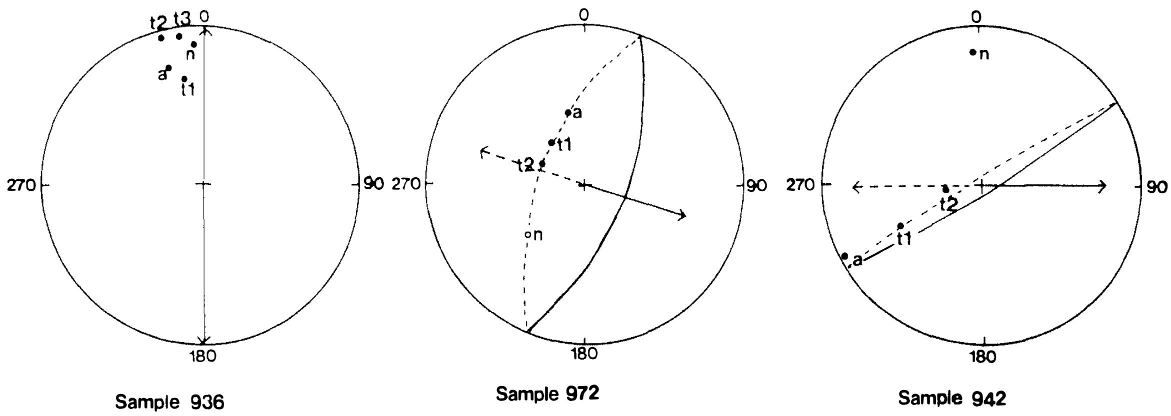

Fig. 5. Change in the direction of NRM during the demagnetizations, and the direction of fabric lineation of minerals within a foliation plane. (The arrow of solid line: upper hemisphere, the arrow of the broken line: the lower hemisphere, n: original NRM, a: after AF demagnetization at 25 mT, t1/t2/t3: after thermal demagnetization at 180°C/230°C/330°C)

