Rb-Sr MINERAL ISOCHRON AGES OF METAMORPHIC ROCKS AROUND SYOWA STATION AND FROM THE YAMATO MOUNTAINS, EAST ANTARCTICA

Ken SHIBATA[1], Keizo YANAI[2] and Kazuyuki SHIRAISHI[2]

[1]*Geological Survey of Japan, 1-3, Higashi 1-chome, Yatabe-machi, Ibaraki 305*
[2]*National Institute of Polar Research, 9-10, Kaga 1-chome, Itabashi-ku, Tokyo 173*

Abstract: Rb-Sr mineral isochron ages were determined for three metamorphic rocks around Syowa Station and from the Yamato Mountains, eastern Queen Maud Land. The Rb-Sr isotopic data demonstrate that the complete Sr isotopic homogenization occurred among K-feldspar, plagioclase, biotite and whole-rock, and define isochron ages of 482.5±9.5, 468.9±7.8 and 493.3±4.5 Ma for rocks from Syowa Station, Skarvsnes and the Yamato Mountains, respectively. These ages probably represent the time of cooling after the regional metamorphism or granite intrusion. K-Ar age determinations on three metamorphic rocks give biotite and hornblende ages of 469±14, 480±15 and 483 ±15 Ma, and 502±15 Ma, respectively.

1. Introduction

Rb-Sr isotopic data for constituent minerals of a rock provide useful information about the extent of Sr isotopic homogenization and also the thermal history. However, no Rb-Sr mineral isochron ages have been reported on metamorphic rocks from the eastern Queen Maud Land, although more than 50 radiometric ages are now available in this region. We carried out Rb-Sr and K-Ar age determinations on constituent minerals separated from whole-rock samples from Syowa Station, Skarvsnes, and the Yamato Mountains. This is a brief report of the results with some discussion.

2. Geological Setting and Brief Description on the Dated Samples

Two major metamorphic complexes in the eastern Queen Maud Land were recently distinguished: Lützow-Holm Complex and Yamato-Belgica Complex to the northeast and southwest, respectively (Fig. 1; HIROI *et al.*, 1984). Both are inferred to have been metamorphosed in the late Proterozoic although the age determination is not enough (HIROI *et al.*, 1984; YOSHIDA *et al.*, 1983). The Lützow-Holm Complex in which Syowa Station and Skarvsnes regions are included, are composed mainly of well-layered pelitic and intermediate gneisses with granitic to granodioritic migmatite of anatectic origin (HIROI *et al.*, 1983b). The regional metamorphism of the complex is kyanite-sillimanite type progressive metamorphism from northeast to southwest (HIROI *et al.*, 1983a, b). The metamorphic condition of the Lützow-Holm Complex is inferred to be up to 850°C and 10 kbar in maximum (MOTOYOSHI *et al.*, 1985).

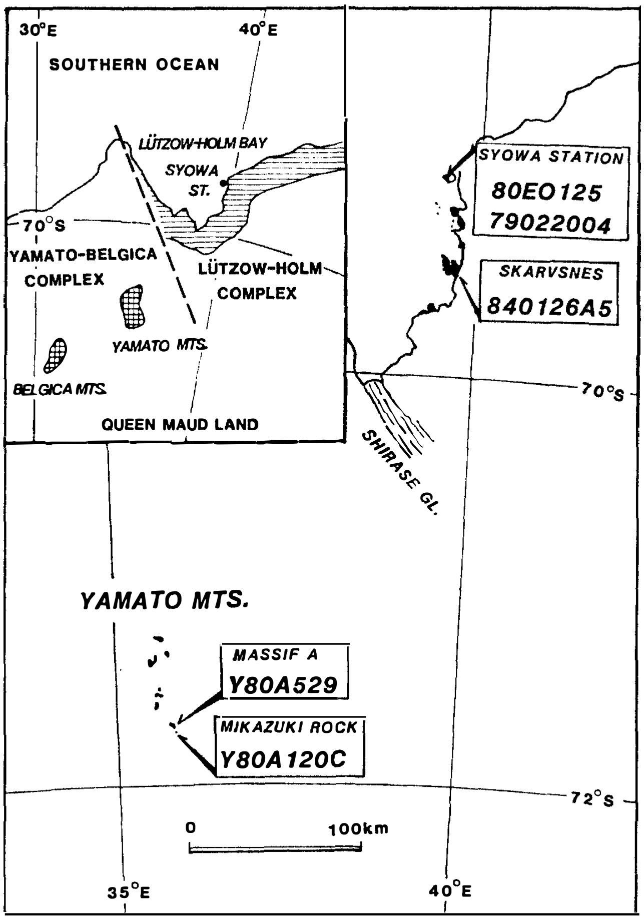

Fig. 1. Map showing the location of samples of this study and two metamorphic complexes in the eastern Queen Maud Land.

