Mem. Geol. Soc. Japan, No. 47, p. 21-27, January 1997

Rb-Sr isochron ages for hornblende tonalite from the southeastern part of the Hidaka metamorphic belt, Hokkaido, Japan : Implication for timing of peak metamorphism

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Received October 15, 1995.
Accepted July 4, 1996.

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Abstract

The southeastern part of the Hidaka metamorphic belt consists mainly of granitic rocks and small amounts of metamorphosed pelitic and psammitic rocks. The granitic rocks are divided into two types : cordierite tonalite and hornblende tonalite. In many cases, the hornblende tonalite intrudes the cordierite tonalite.

The Rb-Sr internal isochron connecting with biotite, whole rock and felsic fraction for the hornblende tonalite indicates an age of 40.5±0.3 Ma. The inclination line is defined largely by the biotite because of its high $^{87}Rb/^{86}Sr$ ratio. Therefore, the internal isochron could be identical with the biotite isochron in the Rb-Sr system. The age of 40 Ma represents the passing time of the hornblende tonalite through the closure temperature of biotite (300℃). On the other hand, the Rb-Sr whole rock isochron age for the hornblende tonalite is 51.2±3.6 Ma (MSWD=0.02) and initial $^{87}Sr/^{86}Sr$ ratio is 0.70452±0.00004. The age of 51 Ma is regarded as the solidification age for the hornblende tonalite. On the basis of the closure temperature, the cooling rate is 40℃to 30℃/Ma at the temperature above 300℃.

The hornblende tonalite intrudes the pelitic gneiss. The cordierite tonalite is cut by the hornblende tonalite, and intrudes the pelitic gneiss. The cordierite tonalite magma gives thermal effect to the host gneiss, which had already undergone the low P/T Hidaka metamorphism. Hence, the timing of the peak metamorphism of the Hidaka metamorphic belt should be older than c. 51 Ma.

Key words : hornblende tonalite, Rb-Sr dating, peak metamorphism, Hidaka metamorphic belt, Hokkaido

Introduction

The Hidaka metamorphic belt consists of mafic to felsic intrusive rocks and various metamorphic rocks attaining up to granulite facies. The pelitic granulites were interpreted to have taken place anatexis giving rise to peraluminous granitic magma at the peak metamorphic condition, based on petrological and geochemical studies (Osanai et al., 1991 ; 1992 ; Tagiri et al., 1989). A Rb-Sr whole rock isochron connecting with pelitic granulites and peraluminous tonalites indicates an age of 56.0±6.1 Ma (Owada et al., 1991). They interpreted that the age of 56 Ma is a timing of anatexis and peak metamorphism in the central to southern part of the Hidaka metamorphic belt. Owada et al. (1992) determined a whole rock isochron age of 54.9±5.5 Ma using the nine pelitic granulites and the two peraluminous tonalites.

K-Ar whole rock and mineral ages and Rb-Sr mineral ages have been obtained from numerous igneous and metamorphic rocks in the Hidaka metamorphic belt (Kawano and Ueda, 1967 ; Okamoto and Honma, 1983; Shibata et al., 1984 ; Maeda et al., 1990 ; Saeki et al., 1991 ; Arita et al., 1993). These ages cluster at 19-15 Ma (Early Miocene) and 36-28 Ma (Late Eocene to Early Oligocene) (Arita et al., 1993). Igneous and metamorphic rocks represented older ages occur only in the southeastern part of the Hidaka metamorphic belt. The younger age group, however, distributes widely throughout the Hidaka metamorphic belt except in the above mentioned area.

Recently, Kimbrough et al. (1994) reported a U-Pb zircon age of 17±4 Ma for the peraluminous tonalite that had intruded into the granulite facies meta-

Table 1. Characteristic mineral assemblages for granitic rocks of the Hidaka metamorphic belt classified in terms of the intrusive levels and peraluminous and metaluminous types.
Abbreviations are after Kretz (1983). Classification of the granitic rocks in the Hidaka metamorphic belt are after Komatsu et al. (1986).

