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GEOMAGNETIC PALEOINTENSITY EXPERIMENT ON IGNEOUS AND METAMORPHIC ROCKS FROM ENDERBY LAND IN NAPIER COMPLEX, ANTARCTICA

Naoko UENO

Toyo University, 11-10, Oka 2-chome, Asaka 351

Abstract: The modified Thelliers' and Shaw's methods are applied to granulite and igneous rocks from Mt. Riiser-Larsen in Enderby Land, some of which were dated by the K-Ar method to be of 1.2-1.4 Ga. Very low paleointensities are suggested from high temperature components of the Thelliers-type results and from the Shaw-type experiment.

1. Introduction

A paleointensity study of Precambrian rocks provides information on development of the earth's core as well as the geomagnetic field. The Napier Complex in Antarctica composes the Archean granulite terrain which has undergone high temperature (950-1050°C) metamorphism (MOTOYOSHI and HENSEN, 1989). BLACK *et al.* (1986) recognized the four events of 3930, 2950, 2480 and 1000 Ma in age based on U-Pb analyses of zircon from granulite-facies orthogneiss in the Napier Complex.

Samples were collected from Mt. Riiser-Larsen in Enderby Land in 1988 by Dr. H. MAKIMOTO, a member of the Japanese Antarctic Research Expedition party (Fig. 1). According to MAKIMOTO *et al.* (1989), various kinds of Archean granulite-facies metamorphic rocks are exposed with minor mafic dike rocks in this area. Magnetiterich rock (meta-ironstone) and pyroxenite also crop out sporadically. All the mafic dikes are weakly metamorphosed but igneous textures are well preserved, and the dikes are not folded. Based on the petrographic features, these mafic dikes can be regarded as part of the Amundsen Dikes with a Rb-Sr whole rock isochron age of 1190$\pm$200 Ma (SHERATON and BLACK, 1981). Alteration is observed in most samples, as shown in petrographic descriptions (Appendix), and may cause non-ideal behavior in the paleointensity experiment. However, the author believes it meaningful to study these rocks to obtain useful information about the characteristics of rock magnetism in Antarctic Precambrian rocks.

2. Dating of Samples

Paleomagnetic studies should basically be done with dated samples. From this standpoint, K-Ar dating was performed. Details of the experiment were described in UENO *et al.* (1994) and results of the analyses are shown in Table 1.

The granulite (No. HM88021803B) contained potassium lower than the detection limit in flame photometry. Under microscopic observation, two of the mafic dikes (Nos.