The Yamato-Belgica Complex, on the other hand, is characterized by the widespread igneous activity. The metamorphic rocks consist mainly of quartzofeldspathic and intermediate to basic rocks of amphibolite-facies condition (ASAMI and SHIRAISHI, 1983). Granulite-facies rocks which are pelitic and intermediate compositions with subordinate amounts of basic and calcareous rocks occur as a tectonic block or inclusions in the syenitic plutonite (SHIRAISHI *et al.*, 1983). Although the relation between the granulite-facies and the amphibolite-facies rocks is not clear, it is probable that they belong to the same metamorphic sequence prior to the tectonic movement (ASAMI and SHIRAISHI, 1983). The maximum metamorphic temperature of the granulite-facies rocks is estimated to be less than 800°C and the pressure is inferred considerably lower than that of the Lützow-Holm Complex (ASAMI and SHIRAISHI, 1983, 1985; HIROI *et al.*, 1984).

Early Paleozoic granite and pegmatite activities are widespread throughout both complexes (YANAI and UEDA, 1974). In the Lützow-Holm Complex, andalusite rarely occurs in the aluminous pelitic rock as a result of the thermal metamorphism of the granite and pegmatite activities (HIROI *et al.*, 1983a).

Three samples from the Lützow-Holm Complex and two from the Yamato-Belgica

Complex were selected for the present study. Brief description of the dated samples is as follows:

1) 80EO125 (granitic gneiss, 100 m east of Lake Taratine, Syowa Station, East Ongul Island)

Granitic gneiss is not common in East Ongul Island. It is a lens-shaped body concordant with the surrounding hornblende gneiss. This rock has a medium- to coarse-grained granular texture and is light gray with pink in color. Mineral assemblage of this rock is green hornblende, pale brown to brown biotite, perthite, plagioclase and quartz. Accessory minerals are muscovite, apatite, zircon and opaque minerals. Hornblende is often altered to biotite, chlorite, calcite and opaque minerals.

2) 840126A5 (garnet-orthopyroxene-biotite gneiss, 1400 m NNE of Maruyama Peak, Skarvsnes)

This rock is a member of the well-layered gneiss consisting of K-feldspar porphyroblastic garnet gneiss, melanocratic garnet-biotite gneiss and biotite amphibolite interlayer. This rock is brown in color, granular in texture with weakly parallel arrangement of mafic minerals. Under the microscope a medium-grained granular texture is characteristic. Mineral assemblage of the rock is garnet, orthopyroxene, brown biotite, perthite, plagioclase and quartz. Accessory minerals are apatite, zircon and opaque minerals. Most mafic minerals are fine-grained euhedral to subhedral and scattered in the leucocratic part. Orthopyroxene is partly altered to chlorite.

3) 79022004 (biotite-hornblende gneiss, Miharasi Peak, East Ongul Island)

This rock is a coarse-grained gneiss and often shows well foliation with lineated hornblende and biotite in light gray color. Main constituent minerals are pale green to pale brown hornblende, brown biotite and plagioclase with minor quartz. Garnet and K-feldspar are found, but not common. Accessory minerals are zircon, apatite and opaque minerals. A part of hornblende is often altered to chlorite, muscovite and calcite.

4) Y80A529 (orthopyroxene-biotite gneiss, near the highest point of Massif A, Yamato Mountains)

This rock occurs as a small mass in syenitic charnockite. It is gray-colored, fine-grained gneiss and shows strong gneissosity. Under the microscope preferred orientation is shown by biotite flakes and flattened salic minerals. This rock consists of brown biotite, orthopyroxene, perthitic microcline, plagioclase and quartz with accessory zircon, ilmenite, apatite and pyrite. Secondary chlorite occurs.

5) Y80A120C (two-pyroxene biotite gneiss, Mikazuki Rock, Yamato Mountains)

This rock occurs as a lens-shaped inclusion, tens of centimeters long, in quartz monzonite. This rock shows a granular texture and consists of orthopyroxene, clinopyroxene, brown biotite, plagioclase and quartz with minor amount of K-feldspar. Accessories are apatite, zircon and opaque minerals.