Depth type	Rock type	Intrusive level	Characteristic mineral assemblage: Peraluminous	Characteristic mineral assemblage: Metaluminous
Upper	granite granodiorite	chlorite-muscovite metasediment unit	Bt+Pl+Qtz±Kfs	Bt±Hbl+Pl+Qtz±Kfs
Middle	granodiorite tonalite	biotite-muscovite gneiss and schist unit	Bt+Ms±Crd+Pl+Qtz±Kfs	Bt±Hbl+Pl+Qtz±Kfs
Lower	tonalite	amphibolite unit	Bt+Grt±Crd+Pl+Qtz±Kfs Bt+Opx±Crd+Pl+Qtz±Kfs	Bt+Hbl+Opx±Cpx+Pl+Qtz
Basal	tonalite	granulite unit	Bt+Opx+Grt±Crd+Pl+Qtz±Kfs	

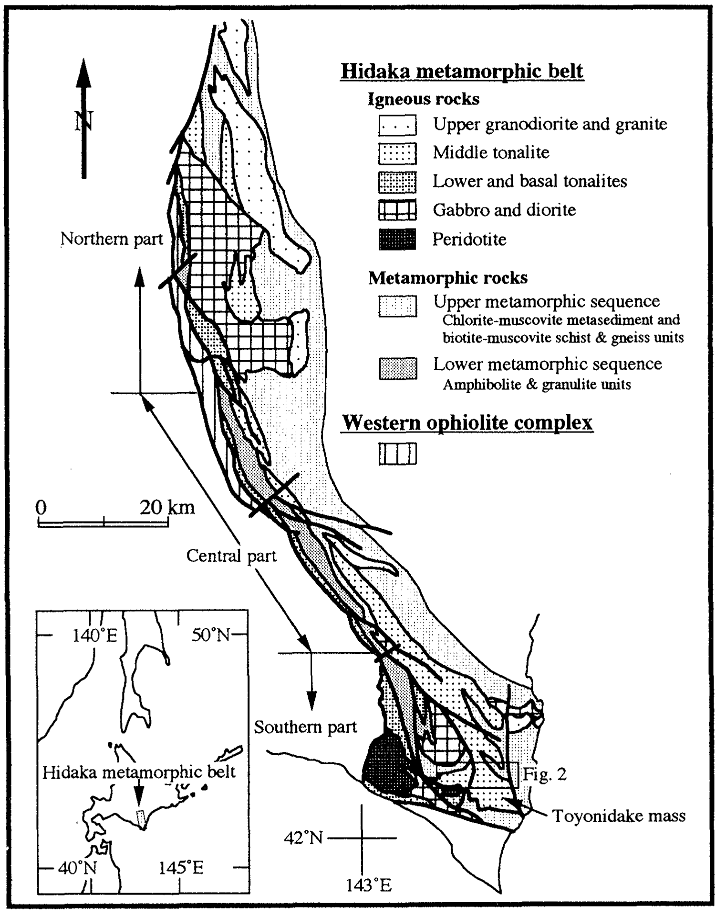

Fig. 1. Geologic sketch map of the Hidaka metamorphic belt (modified from Komatsu et al., 1986). Upper and lower metamorphic sequences are after Komatsu et al. (1983). Western ophiolite complex was described by Miyashita (1983). Geologic map for the square area in the southeastern part of the Hidaka metamorphic belt is given in Fig. 2.

morphic rocks and regarded as the crystallization age of the tonalite. On the other hand, Arita et al. (1986) and Osanai et al. (1986) revealed that the timing of uplift for the Hidaka metamorphic belt had occurred≧17 Ma. The zircon age of 17 Ma overlaps the uplift stage.

In this paper, we present Rb-Sr isochron ages for hornblende tonalite, which intrudes the metamorphic rocks, and discuss the timing of the peak metamorphism in the Hidaka metamorphic belt.