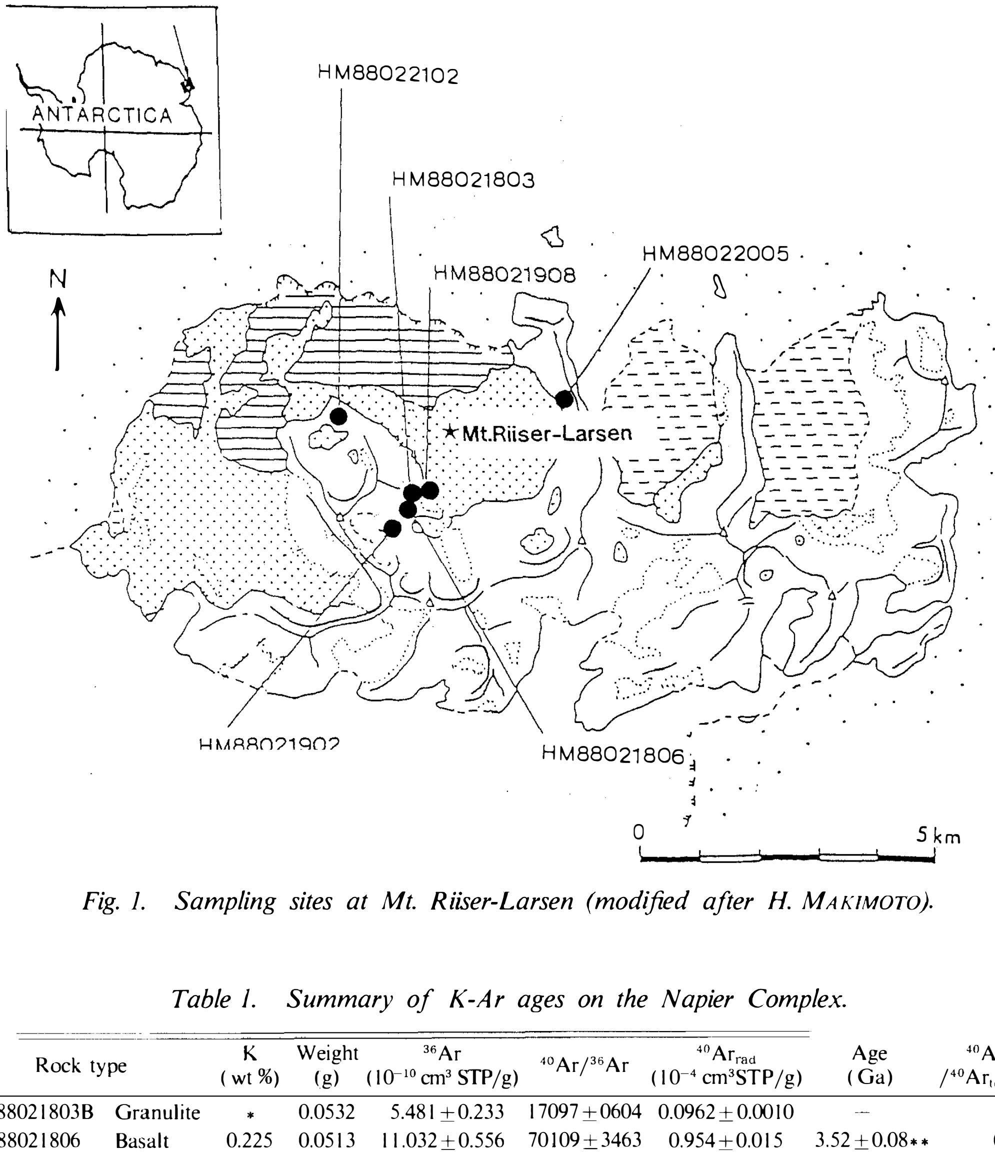


Fig. 1. Sampling sites at Mt. Rüser-Larsen (modified after H. MAKIMOTO).

Table 1. Summary of K-Ar ages on the Napier Complex.

Rock type		K (wt %)	Weight (g)	^{36}Ar (10^{-10} cm^3 STP/g)	^{40}Ar/^{36}Ar	^{40}Ar$_{rad}$ (10^{-4} cm^{3}STP/g)	Age (Ga)	^{40}Ar$_{air}$ /^{40}Ar$_{total}$(%)
HM88021803B	Granulite	*	0.0532	5.481±0.233	17097±0604	0.0962±0.0010	—	1.7
HM88021806	Basalt	0.225	0.0513	11.032±0.556	70109±3463	0.954±0.015	3.52±0.08**	0.4
HM88021902	Mylonite	0.914	0.0638	13.741±0.708	90686±5514	1.446±0.043	2.13±0.07**	0.3
HM88021907A	Basalt	0.337	0.0496	17.746±0.336	15367±0205	0.275±0.003	1.40±0.05	1.9
HM88021907B	Basalt	0.300	0.0475	9.270±0.512	70087±3500	0.805±0.010	2.84±0.07**	0.4
HM88022005A	Granulite	1.438	0.0490	16.814±0.574	51998±1758	0.970±0.014	1.22±0.05	0.6
HM88022102A	Dolerite	0.202	0.0460	44.981±0.602	38370±0801	1.744±0.043	4.67±0.09***	0.8
HM88022102B	Basalt	1.303	0.0606	13.275±0.454	8330±0127	0.833±0.013	1.17±0.05***	0.5

Analytical errors for K concentrations were estimated to be 5%.
± indicates one standard deviation.
* K content with unde limit of detection.
** Samples contain altered minerals.
*** Thermally altered samples. The calculated age may not have geological meaning.

