Polar Geosci., **17**, 35–44, 2004

Geochronological study of post-metamorphic granite from Kasumi Rock, Lützow-Holm Complex, East Antarctica

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(Received February 23, 2004; Accepted May 6, 2004)

Abstract: Kasumi Rock is situated in the amphibolite-facies metamorphic zone in the Lützow-Holm Complex, East Antarctica. In this area, granitic rocks occur as steeply dipping linear dykes with sharp intrusive contacts, and cross-cut the foliation of layered metamorphic rocks. A geochronological study of this post-metamorphic granite (PMG) has been performed. An Rb-Sr whole rock isochron for five granitic rocks defines an age of 492.1±23.4 Ma with an initial $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$ ratio of 0.70535±0.00027 (MSWD=0.08). In the Sm-Nd isochron diagram, four rock samples yield an age of 498.4±90.6 Ma with an initial $^{143}\mathrm{Nd}/^{144}\mathrm{Nd}$ ratio of 0.511782±0.000101 (MSWD=0.05). The whole rock isochron ages and mode of occurrence suggest that the Kasumi PMGs were intruded after regional cooling of the area, and probably affected local reequilibrium for isotopic systems of surrounding metamorphic rocks. The PMGs might have been slowly cooled and crystallized after the intrusion. The Kasumi PMGs have no genetic relation to the Oku-iwa PMGs as regards Rb-Sr and Sm-Nd isotopic systems, because the initial ratios of both PMGs are quite different from each other. This is interpreted to mean that the PMGs in the Lützow-Holm Complex were originated from different source materials or had different chemical reaction processes with crustal materials.

key words: Rb-Sr whole rock isochron, Sm-Nd whole rock isochron, post-metamorphic granite, Kasumi Rock, Lützow-Holm Complex

1. Introduction

Early Paleozoic granitic rocks are distributed throughout the Lützow-Holm Complex (LHC), a Cambrian high-grade metamorphic terrain, East Antarctica (Shiraishi *et al.*, 1994). Some of the granitic rocks in the LHC are pre- to syn-metamorphic, suggested by the irregular shape of the intrusive boundary, intergradational contacts and remarkable deformation. One of the pre- to syn-metamorphic granites in Breidvågnipa was dated to be 576±39 Ma by the Rb-Sr whole rock isochron method (Shimura *et al.*, 1998). The age of the pre- to syn-metamorphic granites is slightly older than the U-Pb zircon ages of metamorphic rocks (520–550 Ma) obtained from several samples of different metamorphic grade within the LHC (Shiraishi *et al*., 1994, 2003).

On the other hand, the abundance of post-metamorphic granites (PMGs) is recognized in the LHC. The post-metamorphic nature of these rocks is suggested by sharp intrusive contacts and/or mode of occurrence, crosscutting the layered gneissose structure of the metamorphic rocks. Furthermore, the granitic rocks are unmetamorphosed and not distinctively deformed. The PMGs are exposed in Oku-iwa Rock situated in the transitional zone between amphibolite facies and granulite facies, and in Kasumi Rock situated in the amphibolite-facies zone of the LHC. The former has already been investigated and the age was determined to be 485±50 Ma by the Rb-Sr whole rock isochron method (Nishi *et al*., 2002). The isotopic age is younger than the peak metamorphic age (540 Ma) of the LHC. The latter has not been studied yet and sufficient data are not available to discuss the relationships between post-metamorphic igneous activity and high-grade metamorphism. In this paper, the authors report the Rb-Sr and Nd-Sm whole rock isochron ages of PMGs from Kasumi Rock in the LHC, and discuss the geological significance of isotopic ages.

