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PALEOMAGNETIC STUDY OF THE BEACON SUPERGROUP IN ANTARCTICA: REMAGNETIZATION IN THE JURASSIC TIME

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Abstract: The Königsberger-Thellier method was applied to the Beacon Supergroup of the Devonian period around the McMurdo Sound. Samples collected at the sites of Mt. Circe and Knobhead A have stable TRM. These sites are about 100 m apart from the Jurassic Ferrar dolerite sill. Samples collected at the sites of Knobhead B and C about 150 m apart from the dolerite sill, have the partial TRM. Microscopically the samples from Mt. Circe exhibit the dust-ring structure, and contain a minor amount of biotite as a secondary mineral. These results indicate that the Beacon Supergroup around the McMurdo Sound was thermally metamorphosed by the intrusion of the Jurassic Ferrar dolerite. This may explain why the Devonian VGP of Antarctica is far from the Devonian VGP of the Gondwanaland.

The paleointensity estimated from the stable TRM in the Beacon sandstones was 50.5 μT, which is slightly weaker than the present field intensity.

1. Introduction

MOREL and IRVING (1978) suggested the alternative solutions of APWP (Apparent Polar Wandering Path) based on the extensive compilations of VGP (Virtual Geomagnetic Pole) in the Gondwanaland, as shown in Fig. 1, which seem to be still valid in the recent studies such as BACHTADSE *et al.* (1987) and HARGRAVES *et al.* (1987). However, there are no paleomagnetic data available from Antarctica, though it constituted the major part of the Gondwanaland.

According to the geological evidence, the formations from the middle Paleozoic to the Mesozoic age in East Antarctica consist of only the Beacon Supergroup in the Transantarctic Mountains and Prince Charles Mountains of the Lambert Glacier (*i.g.* RAVICH and FEDOROV, 1982). Therefore, paleomagnetic investigations of the Beacon Supergroup, Antarctica may contribute not only to determine more plausible APWP, but also to understand the history of the Gondwanaland.

The previous VGP from the Devonian Beacon Supergroup, studied by several researchers such as TURNBULL (1959), BULL *et al.* (1962) and FUNAKI (1983), is far from the Devonian APWP and close to that of the Jurassic. This implies that the Beacon Supergroup is remagnetized by the intrusion of the Ferrar dolerite in the Jurassic time.

In this study, the Königsberger-Thellier method was applied to the Devonian Beacon Supergroup in the McMurdo Sound to examine the remagnetization of the Beacon Supergroup.

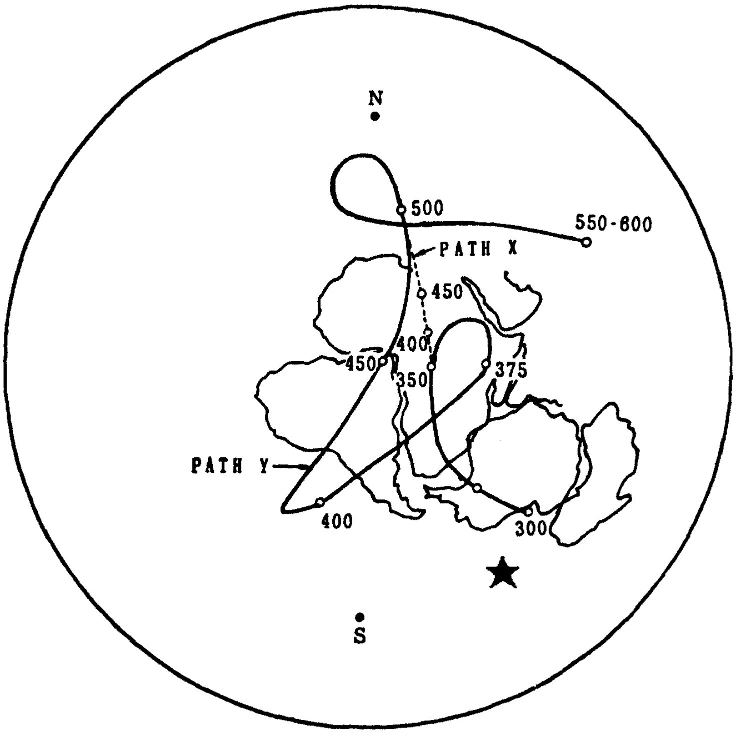

Fig. 1. Alternative (X and Y) APWPs for the Gondwanaland of the lower to middle Paleozoic time (MOREL and IRVING, 1978). Numerals represent the age in Ma. S and N are the south and north geographic poles. The paleomagnetic poles are referred to the reconstruction by SMITH and HALLAM (1970). Star marks the VGP obtained from the Beacon Supergroup.