HM88022102A and HM88022102B) are thought to be affected by thermal alteration and three of them (Nos. HM88021806, HM88021902, HM88021907B) contain altered minerals. The calculated ages of these samples, 4.67, 1.17, 3.52, 2.13 and 2.84 Ga respectively, might have no geological meaning. The K-Ar ages of 1.40 and 1.22 Ga from basaltic dike (No.

HM88021907A) and the granulitic dike (No. HM88022005A) are concordant with each other and similar to the known age of 1.2 Ga for the Amundsen Dikes, which correlate petrographically with the mafic dikes studied in this report (MAKIMOTO *et al*., 1989). These may suggest that the mafic rocks were formed 1.2-1.4 Ga.

3. Thelliers' Method

A preliminary experiment on these samples with Thelliers' method (THELLIER and THELLIER, 1959) gave $63 \pm 22\,\mu T$ in temperature steps under 562°C (UENO and FUNAKI, 1991). The change in the initial susceptibility with temperature is characterized by stability and reversibility at high temperature for all samples (Fig. 2b and Fig. 3b). The author expects that these samples might have stable remanent magnetization at high blocking temperature. A repeat experiment on these samples was performed with Coe's version (COE, 1967) of the Thelliers' method in the same laboratory as in the previous experiment (Tokyo Institute of Technology). The high temperature steps started with 490° C in a nitrogen atmosphere. The field applied to induce TRM was $20\,\mu T$. Typical Arai diagrams are shown in Fig. 2a and Fig. 3a, with Zijdervelt diagrams of the NRM component. Diagrams of the previous experiment in low temperature steps are shown for comparison. Changes in initial susceptibility are small after each step for all samples (Fig. 4). This may possibly support the hypothesis that significant chemical change did not occur during the heating. Paleointensities are estimated from the linear segments between the same temperature step ranges in the Arai diagram and the Zijdervelt diagram by Williamson's method (KONO and TANAKA, 1984). Results are compiled in Table 2.