Outline of geology

1. Distribution of granitic rocks in the Hidaka metamorphic belt

Most granitic rocks intrude concordantly with the structure of the Hidaka metamorphic belt (Komatsu et al., 1986). The granitic rocks are divided into two types : peraluminous granitic rocks and metaluminous granitic rocks, based on petrological characteristics. Komatsu

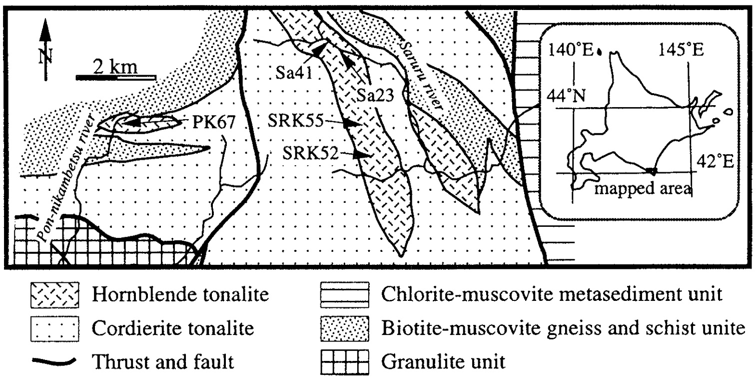

Fig. 2. Simplified geologic map with sampling locations in the southeastern part of the Hidaka metamorphic belt (after Owada, 1989).

et al. (1986) classified these granitic rocks into four groups according to the level of intrusion : 1) basal granitic rocks, 2) lower granitic rocks, 3) middle granitic rocks and 4) upper granitic rocks (Table 1, Fig. 1). The basal and lower granitic rocks are garnet-orthopyroxene tonalite and garnet-cordierite tonalite intruded the granulite to amphibolite units. The middle granitic rocks consist of cordierite tonalite and hornblende tonalite found in the biotite-muscovite gneiss and schist units. The upper granitic rocks are hornblende granodiorite and biotite granite in the chlorite-muscovite metasediment unit. There is the granitic pluton intruded in the lower to upper level of the Hidaka metamorphic belt.

2. Geology of the southeastern part of the Hidaka metamorphic belt

Granitic intrusive rocks and biotite-muscovite gneiss and schist unit are widely distributed in the southeastern part of the Hidaka metamorphic belt (Fig. 2). Mapped area is dominated by the cordierite tonalite (Toyonidake mass, Fig. 1) with small amounts of the hornblende tonalite and the pelitic gneiss that is assigned to the biotite-muscovite gneiss and schist unit (Figs. 1 & 2). Both tonalites correspond to the middle granitic rocks (Table 1). In many case, the hornblende tonalite intrudes the cordierite tonalite.

The cordierite tonalite includes a large amount of metamorphosed pelitic and psammitic blocks derived from the biotite-muscovite unit and rarely from the granulite unit. On the contrary, the hornblende tonalite rarely contains of metamorphic blocks. Both tonalites intrude the pelitic gneiss (Fig. 2). The hornblende tonalite cuts the metamorphic foliation of the pelitic gneiss (Fig. 3).

The cordierite tonalite gives thermal effect to the host gneiss, which had already undergone the low P/T Hidaka metamorphism (Owada, 1989 ; Osanai et al., 1991). The relation between the cordierite tonalite and the pelitic gneiss is well observed in the Saruru river region (Fig. 2), where the cordierite tonalite and andalusite- and sillimanite-bearing gneiss are exposed (Owada, 1989). There is a distinct contact aureole surrounding the cordierite tonalite, and metamorphic reactions are as follows (Owada, 1989) ;

andalusite = sillimanite,

muscovite + quartz = sillimanite + K-feldspar + vapor,

and biotite + sillimanite + quartz = cordierite + K-feldspar + vapor.

These reactions went on the right side due to the thermal effect of the cordierite tonalite magma, suggesting that the cordierite tonalite magma was emplacement at the depth of more than 300 MPa (Owada, 1989).

