Rb-Sr isotope systematics in a phlogopite-bearing spinel lherzolite and its implications for age and origin of metasomatism in the Horoman peridotite complex, Hokkaido, Japan.

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23.0±1.2 Ma was obtained by Rb-Sr method for a phlogopite-bearing spinel lherzolite from the Horoman peridotite complex in the Hidaka metamorphic belt, Hokkaido, Japan. The age is essentially identical to the oldest ages of the country metamorphic rocks reported so far in the Hidaka metamorphic belt, and may indicate the time of a metasomatic event which occurred in the wedge mantle. This metasomatic event may have occurred during uplift of this mantle fragment under mantle conditions contemporaneously with elevation of the Hidaka metamorphic belt resulting from collision between the Eurasian and North American plates.

Keywords: Rb-Sr isotope systematics, Isochron age, Mantle metasomatism, Horoman peridotite complex, Hidaka metamorphic belt

1. Introduction

The Horoman peridotite complex is situated in the Hidaka metamorphic belt, Hokkaido, and is regarded as an orogenic lherzolite body similar to the Lherz (e.g. Bodinier *et al.*, 1988) and the Ronda (e.g. Obata, 1980) peridotite massifs, which represent large upper mantle-derived fragments mechanically emplaced into continental crust (e.g. Niida, 1984; Takahashi, 1991a, b).

The Hidaka metamorphic belt is divided into the Main Zone which is made up of continental or island arc type crust (Komatsu *et al.*, 1986) and the Western Zone which consists of metamorphosed ophiolite succession (Miyashita, 1983). The former has been thrust over the latter by the Hidaka Main Thrust (e.g.

Komatsu *et al.*, 1986; Miyashita, 1983). The Horoman peridotite complex has been interpreted as belonging to the Main Zone of the Hidaka metamorphic belt (Komatsu *et al.*, 1986). There is, however, no geological evidence to support the tectonic setting for the Horoman complex, since this complex and other peridotite complexes located in the Main Zone are completely bounded by faults with shear zones (Niida and Katoh, 1978). Furthermore, contact thermal metamorphism has not been observed in the surrounding metamorphic rocks (Niida, 1975b; Niida, 1984). Therefore, the geochronological relationship between the emplacement of Horoman peridotite complex and the Hidaka metamorphism is still unclear.

In the Horoman complex, phlogopites commonly occur as veinlets or interstitially in harz-

burgite and spinel lherzolite (Niida, 1975; Arai and Takahashi, 1989; Takahashi *et al.*, 1989), and are believed to be formed by alkali metasomatism related to a latent alkali basaltic magmatism (Arai and Takahashi, 1989; Takahashi, 1991a). According to Arai and Takahashi (1989), Takahashi *et al.*, (1989) and Takahashi (1991a), the metasomatism occurred along a shear zone near the boundary between the Eurasian and the North American plates, just before their collision and had slightly modified the chemical composition of the massif at a late stage because alkali magmatism and associated metasomatism were expected to occur along such a transcurrent plate boundary (e.g. Roden *et al.*, 1984). However, there is no evidence of the formation age of the phlogopites except that based on the petrographic observations (Arai and Takahashi, 1989), the phlogopites formed at the latest stage in the Horoman complex. Furthermore, the origin of metasomatic fluids in the upper mantle condition is still not well understood in relation to the tectonic setting even though such metasomatism is believed to play an important role in large ion lithophile element (LILE) enrichment in the source materials of the alkaline magmatism (e.g. Frey *et al.*, 1978; Menzies and Murthy, 1980).

In this paper, we present detailed results of Rb-Sr isotope systematics of a phlogopite-bearing lherzolite from the Horoman complex, and discuss the formation age of the phlogopite and the origin of the metasomatic fluid in relation to the tectonic setting of the Horoman complex and the surrounding metamorphic rocks.