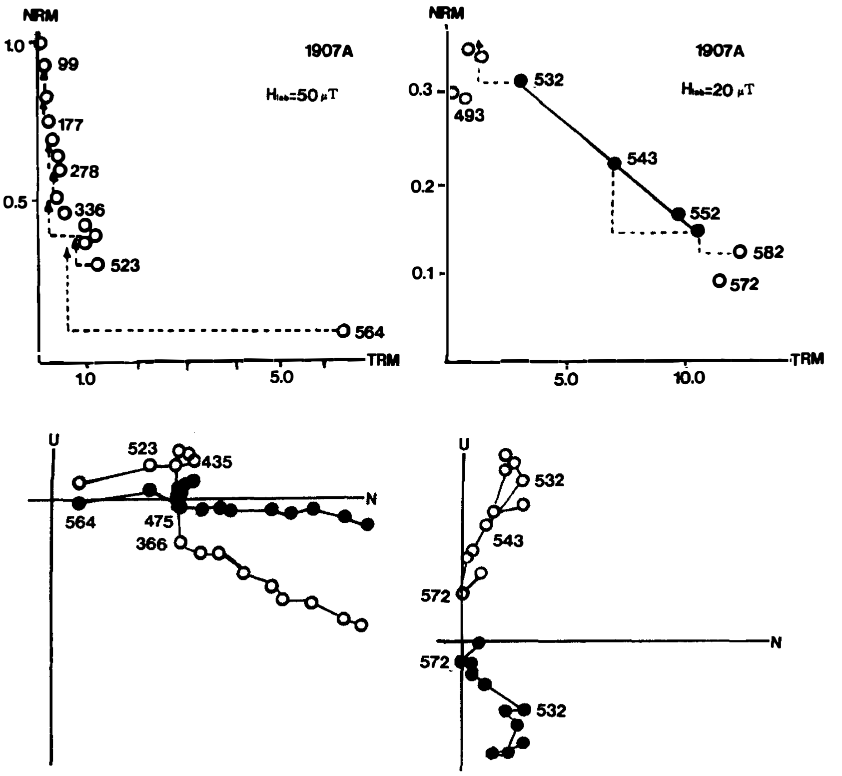
4. Shaw's Method

Shaw's method (SHAW, 1974; ROLPH and SHAW, 1985) was applied to the same samples as Thelliers' method, at Tokyo Institute of Technology. Samples were AF demagnetized up to 220 mT. TRM was induced in a field of 10 or $20\,\mu T$ at a maximum temperature of 600, 610, 620 or 650°C. Anhysteretic remanent magnetizations before and after heating (ARM1 and ARM2 respectively) were induced in a direct field of 10, 20, 30 or $50\,\mu T$ applying an alternating field of 220 mT. The NRM-$*$TRM (TRM after the correction proposed by ROLPH and SHAW, 1985) and ARM1-ARM2 plots are shown in Fig. 2c and Fig. 3c. NRM-TRM spectra were at noise level above AF 80 mT in Fig. 2c and above 140 mT in Fig. 3c. Results are listed in Table 3. Paleointensity was refused when the fraction was less than 10%, the correlation coefficient was less than 0.9, or the adopted maximum coercivity spectrum was less than 50 mT.

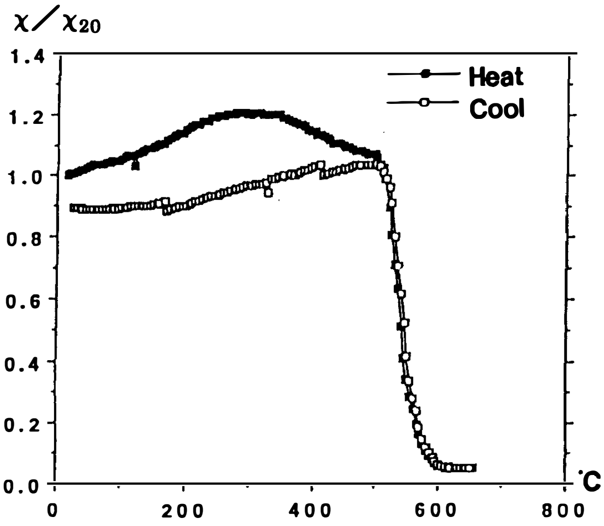
5. Discussion and Conclusions

The results from the high temperature steps of 532-592°C in Thelliers' method in Table 2 show low paleointensities ranging from 0.4 to $7.1\,\mu T$. This is quite different from the previous value of $63 \pm 22\,\mu T$ from the lower steps. As shown in Table 3, the paleointensities from Shaw's method are low, 2.7 and $3.9\,\mu T$. Hence the very low Precambrian paleointensity in Antarctica seems to be preferable. The higher paleointen-

(a)



(b)