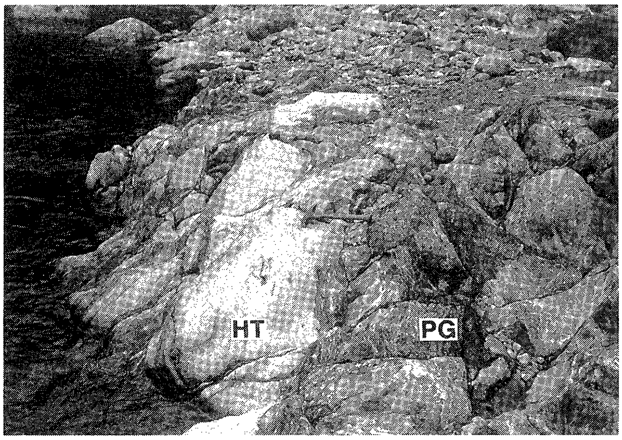

Fig. 3. Field relationship between the hornblende tonalite and the pelitic gneiss. The hornblende tonalite intrudes the pelitic gneiss. HT : hornblende tonalite, PG : pelitic gneiss. Note the hornblende tonalite cuts the metamorphic foliation.

Petrography of hornblende tonalite

The hornblende tonalite consists mainly of plagioclase (43-54% ; modal composition), quartz (22-34%), biotite (12-30%), hornblende (<2%) and K-feldspar (<0.8%), with trace amounts of sphene, zircon and opaque minerals. Hornblende occurs in the inner part of the hornblende tonalite mass, whereas K-feldspar appears mainly in the marginal part.

Plagioclase (An=27-38%) shows euhedral and fine to medium grained (0.3-1.5mm), and conspicuously zoned. Small grains of hornblende are included in plagioclase. Biotite (Mg/(Fe+Mg) : X_{Mg}=0.38-0.50) shows euhedral or subhedral and fine to medium grained (0.3-1.2mm), X'=pale brown and Z'=brown with paleochroism. Small grains of hornblende and plagioclase are included in biotite. Hornblende (X_{Mg}=0.52-0.58) is euhedral or subhedral and fine to medium grained (0.3-1.2mm), X'=pale green yellow and Z'=greenish brown with paleochroism. K-feldspar appears anhedral and fine to medium grained (0.3-0.8mm). It often occurs along the grain boundaries between plagioclase and quartz. Perthite is partly found.

Analyzed samples were collected from the middle stream of Saruru river (samples Sa23, Sa41, SRK52, SRK55) and the middle stream of Pon-nikambetsu river (sample PK67) (Fig. 1). These samples are free from mylonitization and alteration.

Analytical procedure

Extraction procedures used for Rb and Sr are given in Kagami et al. (1987). Sr isotope analyses were performed on a MAT261-type (modified from MAT260) mass spectrometer equipped with five Faraday cups at Institute for Study of Earth's Interior, Okayama university. Rb and Sr concentrations were measured with isotope dilution using a ^{87}Rb-^{86}Sr mixed spike or XRF-analyses. Analytical procedures have been described by Kagami et al. (1987). ^{87}Sr/^{86}Sr ratios were normalized to ^{86}Sr/^{88}Sr=0.1194. The measured ^{87}Sr/^{86}Sr ratio for NBS987 during this study was 0.71025±0.00001 (2s). We estimate an error of 0.5% and 5% for the Rb/Sr ratios by isotope dilution and XRF, respectively. Rb-Sr isochron ages were calculated using the equation of York (1966) and the following decay constants ; λ ^{87}Rb=$1.42\times10^{-11}y^{-1}$ (Steiger and Jäger, 1977). Computer program used for the calculation of Rb-Sr isochron age and mean square of weighted deviation (MSWD) is given by Kawano (1994).

Biotite and felsic fraction of Sa41 separated using an isodynamic separator after arranging 80-100 mesh by a stainless steel sieve.

Results and discussion

Sr isotope compositions and Rb, Sr concentration for the hornblende tonalites and minerals (biotite and felsic fraction) separated from Sa41 are listed in Table 2.