2. Outline of geology of Kasumi Rock

Kasumi Rock on the Prince Olav Coast is located about 150 km NE of Syowa Station, East Ongul Island, its area is approximately 2 km^2 (Nishida *et al*., 1984). It is situated in the amphibolite-facies zone of the LHC (Hiroi *et al*., 1991) (Fig. 1A), and is composed dominantly of biotite gneiss, amphibolite, marble, skarn, granitic gneiss and granitic dykes (Fig. 1B). The biotite gneiss is widely distributed throughout the area and is light gray with dominated plagioclase, quartz and minor potassium feldspar. The rock has foliation defined by the preferred orientation of biotite, parallel to the compositional layers. Biotite-hornblende gneiss, the melanocratic part of the biotite gneiss, is dark gray and is characterized by higher modal amounts of biotite and hornblende than those of the biotite gneiss. Biotite is generally coarser and aligned parallel to the compositional layering in this rock. The marble and skarn beds are intercalated with the biotite gneiss in the northwestern part of the area. The thickness of the layer ranges from 1 to 10 m. The amphibolite is distributed mostly in the southern part and consists of fine-grained melanocratic rocks with slightly massive appearance. The coarse-grained granitic gneiss possesses fairly strong gneissose structure and is composed of biotite, plagioclase, potassium feldspar and quartz. These gneissose rocks have a foliation with general trend striking NW-SE and dipping 40°–70°N or 42°–76°S (Nishida *et al*., 1984).

The granitic dykes intrude steeply, dipping with sharp contacts, and clearly crosscutting layered metamorphic rocks (Fig. 2A, B). Their intrusive trends indicate NW-SE and NE-SW strike. The age of intrusion of the dykes is considered to be post-metamorphism and after deformation. Thus, the granitic dykes are tentatively named the “Kasumi post-metamorphic granites (Kasumi PMGs)”. The Kasumi PMGs are usually pinkish-colored, owing to abundant pinkish potassium feldspar (Fig. 2B), and are approximately 1–4 m wide, and extend for tens to hundreds of meters.