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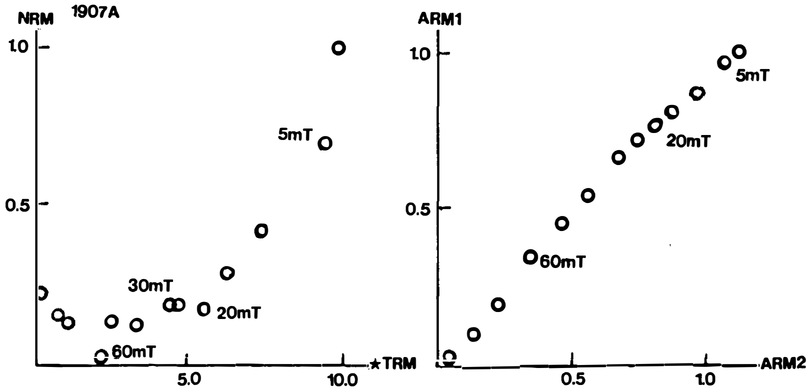
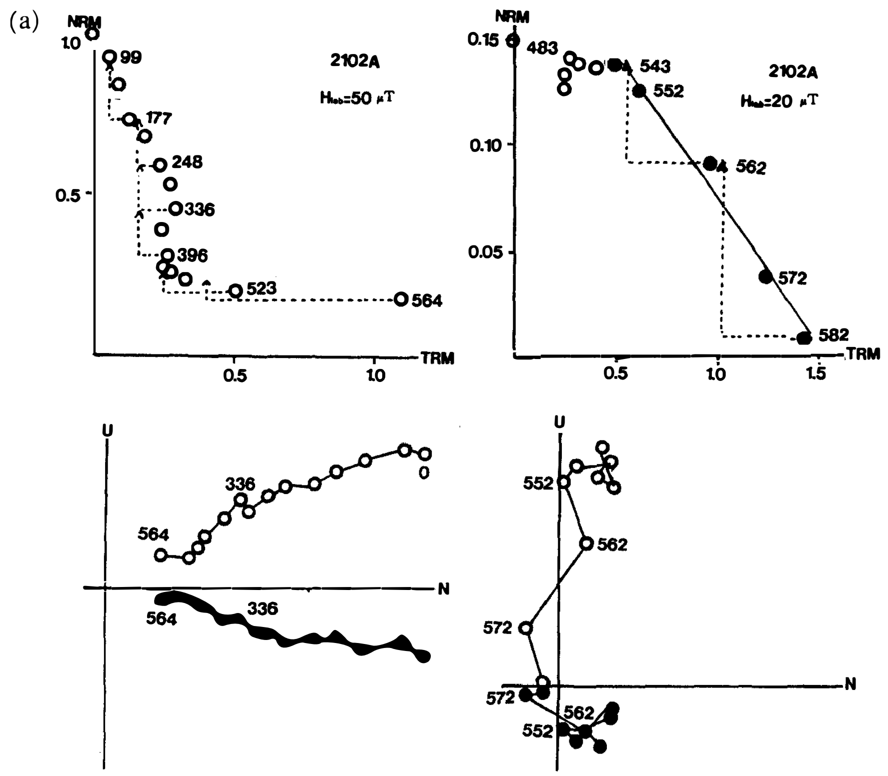
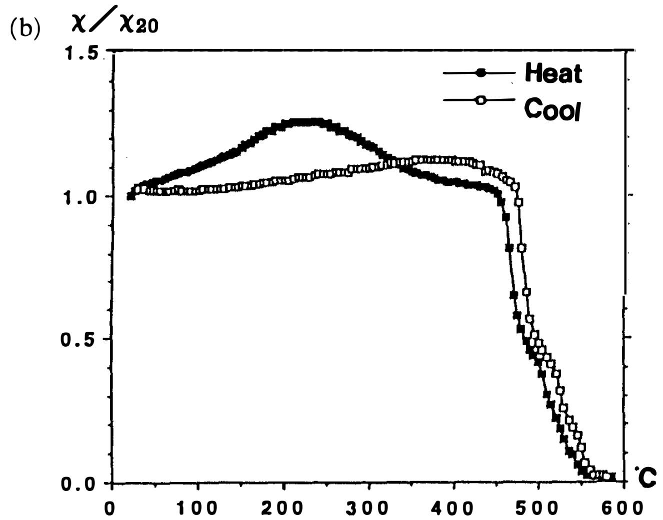


Fig. 2. Paleointensity results of the basaltic dike No. HM88021907A.
(a) Arai diagram with an insert of Zijderbeld diagram in Thelliers' method.
(b) Initial susceptibility versus temperature curve.
*(c) NRM-*TRM and ARM1-ARM2 plots in Shaw's method.*