Table 2. Rb, Sr concentrations and ^{87}Rb/^{86}Sr, ^{87}Sr/^{86}Sr ratios for the analyzed samples. * determined by XRF at Yamaguchi university. Others are measured by isotope dilution method at ISEI, Okayama university.

Sample	Rb (ppm)	Sr (ppm)	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr (±2σ)
SRK52	68.7*	317*	0.6296	0.70499 (1)
SRK55	74.1*	320*	0.6689	0.70502 (1)
Sa23	79.7*	358*	0.6464	0.70499 (1)
PK67	78.4*	190*	1.1920	0.70548 (2)
Sa41	63.4	371	0.4941	0.70496 (2)
Biotite	270	11.1	70.7900	0.74548 (7)
Felsic fraction	21.5	350	0.1777	0.70487 (3)

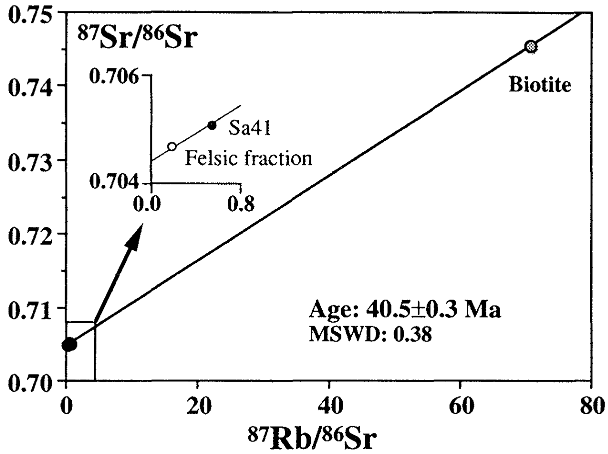

Fig. 4. Rb-Sr whole rock-mineral isochron diagram for hornblende tonalite (sample Sa41). The age of 40.5 Ma indicates the time passing closure temperature of biotite (300 ℃). Felsic fraction : quartz, plagioclase and minor K-feldspar.

In addition to the whole rock (Sa41), both of the biotite and the felsic fraction were used for obtaining mineral isochron. The internal isochron for the biotite, whole rock and felsic fraction indicates an age of 40.5±0.3 Ma (MSWD=0.38) as shown in Fig. 4. The inclination of the isochron is defined largely by the Rb-Sr isotopic composition of the biotite, because of high ^{87}Rb/^{86}Sr ratio for the biotite. Therefore, this internal isochron could be regarded as biotite isochron in the Rb-Sr system. Rb-Sr biotite ages are reset at 300℃ (Harrison et al., 1979). The age of 40 Ma determined here indicates the time passing the closure temperature of biotite (300℃) in the hornblende tonalite.

The whole rock isochron age for the five samples is 51.2±3.6 Ma (MSWD=0.02) and initial ^{87}Sr/^{86}Sr ratio is 0.70452±0.00004 (Fig. 5). It is widely accepted that the Rb-Sr whole rock system in granitic rocks is generally believed to be closed during crystallization and cooling (Moorbath, 1975). This whole rock isochron age is

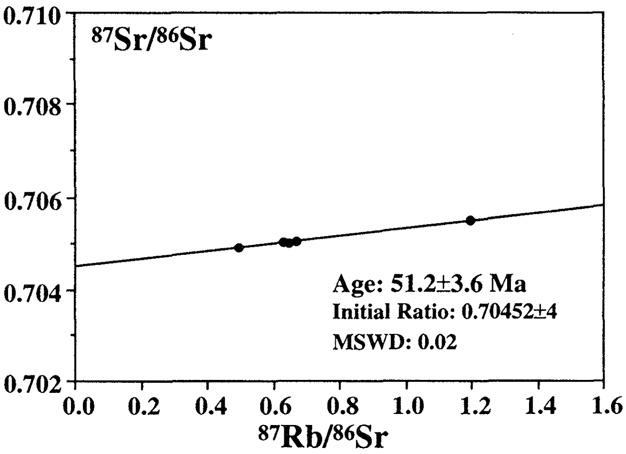

Fig. 5. Rb-Sr whole rock isochron diagram for the hornblende tonalite. The age of 51 Ma is regarded as solidification age of hornblende tonalite

