Proc. NIPR Symp. Antarct. Geosci., 5, 122–135, 1991

^{40}Ar-^{39}Ar AND K-Ar AGES FOR IGNEOUS AND METAMORPHIC ROCKS FROM THE SØR RONDANE MOUNTAINS, EAST ANTARCTICA

Yutaka TAKIGAMI[1] and Minoru FUNAKI[2]

[1]*Kanto Gakuen University, 200, Fujiagu, Ohta 373*
[2]*National Institute of Polar Research, 9-10, Kaga 1-chome, Itabashi-ku, Tokyo 173*

Abstract: Eight ^{40}Ar-^{39}Ar and six K-Ar ages were determined for igneous and metamorphic rocks collected from the Sør Rondane Mountains, East Antarctica. Biotites from granite and syenite show ^{40}Ar-^{39}Ar ages of about 500 Ma, which are similar to the reported Rb-Sr age.

K-Ar and ^{40}Ar-^{39}Ar ages of 440–480 Ma were obtained for igneous dyke samples and metamorphic rocks.

^{40}Ar-^{39}Ar age spectra for K-feldspars, which were separated from the same rocks as biotite, indicate the stair-type patterns.

1. Introduction

In order to investigate the movement of East Antarctica toward other continents of the Gondwana paleoland during the periods of Paleozoic and Precambrian, paleomagnetic studies for the Sør Rondane Mountains had been performed by the 26th and 30th Japanese Antarctic Research Expeditions (JARE-26 and JARE-30). Results of paleomagnetic studies and ^{40}Ar-^{39}Ar and K-Ar ages by JARE-26 were reported by TAKIGAMI *et al.* (1987). Further, paleomagnetic results of JARE-30 have been also reported by FUNAKI and TOKIEDA (1990) and TOKIEDA and FUNAKI (1991). To supply age information, ^{40}Ar-^{39}Ar and K-Ar datings were performed for igneous and metamorphic rock samples of JARE-30, for which paleomagnetic studies had been made (Fig. 1).

Further, by comparing the present results with the reported age data obtained by the Rb-Sr, U-Pb and K-Ar methods (PICCIOTTO *et al.*, 1964, 1966; TAKAHASHI *et al.*, 1990), we have examined the thermal history for the Sør Rondane Mountains in this study.

2. Geology and Samples

The Sør Rondane Mountains are situated in East Antarctica. They were investigated by Belgian parties (1958–1970) and by Japanese parties (1983–). The area is about 200 km × 75 km and composed of high grade metamorphic rocks and igneous intrusive rocks. The reported Rb-Sr, U-Pb, ^{40}Ar-^{39}Ar and K-Ar dates indicate the following events in this area: the metamorphism of gneiss, about 550 Ma (PICCIOTTO *et al.*, 1964, 1966); the younger intrusive activities, between 440–530 Ma (PICCIOTTO *et al.*, 1964, 1966;

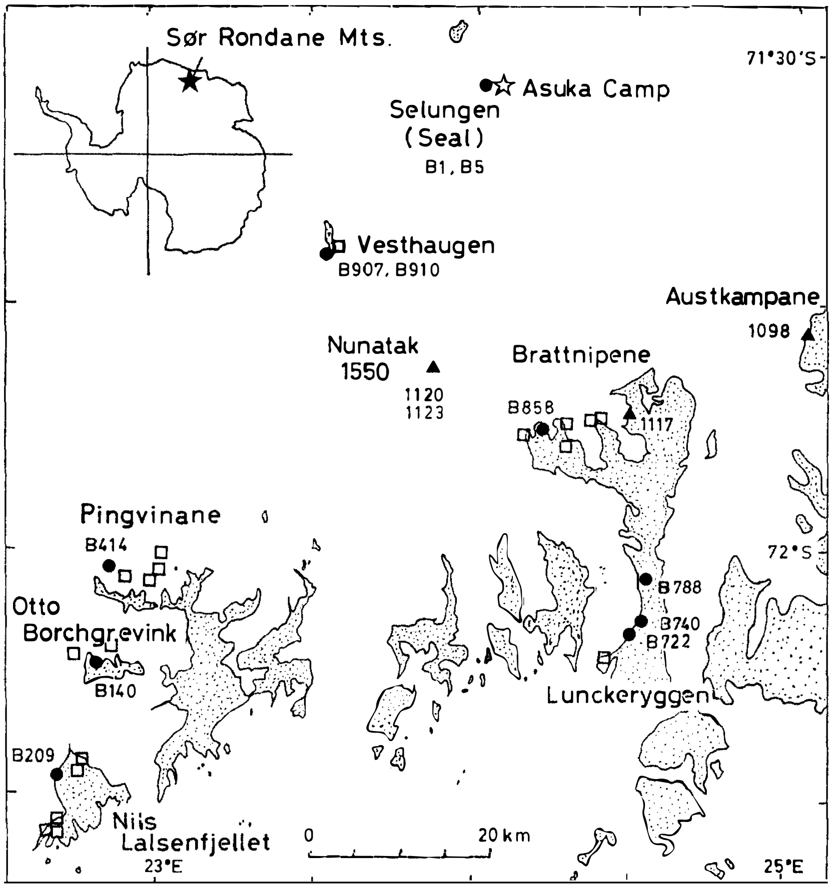

Fig. 1. Sampling sites in the Sør Rondane Mountains (modified after FUNAKI *and* TOKIEDA*, 1990). Open squares and closed circles indicate sampling sites for paleomagnetic studies. Closed circles and triangles indicate sampling sites for age determination in this study and the reported study (*TAKIGAMI *et al., 1987), respectively.*

TAKIGAMI *et al.*, 1987; TAKAHASHI *et al.*, 1990); another thermal event, about 400 Ma (TAKAHASHI *et al.*, 1990).

