Origin of hornblendites in the Ōeyama (Kōmori) ultramafic body in view of hydrogen isotope study

YOSHIMASU KURODA¹, TOMOYASU KINUGAWA¹, TETSURO SUZUOKI²
and SADAŌ MATSUO³

Department of Geology, Shinshu University, Matsumoto 390¹, Marine Department, Japan Meteorological Agency, Otemachi, Chiyoda, Tokyo 100², and Department of Chemistry, Tokyo Institute of Technology, O-Okayama, Meguro, Tokyo 152³, Japan

(Received July 1, 1975)

Abstract—Hornblendes from epidote-hornblendites in the contact aureole of the younger granite in the Ōeyama ultramafic body are concluded to have been formed by recrystallization of clinopyroxenite on the supply of water from the intruding granite. The value of δD of source water is estimated to be $-60 \sim -65\text{‰}$, which is definitely lower than $-29 \sim -37\text{‰}$ of water in granitic magma of the Kitakami mountainous district.

OUTLINE OF GEOLOGY

The Ōeyama (Kōmori) ultramafic body is located along the northern side of the Maizuru structural belt as shown in Fig. 1. It has intruded into Paleozoic sediments and the northern part of the body has been intruded by the Paleogene (?) granite. As already described by KURODA and SHIMODA (1967) and OGURA *et al.* (1970) the mass consists mainly of dunite. The dunite is composed primarily of olivine with well-developed cleavages parallel to (100), (010) and (001). However, olivine has been recrystallized by the contact metamorphism of the granite intrusion and well-developed cleavages have disappeared in the northern part of the mass.

In the area of contact aureole of the dunite mass a fairly large body of clinopyroxenite has intruded. Clinopyroxene crystals of the body are commonly large in size from several to 30 cm in length. Rocks in some part of the body have been recrystallized to hornblendites, and small veins such as white mica-zoisite vein described previously (KURODA *et al.*, 1964) are seen in intimate relation with the recrystallization features. Small dikes or lenses of harzburgite, gabbro, diabase and leucocrates are also observed.

The hornblendites are composed mainly of dark green hornblende (50 ~ 95%), with variable amounts of epidote, chlorite, diopside and serpentine. Small amounts of plagioclase and brucite are also found in some parts. Accessory minerals found are titanite, spinel, magnetite, ilmenite and apatite. The texture of the rocks is usually schistose and metamorphic. It is to be noted that kyanite is rarely found (KUROKAWA, 1975) and staurolite is also sporadically found (KINUGAWA, 1975) as relicts.

The granite mass of the northern side can be regarded as one of the San-in type granites, consisting of coarse-grained hornblende-biotite-granodiorite and biotite-granite. The marginal facies of the mass are various. The rocks are intensely weathered and care should be taken in order to get fresh specimens for analyses.

EXPERIMENTAL RESULTS

The procedure of hydrogen extraction from hydrous minerals and the accuracy of the measurements of water content and D/H ratio are the same as those already reported

Fig. 1. Geology and locality map of the studied specimens

1: Oligocene(?) granite (Miyatsu mass), 2: clinopyroxenite, 3: metamorphic aureole higher than epidote-amphibolite facies, 4: primary dunite, 5: Paleozoic sediments.

K in the index map is the Ōeyama (Kōmori) mass. Numbers in the map are the same as those in Table 1.

Fig. 2. Relationship between δD and X_{Fe} of the studied minerals. Numbers are the same as those in Table 1.

(KURODA *et al.*, 1974a).

A hornblende-biotite pair from the granite, ten samples of hornblende from the hornblendites and a basic xenolith in the granite, a white mica from the white mica-zoisite vein and a tremolite from the tremolite-rodinigte were separated and analyzed chemically and isotopically. The localities of the samples are shown in Fig. 1 and the results are presented in Table 1.

In Fig. 2, the relationship between δD^* and X_{Fe}^{**} of the minerals studied are shown. As seen in Fig. 2, a tie-line of the hornblende-biotite pair of the granite is parallel to Suzuoki-Epstein's experimentally determined equilibrium line for amphiboles and micas on the $\delta D - X_{Fe}$ diagram, which indicates the hydrogen isotope exchange equilibrium of coexisting hydrous mineral pair at a fixed temperature under a hydrous condition where δD of coexisting water is also fixed (SUZUOKI and EPSTEIN, 1970, 1972). It is also seen in Fig. 2 that the two broken lines which border the distribution area of δD of hornblendes from the hornblendites are also nearly parallel to Suzuoki-Epstein's line. Hornblendes from the hornblendite at the very contact to the granite (No. 11) and from the basic xenolith in the granite (No. 12) appear in the intermediate area between the tie-line of the hornblende-biotite pair of the granite and the area of the hornblendes from the hornblendites. The white mica (No. 13) is found on the ordinate of Fig. 2, and the point is regarded to be an extrapolated point of the trend of hornblendes from the hornblendites to $X_{Fe} = 0$, when six per mil enrichment of deuterium in Al-100% hydrous

* $\delta D (‰) \equiv [(D/H)_{\text{sample}} / (D/H)_{\text{SMOW}} - 1] \cdot 10^3$.