c.10 Ma older than the internal isochron age. According to Nakajima et al. (1990), the Rb-Sr whole rock age of granitic rocks indicate the time passing the solidus temperature (650℃ to 700℃). An approximate cooling rate for the hornblende tonalite is 40℃ to 30℃/Ma at the temperature above 300℃, based on the closure temperature. This rate appears to be the same rates for the several granitic intrusions from the San'yo belt in Southwest Japan (Nakajima et al., 1990).

Osanai et al. (1991) investigated the detailed mineral paragenesis and determination of the P-T conditions of the metamorphic rocks in the Hidaka metamorphic belt. They confirmed that the metamorphic grade increases progressively westward from greenschist up to granulite facies. During peak metamorphic event, the regional geothermal gradient had been 30℃ to 40℃/km, and the highest P-T condition obtained from the lowest part of the granulite unite is c. 870℃, 700 MPa.

The hornblende tonalite and the cordierite tonalite intrude the pelitic gneiss (Figs. 2 & 3). As described previously, the intrusion of the cordierite tonalite magma occurs earlier than that of the hornblende tonalite magma. The cordierite tonalite gives thermal effect to the host gneiss, which had already undergone the Hidaka metamorphism characterized by low P/T type metamorphism (Owada, 1989 ; Osanai et al., 1991). Hence, the timing of the peak metamorphism of the Hidaka metamorphic belt should be older than c. 51 Ma.

Kimbrough et al. (1994) reported a U-Pb zircon lower intercept age of 17±4 Ma for a basal tonalite from the granulite unit in the central part of the Hidaka metamorphic belt. They explained that this lower intercept age is the crystallization age of the basal tonalite. Furthermore, they interpreted that the zircon age indicates rapid uplift and cooling of the granulite unit after emplacement of the tonalite magma because the 17 Ma crystallization age for the tonalite overlaps with some of the youngest K-Ar and Rb-Sr mineral determinations from the Hidaka metamorphic belt. Their interpretation indicates that the timing of the peak metamorphism is older than 17 Ma.

The temperature condition for the lower part of the granulite unit, where the basal tonalite had been emplacement, is up to 870℃, as described previously. The closure temperature of zircon in the U-Pb system is estimated=750℃ (Ghent et al., 1988). If cooling rate is 30℃/Ma, the U-Pb zircon closure temperature is 700 ℃ (Dodson and McClelland-Brown, 1985). The metamorphic temperature of the lower part of the granulite unit is much higher than the closure temperature of zircon in the U-Pb system. Accordingly, the U-Pb zircon age of 17 Ma indicates the time passing the closure temperature of zircon (750℃ or 700℃) in the basal tonalite, suggesting that uplift and cooling of the granulite unit occurred rapidly, as mentioned by Kimbrough et al. (1994). In other words, the age of 17 Ma indicates the timing of uplift due to thrusting up the granulite unit in the Hidaka metamorphic belt. In some cases, the U-Pb zircon ages of lower crustal rocks are close to the intrusive age of their host and surrounding rocks (Rudnick and Williams, 1987; Rudnick and Cameron, 1991).

Owada et al. (1991, 1992) determined the isochron ages of 55 to 56 Ma using the pelitic granulite and the peraluminous basal tonalite in the southern part of the Hidaka metamorphic belt, and interpreted that the ages of 55 to 56 Ma would be the timing of the peak metamorphism and, at the same time, that of the tonalitic magma formation. The newly determined isochron age of 51 Ma is consistent with the timing of the peak metamorphism mentioned by Owada et al. (1991, 1992).