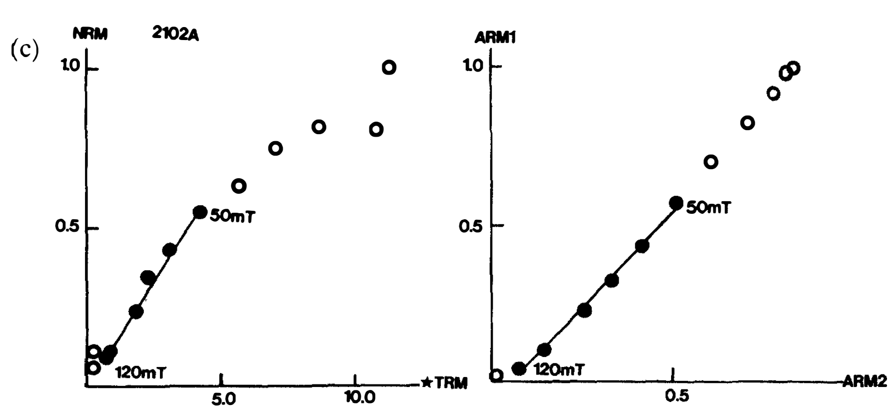


Fig. 3. Paleointensity results of the andesitic dike No. HM88022102A.
(a) Arai diagram with an insert of Zijderbeld diagram in Thelliers' method.
(b) Initial susceptibility versus temperature curves.
(c) NRM-∗TRM and ARM1-ARM2 plots in Shaw's method.

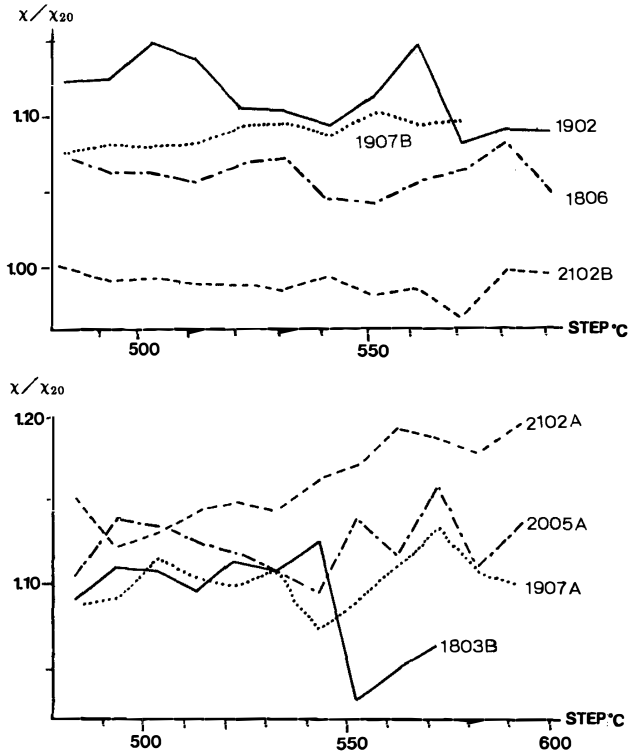


Fig. 4. Change in initial susceptibility during experiment using Thelliers' method.

Table 2. Results of Thelliers' method.

Sample	NRM $10^{-5}Am^2/kg$	T1–T2 °C	n	$-r$	Fraction	F μT
HM88021803B	30	553–582	5	0.998	0.20	1.4
HM88021806	27	543–572	4	0.999	0.20	0.9
HM88021902	233	552–592	5	0.965	0.15	7.1
HM88021907A	9.0	532–562	4	0.999	0.15	0.43
HM88021907B	98	532–562	4	0.996	0.10	5.3
HM88022005A	8.7	543–592	6	0.958	0.25	0.82
HM88022102A	12	543–582	5	0.991	0.10	2.6
HM88022102B	212	543–592	6	0.985	0.25	5.6

Notes: T1–T2: Temperature range used in the paleointensity estimate.
n: The number of points between T1 and T2.
-r: Correlation coefficient of fitted line.
Fraction: Fraction of initial NRM used in the paleointensity estimate.
F: Estimated paleointensity.

sity of $63 \pm 22\ \mu T$ from the lower temperature steps in the previous experiment might arise from the secondary component.