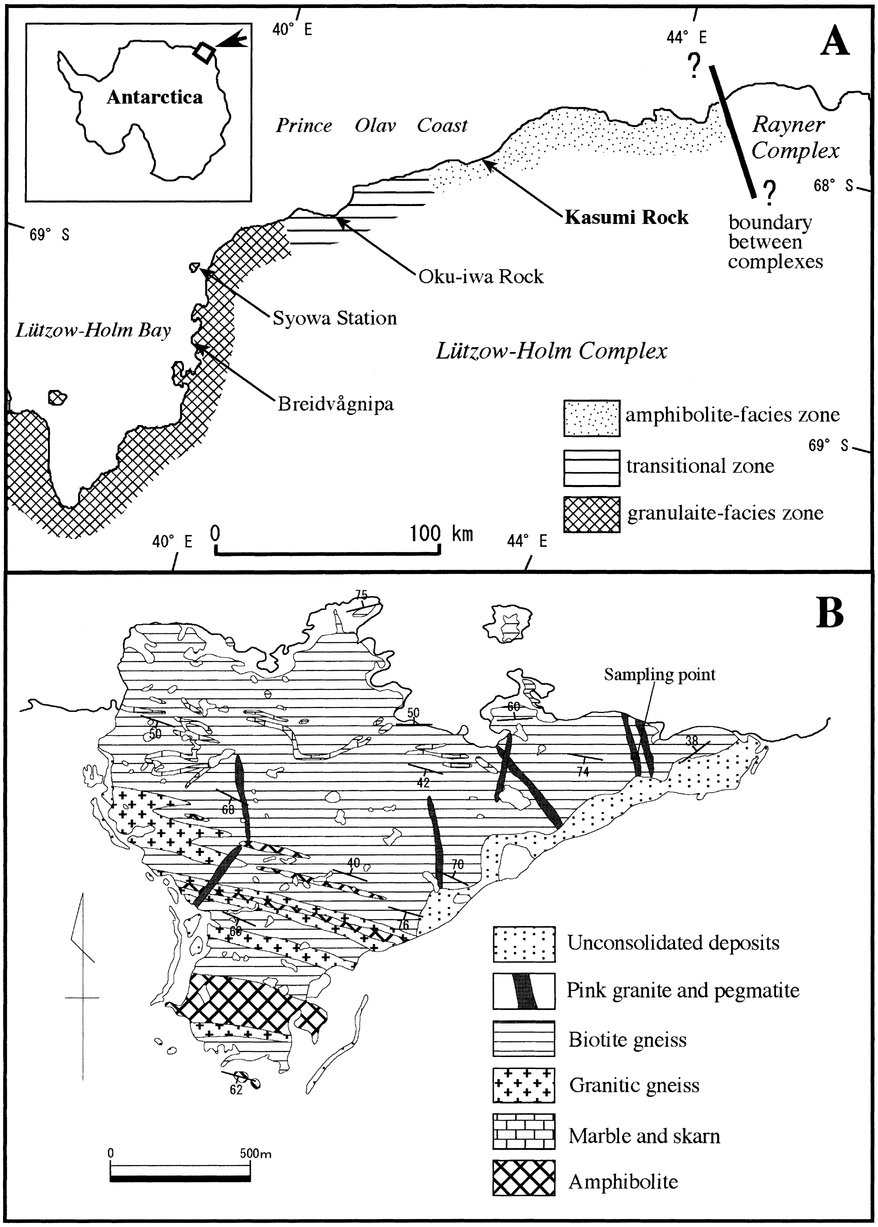

Fig. 1. Geological map of the study area (A, B) (simplified from Nishida et al., 1984). Boundaries of metamorphic zones are after Hiroi et al. (1991).

3. Descriptions of analyzed samples

One biotite gneiss and five PMGs were collected for isotope analysis. They are taken from a single outcrop at the northeastern part of Kasumi Rock (Fig. 1B, Fig. 2C,

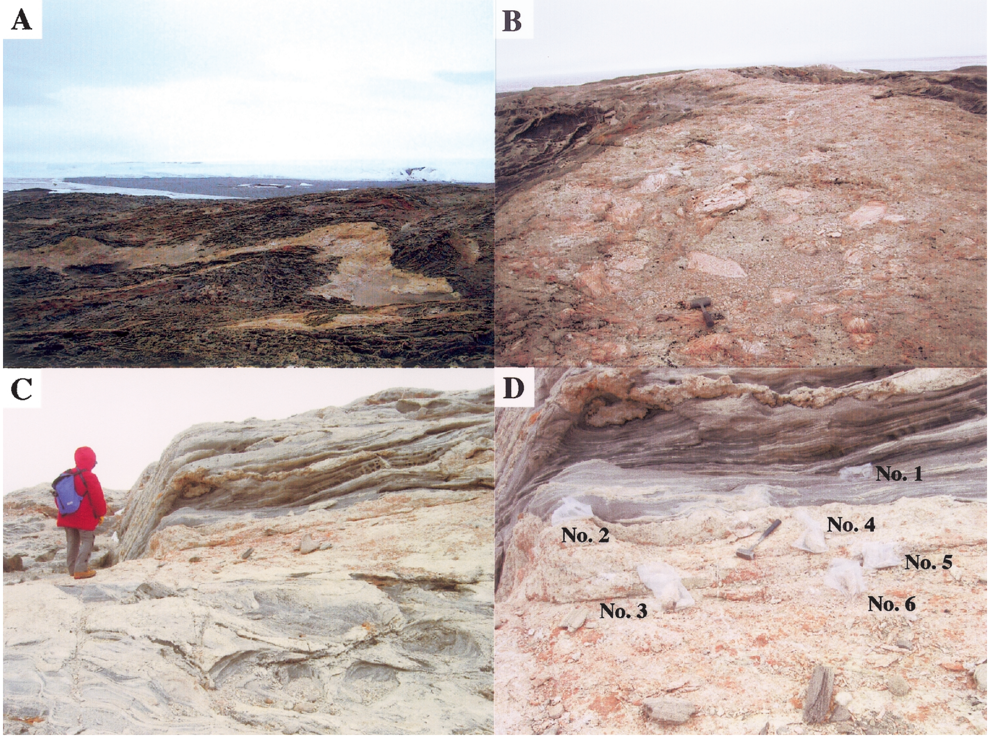

Fig. 2. Modes of field occurrence of the Kasumi PMG rocks. A: The granitic dyke intruded into biotite gneiss is used for this study. B: The dyke generally contains megacrysts of potassium feldspars. C: Mode of occurrence of the Kasumi PMG dyke about 4 m wide. D: Sampling site for isotopically analyzed samples. Numbers indicate sample names of the rocks.

D). The analyzed sample of biotite gneiss (No. 1) is collected very close to the Kasumi PMG dyke (Fig. 2D). It is medium-grained and massive in appearance. The rock is dark gray, and composed of plagioclase (64.7 modal%), quartz (20.6%) and biotite (10.7%) with minor potassium feldspar (4%). They have a general grain size of around 1 to 3 mm in diameter and exhibit equigranular texture (Fig. 3A). Apatite and opaque minerals are present as accessory minerals. Plagioclase is partly corroded. Quartz is subhedral to anhedral, and usually exhibits very weak undulatory extinction. Two types of biotites are recognized in this rock. One is partly corroded, and the other is subhedral flaky biotite, aligned parallel to the gneissose structures. The corroded biotites are slightly large and show weak pleochroism in comparison with the flake biotites.