Samples for ^{40}Ar-^{39}Ar and K-Ar studies were selected from those used for paleomagnetic studies (MORIWAKI *et al.*, 1989), considering the good stability of Natural Remanent Magnetization (NRM) at AF demagnetization (Fig. 1). In Table 1, we list sample name used in this study, sampling site number used in JARE-30 (MORIWAKI *et al.*, 1989), site name, rock type, mineral and sample number in the paleomagnetic study (FUNAKI and TOKIEDA, 1990; TOKIEDA and FUNAKI, 1991).

Biotite and K-feldspar were separated by hand picking from crushed rock samples (32–64 mesh). B722# is the crushed sample (32–64 mesh) from which biotite was removed and the main constituent minerals are K-feldspar, quarts, plagioclase, titanite and blue-green hornblende. Whole rock samples were cut into cylindrical shapes of about 10 mm × 7 mmϕ.

Constituent minerals of each rock are given in Appendix.

Table 1. Sample names and rock types.

Sample(1) name	Site name	Site(2) number	Rock type	Mineral	(Sample number)(3)
^{40}Ar-^{39}Ar method					
B414BT	Pingvinane	MPn4	Granite	Biotite	(B414)
B722BT	Lunckeryggen	ML2	Granite	Biotite	(B722)
B722♯				No Biotite	(B722)(4)
B740BT	Lunckeryggen	ML3	Syenite	Biotite	(B740)
B740KF				K-feldspar	(B740)
B788BT	Lunckeryggen	ML4	Syenite	Biotite	(B788)
B788KF				K-feldspar	(B788)
B858	Brattnipene	MB3	Basalt (dyke)	Whole rock	(B858)
K-Ar method					
B1BT	Selungen (Seal rock)	—	Qz Monzonite (dyke; B1 intrudes into B5)	Biotite	(B1)
B5BT	Selungen (Seal rock)	—	Qz Syenite	Biotite	(B5)
B140BT	Otto Borchgrevink	MO1	Gneiss	Biotite	(B140)
B209BT	Nils Larsenfjellet	MN1	Gneiss	Biotite	(B209)
B907	Vesthaugen	—	Hornfels	Whole rock	(B907)
B910	Vesthaugen	—	Trachybasalt	Whole rock	(B910)

(1) This sample name is used in this study.
(2) This site number is used in JARE-30 (MORIWAKI *et al.*, 1989).
(3) This sample number is used in the paleomagnetic study (FUNAKI and TOKIEDA, 1990; TOKIEDA and FUNAKI, 1991).
(4) "No Biotite" means the sample from which biotite is removed and the constituent minerals are mainly K-feldspar, quartz, plagioclase, titanite and hornblende.

3. Experiments

3.1. The ^{40}Ar-^{39}Ar method

Samples were wrapped in Al foils and sealed in a quartz tube (70 mm × 10 mmϕ) together with standard samples (biotite separated from JG-1; $K_2O=7.64\pm0.05$ wt%; 90.8 ± 1.7 Ma), CaF_2 and K_2SO_4 in vacuum (about 10^{-1} Pa). They were irradiated with fast neutrons for 24 hours in the JMTR (Tohoku University) receiving the total neutron flux of about 10^{18} n/cm^2.

Irradiated samples were put in a Mo crucible and gases were extracted at each temperature stepwisely from samples using an induction heater at the Radio Isotope Center, University of Tokyo. Temperature was controlled by the output power of the induction heater by monitoring the temperature of a top part of the Mo crucible with the aid of an optical pyrometer. Each temperature was kept for 70 minutes to extract gases.

Extracted gases were purified with titanium heated up to about 900°C and they were introduced into a Quadrupole Mass Spectrometer (QMS). Ar isotopes were analyzed on the QMS automatically with the use of a micro-computer (TAKIGAMI *et al.*, 1984).

After the correction of the mass discrimination effect, data were further corrected for the K- and Ca-derived interference Ar isotopes to the ^{40}Ar, ^{39}Ar and ^{36}Ar, using the values mentioned below. They have been determined based on Ar isotope data for neutron irradiated K_2SO_4 and CaF_2.

$$({}^{40}Ar/{}^{39}Ar)_K = 0.0787 \pm 0.0004;$$
$$({}^{39}Ar/{}^{37}Ar)_{Ca} = 0.00144 \pm 0.00005; \quad ({}^{36}Ar/{}^{37}Ar)_{Ca} = 0.000389 \pm 0.000202.$$

Though the error of $({}^{36}Ar/{}^{37}Ar)_{Ca}$ is very large, the influence for the age uncertainty is negligible because of the larger amount of the radiogenic ^{40}Ar and the small rate of air contamination below 5%.

We calculated an ^{40}Ar-^{39}Ar age using the J-value in the following way:

$$t = \ln({}^{40}Ar^*/{}^{39}Ar_K \times J + 1)/\lambda$$
$$J = (\exp(\lambda \times t_s) - 1)/({}^{40}Ar/{}^{39}Ar)_{\text{standard sample}},$$

where, $\lambda = 5.543 \times 10^{-10}/y$ (STEIGER and JÄGER, 1977), $^{40}Ar^*$; radiogenic ^{40}Ar, $^{39}Ar_K$; K-derived ^{39}Ar due to neutron irradiation and t_s; age of standard sample.

3.2. *The K-Ar method*

Ar gases were analyzed by the same procedure as the ^{40}Ar-^{39}Ar method. The amount of radiogenic ^{40}Ar was determined based on the sensitivity of the QMS, which was estimated by analyzing the known amount of radiogenic ^{40}Ar in the standard sample. Stability of the sensitivity was estimated to be about 1% from the analytical results of standard samples.

The K content was determined by means of a flame photometry and the uncertainty in the listed K indicates the range of reproducibility for experiments on the same sample.

4. Results and Discussions

Table 2, Table 3, Figs. 2a–2h and Fig. 3 show the results of ^{40}Ar/^{39}Ar analyses and Table 4 indicates the results of K-Ar analyses.