2. Sampling Site

In the McMurdo Sound, more than 2100 m thick sedimentary rocks, predominantly pale yellow sandstone, unconformably overlie the igneous and metamorphic rocks. These sandstone-dominant sequences, together with minor carbonaceous siltstone and limestone, have been regarded as the Devonian Beacon System (HARRINGTON, 1958). Paleomagnetic samples were collected by FUNAKI (1983) at Mt. Circe and Knobhead (Fig. 2).

Mt. Circe, in the upper Olympus Range between the Wright and Victoria Valleys, is underlain by the Odin Arkose Formation including the Boreas subgraywacke member and the Beacon Heights Orthoquartzite Formation ranging from the early to middle Devonian period. The sampling site at Mt. Circe is situated 80 m above the upper boundary of a 180 m thick Ferrar dolerite sill (McKELVEY and WEBB, 1962), and is located at an altitude of 1540 m. The formation at this site has been identified as the Beacon Heights Orthoquartzite by WEBB (1963).

At Knobhead, the Devonian formations named the Beacon Heights Orthoquartzite and the Aztec Siltstone are exposed in the upper Ferrar and Taylor Glaciers. Intrusions of two dolerite sills, one atop the mountain and the other about 470 m below the top, can be observed at Knobhead (WEBB, 1963). Sampling was made at three sites on the northern flank of Knobhead. The Knobhead A site is located at about 2000 m in altitude and probably lies 140 m above the upper boundary of a dolerite sill. The Knobhead B site is 50 m above site A. The Knobhead site C is further 20 m above site B. These samples are all in the Aztec Siltstone Formation (WEBB, 1963). NRM measurements of these samples and their stability study by alternating field demagnetization were already made by FUNAKI (1983). Table 1 summarizes these data.

The Ferrar dolerites of the Allan Hills and Mt. Fleming (Fig. 2), were also submitted to the study for comparison.