The Kasumi PMG dykes have no chilled margin. Samples No. 2 and No. 4 are taken from 5 cm and 30 cm from the contact, whereas samples No. 3, No. 5 and No. 6 are collected from the central part of the dyke (Fig. 2D). Sample No. 6 is characterized by the presence of a large amount of potassium feldspar. These samples are equigranular, and composed mainly of quartz (22.5–34.2%), potassium feldspar (26.9–64.2%), plagioclase (4.2–36.1%) and biotite (0.2–3.4%). Muscovite and

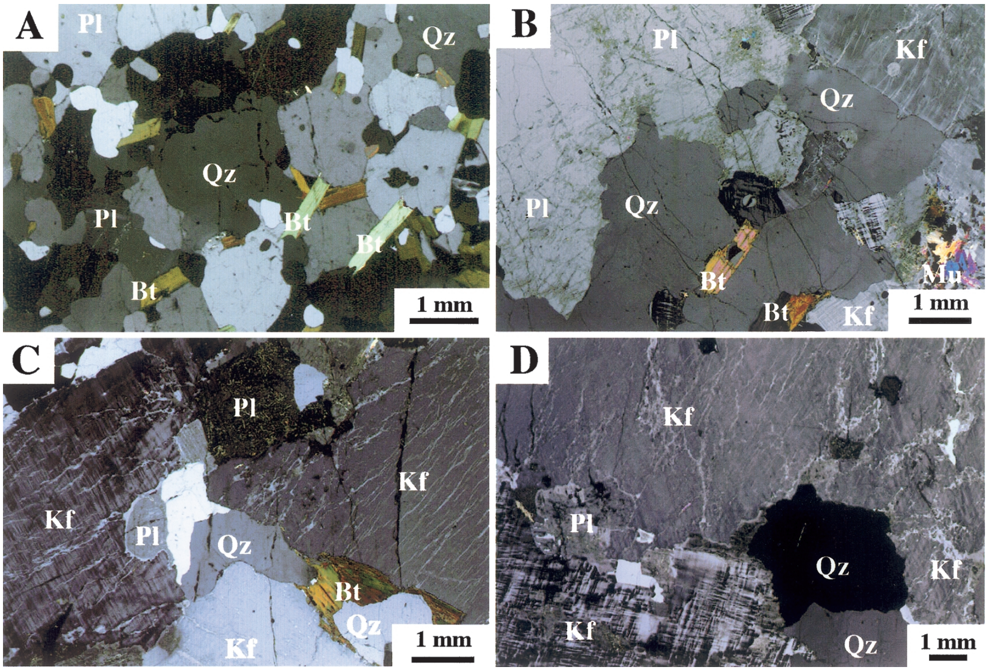

Fig. 3. Photomicrographs (crossed polarized lights) of the biotite gneiss and the Kasumi PMGs. A: biotite gneiss (No. 1). B: Sp. No. 2 of the Kasumi PMGs collected from intrusive contact. C: Sp. No. 5 of the Kasumi PMGs from the central part of the dyke. D: Sp. No. 6 of the Kasumi PMGs. Qz: quartz, Pl: plagioclase, Kf: potassium feldspar, Bt: biotite, Mu: muscovite.

allanite are present as accessory minerals. Sp. No. 2 has larger amounts of quartz and plagioclase compared with other samples, so that it is plotted in the field of adamellite in the quartz-plagioclase-potassium feldspar triangular diagram (Fig. 4). The other four PMGs contain higher amounts of potassium feldspar and, therefore, are plotted in the field of granite (Fig. 4). Subhedral to anhedral quartz usually exhibits weak undulatory extinction. The potassium feldspar is euhedral and perthitic with a diameter up to 10 cm. Subhedral plagioclases are partly corroded; some of them show myrmekite texture. Subhedral to anhedral biotites are partly altered to secondary chlorites.