Biotite samples (B414BT, B722BT, B740BT, B788BT) separated from granite and syenite of Pingvinane and Lunckeryggen give good ^{40}Ar-^{39}Ar plateau ages of 496–501 Ma (Table 2, Figs. 2a, 2b, 2d and 2f). These ages agree well with one another within their uncertainties and are similar to a Rb-Sr whole rock isochron age ($525 \pm 16(1\sigma)$ Ma) of Lunckeryggen granite (TAKAHASHI *et al.*, 1990).

The ^{40}Ar/^{39}Ar total fusion ages of biotite samples are 1–11 million years younger than the plateau ages of about 500 Ma, which may be due to the weak thermal metamorphism. Accordingly, the K-Ar ages of sample B5BT (492 ± 6 Ma) and B140BT (479 ± 15 Ma), which mean the same ages as the ^{40}Ar-^{39}Ar total fusion ages, are considered to have become young from the original ages of about 500 Ma.

Further, previously reported K-Ar results for gneiss samples of 1117 (551 ± 56 Ma) and 1098 (468 ± 21 Ma) from Brattnipene and Austkampane (TAKIGAMI *et al.*, 1987) might also correspond to the 500 Ma thermal event.

Since the ages of around 500 Ma were often obtained from various sites such as Lunckeryggen, Pingvinane, Selungen, Otto Borchgrevink and Brattnipene, the intrusive igneous activity of about 500 Ma seems to have occurred widely in the Sør Rondane Mountains area.

Table 2. Analytical data of ^{40}Ar-^{39}Ar ages.

Sample B414BT (0.1287 g; J=0.003504±0.000087)

Step No.	Temperature (°C)	^{40}Ar ($\times 10^{-6}$ cm^3/g)	$^{36}Ar/^{40}Ar$ ($\times 10^{-4}$)	$^{37}Ar/^{40}Ar$ ($\times 10^{-3}$)	$^{39}Ar/^{40}Ar$ ($\times 10^{-2}$)	^{39}Ar (%)	$^{40}Ar^*/^{39}Ar_K$ (1) ($\times 10^{-2}$)	Age (2) (Ma)
1	600	1.69	8.325 ±0.286	1.665 ±0.103	2.520 ±0.017	3.3	29.86 ±0.40	179.5 ±4.1
2	700	4.18	1.188 ±0.060	0.4151 ±0.0192	1.161 ±0.007	3.8	83.04 ±0.55	460.8 ±8.6
3	800	10.7	1.852 ±0.048	0.1692 ±0.0169	1.047 ±0.006	8.7	90.24 ±0.50	495.7 ±9.0
4	900	18.4	0.1817 ±0.0099	0.2546 ±0.0126	1.100 ±0.005	15.8	90.33 ±0.39	496.2 ±8.9
5	980	11.4	0.2155 ±0.0085	0.3069 ±0.0143	1.097 ±0.007	9.8	90.49 ±0.59	496.9 ±9.2
6	1060	16.1	0.2678 ±0.0058	1.929 ±0.052	1.075 ±0.006	13.5	92.30 ±0.55	505.5 ±9.2
7	1120	45.0	0.1216 ±0.0043	1.226 ±0.011	1.096 ±0.004	38.5	90.87 ±0.34	498.7 ±8.9
8	1200	6.71	0.4224 ±0.0167	6.854 ±0.145	1.100 ±0.006	5.7	89.86 ±0.45	493.7 ±9.0
9	1500	1.30	8.428 ±0.185	2.011 ±0.068	0.8800 ±0.0086	0.9	85.32 ±1.04	471.9 ±9.8
Total		116	0.5904	1.293	1.110	100.0	88.47	487.2 ±8.6

Sample B722BT (0.1213 g; J=0.003536±0.000070)

Step No.	Temperature (°C)	^{40}Ar ($\times 10^{-6}$ cm^3/g)	$^{36}Ar/^{40}Ar$ ($\times 10^{-4}$)	$^{37}Ar/^{40}Ar$ ($\times 10^{-3}$)	$^{39}Ar/^{40}Ar$ ($\times 10^{-2}$)	^{39}Ar (%)	$^{40}Ar^*/^{39}Ar_K$ (1) ($\times 10^{-2}$)	Age (2) (Ma)
1	600	0.391	14.87 ±0.45	5.627 ±0.367	1.247 ±0.015	0.3	45.01 ±1.20	266.2 ±8.2
2	700	2.43	5.456 ±0.109	1.138 ±0.035	1.114 ±0.006	1.4	75.26 ±0.50	425.6 ±7.9
3	800	8.54	3.690 ±0.052	0.3992 ±0.0153	1.018 ±0.004	4.4	87.49 ±0.41	486.2 ±8.7
4	900	26.9	0.2846 ±0.0080	0.1574 ±0.0083	1.103 ±0.005	15.1	89.83 ±0.44	497.6 ±8.9
5	910	11.0	0.1725 ±0.0089	0.1459 ±0.0112	1.112 ±0.006	6.2	89.36 ±0.48	495.3 ±8.9
6	1000	20.4	0.1706 ±0.0079	0.1135 ±0.0119	1.098 ±0.005	11.4	90.56 ±0.42	501.1 ±8.9
7	1100	26.5	0.1628 ±0.0065	0.2412 ±0.0063	1.098 ±0.004	14.9	90.55 ±0.34	501.0 ±8.8
8	1200	38.8	0.1324 ±0.0079	0.2175 ±0.0082	1.098 ±0.006	21.8	90.62 ±0.49	501.4 ±9.0
9	1300	37.4	0.1533 ±0.0026	1.454 ±0.025	1.081 ±0.006	20.6	92.07 ±0.48	508.4 ±9.1
10	1500	7.20	1.511 ±0.060	5.133 ±0.126	1.058 ±0.005	3.9	90.35 ±0.43	499.9 ±8.9
Total		180	0.4996	0.6834	1.091	100.0	90.24	499.6 ±8.7

± in values are errors of one standard deviation.