3. Analytical Methods

Rb and Sr concentrations of mineral and whole-rock samples were determined by the standard isotope dilution using ^{87}Rb and ^{84}Sr spikes. Isotopic analyses of Rb and Sr were made on a VG Isomass 54E mass spectrometer. The uncertainty in the

$^{87}Rb/^{86}Sr$ ratio was estimated to be $\pm 2\%$ (1σ), based on uncertainties of ± 2 and 1% in Rb and Sr concentrations, respectively. All the $^{87}Sr/^{86}Sr$ ratios were normalized to $^{86}Sr/^{88}Sr$ ratio=0.1194. The uncertainty in the $^{87}Sr/^{86}Sr$ ratio was estimated to be $\pm 0.015\%$ (1σ) based on the replicate analyses of standard samples. Analyses of the E and A standard during this study gave an average $^{87}Sr/^{86}Sr$ ratio of 0.70808 ± 0.00002 (1σ). Isochron ages were calculated by the least-squares method of YORK (1966), and errors in Rb-Sr age and intercept were given on 2σ level.

K-Ar age determination was carried out on biotite and hornblende. Argon was extracted and purified in a pyrex, high vacuum system, and isotopic ratios of argon were measured on a Micromass 6 mass spectrometer. Potassium content was determined by atomic absorption analysis. Error in K-Ar age, given on 1σ level, was calculated according to the uncertainties of 2, 1, 2 and 2% in potassium analysis, $^{40}Ar/^{38}Ar$ and $^{36}Ar/^{38}Ar$ ratios, and spike calibration, respectively.

Decay constants used in age calculation are: $\lambda^{87}Rb = 1.42 \times 10^{-11}/y$, $\lambda_{\beta}{}^{40}K = 4.962 \times 10^{-10}/y$, $\lambda_{e}{}^{40}K = 0.581 \times 10^{-10}/y$, $^{40}K/K = 0.01167$ atom% (STEIGER and JÄGER, 1977).

4. Results and Discussion

Rb-Sr analytical data for mineral and whole-rock samples are given in Table 1, and K-Ar ages in Table 2.

The Rb-Sr mineral isochron plot for granitic gneiss (80EO125) from Syowa Station is shown in Fig. 2. K-feldspar, plagioclase (+quartz) and whole-rock points define an isochron age of 482.5 ± 9.5 Ma with an initial $^{87}Sr/^{86}Sr$ ratio of 0.71095 ± 0.00014. The well-defined isochron indicates complete homogenization of Sr isotopes among minerals, thus suggesting the age of a definite thermal event.

The Rb-Sr data for garnet-biotite gneiss (840126A5) from Skarvsnes are plotted in Fig. 3. Biotite, K-feldspar, plagioclase (+quartz) and whole-rock points define a well-correlated isochron age of 468.9 ± 7.8 Ma with an initial $^{87}Sr/^{86}Sr$ ratio of 0.72304

Table 1. Rb-Sr analytical data for metamorphic rocks around Syowa Station and from the Yamato Mountains, East Antarctica.

Sample	Rb (ppm)	Sr_N (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
80EO125 (granitic gneiss, Syowa Station)				
Whole rock	183.4	217.4	2.443	0.72789
K-feldspar	450.7	367.9	3.548	0.73514
Plagioclase	11.36	146.2	0.2250	0.71249
840126A5 (garnet-orthopyroxene-biotite gneiss, Skarvsnes)				
Whole rock	73.51	187.0	1.138	0.73073
Biotite	728.1	5.868	359.3	3.1005
K-feldspar	309.0	373.6	2.395	0.73911
Plagioclase	14.12	153.3	0.2667	0.72478
Y80A529 (orthopyroxene-biotite gneiss, Yamato Mountains)				
Whole rock	145.2	218.9	1.921	0.72895
Biotite	635.5	7.625	241.4	2.4073
K-feldspar	181.8	348.8	1.509	0.72617
Plagioclase	28.40	198.8	0.4136	0.71837