II. Petrological background and sample description

The Horoman peridotite complex has a total thickness exceeding 3000 m and exhibits a layered structure on the scale of centimeters to

several hundred metres, consisting of dunite, harzburgite, spinel lherzolite, plagioclase lherzolite, gabbro and pyroxenite (e.g. Niida, 1984; Takahashi, 1991b). Takahashi (1991a, b, 1992) inferred that the complex is composed of three peridotite suites each of which has a different age and origin: i.e. that is, the Main Harzburgite Lherzolite suite (MHL) with a subordinate Spinel-rich Dunite-Wehrlite suite (SDW) and a minor Banded Dunite-Harzburgite suite (BDH).

Phlogopites are heterogeneously distributed mainly in the MHL (Takahashi *et al.*, 1989) (Fig. 1) and are classified into two types, interstitial-type and vein-type (Arai and Takahashi, 1989). The interstitial-type phlogopites most commonly occur among orthopyroxene grains with a minor association of clinopyroxene and frequently enclose relics of orthopyroxene (Arai and Takahashi, 1989; Takahashi *et al.*, 1989). On the other hand, vein-type phlogopites form veinlets or aggregates sometimes exceeding 40 cm in length and 1 mm in width, and usually cut olivine-rich parts of the rocks parallel to the foliation plane of peridotites (Niida, 1974; Arai and Takahashi, 1989, Takahashi *et al.*, 1989). Such phlogopites usually exhibit irregular grain boundaries with associated olivine indicating a replacement relationship (Arai and Takahashi, 1989; Takahashi *et al.*, 1989). Based on detailed petrological observations, Arai and Takahashi (1989) inferred that the phlogopites were formed under upper mantle condition because there is no correlation between the distribution of phlogopite veins and low-temperature deformation, and the phlogopites never coexist with serpentine. Furthermore, it is also suggested that the phlogopites from the Horoman peridotite complex could have formed at 750–950°C in the spinel to plagioclase peridotite stability field of the upper mantle, because of chemical equilibrium between phlogopite and olivine and their higher Al/Si ratios than those of

Fig. 1. Lithological map and occurrence of phlogopite in the southern part of the Horoman peridotite complex (after Takahashi *et al.*, 1989). The sample locality is shown as a star.

phlogopite in garnet peridotite (Arai, 1984; Takahashi *et al.*, 1989).

The studied sample of phlogopite-bearing spinel lherzolite was collected from a location along the Horoman River (Fig. 1). The sample rock contained a phlogopite vein of less than 1 mm thickness and approximately 30 mm length. Interstitial phlogopites were also found in the sample and their modal abundance tends to decrease with increasing distance from the vein although their mode is less than 1% on the thin-section scale. The petrographical characteristics of both types of phlogopites are essentially identical to those described by Arai and Takahashi (1989) and Takahashi *et al.* (1989). No serpentine was identified in association with the phlogopites in this sample by microscope observations.

III. Sample preparation and analytical method.

The hand specimen was cut perpendicular to a phlogopite vein with a diamond saw and then parallel to the phlogopite vein in order to obtain three slices at the different distances from the vein as shown in Fig. 2. Each slice was loosely crushed using a silicon nitride mortar to avoid destruction of constituent mineral grains. Minerals were then separated from the slices by hand-picking under a binocular microscope. The first slice, 1 mm from the phlogopite vein, contained approximately 3% of phlogopite in modal composition. After separation of clinopyroxene, the rest of the sample, containing phlogopite, orthopyroxene, olivine and spinel, was used as a whole rock sample. In order to remove any alteration,

Fig. 2. A schematic diagram of the studied spinel lherzolite sample, showing the locations of the slices analyzed for Rb-Sr isotope systematics.

inclusions and grain-boundary enrichment, the following procedure was performed on the samples: The separated clinopyroxenes and orthopyroxenes were leached with 4 M HCl at a temperature of 80°C for 3 hours followed by ultrasonic treatment. Optically clear grains were hand-picked and then individually crushed to <1 mm sized fragments in a silicon nitride mortar. Afterwards, very clear fragments of pyroxenes were again hand-picked under the binocular microscope and were soaked in 1.5 M HF at 50°C for 30 minutes and subsequently agitated in water in an ultrasonic bath. The phlogopites were repeatedly washed with distilled water for 3 minutes using the ultrasonic bath. The whole rock sample was ground to under 200 mesh using the silicon nitride mortar. After that, the powdered sample was leached

with 4 M HCl at 80°C for 3 hours. The sample was finally rinsed with water. The finally cleaned samples were then evaporated to dryness at 110°C on the hot plate.