The uncertainties in ages and $^{40}Ar^*/^{39}Ar_K$ ratio do not include those of correction factors for K- and Ca- derived interference isotopes.

(1) $^{40}Ar^*$ and $^{39}Ar_K$ means the radiogenic ^{40}Ar and the K-derived ^{39}Ar, respectively.

(2) ^{40}Ar-^{39}Ar ages were calculated by using following constants. $\lambda_e=0.581\times 10^{-10}$/y, $\lambda_\beta=4.962\times 10^{-10}$/y, $^{40}K/K=1.167\times 10^{-4}$ (STEIGER and JÄGER, 1977).

(3) "n.d." represents "not determined" owing to the small amount of ^{37}Ar.

Table 2. (Continued)

Sample B722# (0.3962 g; J=0.003661±0.000073)

Step No.	Temperature (°C)	^{40}Ar (×10^{-6} cm^3/g)	$^{36}Ar/^{40}Ar$ (×10^{-4})	$^{37}Ar/^{40}Ar$ (×10^{-3})	$^{39}Ar/^{40}Ar$ (×10^{-2})	^{39}Ar (%)	$^{40}Ar^{*}/^{39}Ar_K$ (1) (×10^{-2})	Age (2) (Ma)
1	600	1.17	2.746 ±0.053	0.6691 ±0.0821	0.9885 ±0.0064	1.1	92.89 ±0.62	528.1 ±9.6
2	700	3.71	0.7423 ±0.0215	0.5770 ±0.0354	1.427 ±0.005	5.2	68.49 ±0.24	403.6 ±7.3
3	800	4.88	1.575 ±0.027	0.5772 ±0.0292	1.382 ±0.006	6.6	68.95 ±0.29	406.0 ±7.4
4	900	11.2	0.1794 ±0.0053	1.092 ±0.019	1.354 ±0.006	14.9	73.41 ±0.31	429.4 ±7.8
5	980	7.75	0.3931 ±0.0111	1.025 ±0.034	1.345 ±0.009	10.3	73.42 ±0.49	429.4 ±8.0
6	1060	6.85	0.1722 ±0.0046	1.513 ±0.019	1.316 ±0.006	8.9	75.57 ±0.33	440.6 ±7.9
7	1120	7.04	0.3558 ±0.0113	1.551 ±0.042	1.267 ±0.005	8.8	78.05 ±0.32	453.4 ±8.1
8	1200	13.0	0.4901 ±0.0088	1.969 ±0.027	1.211 ±0.005	15.4	81.33 ±0.33	470.1 ±8.4
9	1300	20.9	0.6019 ±0.0116	2.819 ±0.034	1.176 ±0.007	24.1	83.48 ±0.53	481.0 ±8.8
10	1500	4.30	0.9236 ±0.0119	10.42 ±0.19	1.112 ±0.005	4.7	87.67 ±0.38	501.9 ±8.9
Total		80.7	0.5609	2.185	1.260	100.0	78.19	454.1 ±8.1

Sample B740BT (0.1276 g; J=0.003457±0.000071)

Step No.	Temperature (°C)	^{40}Ar (×10^{-6} cm^3/g)	$^{36}Ar/^{40}Ar$ (×10^{-4})	$^{37}Ar/^{40}Ar$ (×10^{-4})	$^{39}Ar/^{40}Ar$ (×10^{-2})	^{39}Ar (%)	$^{40}Ar^{*}/^{39}Ar_K$ (1) (×10^{-2})	Age (2) (Ma)
1	600	5.77	33.60 ±0.53	2.003 ±0.139	0.03272 ±0.00045	0.1	21.92 ±47.44	131.5 ±275.1
2	700	0.706	13.94 ±0.46	15.67 ±1.75	0.8610 ±0.0086	0.3	68.27 ±1.73	382.2 ±11.2
3	800	9.85	27.09 ±0.33	4.995 ±0.247	0.2468 ±0.0012	1.2	80.79 ±3.92	444.3 ±20.7
4	900	9.78	2.788 ±0.038	0.2850 ±0.0307	1.015 ±0.006	4.9	90.35 ±0.53	490.4 ±9.1
5	980	15.1	0.3058 ±0.0119	n.d. (3)	1.089 ±0.004	8.1	90.93 ±0.38	493.2 ±9.0
6	1060	14.3	0.6876 ±0.0153	n.d.	1.072 ±0.005	7.5	91.35 ±0.40	495.1 ±9.1
7	1120	13.4	0.1428 ±0.0099	1.240 ±0.099	1.080 ±0.004	7.1	92.16 ±0.34	499.0 ±9.0
8	1200	32.0	0.2373 ±0.0046	0.6493 ±0.0669	1.072 ±0.007	16.8	92.57 ±0.58	500.9 ±9.4
9	1300	61.8	0.2272 ±0.0059	0.4244 ±0.0364	1.069 ±0.004	32.4	92.81 ±0.39	502.1 ±9.1
10	1500	41.8	0.7738 ±0.0136	2.887 ±0.051	1.054 ±0.005	21.6	92.66 ±0.47	501.4 ±9.2
Total		205	2.778	1.266	0.9966	100.0	92.03	498.4 ±9.0

Table 2. (*Continued*)

Sample B740KF (0.1319 g; J=0.003425±0.000070)

