A preliminary study on D/H ratios of hornblendes from granites and ultramafic-mafic rocks

YOSHIMASU KURODA¹, TETSURO SUZUOKI² and SADA0 MATSUO³

Department of Geology, Shinshu University, Matsumoto, Nagano Pref., 390 Japan¹,
Meteorological College, Kashiwa, Chiba Pref., 277 Japan², and Department of Chemistry,
Tokyo Institute of Technology, O-okayama, Meguro-ku, Tokyo 152 Japan³

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Abstract—The δD values of hornblendes from some granites and ultramafic-mafic rocks suggest that the water in granitic magma and the water equilibrated with hornblendes in ultramafic-mafic rocks associated with peridotites seem to be the same with respect to δD values which range from -29 to -37 ‰. Water contents of hornblendes in ultramafic-mafic rocks are clearly higher than those in granitic rocks. The δD values and water contents of hornblendes from nodules in some alkali basalts and possibly metamorphosed ultramafic-mafic rocks are quite different from those of the rocks mentioned above.

Cretaceous granitic rocks of Northeast Japan have been studied by KURODA *et al.* (1974) for the purpose of revealing the relationship between D/H ratios of coexisting biotite and hornblende. According to their study, most of biotite-hornblende pairs are in equilibrium with respect to hydrogen isotope exchange. On this basis, D/H ratio of water in the granitic magma was discussed.

In this study we measured D/H ratios of hornblendes from hornblendites, gabbros and gabbro-amphibolites associated with peridotites with the intension of obtaining the following information (Table 1); 1), D/H ratio of the water coexisting with such hornblendes, and 2), differences in both D/H ratio and water content between hornblendes from granitic rocks and from such ultramafic-mafic rocks.

Hornblendes were separated from hornblendites, gabbros and gabbro-amphibolites accompanied by peridotite(serpentinite) in glaucophane-schist metamorphic belts (Sanbagawa, Kamuikotan and Franciscan belts). The method of analysis was the same as that described in KURODA *et al.* (1973, 1974). D/H ratio is expressed in terms of the usual δD (‰)* presentation with respect to SMOW. The error attached

$$* \delta D (\text{‰}) = \frac{(D/H)_{\text{sample}} - (D/H)_{\text{SMOW}}}{(D/H)_{\text{SMOW}}} \times 1,000$$

Table 1. *Analytical results and pertinent chemical information*

No.	δD_{SMOW} (‰)	H ₂ O (wt. %)	X _{Fe}
1	-54.6	2.73	0.20
2	-68.4	3.06	0.26
3	-62.8	3.16	0.30
4	-43.8	2.66	0.27
5	-54.9	2.70	0.31
6	-67.4	2.99	0.39
7	-58.1	2.82	0.35
8	-47.0	3.20	0.05
9	-62.5	2.46	0.37
10	-61.4	2.67	0.42
11	-23.1	1.73	0.31
12	-27.8	1.98	0.31
13	-29.2	1.97	0.32
14	-26.3	1.95	0.21
15	-45.4	2.20	0.37
16	-74.5	2.46	0.22
17	-67.7	2.46	0.35
18	-74.6	2.18	0.39

1, No.133-a, hornblende-pyroxene gabbro, Ogawara, Sanbagawa belt (S. IIZUMI); 2, No.62004, diopside-hornblende, Kanto mountainland, Sanbagawa belt (K. TAZAKI); 3, No.3272803, hornblende gabbro, Kanto mountainland, Sanbagawa belt (K. TAZAKI); 4, No.5080902, hornblende, Kanto mountainland, Sanbagawa belt (K. TAZAKI); 5, No. Ub.47, hornblende, Kamuikotan belt (Y. KURODA); 6, No.28909, hornblende, Kamuikotan belt (K. TAZAKI); 7, No.82908, diopside-hornblende, Kamuikotan belt (K. TAZAKI); 8, No.63-49, tremolite rock, Kômorî (Y. KURODA); 9, No. F.74, amphibolite, Santa Catalina Island (H. ONUKI); 10, No. F.84, amphibolite, Santa Catalina Island (H. ONUKI); 11, No. Hbt-1, hornblende, Ichinomegata (H. ONUKI); 12, No. Hg-1, Hornblende gabbro, Ichinomegata (H. ONUKI); 13, No.72601, diopside-hornblende, Ichinomegata (Y. KURODA); 14, No. Kn-1, hornblende gabbro, Kujiranami (H. ONUKI); 15, No. U7207B, hornblende, Abukuma (H. ONUKI); 16, No. M902, amphibolite, Kitakami (H. ONUKI); 17, No. MY151, clinopyroxene-hornblende, Kitakami (H. ONUKI); 18, No. 47, hornblende, Kitakami (M. GORAI). Each sample was collected by the person named in parentheses.

to δD measurements was $\pm 0.7\text{‰}$.