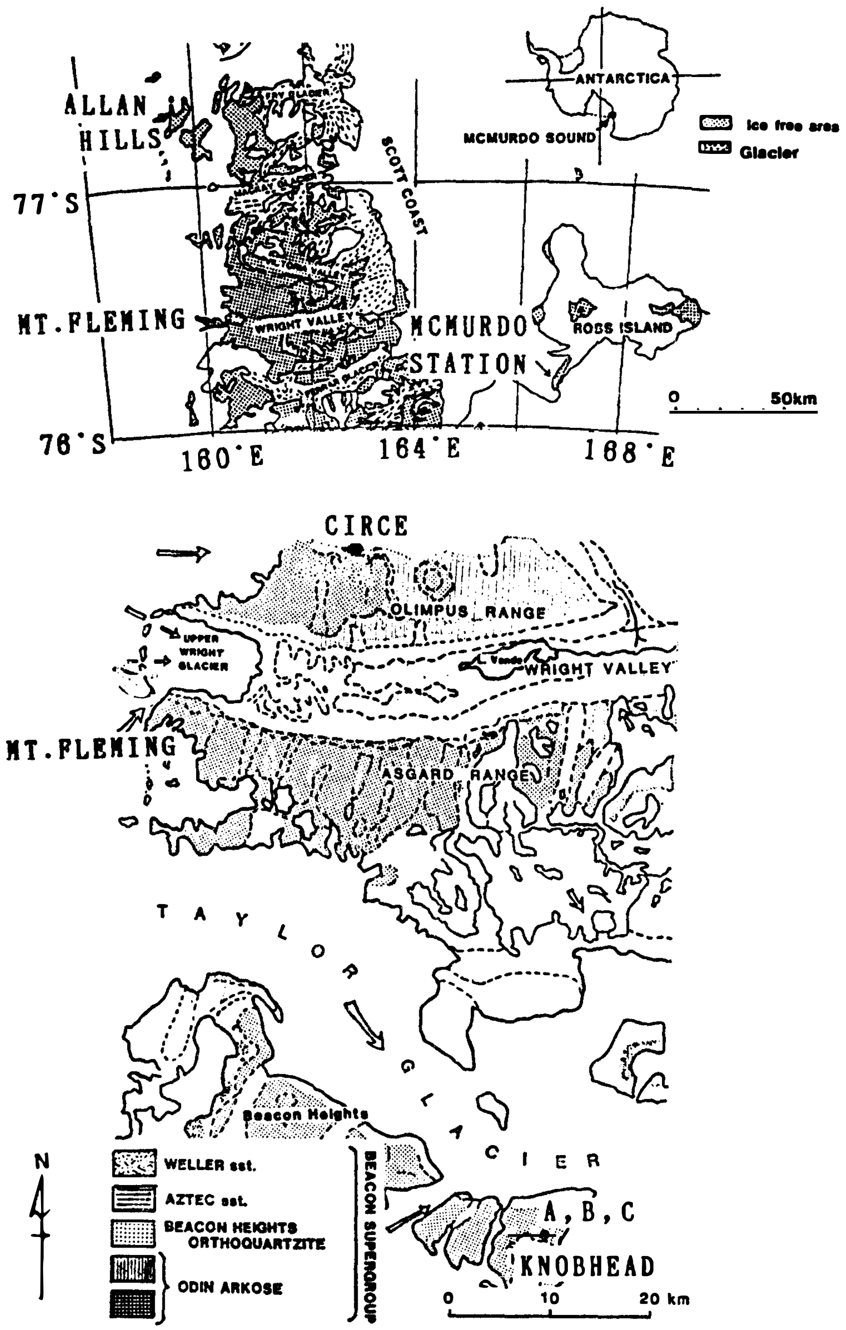

Fig. 2. Geological sketch map and sampling sites of the Beacon Supergroup in the McMurdo Sound region.

3. Königsberger-Thellier Method

Natural remanent magnetization (NRM) of sedimentary materials acquired through depositional process is called detrital remanent magnetization (DRM). When these materials are heated, the thermoremanent magnetization (TRM) may be added to the NRM. When the heating temperature is below the Curie temperature, the NRM becomes the resultant vector with partial DRM and partial TRM. When the heating temperature exceeds the Curie temperature, the primary DRM disappears and the secondary TRM remains solely.

TRM has the general property that, when it is acquired under the weak magnetic field, its intensity is proportional to the field intensity. Therefore, the TRM reproduced by heating in the laboratory has a linear correlation to the TRM acquired in nature as follows:

$$\frac{\text{TRM (natural)}}{\text{TRM (laboratory)}} = \frac{\text{paleointensity of geomagnetic field}}{\text{intensity of laboratory field}} \qquad (1)$$

where, all terms are intensity value.

The Königsberger-Thellier method (K-T method) is used to determine the paleogeomagnetic field intensity utilizing the above properties of TRM (KÖNIGSBERGER, 1938; THELLIER and THELLIER, 1959). This method involves the following processes:

(1) Heat the sample to a certain temperature ($T1$) and cool it in a zero field condition, and calculate the demagnetized component $R1$ at this temperature.

(2) Heat the sample to the same temperature ($T1$) and then cool it in a nonzero magnetic field. The newly acquired remanence, $S1$, is induced by this field.

(3) We can obtain the relation between the intensities of the two remanences ($R1$, $S1$) and the intensities of the magnetic field as Eq. (1).

(4) These paired data ($R1$, $S1$) are obtained at several temperature intervals until the original remanence disappears.

The NRM-TRM diagram (Fig. 3) is used for analysis by the K-T method. The ordinate is the intensity of NRM and the abscissa is that of TRM. When the K-T method is applied to samples free of DRM, the points on the NRM-TRM diagram should fall on a straight line. The slope represents the ratio of the laboratory-induced and the paleogeomagnetic intensity. Generally, TRM is much stronger than DRM and we cannot identify any correlation between DRM and TRM. When the remanence is composed of DRM with secondary TRM acquired by heating to a certain temperature T, the points of the temperatures below T may be colinear but those above T may deflect, probably to a much lower slope. So, from the colinear part of the NRM-TRM curve we can determine the origin of the remanence (whether DRM or TRM) and estimate the paleotemperature in the heating event after the deposition of the sediments.

Generally, the alteration of the magnetic properties of the sample occurs in the high temperature range, which distorts the linear relation between NRM and TRM, so one must be wary of irreversible change in magnetic properties during the experiments.