Step No.	Temperature (°C)	^{40}Ar (×10^{-6} cm^3/g)	$^{36}Ar/^{40}Ar$ (×10^{-4})	$^{37}Ar/^{40}Ar$ (×10^{-4})	$^{39}Ar/^{40}Ar$ (×10^{-2})	^{39}Ar (%)	$^{40}Ar^*/^{39}Ar_K$(1) (×10^{-2})	Age(2) (Ma)
1	500	0.223	12.07 ±0.49	n.d.(3)	0.3791 ±0.0093	0.1	169.6 ±5.7	826.3 ±26.0
2	600	1.62	3.452 ±0.108	8.290 ±0.545	0.4087 ±0.0040	0.3	219.7 ±2.3	1012 ±18
3	700	1.90	0.6031 ±0.0236	n.d.	1.327 ±0.007	1.3	73.94 ±0.40	407.3 ± 7.7
4	800	4.72	4.441 ±0.079	4.076 ±0.475	1.205 ±0.008	3.0	72.03 ±0.51	397.8 ± 7.7
5	880	9.17	0.4124 ±0.0147	n.d.	1.347 ±0.007	6.6	73.23 ±0.39	403.8 ± 7.6
6	960	12.6	0.2769 ±0.0105	0.7682 ±0.1037	1.321 ±0.006	8.9	75.00 ±0.34	412.5 ± 7.7
7	1020	7.49	0.1478 ±0.0096	0.5918 ±0.0788	1.317 ±0.008	5.3	75.52 ±0.44	415.0 ± 7.9
8	1100	7.91	0.4625 ±0.0203	1.300 ±0.087	1.270 ±0.007	5.4	77.60 ±0.43	425.2 ± 8.0
9	1200	21.0	0.2177 ±0.0093	0.3282 ±0.0345	1.227 ±0.004	13.8	80.89 ±0.28	441.2 ± 8.1
10	1500	87.9	0.3493 ±0.0050	0.5265 ±0.0190	1.178 ±0.004	55.3	83.94 ±0.27	455.9 ± 8.3
Total		155	0.5027	0.7132	1.211	100.0	81.27	443.1 ± 8.1

Sample B788BT (0.1374 g; J=0.003385±0.000069)

Step No.	Temperature (°C)	^{40}Ar (×10^{-6} cm^3/g)	$^{36}Ar/^{40}Ar$ (×10^{-4})	$^{37}Ar/^{40}Ar$ (×10^{-4})	$^{39}Ar/^{40}Ar$ (×10^{-2})	^{39}Ar (%)	$^{40}Ar^*/^{39}Ar_K$(1) (×10^{-2})	Age(2) (Ma)
1	500	0.0199	13.95 ±1.01	123.6 ±4.6	1.232 ±0.045	0.01	48.38 ±3.00	270.6 ±16.6
2	600	1.01	14.79 ±0.34	13.07 ±0.38	1.425 ±0.013	0.8	39.50 ±0.78	226.1 ± 6.0
3	700	1.13	6.207 ±0.235	5.045 ±0.157	1.178 ±0.007	0.7	69.26 ±0.72	379.8 ± 7.9
4	800	10.6	2.804 ±0.064	1.773 ±0.055	1.039 ±0.004	5.7	88.18 ±0.42	471.2 ± 8.7
5	880	8.44	0.8031 ±0.0503	0.6809 ±0.0293	1.068 ±0.007	4.6	91.32 ±0.65	485.9 ± 9.2
6	960	12.6	0.5725 ±0.0174	1.087 ±0.030	1.078 ±0.005	7.0	91.16 ±0.40	485.1 ± 8.9
7	1040	21.6	0.5317 ±0.0123	1.478 ±0.039	1.019 ±0.003	11.3	96.52 ±0.33	510.0 ± 9.2
8	1120	31.3	0.2182 ±0.0032	1.197 ±0.019	1.073 ±0.005	17.3	92.52 ±0.43	491.5 ± 9.0
9	1200	49.0	0.1729 ±0.0034	0.5945 ±0.0175	1.061 ±0.004	26.7	93.72 ±0.35	497.1 ± 9.0
10	1500	48.6	1.032 ±0.014	3.674 ±0.052	1.037 ±0.005	25.9	93.43 ±0.42	495.6 ± 9.1
Total		184	0.7750	1.826	1.055	100.01	92.54	491.6 ± 8.8

Table 2. (*Continued*)

Sample B788KF (0.1367 g; J=0.003348±0.000068)

Step No.	Temperature (°C)	^{40}Ar ($\times 10^{-6}$ cm^3/g)	$^{36}Ar/^{40}Ar$ ($\times 10^{-4}$)	$^{37}Ar/^{40}Ar$ ($\times 10^{-4}$)	$^{39}Ar/^{40}Ar$ ($\times 10^{-2}$)	^{39}Ar (%)	$^{40}Ar^*/^{39}Ar_K$ [1] ($\times 10^{-2}$)	Age [2] (Ma)
1	600	3.48	2.760 ±0.079	0.5711 ±0.0720	0.7791 ±0.0089	1.1	117.8 ±1.4	599.8 ±12.0
2	700	3.39	0.6774 ±0.0321	n.d. [3]	1.440 ±0.011	2.0	67.97 ±0.53	369.8 ± 7.3
3	800	5.62	6.255 ±0.115	2.117 ±0.249	1.164 ±0.006	2.7	69.95 ±0.46	379.6 ± 7.4
4	900	12.3	0.3285 ±0.0132	n.d.	1.379 ±0.005	7.0	71.75 ±0.25	388.4 ± 7.2
5	1000	15.0	0.4454 ±0.0099	n.d.	1.357 ±0.006	8.4	72.66 ±0.31	392.8 ± 7.4
6	1100	18.3	0.2694 ±0.0063	0.3620 ±0.0337	1.331 ±0.006	10.1	74.46 ±0.34	401.5 ± 7.5
7	1200	41.1	0.3329 ±0.0053	0.6689 ±0.0272	1.130 ±0.006	22.1	76.23 ±0.36	410.0 ± 7.7
8	1300	48.1	0.2575 ±0.0051	0.2949 ±0.0299	1.273 ±0.004	25.4	77.90 ±0.27	418.0 ± 7.7
9	1400	33.6	0.4024 ±0.0058	n.d.	1.222 ±0.006	17.0	80.81 ±0.41	431.9 ± 8.1
10	1500	8.60	1.356 ±0.026	1.950 ±0.147	1.181 ±0.005	4.2	81.20 ±0.35	433.8 ± 8.1
Total		189	0.6014	0.4166	1.275	100.0	76.96	413.5 ± 7.6

Sample B858 (0.7751 g; J=0.003582±0.000071)