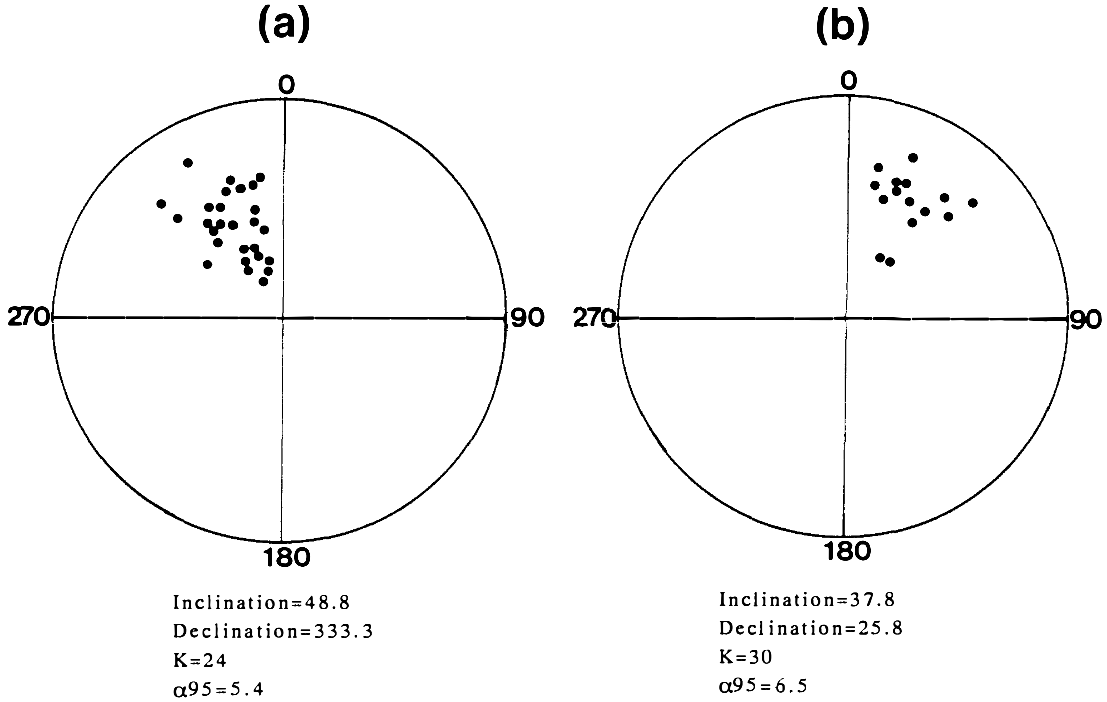

Fig. 6. The paleomagnetic results of the gneissic rocks from Skarvsnes area.
(a) VGP: Lat. = 11.2°S, Lon. = 16.0°E
(b) VGP: Lat. = 2.5°S, Lon. = 63.2°E

and 330°C) demagnetizations are denoted *n, a, t*1, *t*2 and *t*3, respectively. The direction of the original NRM for sample 936 is nearly parallel to that of the lineation. In the case of sample 972 and sample 942, the NRM directions during demagnetizations align along a great circle. For these two cases, the NRM direction after thermal demagnetization at 280°C (*t*2) finally aligned with the lineation.

After thermal demagnetization at 280°C, the NRM directions of the samples of group (ab), fall into two sub-groups with different mean directions. The mean direction of group (a) is inclination $(I)=48.8°$, declination $(D)=333.3°$ with the sample number $(N)=27$, precision $K=24$ and confidence of 95% probability $(\alpha_{95})=5.4°$. The mean direction of group (b) is ; $I=37.8°$, $D=25.8°$, $N=15$, $K=30$ and $\alpha_{95}=6.5°$. From these results, vertical pole positions (VGP) were derived from the mean NRM directions of data sets shown in Fig. 6.

4. Magnetic Anisotropy

In order to elucidate the relation between the NRM direction and the anisotropy of the magnetic properties, we subjected cylindrical core samples to magnetic hystereanial; from which magnetic properties (I_R, H_C and χ_{diff}) were derived. Figure 7 shows an example of the variation of I_R, H_C and χ_{diff} values in the x-y plane for one sample from each group (sample 926 : group (a), sample 921 : group (b) and sample 942 : group (c)).