Arita et al. (1993) analyzed K-Ar biotite and hornblende ages from the central part of the Hidaka metamorphic belt. The data range from 19 Ma to 16 Ma regardless of rock type and metamorphic grade. They interpreted that present metamorphic rock sequence and steeply eastward dipping structure of the central part of the Hidaka metamorphic belt had formed before the Early Miocene (<18 Ma). On the other hand, the mineral ages from the southeastern part of the Hidaka metamorphic belt show the Late Eocene to Early Oligocene. The newly determined Rb-Sr whole rock-biotite age of 40 Ma is consistent with the older age group.

It is possible to explain the age difference between the Late Eocene to Early Oligocene group and the Early

Miocene one by different cooling processes in the Hidaka metamorphic belt. Saeki et al. (1995) reported two different group of biotite K-Ar ages from the cordierite tonalite pluton (Toyonidake mass) in the southern part of the Hidaka metamorphic belt (Fig. 1). The ages of the Late Eocene to Early Oligocene group and the Early Miocene one were obtained on the northeast side of the pluton and the southwest side, respectively. This fact is consistent with the above idea.

Conclusions

The Rb-Sr internal isochron connecting with the biotite, whole rock and felsic fraction for the hornblende tonalite (Sa41) indicates an age of 40.5±0.3 Ma. The age of 40 Ma indicates the time passing the closure temperature of biotite (300℃) in the hornblende tonalite. The Rb-Sr whole rock isochron age for the five samples including sample Sa41 is 51.2±3.6 Ma (MSWD=0.02) and initial $^{87}Sr/^{86}Sr$ ratio is 0.70452±0.00004. The age of 51 Ma is regarded as the solidification age for the hornblende tonalite. The cooling rate is 40℃ to 30 ℃/Ma at the temperature above 300℃, based on the closure temperature.

In many cases, the hornblende tonalite intrudes into the cordierite tonalite. The cordierite tonalite magma was emplacement in the andalusite-bearing gneiss, and gives thermal effect to the host gneiss, which had already undergone the low P/T Hidaka metamorphism. Hence, the timing of the peak metamorphism of the Hidaka metamorphic belt should be older than c. 51 Ma.

Acknowledgments

The authors express their appreciation to Prof. M. Komatsu (Ehime University) and Dr. J. Maeda (Hokkaido University) for critical reading and improving the manuscript. We wish to thank Prof. H. Honma, Drs. S. Kakubuchi, M. Yuhara and Mr. M. Ohishi (ISEI) for suggestions and help during experiments. This work was supported by a Grant-in-Aid for Scientific Research (No. 0674039 : M. O., No. 04453053 : H. K. and No. 07640606 : Y.O.) from the Ministry of Education, Science, Sports and Culture of Japan.

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** In Japanese

（要　旨）

Owada, M., Osanai, Y. and Kagami, H., 1997, Rb-Sr isochron ages for hornblende tonalite from the southeastern part of the Hidaka metamorphic belt, Hokkaido, Japan : Implication for the timing of peak metamorphism. *Mem. Geol. Soc. Japan* no. 47, 21-27. (大和田正明・小山内康人・加々美寛雄，1997，日高変成帯南東部，角閃石トーナル岩のRb-Srアイソクロン年代：ピーク変成作用の時期について．地質学論集，no. 47, 21-27.)

日高変成帯南東部には，砂泥質変成岩類を貫く花崗岩類が広く分布する．花崗岩類は，菫青石トーナル岩と角閃石トーナル岩に区分され，多くの場合後者が前者を貫く．角閃石トーナル岩のRb-Sr全岩・黒雲母年代は40.5±0.3 Maで，岩体の冷却年代を示している．一方，岩体の固結・冷却年代を示すRb-Sr 全岩年代は鉱物年代より約10Ma古く，51.2±3.7 Maである．両年代の閉止温度を考慮し岩体の冷却速度を求めるとおよそ30〜40℃/Maとなる．菫青石トーナル岩は，低P/Tで特徴づけられる日高変成帯の広域変成作用をすでに被っていた泥質片麻岩に貫入し，岩体の周辺では母岩に熱変成を与えている．角閃石トーナル岩は，泥質片麻岩および菫青石トーナル岩に貫入していることから，日高変成作用がピークに達した時期は少なくとも51 Maより古くなる．