Step No.	Temperature (°C)	^{40}Ar ($\times 10^{-6}$ cm^3/g)	$^{36}Ar/^{40}Ar$ ($\times 10^{-4}$)	$^{37}Ar/^{40}Ar$ ($\times 10^{-2}$)	$^{39}Ar/^{40}Ar$ ($\times 10^{-2}$)	^{39}Ar (%)	$^{40}Ar^*/^{39}Ar_K$ [1] ($\times 10^{-2}$)	Age [2] (Ma)
1	600	1.46	1.199 ±0.027	0.4031 ±0.0052	0.2472 ±0.0017	0.6	391.3 ±2.7	1581 ±22
2	700	0.795	1.416 ±0.050	1.521 ±0.022	0.8558 ±0.0058	1.2	112.5 ±0.8	610.3 ±10.9
3	800	3.14	1.228 ±0.017	1.466 ±0.016	0.9427 ±0.0045	5.4	102.7 ±0.5	564.5 ± 9.9
4	900	9.13	0.2212 ±0.0071	1.027 ±0.012	1.161 ±0.007	19.2	85.77 ±0.49	483.1 ± 8.8
5	980	10.6	0.1464 ±0.0020	0.8674 ±0.0096	1.160 ±0.005	22.3	85.96 ±0.37	484.0 ± 8.6
6	1060	5.78	0.2296 ±0.0050	0.9966 ±0.0088	1.113 ±0.006	11.7	89.44 ±0.47	501.1 ± 9.0
7	1120	4.16	0.6774 ±0.0214	2.086 ±0.020	1.097 ±0.004	8.3	89.87 ±0.36	502.9 ± 8.9
8	1200	6.54	0.2449 ±0.0045	1.014 ±0.009	1.081 ±0.005	12.8	92.06 ±0.46	513.9 ± 9.1
9	1300	11.2	0.2869 ±0.0054	1.934 ±0.018	0.8965 ±0.0042	18.3	111.3 ±0.5	604.5 ±10.5
10	1500	0.278	18.77 ±0.39	4.217 ±0.063	0.3378 ±0.0025	0.2	136.4 ±3.6	714.4 ±19.7
Total		53.1	0.4601	1.298	1.038	100.0	95.27	529.7 ± 9.2

Table 3. Summary of ^{40}Ar-^{39}Ar ages.

Sample name	Plateau age (Ma)	(temperature; released ^{39}Ar)	Total fusion age (Ma)	Minimum age (Ma)
B414BT	498.5±8.8	(800–1200°C; 92.0%)	487.2±8.6	—
B722BT	501.1±8.7	(800–1500°C; 98.3%)	499.6±8.7	—
B722♯	—		454.1±8.0	405.0±7.3
B740BT	499.7±9.0	(900–1500°C; 98.4%)	498.4±9.0	—
B740KF	—		443.1±8.1	402.6±7.7
B788BT	495.7±8.9	(880–1500°C; 92.8%)	491.6±8.8	—
B788KF	—		413.5±7.6	369.8±7.3
B858	isochron age 476.3±22.6 Ma		529.7±9.2	—
1123(1)	439±13	(900–1500°C; 99.3%)	438±13	—
1120(2)	—		412±13	355±11

± indicates one standard deviation.

(1) Sample 1123; Nunatak 1550; Metadolerite, whole rock (TAKIGAMI *et al.*, 1987).

(2) Sample 1120; Nunatak 1550, Gneiss, whole rock (TAKIGAMI *et al.*, 1987).

A dyke sample of B858 shows the typical excess ^{40}Ar age spectrum (U-shape) (Fig. 2h). An isochron plot supports the excess ^{40}Ar by the high initial $^{40}Ar/^{36}Ar$ ratio (4541 ±2670) and gives an isochron age of 476.3±22.8 Ma (Fig. 3). Another dyke sample B1BT shows a K-Ar age of 452±6 Ma. Moreover, the metadolerite dyke sample 1123 of Nunatak 1550 (TAKIGAMI *et al.*, 1987) shows an $^{40}Ar/^{39}Ar$ plateau age of 439±13 Ma, and K-Ar ages of thermally metamorphosed samples B907 and B910 are 439±10 Ma and 467±7 Ma, respectively. Hence, it seems that the thermal activity had continued till about 440 Ma in the northern part of the Sør Rondane Mountains; namely Brattnipene, Vesthaugen, Nunatak 1550 and Selungen.

Since the ages of 440–500 Ma are often obtained in East Antarctica (*e.g.* Lützow-Holm Bay) (HIROI and SHIRAISHI, 1986), the igneous activities of the Sør Rondane Mountains at 440–500 Ma probably represent part of late Ross Orogeny (the Queen Maud Orogeny) (KIZAKI, 1979; SUZUKI, 1986).

B740KF and B788KF (K-feldspar from syenites) and B722♯ (a fraction without biotite from granite) show ^{40}Ar-^{39}Ar stair-type age spectra (Figs. 2c, 2e and 2g). We already reported a similar stair-type spectrum for a gneiss sample (1120: Nunatak 1150) obtained from the same sampling field (TAKIGAMI *et al.*, 1987). Slow cooling mechanism or thermal metamorphism may explain such stair-type age spectra (MCDOUGALL and HARRISON, 1988).

HARRISON and MCDOUGALL (1982) presented such stair-type age spectra for the microcline samples and explained by the slow cooling (about 5°C/Ma) of the samples. Then, we can calculate the cooling rate of the syenite to be about 2.2°C/Ma from the results of biotite samples (age, 500 Ma; closure temperature, about 350°C) and K-feldspar samples (minimum age, about 410 Ma: closure temperature, about 150°C (for microcline: HARRISON and MCDOUGALL, 1982)). This cooling rate is lower than that of an igneous intrusion (about 5°C/Ma) reported by HARRISON and MCDOUGALL (1982).