The employed procedure of the chemical separations of Rb and Sr and their isotopic analyses are the same as those described in Yoshikawa and Nakamura (1992). The prepared samples for isotopic analyses were weighed in a 7 ml PFA Teflon beaker together with Rb and Sr spikes and decomposed with HF and HClO₄ in the tightly sealed Teflon beaker. After complete decomposition of the sample, Rb and Sr were chemically separated by adopting a combination of cation-exchange chromatography in H⁺ form and pyridinium form with DCTA complex using 1 ml and 0.5 ml of cation-exchange resin, respectively (Yoshi-

Table 1. Sr isotopic compositions and concentrations of Rb and Sr of mineral separates and whole rock sample from a spinel lherzolite

Sample	weight (mg)	Rb (ppm)	Sr (ppm)	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$	2 σ
Phlogopite	14.03	29.027	75.03	1.178	0.704236	± 10
Cpx (-1mm)	3.91	0.0395	115	0.0105	0.703887	± 15
Whole rock (-1mm)	45.36	0.6888	27.35	0.0767	0.703900	± 15
Cpx (-10mm)	5.98	0.0075	128.5	0.0002	0.703857	± 14
Cpx (-55mm)	4.56	0.0002	143.5	0.0000	0.703870	± 19
Opx (-55mm)	71.96	0.0307	1.717	0.0517	0.703885	± 11
Cpx (+100mm)	6.55	*	61.644	*	0.702783	± 14

Parentheses show the distance from the phlogopite vein.

* indicates concentration below the detection limit.

kawa and Nakamura, 1992). All isotopic measurements were performed on a thermal ionization mass spectrometer, Finnigan MAT 261, equipped with five Faraday cup collectors and a secondary electron multiplier (SEM). Sr and Rb samples were loaded on V-shaped tungsten filaments with Ta-oxide. Static multicollection mass spectrometry was applied for the simultaneous determination of isotope ratio and concentration of Sr with isotope dilution mass spectrometry (IDMS) (Yoshikawa and Nakamura, 1992). Rb concentration was measured by IDMS using a SEM.

Measured concentrations of Rb and Sr and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in BCR-1 (basaltic rock standard) were: 47.1 ± 1.0 ppm, 330 ± 2 ppm and 0.704991 ± 0.000012 ($n=8$). For PCC-1 (ultramafic rock standard), the analytical reproducibilities were: Rb = 0.0598 ± 0.0007 ppm, Sr = 0.3817 ± 0.0085 ppm, and $^{87}\text{Sr}/^{86}\text{Sr} = 0.710566 \pm 0.000026$ ($n=4$). Procedural total blanks of Rb and Sr in the course of this study were 25 and 32 pg, respectively.

We used $\lambda = 1.42 \times 10^{-11}/\text{y}$ for the decay constant of ^{87}Rb (Steiger and Jäger, 1977). The Rb-Sr isochron data were fitted after the methods developed by York (1969). The errors in determination of age and initial ratio are expressed by the expanded uncertainties (e.g. Kullerød, 1991), which is a multiplication of the "2 σ error" in York (1969) by the square root of

MSWD (mean square of weighted division).

IV. Results and discussion

The results obtained in this study are summarized in Table 1. The Rb content of phlogopite in the vein (29 ppm) is distinctly lower than that of typical mantle phlogopite which range from 200 to 600 ppm (e.g. Richardson *et al.*, 1985; Erlank *et al.*, 1987), although the Sr content (75 ppm) is within the range of mantle phlogopite (10–170 ppm). This results in an extremely low Rb/Sr ratio (0.39) for the studied phlogopite in comparison to ratios for the typical mantle phlogopite (1.2–45). The concentration of Sr in the clinopyroxenes increases with increasing distance from the phlogopite vein (Fig. 3) and is significantly higher than that of clinopyroxenes in phlogopite-free spinel lherzolite (62 ppm, Table 1) which was collected at an approximately 10 cm from the phlogopite vein. In contrast, the Rb concentration decreases with distance from the vein (Fig. 3). The systematic changes of Sr and Rb concentrations in the clinopyroxenes indicate that the metasomatic fluid from which the phlogopite vein formed, percolated into the spinel lherzolite with changes in the fluid composition occurring over a distance of at least 60 mm.