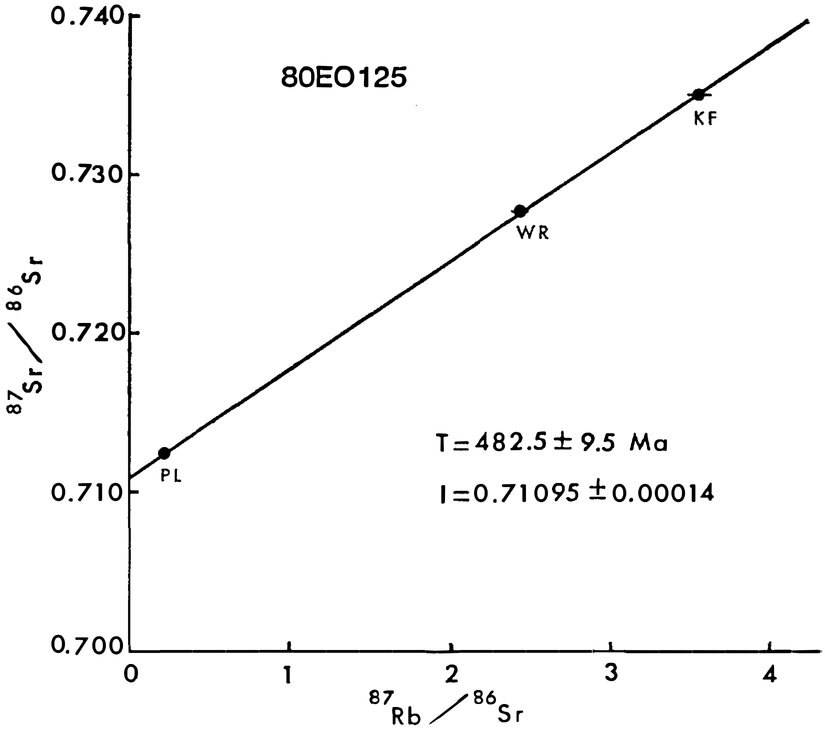

Fig. 2. Rb-Sr mineral isochron plot for granitic gneiss from Syowa Station.

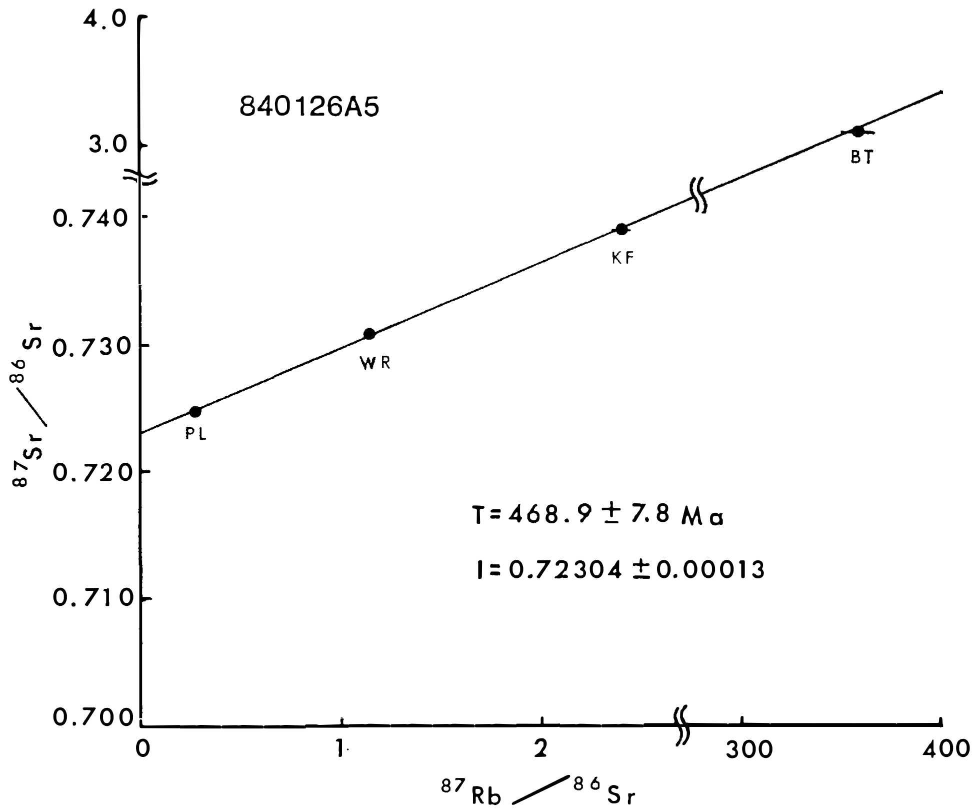

Fig. 3. Rb-Sr mineral isochron plot for garnet-orthopyroxene-biotite gneiss from Skarvsnes.