Experiments were performed at Toyama University. Measurements of the remanent magnetization were made using the Schonstedt spinner magnetometer (SSM-1A) and a Cryogenic magnetometer (CCL GM-401). Samples were cut into cubes of 5 to

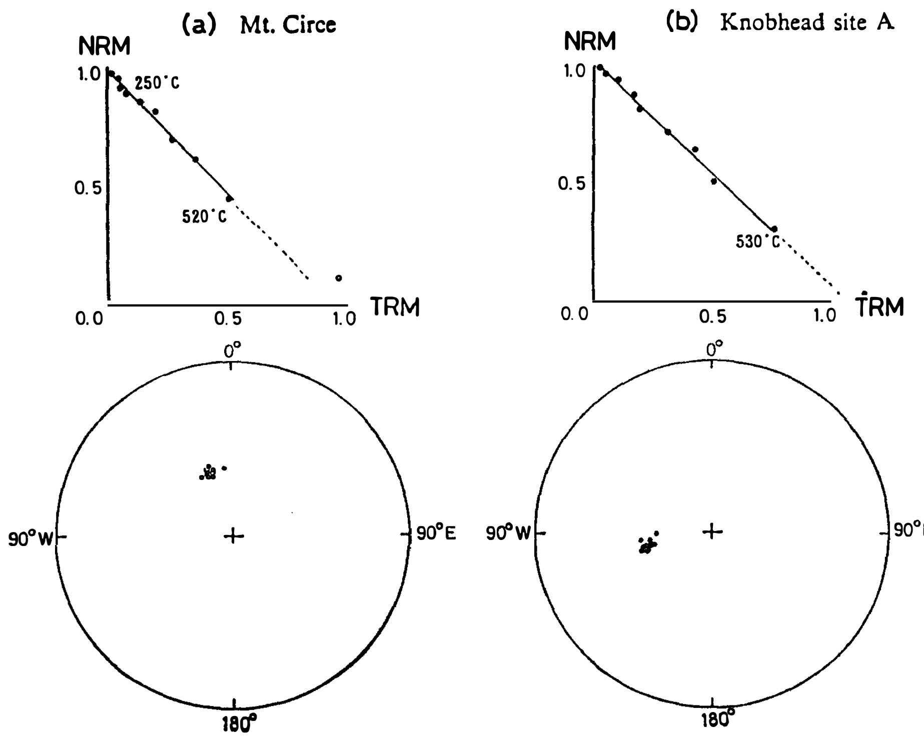

Fig. 3. Results of the K-T method are shown by the NRM-TRM diagram. Directional change of NRM during thermal demagnetization is represented on the Schmidt's equal-area net. (a) Mt. Circe site. (b) Mt. Knobhead site A.

8 mm side length. Samples were heated in a nitrogen atmosphere to avoid mineralogical disturbances.

4. Petrography of the Beacon Sandstone

The representative sandstones from the Beacon Sandstone Formation were thin-sectioned. The sandstones collected at Mt. Circe are all orthoquartzite composed more than 95% of well sorted, rounded quartz detritus, with minor feldspars. Trails of fine-grained dusty materials form "dust-ring" structures, outlining the original detrital surfaces of quartz grains. Minor idioblastic biotites appear only along the boundaries of quartz grains.

The samples of site A in Knobhead also exhibit the dust-ring structure, but no biotites were observed. The samples from sites B and C in Knobhead show neither the dust-ring structure nor the signs of recrystalization such as idioblastic biotite.

The development of dust-ring structure and the presence of idioblastic biotite correlate well with the distance from the dolerite sill, indicating that most samples collected at Mt. Circe and Knobhead site A are thermally metamorphosed.

5. Results of the K-T Method

The NRM-TRM diagrams for the samples of Mt. Circe are shown in Fig. 3(a). This figure also shows the Schmidt's equal area net indicating the directional change of NRM during thermal demagnetization. As shown in the stereo net, the remanence is almost unidirectional, indicating that it is from one component. The linearity of the NRM-TRM diagram holds up to 500°C, which means that the primary DRM in sandstones of Mt. Circe was replaced by TRM.

Figure 3(b) shows the results of the K-T method applied to the samples from site A in Knobhead, which is 140 m apart from the dolerite sill. The NRM intensity, on the order of 10^{-6} Am^2/kg, is similar to that of Mt. Circe. The linear trend of the NRM-TRM diagram and the stable NRM directions show that NRM of site A is really almost all TRM.

Figure 4(a) shows the results of site B of Knobhead. Site B is 50 m above site A. The NRM intensity is less than half of that of the site A samples. The directional change of NRM during thermal cleaning occurred at high temperatures. Below 300°C, NRM and TRM share a linear relation and the NRM direction is consistent. These results indicate that the remanent magnetization in site B includes partial TRM.