Rb and Sr are compatible and incompatible respectively with phlogopite in the upper man-

Fig. 3. Variations of Rb and Sr concentrations and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of clinopyroxenes and phlogopite as a function of distance from phlogopite vein. Open circles and solid circles represent phlogopite and clinopyroxene, respectively. The analytical errors are within the symbols.

tle (e.g. Ujiie, 1988). Thus if phlogopite fractionation occurs in the metasomatic fluid during its migration through the conduit, then the metasomatic fluid would also change with its Rb/Sr ratio becoming lower and lower. The phlogopite in the vein, which has an extremely low Rb/Sr ratio compared with those of typical mantle phlogopites, which may have formed from such an evolved metasomatic fluid. Such an evolved metasomatic fluid would also percolate into the host spinel lherzolite and in the process, interstitial-type phlogopite could be precipitated replacing olivine and orthopyroxene and the Rb and Sr contents in the residual fluid would decrease and increase, respectively, with the advance of the fluid front away from the vein. This mechanism is also supported by the observation that the Ti content in the interstitial-type phlogopite decreases with increasing distance from phlogopite veins (Takahashi, unpublished data). The coexisting clinopyroxenes could be reacted with the progressively evolved metasomatic fluids with resulting change in their Rb and Sr contents without destruction of

the clinopyroxene crystal structure. Consequently, the Rb and Sr contents of clinopyroxenes systematically change with increasing the distance from the vein.

Clinopyroxenes at the distances of 10 mm and 55 mm from the phlogopite vein have identical $^{87}\text{Sr}/^{86}\text{Sr}$ ratios within the analytical errors with extremely low $^{87}\text{Rb}/^{86}\text{Sr}$ ratios (see Table 1). Clinopyroxene from the 1 mm slice also has an indistinguishable Sr isotopic composition with slightly higher $^{87}\text{Rb}/^{86}\text{Sr}$ ratio from those of the other slices. Therefore, the present $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of these clinopyroxenes are essentially same as the initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios. The identical initial ratios with different Sr concentrations of the clinopyroxenes from three slices indicate that isotopic equilibration among the clinopyroxenes was achieved by the metasomatic fluid in the upper mantle condition at least as far as 60 mm from the phlogopite vein. These isotopic compositions (0.703857–0.703887) are distinctly higher than those of clinopyroxenes in the phlogopite-free spinel lherzolite (<0.7028), which locate in more than 10 cm from the phlogopite vein. These obser-

Fig. 4. A Rb-Sr isochron diagram for the analyses of mineral separates and a whole rock sample from a phlogopite-bearing spinel lherzolite. Analytical error for $^{87}\text{Rb}/^{86}\text{Sr}$ ratio is quoted for the analytical reproducibility in PCC-I.

variations suggest that the metasomatic fluid which formed the phlogopite in the spinel lherzolite had an exotic origin.

The determined $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{87}\text{Rb}/^{86}\text{Rb}$ ratios for phlogopite, clinopyroxenes, orthopyroxene and whole rock sample are plotted on the isochron diagram (Fig. 4). All the data from the phlogopite-bearing spinel lherzolite form a well fitted isochron even though the variation of $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{87}\text{Rb}/^{86}\text{Sr}$ ratios, excluding those of phlogopite, are fairly small (Fig. 4). This isochron gives an age of 23.0 ± 1.2 (2σ) Ma with an initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of $0.703871 \pm 0.000007(2\sigma)$. Considering the systematic changes of Rb and Sr contents in clinopyroxenes as a function of distance from the phlogopite vein, as discussed the above, all the data should represent the time-integrated isotopic variation with the different parent/daughter ratios after isotopic re-equilibration by the metasomatic fluid. It is, therefore, concluded that the age obtained in this study repre-

sents the time when the metasomatism occurred in the spinel lherzolite in the upper mantle. This age is consistent with the oldest age (23.4 Ma, Hashimoto, 1976) determined for the country metamorphic rocks of the Horoman peridotite complex.