The minimum ages in lower termperature fractions are 355–405 Ma and might represent the age of a later weak thermal metamorphism, which has not influenced biotite to degass radiogenic Ar. TAKAHASHI *et al.* (1990) have reported similar K-Ar

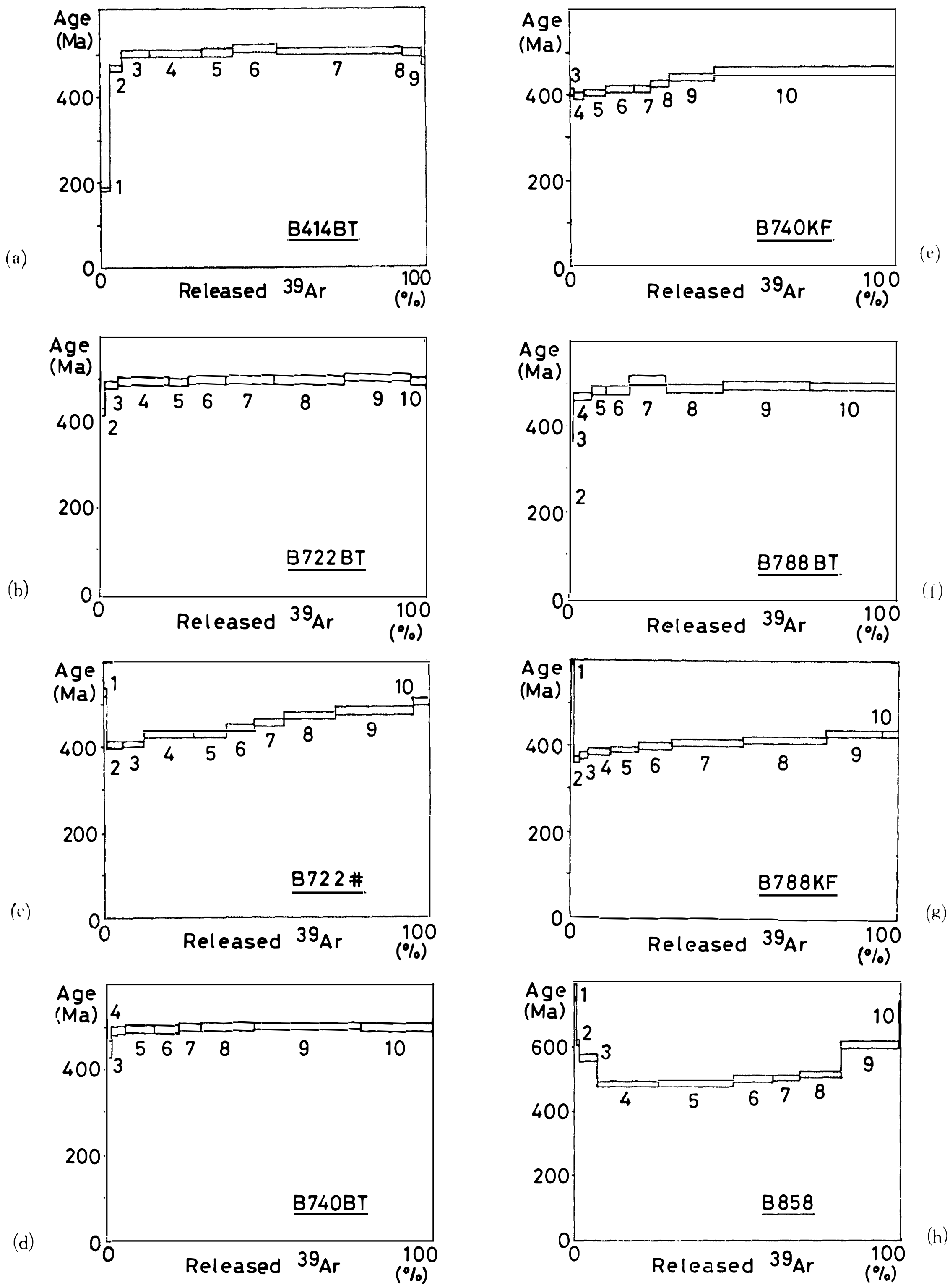

Fig. 2. Vertical and horizontal axes indicate the apparent age and the released ^{39}Ar *(%). The bands in the age represent errors of one standard deviation. Numerical figure at each column indicates the step number in Table 2.*

(a) The ^{40}Ar–^{39}Ar *age spectrum for B414BT.*
(b) The ^{40}Ar–^{39}Ar *age spectrum for B722BT.*
(c) The ^{40}Ar-^{39}Ar *age spectrum for B722#.*
(d) The ^{40}Ar-^{39}Ar *age spectrum for B740BT.*
(e) The ^{40}Ar-^{39}Ar *age spectrum for B740KF.*
(f) The ^{40}Ar-^{39}Ar *age spectrum for B788BT.*
(g) The ^{40}Ar-^{39}Ar *age spectrum for B788KF.*
(h) The ^{40}Ar-^{39}Ar *age spectrum for B858.*

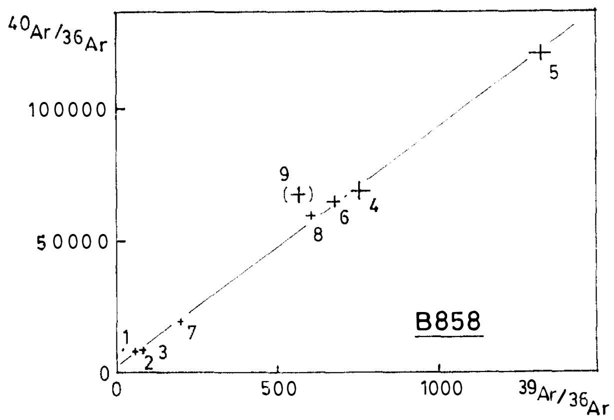

Fig. 3. The ^{40}Ar-^{36}Ar-$^{39}Ar/^{36}Ar$ plot for B858.
Using all temperature fractions except 1300°C, the isochron age is determined to be 476.3±22.6 Ma and the line intercepts the $^{40}Ar/^{36}Ar$ axis at 4541±2670.