The result of measurements on the relationship between δD and $Fe/(Fe+Mg)$ is shown in Fig.1. The broken line in Fig.1 represents the dependence of δD on cation composition in the six-coordination position of hornblende under the equilibrium with the water of constant δD at a constant temperature, established experimentally by SUZUOKI and EPSTEIN (1972, 1974). The line shifts parallel to the ordinate when the equilibrium temperature or δD of the coexisting water is changed. In the previous report (KURODA *et al.*, 1974) we found that hornblendes from granite masses of Kitakami mountainous district were in equilibrium with coexisting water in magma in regard to the hydrogen isotope exchange equilibrium in the temperature range from 450 to 700°C or 550 to 1,000°C. Moreover, the δD value of the coexisted

magmatic water was estimated to be $-29 \sim -37\text{‰}$, by using SUZUOKI and EPSTEIN's formula* as to the relationship between δD values of coexisting hornblende and biotite (SUZUOKI and EPSTEIN, 1972, 1974). δD values of hornblendes in granites are reproduced in Fig.1 (open circles).

Fig.1. Relationship between δD and $Fe/(Fe + Mg)$ of hornblendes from various rocks (open circles; granites, solid circles; ultramafic-mafic rocks from glaucophane-schist belts, solid triangles; ultramafic-mafic rocks from the Kitakami and Abukuma mountainous districts, crosses; nodules in alkali-basalts).

It should be noted that δD values of hornblendes in ultramafic-mafic rocks from the glaucophane-schist belts (solid circles, in Fig.1) are distributed conformably with those from granites. The temperature of formation of hornblendites, gabbros and gabbro-amphibolites associated with peridotites in glaucophane-schist belts is not yet known. As is well known the glaucophanitic metamorphism is characterized by high pressure and low temperature conditions. The highest temperature of the metamorphism may be similar to that of the establishment of amphibolite facies which seems to be rather lower than the average temperature of granite magma. Whereas, as far as hornblendites, gabbros and gabbro-amphibolites in the glaucophane-schist belts are concerned, we infer that the temperature of formation of these rocks is slightly

* $10^3 \ln \alpha_{M-W} = 22.4 \times 10^6 T^{-2} + 28.2 + 2X_{Al} - 4X_{Mg} - 68X_{Fe}$ where α_{M-W} denotes $(D/H)_{mineral}/(D/H)_{water}$ or $1 + 10^{-3} \cdot \delta D_{mineral}/1 + 10^{-3} \cdot \delta D_{water}$, and X the atomic fraction of the six-coordinated cations.

higher than or similar to that of granitic magma, although there is no definite basis for the estimation of their temperature of formation. The δD value of the water in equilibrium with hornblendes in these ultramafic-mafic rocks can be estimated to be $-29 \sim -37\text{‰}$. This result indicates that the water in equilibrium with granitic rocks and ultramafic-mafic rocks could be the same with respect to hydrogen isotopic composition.

The relationship between the water content and δD value of hornblendes is shown in Fig.2. δD values are normalized to the value at $X_{Mg} = 1.0$. As is clearly recognized in Fig.2, water contents of hornblendes from these ultramafic-mafic rocks are definitely higher than those from granites in spite of the similarity in δD values. These facts are important for elucidating the origin of hornblende and water in ultramafic-mafic rocks and granitic rocks.

Fig.2. Relationship between δD and H_2O yield of hornblendes from various rocks (marks are the same as those in Fig.1).

Hornblendes were also separated from hornblendites and olivine-hornblendites of nodules included in the Tertiary alkali basalts at Ichinomegata (Akita Pref.) and Kujiranami (Niigata Pref.). Here it is tentatively assumed that hornblendites of nodules in alkali basalts are similar in origin to those associated with peridotite described above. It is interesting to see that the values of δD and water content of hornblendes of nodules (crosses in figures) lie within the area of high δD and low water content. This fact could be accounted for by the kinetic isotopic effect in the process of the partial dehydration of hornblendes due to the heating of nodules in the ascending magma.

The δD and water content of hornblendes of hornblendites associated with

peridotites in the Kitakami and Abukuma mountainous districts were also determined and are given in Figs. 1 and 2 (solid triangles). The δD values spread widely while the water content is in an intermediate range compared with those of granites and ultramafic-mafic rocks from the glaucophane-schist belts. The Kitakami and Abukuma mountainous districts have been subjected to different types of metamorphism at least twice (e.g., KURODA, 1968; KANO and KURODA, 1968; KANO *et al.* 1973; KANO and KURODA, 1973), i.e., an earlier metamorphism under higher pressure and a later contact-type metamorphism by a vast intrusion of granite. On the basis of such geological history the characteristics of the water content and δD value of hornblendes from hornblendites associated with peridotites in these districts are inferred to be the result of the interaction of granite with the pre-existed hornblendites.

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