Since the Lherz and the Ronda peridotite complexes caused thermal metamorphism to the country metamorphic rocks, the emplacement ages of these orogenic peridotite bodies were indirectly determined from the contact metamorphic minerals in the country rocks by ^{40}Ar - ^{39}Ar , K-Ar and Rb-Sr age dating methods (Albarede and Michard-Vitrac, 1978; Preim *et al.*, 1979). However, the country rock surrounding the Horoman complex has not suffered such contact metamorphism by the intrusion of the complex (Niida, 1974), and the complex is in fault and shear zone contact with the country rocks (Niida, 1974). It has been, therefore, difficult to determine the emplacement age of the Horoman complex so the

tectonic relationship between the complex and the surrounding metamorphic rocks has remained enigmatic.

This study presents the first determination of the age of a metasomatic event in the Horoman peridotite complex. The implication of this metasomatic age to the Hidaka metamorphic belt is discussed below.

The Hidaka metamorphic belt is recognized to be a collision zone between the Main Zone and the Western Zone; in other words, the Eurasian and the North American plates, respectively (e.g. Komatsu, 1985). The collision took place during the late Miocene to Pliocene (Komatsu, 1985; Komatsu *et al.*, 1986). The ages of metamorphic rocks reported so far range from 17 to 23 Ma (Hashimoto, 1976; Shibata *et al.*, 1984) and imply the cooling ages after peak metamorphism (granulite facies) due to the uplift of the Hidaka metamorphic belt induced by the collision (Osanai *et al.*, 1986). The coincidental agreement between the metasomatic age (23 Ma) in the Horoman peridotite complex and the oldest age (23.4 Ma) of the Hidaka metamorphic rocks suggests they had a similar tectonic setting at this time. If this is the case, the metasomatism might have occurred when the Horoman complex started to rise from the upper mantle together with the Hidaka metamorphic belt. Under such conditions, the total pressure could be reduced to form cracks in the peridotite complex. Then the metasomatic fluids might be easily introduced along the cracks in the upper mantle. The reason the influence of metasomatism is restricted to a very small distance from the phlogopite vein (<10 cm), may be related to the slightly lowered total pressure in the upper mantle caused by the uplifting.

From detailed mineralogical and petrological studies, Takahashi (1991a) inferred that the Horoman peridotite complex had expe-

rienced a fore-arc setting. The Sr isotopic compositions of clinopyroxenes from phlogopite-free peridotites have very depleted signatures as low as those of MORB (<0.7027). It is, therefore, difficult to produce the higher initial ratio (0.7039) of the metasomatic fluid by auto-metasomatism in the MORB-type mantle. Therefore, the metasomatic fluid may have been derived from different reservoir with a distinctly high Sr isotopic composition. If Takahashi's model (1991a) is correct in terms of the tectonic setting, the metasomatic fluid could have been derived from fluids caused by the dehydration of subducted oceanic sediments and altered MORB. This initial Sr isotopic composition is somewhat lower than that of a slab-derived fluid component (0.7045) estimated from northeastern Japan (Shibata and Nakamura, 1992). This is because the fluid reacted with the Horoman peridotites, which decreased its Sr isotopic composition, along with phlogopite fractionation during its migration through the cracks. The partial pressure of the metasomatic fluid must have been sufficiently higher than the total pressure of the host peridotite, which was reduced by uplift, for fluid to percolate into the spinel lherzolite as far as 10 cm from the phlogopite vein as described in this study.