Figure 4(b) shows the results of the sample of site C in Knobhead which is still farther from the dolerite sill. The directional change in NRM during thermal cleaning started at a lower temperature than that of site B, and the linearity in NRM vs. TRM is not clear. But the NRM intesity is not so weak compared with those of sites A and B, and the NRM direction is similar to those of sites A and B (Table 1). Therefore, we consider that NRM of the site C sample also has partial TRM.

Deviations from linearity in the NRM-TRM diagram at high temperatures may

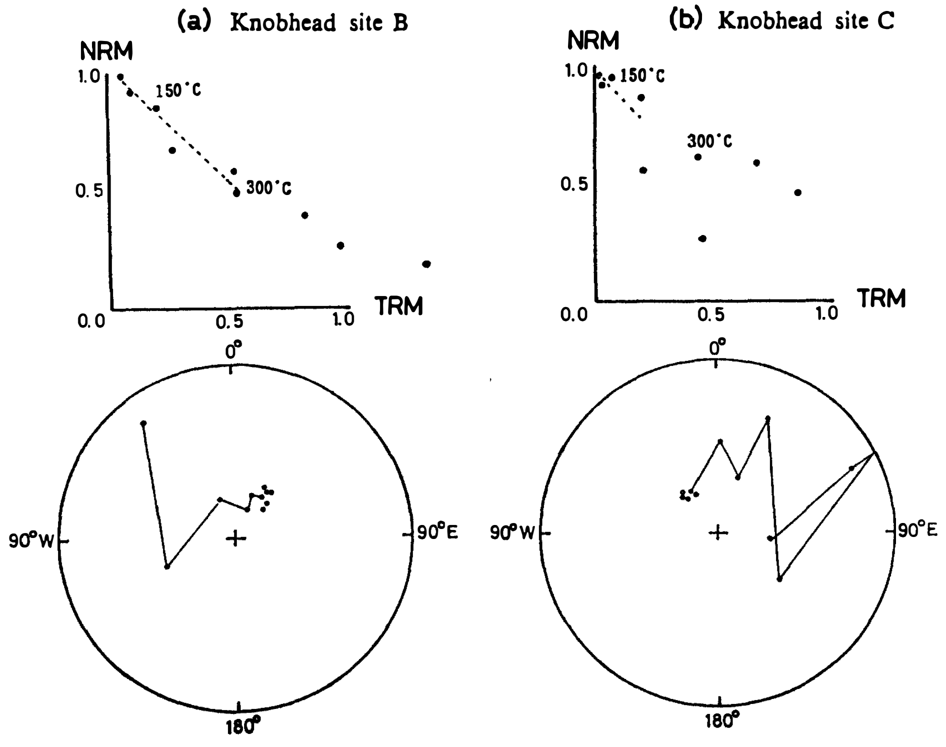

Fig. 4. Results of the K-T method are shown by the NRM-TRM diagram. Directional change of NRM during thermal demagnetization is represented on the Schmidt's equal-area net. (a) Mt. Knobhead site B. (b) Mt. Knobhead site C.

Table 1. Results of NRM measurements.

Sampling site	Demag. (mT)	N	R (Am²/kg)	Inc. (°)	Dec. (°)	K	α_{95} (°)	pLat. (°)	pLon. (°)
Mt. Circe	0	6	3.55×10^{-6}	−78.2	267.7	1040	2.1		
	15		3.30×10^{-6}	−77.1	266.9	1258	1.9	61.9S	223.1W
Knobhead A	0	37	9.78×10^{-7}	−81.8	277.0	132	2.1		
	15		9.79×10^{-7}	−81.7	280.7	354	1.3	76.6S	136.9W
B	0	10	3.47×10^{-7}	−75.6	231.3	14	13.1		
	15		3.22×10^{-7}	−84.1	245.3	56	6.5	69.9S	165.8W
C	0	17	1.51×10^{-7}	−88.1	234.3	6	16.4		
	15		1.42×10^{-7}	−87.0	201.5	5	19.0		

Demag.: optimum AF demagnetization field, N: sample number, R: mean intensity of NRM, Inc. and Dec.: mean inclination and declination of NRM, K: precision parameter, α_{95}: radius of 95% confidence circle about mean direction, pLat. and pLon.: paleo-latitude and paleo-longitude. Detailed data are shown in FUNAKI (1983).

be caused not only by the low grade of thermal remagnetization but also by the chemical changes due to oxidation during heating (NAGATA and KOBAYASHI, 1963). Knobhead sites A, B and C belong to the same formation whose rocks are lithologically similar and homogeneous. Therefore, when the chemical changes occur during heating, all the NRM-TRM diagrams of the samples in Knobhead may show the similar deviation from linearity. Results of K-T method show that the linearity in the NRM-TRM plots holds up to 500°C in the sample of Knobhead A, but no clear linearity is obtained in the sample of Knobhead C. We consider that such different patterns of the NRM-TRM diagram indicate the difference in grade of thermal remagnetization and that the effect of chemical changes is not serious.