4. Analytical procedures

Extraction procedures for Sr, Sm and Nd from rock powders follow Kawano *et al*. (1999). Isotopic analyses were performed on a MAT262 mass spectrometer at the Graduate School of Science and Technology, Niigata University equipped with five faraday cups. The ^{87}Sr/^{86}Sr and ^{143}Nd/^{144}Nd ratios are normalized to ^{86}Sr/^{88}Sr$=0.1194$ and ^{146}Nd/^{144}Nd$=0.7219$, respectively. The average ^{87}Sr/^{86}Sr ratio of NBS987 during this study is 0.710184 ± 0.000013 (2σ, $n=5$). The ^{87}Sr/^{86}Sr ratios in Table 1 are reported relative to NBS987$=0.710218$ (Nishi *et al*., 1999). The ^{143}Nd/^{144}Nd ratios in

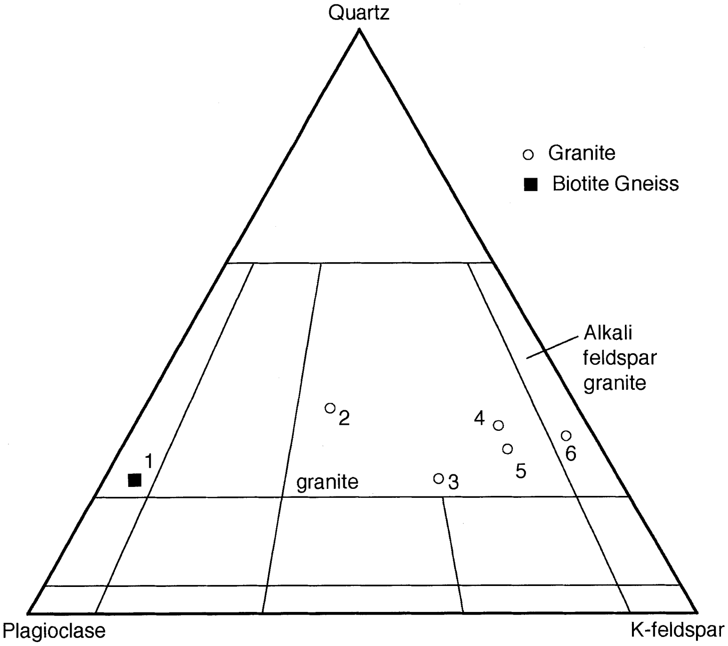

Fig. 4. *Modal quartz–plagioclase–potassium feldspar triangular diagram for analyzed samples. The sample numbers are the same as in Fig. 2D.*

Table 1. *Rb, Sr, Sm and Nd concentrations and* $^{87}Sr/^{86}Sr$ *and* $^{143}Nd/^{144}Nd$ *isotopic ratios of the biotite gneiss and the PMGs in Kasumi Rock.*

Sample	Rb (ppm)	Sr (ppm)	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr	Sm (ppm)	Nd (ppm)	^{147}Sm/^{144}Nd	^{143}Nd/^{144}Nd
No. 1	79	599	0.380	0.70783(1)	3.548	23.901	0.0898	0.512139(13)
No. 2	81	409	0.577	0.70941(1)	0.272	0.996	0.1650	0.512303(14)
No. 3	119	522	0.657	0.70995(1)	0.253	0.947	0.1614	0.512307(14)
No. 4	147	485	0.878	0.71159(1)	0.121	0.549	0.1335	0.512230(25)
No. 5	181	491	1.070	0.71271(1)	0.231	0.815	0.1713	0.512258(17)
No. 6	227	533	1.232	0.71407(1)	0.409	1.180	0.2096	0.512475(25)

Table 1 are reported relative to 0.512115 (JNdi-1, Geological Survey of Japan standard) corresponding to 0.511858 of La Jolla (Tanaka *et al.*, 2000). The blanks for the whole procedures are 26 pg of Sm, 227 pg of Nd and 620 pg of Sr (Kawano *et al.*, 1999). Concentrations of major and minor elements including Rb and Sr were determined by XRF (JEOL 60S7) at the Analytical Research Center for Experimental Sciences, Saga University following the procedure of Kakubuchi *et al.* (1999). The ages and initial $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios were calculated by the computer program of Kawano (1994) using the equation of York (1966) and the decay constants; $\lambda^{87}Rb = 1.42 \times 10^{-11}$ y^{-1} (Steiger and Jäger, 1977) and $\lambda^{147}Sm = 6.54 \times 10^{-12} y^{-1}$ (Lugmair and Marti, 1978).