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References

- Albarède, F. and Michard-Vitrac, A. (1978), Age and significance of the North Pyrenean metamorphism. *Earth Planet. Sci. Lett.*, **40**, 327-332.
- Arai, S. (1984), Pressure-temperature depended compositional variation of phlogopite micas in upper mantle peridotites. *Contrib. Mineral. Petrol.*, **87**, 260-264.
- Arai, S. and Takahashi, N. (1989), Formation and compositional variation of phlogopites in the Horoman peridotite complex, Hokkaido, northern Japan: implications for origin and fractionation of metasomatic fluids in the upper mantle. *Contrib. Mineral. Petrol.*, **101**, 165-175.
- Bodinier, J.L., Dupuy, C., and Dostal, J. (1988), Geochemistry and petrogenesis of Eastern Pyrenean peridotites. *Geochim. Cosmochim. Acta*, **52**, 2897-2907.
- Earlank, J.A., Waters, F.G., Hawkesworth, C.J., Haggerty, S.E., Allsopp, H.L., Rickard, R.S. and Menzies, M.A. (1987), Evidence for mantle metasomatism in peridotite nodules from the Kimberley Pipes, South Africa. In *Mantle metasomatism (Menzies and Hawkesworth, C.J. ed.)*, Academic Press. 211-311.
- Frey, F.A., Green, D.H. and Roy, S.D. (1978), Integrated models of basalt petrogenesis: a study of quartz tholeiites to olivine melilitites from south eastern Australia utilizing geochemical and experimental petrological data. *J. Petrol.*, **19**, 463-513.
- Hashimoto, S. (1976), Structural significance of the Western Zone in Hidaka metamorphic belt. *Contribution from the Department of Geology and Mineralogy Niigata University (Professor Nishida Commemorial Volume)*, **4**, 490-415.*
- Komatsu, M. (1985), Structural framework of the axial zone in Hokkaido -its composition, characters and tectonics- *Mem. Geol. Soc. Japan*, **25**, 137-155.**
- Komatsu, M., Miyashita, S. and Arita, K. (1986), Composition and structure of the Hidaka metamorphic belt, Hokkaido -historical review and present status-. *Monograph Assoc. Geol. Collab. Japan*, 189-203.**
- Kullerød, L. (1991), On the calculation of isochrons. *Chem. Geol. (Isot. Geosci.)*, **87**, 115-124.
- Menzies, M.A. and Murthy, V.R. (1980), Nd and Sr isotope geochemistry of hydrous mantle nodules and their host alkali basalts: implications for local heterogeneities in metasomatically veined mantle. *Earth Planet. Sci. Lett.*, **46**, 323-334.
- Miyashita, S. (1983), Reconstruction of the ophiolite succession in the western zone of the Hidaka Metamorphic Belt, Hokkaido. *J. Geol. Soc. Japan*, **89**, 69-86.**
- Niida, K. (1974), Structure of the Horoman ultramafic massif of the Hidaka metamorphic belt in Hokkaido, Japan. *J. Geol. Soc. Japan*, **80**, 31-44.
- Niida, K. (1975a), Phlogopite from the Horoman ultramafic rocks. *J. Fac. Sci., Hokkaido Univ., Ser. IV*, **16**, 511-518.
- Niida, K. (1975b), Textures and olivine fabrics of the Horoman ultramafic rocks, Japan. *J. Min. Petr. Econ. Geol.*, **70**, 265-285.
- Niida, K. (1984), Petrology of the Horoman ultramafic rocks. *J. Fac. Sci. Hokkaido Univ. Ser. IV*, **21**, 61-81.
- Niida, K. and Katoh, T. (1978), Ultramafic rocks in Hokkaido. *Monograph Assoc. Geol. Collab. Japan*, **21**, 61-81.**
- Obata, M., (1980), The Ronda peridotite: garnet-, spinel-, and plagioclase-lherzolite facies and the P-T trajectories of a high-temperature mantle intrusion. *J. Petrol.*, **21**, 533-572.
- Osanai, Y., Miyashita, S., Arita, K. and Bamba, M. (1986), The metamorphism and thermal structure of the collisional terrain of a continental and oceanic crusts: a case of the Hidaka metamorphic belt, Hokkaido, Japan. *Monograph Assoc. Geol. Collab. Japan*, **31**, 205-222.
- Priem, H.N.A., Boelrijk, N.A.I.M., Hebeda, E.H., Oen, I.S., Verdurmen, E.A.Th. and Verschure, R.H. (1979), Isotopic dating of the emplacement of the ultramafic masses in the Serrania de Ronda, southern Spain. *Contrib. Mineral. Petrol.*, **70**, 103-109.
- Richardson, S., Eralank, A.J. and Hart, S.R. (1985), Kimberlite-born garnet peridotite xenoliths from old enriched subcontinental lithosphere. *Earth Planet. Sci. Lett.*, **75**, 116-128.
- Roden, M.K., Hart, S.R., Frey, F.A. and Melson, W. G. (1984), Sr, Nd and Pb isotopic and REE geochemistry of St. Paul's rocks: The metamorphic and metasomatic development of an alkali basalt mantle source. *Contrib. Mineral. Petrol.*, **85**, 376-390.
- Shibata, K., Uchiumi, S., Uto, K. and Nakagawa, T. (1984), K-Ar age results-2 new data from