The residual NRM after thermal cleaning at high temperatures is considered to be the original DRM. But this component is unstable and we could not determine the primary DRM.

The K-T method was also used on the Ferrar dolerite samples from the Allan Hills and Mt. Fleming (of Jurassic age). These dolerite samples have stable remanent magnetization with a high blocking temperature. The NRM-TRM data below 500°C were used in the paleointensity determination for each sample, since above this temperature the data lose their colinearity. This is induced by the chemical change in the magnetic minerals during the experimental heating.

6. Discussion

We examined a linear relation in the NRM-TRM plots on 37 samples. In Table 2 are shown 18 samples' data whose correlation coefficient is over 0.985 calculated from more than 6 plots. As seen in Table 2, the paleointensities of the Beacon Supergroup (Mt. Circe and Mt. Knobhead) and those of the Ferrar dolerites from the Allan Hills and Mt. Fleming are consistent with each other. This indicates that the Beacon Supergroup was thermally affected by the Jurassic dolerite.

It is thus concluded that the Beacon Supergroup in Mt. Circe and Mt. Knobhead

Table 2. Paleointensities deduced from Beacon Supergroup and Ferrar dolerites.

Sample	Temperature (°C)	N	Paleointensity (μT)
Beacon Supergroup			
Mt. Circe			
C-1	50–550	8	48.6±2.8
C-2	50–520	9	51.2±2.6
C-4	110–570	10	54.7±1.5
C-5	50–530	9	47.4±2.1
C-13	50–400	6	60.8±4.1
C-14	0–400	6	47.3±2.8
C-16	50–550	9	65.3±4.9
C-17	50–530	8	42.8±1.9
Mt. Knobhead			
K-A1	50–530	10	50.3±4.5
K-A2	0–450	7	35.4±1.8
K-A3	120–550	9	55.4±2.4
K-A5	50–530	9	46.4±3.1
Average of Beacon Supergroup			F=50.5±7.9μT
Ferrar dolerite			
Allan Hills			
FA-2	50–450	8	52.2±4.6
FA-3	50–450	9	44.3±3.6
Mt. Fleming			
FF-1	50–480	8	47.5±2.4
FF-3	0–450	7	73.1±5.3
FF-5	0–450	6	38.8±2.0
FF-6	50–470	7	63.8±2.2
Average of Ferrar Dolerites			F=53.3±12.9μT

Paleointensity: estimated paleointensity and its standard deviation, Temperature: temperature interval where NRM-TRM relation is linear, N: the number of points in this temperature interval.

site A, B, C was remagnetized. The heating temperature of samples from Mt. Circe and Mt. Knobhead site A reaches at least the Curie temperature. These paleomagnetic results are concordant with the microscopic observations.

From this and previous paleomagnetic studies, it is likely that the Beacon Supergroup of the Transantarctic Mountains was remagnetized by the intrusion of the Ferrar dolerite. This may account for the record that the previously obtained Devonian VGP from Antarctica is far from the Devonian VGP and close to the Jurassic one on the alternative APWPs by MOREL and IRVING (1978). However, the Beacon Supergroup in the Prince Charles Mountains near the Lambert Glacier seems to be free from such remagnetization effects, which are less frequent in intrusive bodies. So, this region may become the next target to elucidate the VGP structures of the Gondwanaland during the Devonian to Triassic time.

Paleointensity of the Jurassic age has been reported by BRIDEN (1966) using the

Ferrar dolerite in Antarctica. His paleointensity 16.6 μT is much lower than the value estimated in this study. Presumably, these low paleointensities are due to that they were calculated from one NRM-TRM ratio at a rather high temperature, where magnetic minerals might have been thermally altered.

The present study suggests that some of the thermally metamorphosed sedimentary rocks have suitable TRM for paleointensity study. The Jurassic paleointensity calculated from this study is 50.5 μT which is slightly lower than the present intensity at the McMurdo Sound.

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