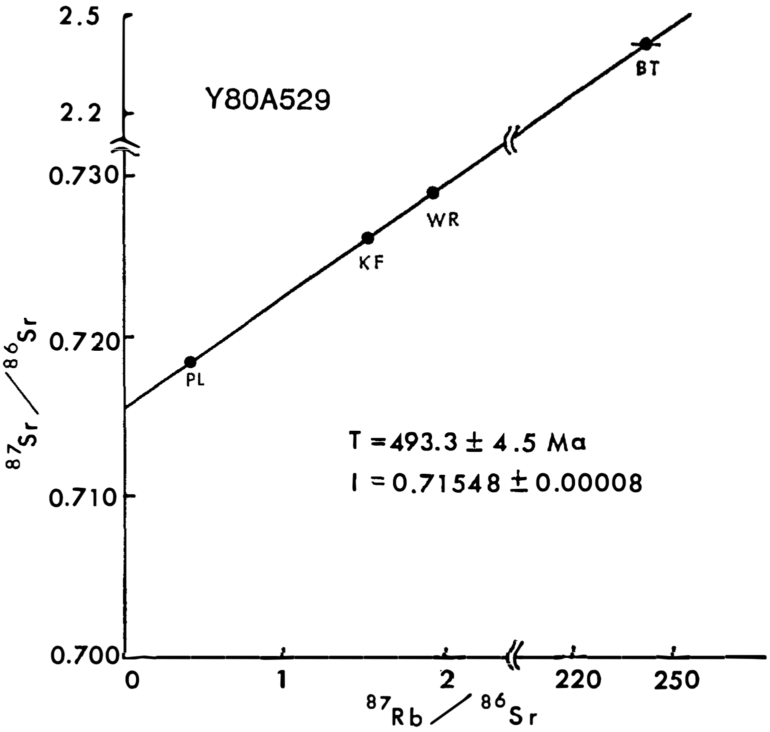

Fig. 4. Rb-Sr mineral isochron plot for orthopyroxene-biotite gneiss from the Yamato Mountains.

$\pm$0.00013. The Rb-Sr data for orthopyroxene-biotite gneiss (Y80A529) from the Yamato Mountains are plotted in Fig. 4. This is also a well-correlated isochron, giving an age of 493.3$\pm$4.5 Ma with an initial ratio of 0.71548$\pm$0.00008. The K-feldspar point, however, is plotted to the lower left of the whole-rock point. Since this is rather an unusual case, the material balance using mineral and whole-rock Rb and Sr concentrations was examined. The mineral composition of the rock is calculated as biotite 11%, K-feldspar 30%, and plagioclase + quartz + minor minerals 59%. The result is roughly comparable with the mode by the microscopic observation; biotite 13%, K-feldspar 19%, plagioclase 31%, quartz 34%, and others 3%. The unusual plot of the K-feldspar point on the isochron is simply the result of high content of biotite with high Rb concentration. Nevertheless, an important conclusion from this isochron is that the model age of K-feldspar, calculated by assuming an initial $^{87}Sr/^{86}Sr$ ratio lower than that of the mineral isochron, is older than the whole-rock model age in such a case, and does not indicate a useful minimum age for the original formation of the rock.

The results of K-Ar dating of minerals are shown in Table 2. K-Ar age of biotite from Y80A529 is 469$\pm$14 Ma, which is slightly younger than the Rb-Sr age. Biotite in two-pyroxene-biotite gneiss (Y80A120C) from the Yamato Mountains gives an age of 483 Ma. Biotite and hornblende in biotite-hornblende gneiss (79022004) from Syowa Station give slightly discordant ages of 480 and 502 Ma, respectively.

Many isotopic ages have been reported on metamorphic rocks from the Lützow-Holm Bay region (KANEOKA *et al.*, 1968; MAEGOYA *et al.*, 1968; YANAI and UEDA,

Table 2. K-Ar ages for metamorphic rocks from Syowa Station and the Yamato Mountains, East Antarctica.

Sample No.	Rock	Mineral	K_2O (%)	^{40}Ar rad (10^{-6}mlSTP/g)	Atm. ^{40}Ar (%)	Age (Ma)
79022004*	Biotite-hornblende gneiss	Biotite	9.06	161	3.6	480±15
		Hornblende	1.72	32.1	4.3	502±15
Y80A120C**	Two-pyroxene-biotite gneiss	Biotite	9.08 8.89	161	2.5	483±15
Y80A529**	Orthopyroxene-biotite gneiss	Biotite	9.11 9.14	157	5.5	469±14

* Syowa Station, ** Yamato Mountains.