The estimated precisions in the age calculation of ^{87}Rb/^{86}Sr and ^{87}Sr/^{86}Sr ratios are 5% (1σ) and 0.015% (1σ), respectively. Likewise, those of ^{147}Sm/^{144}Nd and ^{143}Nd/^{144}Nd ratios are 0.2% (1σ) and 0.010% (1σ), respectively.

5. Results and discussion

5.1. Cooling process of the Kasumi PMGs estimated from isochron ages and mode of occurrence

The analytical results are listed in Table 1. Five whole rock samples from the Kasumi PMGs give a Rb-Sr isochron age of 492.1±23.4 Ma with an initial ^{87}Sr/^{86}Sr ratio of 0.70535±0.00027 (MSWD=0.08) (Fig. 5). The biotite gneiss (Sp. No. 1) plots close to the isochron, suggesting that the Sr isotopic compositions of the metamorphic rocks around the PMG dyke were probably reset in the Rb-Sr whole rock system by heating accompanied by the intrusion. Four whole rock samples (excepting Sp. No. 5) give an Sm-Nd isochron age of 498.4±90.6 Ma with an initial ^{143}Nd/^{144}Nd ratio of 0.511782±0.000101 (MSWD=0.05) (Fig. 6). Sp. No. 5 does not plot on the isochron. The reason for this may be that the source magma of the Kasumi PMGs was isotopically homogeneous in the Rb-Sr isotopic system, but not completely homogeneous in the Sm-Nd isotopic system. The isochron has relatively large uncertainty, since the ^{147}Sm/^{144}Nd

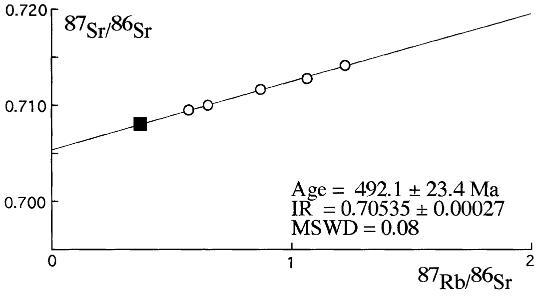

Fig. 5. Rb-Sr whole rock isochron diagram for the Kasumi PMGs. Symbols are the same as those in Fig. 4. IR: initial ^{87}Sr/^{86}Sr ratio.

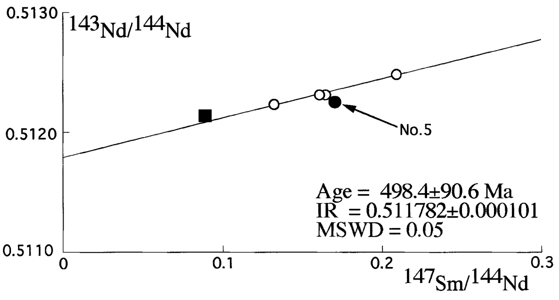

Fig. 6. Sm-Nd whole rock isochron diagram for the Kasumi PMGs. Symbols are the same as those in Fig. 4. IR: initial ^{143}Nd/^{144}Nd ratio.

ratio has a very narrow range (0.13 to 0.21). The biotite gneiss (Sp. No. 1) is not plotted on the Sm-Nd whole rock isochron and is outside of the Rb-Sr systems.

Closure temperatures of the Rb-Sr and Sm-Nd whole rock isochron ages are generally estimated to be 700°C and >700°C, respectively (Harrison *et al.*, 1979). As mentioned above, it can be considered that Sr and Nd isotopic resetting for the metamorphic rocks around the Kasumi PMGs was caused at the timing of the intrusion. Bulk chemical compositions of the Kasumi PMGs (Appendix 1) are not consistent with the compositions for granitic minimum melt, and are scattered in the normative albite, orthoclase and quartz triangular diagram (Tuttle and Bowen, 1958). Accordingly, it seems that the felsic magma for the PMGs had temperatures higher than 700°C at the time. The age data are interpreted as the felsic magma rapidly cooled down to about 700°C, because the Rb-Sr whole rock isochron age is consistent with the Sm-Nd isochron age. As mentioned in the sample description, the Kasumi PMG dykes have no chilled margin, suggesting that the magma for the PMGs slowly crystallized after intrusion, the surrounding metamorphic rocks therefore did not achieve a state of absolute cooling. Fraser and McDougall (1995) reported K-Ar and ^{40}Ar-^{39}Ar mineral ages of the metamorphic rocks in this area. The K-Ar biotite ages from gneisses ranging between 492 and 472 Ma, and closure temperature for the K-Ar biotite age, has been generally considered to be ~300°C (McDougall and Harrison, 1988). Additionally, the biotite gneiss (Sp. No. 1) contains the flaky biotites, which are products by thermal metamorphism. From these data, the metamorphic rocks probably cooled down to ~300° C at the time of intrusion. The Kasumi PMGs were intruded after regional cooling, and presumably affected local reequilibrium in the whole rock scale for Rb-Sr isotopic systems of surrounding metamorphic rocks. After that the Kasumi PMGs might have been slowly cooled and crystallized after the intrusion.