Thermal alteration during laboratory heating was reported by KONO (1987). PTRM test was effectively applied in Thelliers' method, but a possibility of alteration during the first step in the experiment cannot be denied. Low intensity in higher steps in Thelliers' method could be attributed to the thermal alteration in the experiment. As Shaw's

Table 3. Results of Shaw's method.

Sample	ARM F μT	TRM T °C	TRM F μT	χafter /before	AF range mT	*n*	-*r*	Fraction	ARM1 /ARM2	*F* μT	*Y*/*N*
HM88021803 B	50	650	10	1.19	0- 50	6	0.997	0.80	0.85	0.58	*N*
HM88021806	20	620	20	1.00	20- 60	5	0.989	0.35	0.94	0.54	*N*
					80-140	4	0.966	0.08	0.87	0.79	*N*
HM88021902	20	650	10	1.07	10- 30	5	0.996	0.20	1.06	2.6	*N*
HM88021907 A	10	650	10	1.03	5- 20	4	0.999	0.50	0.70	1.3	*N*
					30- 60	4	0.838	0.15	0.94	0.61	*N*
HM88021907 B	50	650	10	1.13	10- 25	4	0.991	0.30	0.93	5.2	*N*
					40- 60	3	0.996	0.05	0.87	3.3	*N*
HM88022005 A	30	610	20	1.13	10- 45	8	0.928	0.05	1.02	5.4	*N*
HM88022102 A	20	600	20	1.14	50-120	6	0.994	0.45	1.23	2.7	*Y*
HM88022102 B	20	600	20	1.02	50-120	5	0.992	0.12	0.99	3.9	*Y*

Notes: ARM F: Applied direct field in ARM acquisition.
TRM T: Maxmum temperature in TRM acquisition.
TRM F: Applied direct field in TRM acqisition.
χafter/before: Ratio of initial susceptibility after to before TRM acquisition.
AF range: AF range used in the paleointensity estimate.
n: The number of points in the AF range used.
-*r*: Correlation coefficient of fitted line.
Fraction: Fraction of initial NRM used in the paleointensity estimate.
ARM1/ARM2: The ratio of ARM1 to ARM2 in the AF range used.
F: Estimated paleointensity.
Y/*N*: Result was used in the calculation of the average (*Y*) or rejected (*N*).

method requires heating at high temperature, the low intensity of Shaw's method might be from sample oxidation in the high temperature experiment and thus may conceivably have no geoscientific meaning. The double-heating thermal alteration test proposed by TSUNAKAWA and SHAW (1994) would be effective for these samples, though it was not applied because of the time limit.

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Appendix. Rock types and constituent minerals after Dr. T. TIBA, National Science Museum.

ph: phenocryst. gr: groundmass. ap: apatite. bi: biotite. cpx: clinopyroxene.
ho: hornblende. il: ilmenite. op: opaque mineral. opx: orthopyroxene.
pl: plagioclase. qz: quartz

HM88021803:	Granulite (major: opx, cpx, qz, pl. minor: op)
BHM88021806:	Basalt, slightly altered (ph: pl with clay mineral along cracks. gr: pl, cpx altered to clay mineral+op, op)
HM88021902:	Mylonite (crystals: pl, ho, op, cpx, carbonate, qz, smectite)
HM88021907A:	Basalt (ph: pl, cpx, ho. gr: pl, cpx, bi, op)
HM88021907B:	Basalt (ph: pl with clay mineral along cracks. gr: pl, cpx with il lamellae, opx, bi, op)
HM88022005A:	Granulite, fine-grained (majar: pl, cpx, opx, ho, bi, K-feldspar, qz. minor: op, ap)
HM88022102A:	Dolerite thermally altered (primary: pl, cpx, op. secondary: ferro-ho, ferroactinolite, calcite, hematite)
HM88022102B:	Basalt thermally altered (primary: pl, cpx, op. secondary: bi, ho, smectite)