1974). Mineral ages concentrate between 350 and 560 Ma and are interpreted to indicate the time of regional metamorphism or granite intrusion (YANAI and UEDA, 1974; HIROI *et al.*, 1983b; YOSHIDA *et al.*, 1983). Rb-Sr mineral isochron and K-Ar ages obtained in this study are within this age range. In addition, the isochrons clearly demonstrate that the complete Sr isotopic homogenization occurred among constituent minerals of each rock. Probably these isochron ages represent the time of cooling after the regional metamorphism or granitic intrusion, and suggest a simple cooling history for these metamorphic rocks.

Acknowledgments

We thank Dr. T. NAKAJIMA for microscopic observations and Mr. S. UCHIUMI for assistance in K-Ar dating.

References

ASAMI, M. and SHIRAISHI, K. (1983): Mineral parageneses of basic to intermediate metamorphic rocks in the Yamato Mountains, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **28**, 198–214.

ASAMI, M. and SHIRAISHI, K. (1985): Retrograde metamorphism in the Yamato Mountains, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **37**, 147–163.

HIROI, Y., SHIRAISHI, K., YANAI, K. and KIZAKI, K. (1983a): Aluminum silicates in the Prince Olav and Sôya Coasts, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **28**, 115–131.

HIROI, Y., SHIRAISHI, K., NAKAI, Y., KANO, T. and YOSHIKURA, S. (1983b): Geology and petrology of Prince Olav Coast, East Antarctica. Antarctic Earth Science, ed. by R. L. OLIVER *et al.* Canberra, Aust. Acad. Sci., 32–35.

HIROI, Y., MOTOYOSHI, Y., SHIRAISHI, K. and YANAI, K., (1984): Nankyoku, Syowa Kiti shûhen no genseidai henseigan no keiseishi (moderu) (Development of Proterozoic metamorphic rocks around Syowa Station, Antarctica). Syowa 59-nen Nihon Kôbutsu Gakkai, Nihon Kôzan Chishitsu Gakkai, Nihon Ganseki Kôbutsu Kôsho Gakkai Kôen Yôshisyû (Abstr. Joint Ann. Meet., Mineral. Soc. Japan, Soc. Mining Geol. Japan and Jpn. Assoc. Mineral. Petrol. Econ. Geol.), Ehime, 166.

KANEOKA, I., OZIMA, Minoru, OZIMA, Mituko, AYUKAWA, M. and NAGATA, T. (1968): K-Ar ages and palaeomagnetic studies on rocks from the east coast of Lützow-Holm Bay, Antarctica. Nankyoku Shiryô (Antarct. Rec.), **31**, 12–20.

MAEGOYA, T., NOHDA, S. and HAYASE, I. (1968): Rb-Sr dating of the gneissic rocks from the east coast of Lützow-Holm Bay, Antarctica. Mem. Fac. Sci., Kyoto Univ., Ser. B, **35**, 131–138.

MOTOYOSHI, Y., MATSUBARA, S., MATSUEDA, H. and MATSUMOTO, Y. (1985): Garnet-sillimanite gneisses from the Lützow-Holm Bay region, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **37**, 82–94.

SHIRAISHI, K., ASAMI, M. and OHTA, Y. (1983): Geology and petrology of the Yamato Mountains. Antarctic Earth Science, ed. by R. L. OLIVER *et al.* Canberra, Aust. Acad. Sci., 50–53.

STEIGER, R. H. and JÄGER, E. (1977): Subcommission on geochronology; Convention on the use of decay constants in geo- and cosmochronology. Earth Planet. Sci. Lett., **36**, 359–362.

YANAI, K. and UEDA, Y. (1974): Absolute ages and geological investigations on the rocks in the area of around Syowa Station, East Antarctica. Nankyoku Shiryô (Antarct. Rec.), **48**, 70–81.

YORK, D. (1966): Least squares fitting of a straight line. Can. J. Phys., **44**, 1079–1086.

YOSHIDA, M., SUZUKI, M., SHIRAHATA, H., KOJIMA, H. and KIZAKI, K. (1983): A review of the tectonic and metamorphic history of the Lützow-Holm Bay region, East Antarctica. Antarctic Earth Science, ed. by R. L. Oliver *et al.* Canberra, Aust. Acad. Sci., 44–47.

(*Received May 14, 1985; Revised manuscript received May 31, 1985*)