5.2. *Comparison with other PMGs in the LHC*

The Rb-Sr whole rock isochron age of the Kasumi PMGs is consistent with that of the PMGs (485±50 Ma) occurring in the Oku-iwa Rock (Nishi *et al.*, 2002), which is located about 90 km southwest of Kasumi Rock (Fig. 1A). The Oku-iwa PMGs intrude into hornblende biotite gneiss, forming two discordant masses and narrow dykes. The dykes derived from the masses crosscut gneissose structures as in the case of the Kasumi PMGs. However, the initial ^{87}Sr/^{86}Sr ratio (0.70607±0.00023) of the Oku-iwa PMGs is different from that of the Kasumi PMGs, and the initial ^{143}Nd/^{144}Nd ratio (0.51166) of the former (Nishi *et al.*, 2002) calculated using an age of 485 Ma is also quite different from that of the latter. It seems that the two PMG rocks have less genetic relation to each other as regards Rb-Sr and Sm-Nd isotopic systems. This suggests that the PMGs in the Lützow-Holm Complex were originated from different source materials or had different chemical reaction processes with crustal materials.

During the geological field survey of JARE-44 in 2002–2003, the PMG dykes were found in several areas in the granulite-facies to amphibolite-facies zones of the LHC. In this study, the PMGs of Kasumi Rock are dated, but ages and geochemical data of other PMGs are not sufficiently available. Remaining PMG rocks must be dated and investigated in order to reveal igneous activity of the late Pan-African orogeny in East Antarctica.

Acknowledgments

The authors are grateful to all members of JARE-44 led by Prof. M. Ayukawa of NIPR and all crewmembers of the icebreaker "*Shirase*". Special thanks are due to Prof. T. Masuzawa of Shizuoka University and Mr. Y. Yamamoto of GIS for their collaboration in the field work. We also thank Prof. T. Kawasaki of Ehime University for coordination of the field survey in Kasumi Rock. We would like to express our thanks to Dr. Y. Hirahara of Niigata University for measurement of isotope ratios.

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Appendix 1. Major and minor elements of the biotite gneiss and the PMGs in Kasumi Rock.

	Bt Gneiss	Kasumi PMGs				
Sample	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
SiO_2(wt%)	69.33	75.88	70.49	73.67	73.19	69.22
TiO_2	0.32	0.09	0.03	0.03	0.04	0.02
Al_2O_3	16.45	13.12	16.81	15.04	14.66	16.68
Fe_2O_3*	2.08	0.74	0.42	0.29	0.37	0.23
MnO	0.03	0.01	----	----	----	----
MgO	0.79	0.26	0.44	0.39	0.37	----
CaO	3.10	1.49	1.68	0.92	0.66	0.27
Na_2O	4.79	3.86	5.24	3.45	2.40	3.75
K_2O	2.09	3.51	5.26	6.68	7.68	10.67
P_2O_5	0.09	----	----	----	0.01	0.01
Total	99.07	98.97	100.38	100.47	99.37	100.84
Ba (ppm)	1041	867	1282	1809	2075	2464
Cu	16	7	10	6	11	6
Nb	3.4	2.3	1.2	----	< 1.0	24.5
Rb	79	81	119	147	181	227
Sr	599	409	522	485	491	533
V	17	6	----	----	----	----
Y	7	3	6	1	2	4
Zn	42	18	8	2	7	11
Zr	169	19	100	29	29	112

Total Fe as Fe_2O_3*