- the Geological Survey of Japan-. *Bull. Geol. Surv. Japan*, **35**, 331-340.**
- Shibata, T. and Nakamura, E. (1992), Interaction between subducted oceanic slab and wedge mantle inferred from across-arc variations of Pb, Sr and Nd isotopic compositions in northern Japan. *Abstract for the 29th International Geological Congress, Kyoto, Japan*, pp. 184.
- 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.
- Takahashi, N. (1991a), Evolutional history of the uppermost mantle of an arc system: petrology of the Horoman peridotite massif, Japan. In *Ophiolite Genesis and Evolution of Oceanic Lithosphere: Proceedings of Oman ophiolite Symposium, 1990* (Peter, Tj. ed.), Kluwer Academic Publishers, Dordrecht. 197-208.
- Takahashi, N. (1991b), Origin of three peridotite suites from Horoman peridotite complex, Hokkaido, Japan; Melting, melt segregation and solidification processes in the upper mantle. *J. Min. Petr. Econ. Geol.*, **86**, 199-215.
- Takahashi, N. (1992), Evidence for melt segregation towards fractures in the Horoman mantle peridotite complex. *Nature*, **359**, 52-55.x
- Takahashi, N., Arai, S. and Murota, Y. (1989), Alkali metasomatism in peridotite complexes from the Hidaka belt, Hokkaido, northern Japan. *J. Geol. Soc. Japan*, **9**, 311-329.**
- Ujike, O. (1988), Probable mineralogic control on the mantle metasomatic fluid composition beneath the Northeast Japan arc. *Geochim. Cosmochim. Acta*, **52**, 2037-2046.
- York, D. (1969), Least-squares fitting of a straight line with correlated errors. *Earth Planet. Sci. Lett.*, **5**, 320-324.
- Yoshikawa, M and Nakamura, E (1992), Precise isotope determination of trace amounts of Sr in magnesium-rich samples. *Technical report of ISEI, Okayama University, Ser. A*, **50**, 1-42.
- (*: in Japanese)
- (**: in Japanese with English abstract)

金雲母を含むスピネルレルゾライトのRb-Sr同位体システマティックスによる 北海道幌満かんらん岩体での交代作用の時期と起源

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北海道日高変成帯南端部に位置する幌満かんらん岩体中の、金雲母を含むスピネルレルゾライトから、Rb-Sr法を用い $23 \text{ Ma} \pm 1.2 \text{ Ma}$ の年代を得た。この年代は、現在までに報告されている日高変成帯の変成岩類の年代中、最も古いものとはほぼ一致する。また、この年代は、幌満かんらん岩体がウェッジマントル中にあったときに、交代作用を受けた時期を示していると考えられる。この交代作用は、ユーラシアプレートと北アメリカプレートの衝突による日高変成帯の上昇に伴い幌満岩体上昇期にマントル条件下で起きたと考えられる。