In the case of the samples in group (a), H_C and I_R values are regarded as

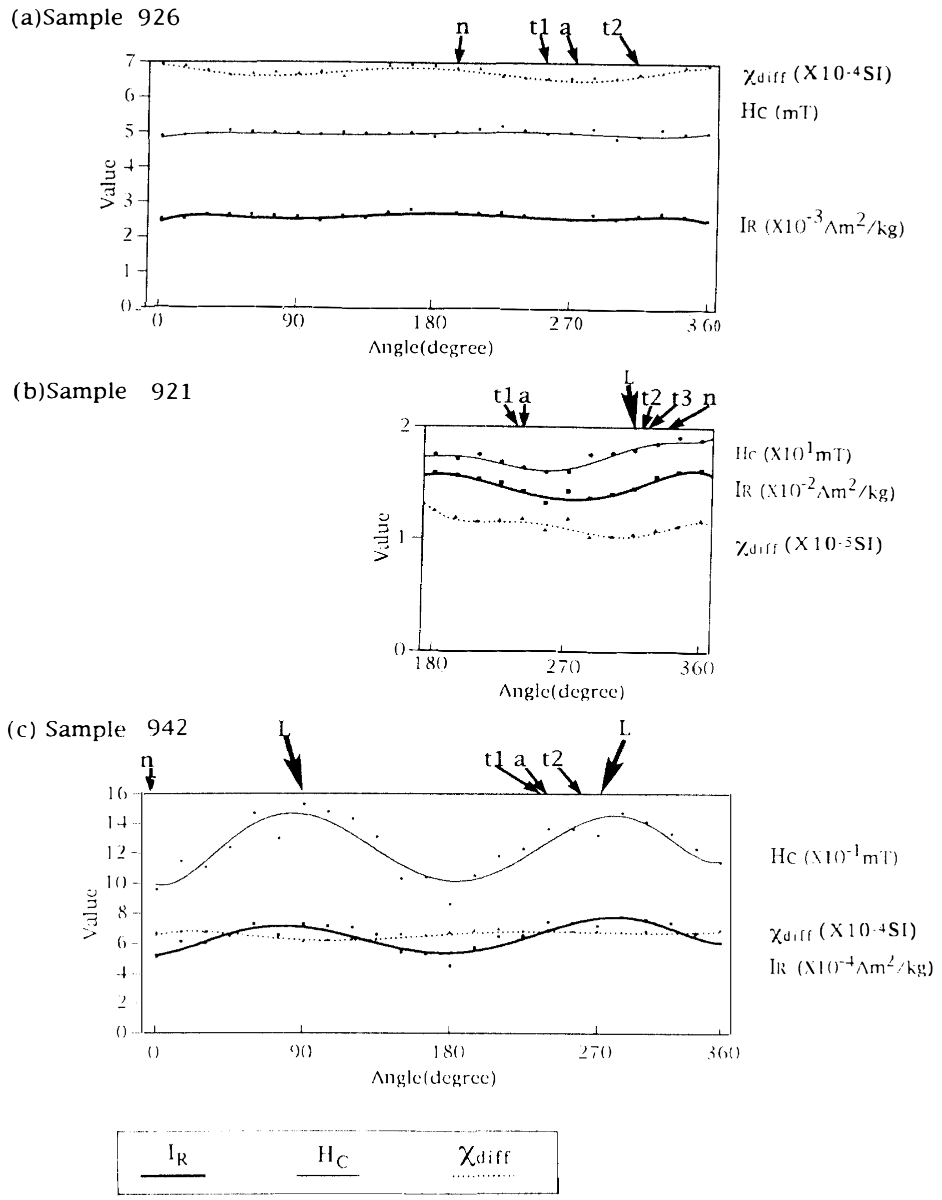

Fig. 7. The magnetic anisotropy of gneissic rocks from Skarvsnes. I_R: saturation isothermal remanent magnetization, H_C : coercive force, χ_{diff}: differential susceptibility at abscissa of the hysteresis loop, ↓ L: the direction of the lineation, ↓ : the direction of NRM (n: original NRM, a: after AF demagnetization at 25 mT, t1, t2, t3: after thermal demagnetization at 180° C, 280° C, 330° C).

(a) The sample which belongs to group (a) in Fig. 6, with no developed foliation.

(b) The sample which belongs to group (b) in Fig. 6, with poorly developed foliation.

(c) The sample which belongs to group (c) with well developed lineation and foliation.

isotropic within experimental error. On the other hand, a maximum value ($\chi_{diff(max)}$) can be recognized at 0° and 180°, and a minimum one ($\chi_{diff(min)}$) at 90° and

270°. The NRM direction does not shift toward the ($\chi_{diff(min)}$) or ($\chi_{diff(max)}$) during the demagnetizations. The sample of group (b) shows small anisotropy in H_C and I_R, indicating maximum values ($H_{C(max)}$, $I_{R(max)}$) at 180° and 360° and minimum values ($H_{C(min)}$, $I_{R(min)}$) at about 270°. The χ_{diff} value of this sample is too small (19%, $((\chi_{diff(max)}-\chi_{diff(min)})/\chi_{diff(mean)})\times 100(\%)$) to observe anisotropy. The NRM declinations after thermal demagnetizations (*t*2 and *t*3) are almost parallel to the direction of the lineation within a foliation plane. The group (c) sample shows large anisotropy in I_R and H_C, indicating maximum values ($H_{C(max)}$, $I_{R(max)}$) at 90° and 280° and minimum values ($H_{C(min)}$, $I_{R(min)}$) at 0° and 190°. On the other hand, the anisotropy in χ_{diff} of this sample is small and anti-phase to that of H_C and I_R. The direction of $H_{C(max)}$ and $I_{R(max)}$ is almost parallel to that of the lineation. The NRM declination shifts toward the direction of the lineation during the progressive demagnetizations up to 280°C (*t*2).