Table 4. Summary of K-Ar ages.

Sample name	K (wt%)	$^{40}Ar_{rad}$ ($\times 10^{-5}$ cm^3/g)	$^{40}Ar_{air}/^{40}Ar_{total}$ (%)	Age$^{(1)}$ (Ma)
B1BT	5.76±0.04	11.3±0.1	5.3	452±6
B5BT	5.63±0.04	12.4±0.1	1.2	492±6
B140BT	7.63±0.23	16.0±0.1	3.2	479±15
B209BT	7.37±0.25	22.8±0.2	1.3	662±23
B907	2.50±0.05	4.84±0.04	0.5	439±10
B910	1.97±0.03	4.07±0.03	0.1	467±7
1098$^{(2)}$	1.07±0.04	2.17±0.03	1.8	468±21
1117$^{(3)}$	0.88±0.03	2.15±0.22	5.4	551±56

± indicates one standard deviation.
(1) K-Ar ages were calculated with the following values (STEIGER and JÄGER, 1977). $\lambda_e=0.581\times10^{-10}$/y, $\lambda_\beta=4.962\times10^{-10}$/y, $^{40}K/K=1.167\times10^{-4}$ moles/mole.
(2) Sample 1098; Austkampane, Gneiss, whole rock (TAKIGAMI *et al.*, 1987).
(3) Sample 1117; Brattnipene, Gneiss, whole rock (TAKIGAMI *et al.*, 1987).

whole rock ages of 406 and 415 Ma for the Lunckeryggen granite. Similar young K-Ar ages of 350–400 Ma were reported for igneous and metamorphic rocks from Ongul Islands, Yamato Mountains and Belgica Mountains (HIROI and SHIRAISHI, 1986). However, as such ages have been determined by the K-Ar method and no clear evidence of the weak metamorphism has been found so far from microscopic examinations for samples used in this study, the possibility for the existence of a weak thermal event at about 350–400 Ma should be clarified by a more sophisticated way in future.

For the Nils Larsen tonalite, TAKAHASHI *et al.* (1990) and PASTEELS and MICHOT (1968) reported a Rb-Sr whole rock isochron age (956±20(1σ) Ma) and a U-Pb zircon age (about 950 Ma), respectively. In this study, we obtained a K-Ar age of 662±23 Ma for biotite from a gneiss sample (B209). The younger age of gneiss than that of tonalite may be explained by the several reasons; the different thermal events, the release of radiogenic ^{40}Ar by thermal event and/or weathering effect and so on.

5. Summary

(1) ^{40}Ar-^{39}Ar plateau ages and K-Ar ages indicate that an intrusive activity occurred at about 500 Ma widely in the Sør Rondane Mountains area.

(2) The igneous activity may have continued to about 440 Ma, especially in the northern part of the Sør Rondane Mountains.

(3) The stair-type age spectra of K-feldspar samples may be caused by the slow cooling of the samples or the weak thermal metamorphism at about 350–400 Ma.

(4) The K-Ar age (662 Ma) for a biotite from gneiss of Nils Larsenfjellet is definitely younger than reported Rb-Sr and U-Pb ages of tonalites from the same area. Several possibilities can be raised to explain the apparent difference in the ages, but it is difficult to specify it at present.

Acknowledgments

We wish to thank Prof. N. UENO, Toyo University, for cooporating in the K measurement and Dr. T. TIBA, National Science Museum, for sample descriptions. We also grateful to Prof. I. KANEOKA for critical reading of the manuscript. This study is financially supported by the Grant-in-Aid for Science Research from the Kanto Gakuen University.

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(Received March 19, 1991; Revised manuscript received May 28, 1991)

Appendix

Rock types and constituent minerals ([ ]: minor minerals) for each sample are described as below (after T. TIBA)

^{40}Ar-^{39}Ar sample

B414: GRANITE
K-feldspar (orthoclase-perthite), biotite (slightly metamorphosed), plagioclase, green hornblende, [quarts, allanite, magnetite, titanite, ilmenite]

B722: GRANITE
K-feldspar (microcline), biotite (partly zircon halo), quartz. plagioclase, titanite, blue-green hornblende, [magnetite, apatite]

B740: SYENITE
K-feldspar (orthoclase-perthite, microcline: sieve texture), biotite, titanite, blue-green hornblende, plagioclase, [quartz, magnetite, apatite]

B788: SYENITE
K-feldspar (orthoclase-perthite, microcline: sieve texture), clinopyroxene, biotite, titanite, blue-green hornblende, [magnetite, apatite, quartz]

B858: fine-grained BASALT (basaltic texture)
clinopyroxene, orthopyroxene, plagioclase (slightly metamorphosed), [magnetite, ilmenite, biotite (primally? secondary?), smectite, carbonate]

K-Ar sample

B1: Qz-MONZONITE
K-feldspar (orthoclase-perthite, microcline: fresh), biotite (slightly metamorphosed), plagioclase, quartz, hornblende, [magnetite, apatite, clinopyroxene, white mica]

B5: Qz-SYENITE
K-feldspar (orthoclase-perthite), plagioclase, quartz, hornblende, biotite, [zircon, magnetite, apatite, goethite]

B140: GNEISS
K-feldspar (orthoclase-perthite, microcline: slightly metamorphosed), plagioclase, quartz, biotite (partly zircon halo), [titanite, zircon, magnetite, apatite, calcite, sericite]

B209: GNEISS
plagioclase, K-feldspar (orthoclase-perthite: slightly sericite), biotite, quartz, hornblende, [titanite, apatite, epidote]

B907: HORNFELS
plagioclase, quarts, biotite, hornblende, titanite, [ilmenite, apatite]

B910: thermally metamorphosed TRACHYBASALT?
plagioclase, biotite, ilmenite, hornblende, [apatite]