5. Discussion

In this study, the samples with stable NRM's against AF demagnetization, are classified into 3 groups (a, b, c) based on demagnetization characteristics and NRM clusters; group (a): the NRM's cluster (the mean direction: $I=48.8°$, $D=333.3°$) and the directions do not shift during the demagnetizations; group (b): they make a cluster (the mean direction: $I=37.8°$, $D=35.8°$) but the direction is shifted; group (c) scatters widely. The VGP position calculated from the mean NRM of group (a) is Lat. = 11.2°S and Lon. = 16.0°E with $\alpha_{95}=5.4°$, and that of group (b) is Lat. = 2.5° S, Lon. = 63.2°E and $\alpha_{95}=6.5°$. VGP positions (similar to group (a)) have been reported from the various Lützow-Holm Bay areas (NAGATA and YAMA-AI, 1961; KANEOKA *et al.*, 1968; FUNAKI and WASILEWSKI, 1986). The VGP position fits the apparent polar wander path (APWP) of Gondwana at 430–450 or 510–530 Ma (THOMPSON and CLARK, 1982). The ages of the rocks from Skarvsnes were reported to be 510±30 Ma (Rb-Sr; NICOLAYSEN *et al.*, 1961) and 458±10 Ma (Rb-Sr isochron; MAEGOYA *et al.*, 1968), and therefore the VGP position is supported by the geochronological results. This consistency of the VGP and correlative dating may suggest that the NRM direction of the group (a) was not disturbed drastically by minor amounts of magnetic anisotropy resulting from the gneissosity. Actually, extremely small anisotropy is observed (Fig. 7a) for the samples in this group. However, the VGP position obtained from the NRM's for group (b) was inconsistent with the APWP of Gondwana throughout the Paleozoic and Mesozoic. The samples in this group had measurable anisotropy and the data imply that the NRM shifted in the direction of lineation during the demagnetization. The VGP position of group (b) is located eastward from the expected site, as discussed above. The cause of the result may be the development of foliation in the granulites along an E-W strike (ISHIKAWA *et al.*, 1977).

From these viewpoints, the reliable NRM directions cannot be obtained from the samples of group (a) which have not been significantly affected by the foliation. Therefore, we must check influences of foliation and lineation on NRM arrays when we study paleomagnetism of gneissic rocks.

Another important feature in this study is the obvious and useful use of hysteresis loop analysis with the VSM. Figure 7 shows the χ_{diff} anisotropy curves for sample 942 of group (c) anti-phase to that of H_C and I_R. The $H_{C(max)}$ and $I_{R(max)}$ of this sample are approximately in the directions of lineation within a foliation plane, but the direction of $\chi_{diff(max)}$ deviated 90° from the direction of lineation. POTTER and STEPHENSON (1990) observed similar phenomena in samples with uniaxial anisotropy whether SD or multi-domain (MD) grains. The systematic changes of declination toward the direction of lineation within a foliation plane, during thermal demagnetization, may be explained by the characteristic distributions of MD and SD grains. The NRM consists of hard and soft components; the stable (hard) component should be carried by the SD grains, while the unstable part reflects the MD grains.

STEPHENSON *et al.* (1986) reported that the anisotropy of isothermal remanent magnetization (IRM) acquired at 0.2 T was larger than that of χ_i. We show that the anisotropies of H_C and I_R curves (Fig. 7c) are larger than that of χ_{diff}. The χ_{diff} value which we obtain by a VSM is similar to χ_i value physically. Therefore, the anisotropy degree is more effectively measured by the IRM, I_R and H_C values than χ_i and χ_{diff} values for gneissic rocks.

6. Concluding Remarks

(1) Only samples without gneissosity carry the reliable NRM's. The NRM's of gneissic samples are disturbed by the anisotropy of magnetic properties due to lineation fabric.

(2) The reliable 500 Ma VGP position obtained from granulites in the Skarvnes area comes from samples without significant magnetic anisotropy. The VGP is 11.2°S latitude and 16.0°E longiude, consistent with prior work form Lützow-Holm Bay.

(3) The maximum anisotropy axis of the H_C and I_R values coincide with the direction of lineation in the sample; the maximum value of χ_{diff} is observed perpendicular to the direction of lineation.

(4) The H_C and I_R values are a more effective measure of the magnetic anisotropy than the χ_{diff} value.

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