** X_{Fe} denotes the atomic fraction of ferrous iron in the octahedral cation site. Ferrous iron and magnesium are assumed to occupy the octahedral site.

Table 1. Analytical results and pertinent chemical information

Sample number	H ₂ O (wt%)	δD (‰)	X _{Fe}
1	1.87	-84.9	0.31
2	2.93	-90.5	0.40
3	2.12	-114.4	0.26
4	2.02	-110.8	0.24
5	2.25	-103.4	0.16
6	2.19	-103.3	0.22
7	2.36	-104.9	0.15
8	2.17	-108.7	0.19
9	2.23	-97.7	0.15
10	2.19	-106.3	0.20
11	2.15	-85.2	0.12
12	2.12	-107.5	0.41
13	5.03	-83.1	—
14	3.20	-47.0	0.05

1: hornblende from the granite, No. 61101, 2: biotite from the granite, No. 61101, 3: hornblende from the hornblendite, No. 64-43, 4: hornblende from the hornblendite, No. 64-41, 5: hornblende from the hornblendite, No. 70-147, 6: hornblende from the hornblendite, No. 70-107, 7: hornblende from the hornblendite, No. 51611, 8: hornblende from the hornblendite, No. 50707-1, 9: hornblende from the hornblendite, No. 51707, 10: hornblende from the hornblendite, No. 50707-2, 11: hornblende from the hornblendite, No. 50704, 12: hornblende from the basic xenolith, No. 72901, 13: white mica from the white mica-zoisite vein, No. 63-51, 14: tremolite from the tremolite-rodningite, No. 63-48.

minerals compared with Mg-100% hydrous minerals is taken into account (SUZUOKI and EPSTEIN, 1970, 1972). The tremolite (No. 14) from the tremolite-rodningite in the primary dunite outside the contact aureole of the granite is an isolated point in Fig. 2.

DISCUSSION

Based on the previous investigations (KURODA and SHIMODA 1967; OGURA *et al.*, 1970), it has been pointed out that the hornblendites were formed by recrystallization from clinopyroxenites in the contact aureole of the granite intrusion. The mineral paragenesis suggests that the grade of the metamorphism is epidote-amphibolite facies.

Assuming that the temperature of recrystallization of the hornblendites during the metamorphism is about 400°C, we estimate with SUZUOKI-EPSTEIN's experimental equation* the δD value of the water equilibrated with the hornblende to be -60 ~ -65‰. Provided that the hornblende (No. 1)-biotite (No. 2) pair was crystallized at about 700°C in the intruding granite magma, δD of the water in the magma is calculated to be also -60 ~ -65‰. On the basis of the above result, the hornblende in the contact aureole of the Ōeyama ultramafic body is concluded to have been formed by recrystallization with the water supplied by the granitic intrusion at about 400°C.

The higher δD values of hornblendes from the hornblendites at the very contact (No. 11) and from the basic xenolith in the granite (No. 12) are interpreted to be the result of hydrogen isotope exchange equilibrium with water in the granite magma at the temperature of recrystallization between 400°C and 700°C.

In the previous paper (KURODA *et al.*, 1974a), it was emphasized that δD value of the

* $\delta D^{\circ}_{\text{mineral}} - \delta D_{\text{water}} = -22.4 \times 10^6 T^{-2} + 24.2$, where $\delta D^{\circ}_{\text{mineral}}$ is a value of $\delta D_{\text{mineral}}$ obtained by extrapolation to $X_{\text{Fe}} = 0$ in Fig. 2 with the inclination of 64‰/X_{Fe}.

water in granite magma of the Kitakami mountainous district was in the range from $-29 \sim -37\%$. The present result, however, suggests that δD values of water of granitic magmas are not the same. It is indicated that the origin of water of granitic magmas is different in place and time.

The higher δD value of tremolite from the tremolite-rodingite outside the contact aureole may be indicative of the higher δD value of the water coexisting with the original ultramafic body.

The water content of hornblende from the hornblendites is shown in Fig. 3 together with δD values. As seen in Fig. 3, the water content of these hornblendes is similar to that of hornblendes from granites of the non-metamorphic terrains and is lower than that of hornblendes from ultramafic-mafic rocks of the glaucophane schist metamorphic terrains, even though the composition of the rocks is ultramafic. This may also suggest that the hornblendites were formed by recrystallization of clinopyroxenites.

Fig. 3. Relationship between δD and water content of the studied hornblendes. Open circle without number: from granitic rocks of the nonmetamorphic terrains (after KURODA *et al.*, 1974b), solid circle: from ultramafic-mafic rocks of the glaucophane schist metamorphic terrains (after KURODA *et al.*, 1974b), open circle with numbers: specimens in this study.

REFERENCES

- KINUGAWA, T. (1975) Geochemical and petrological study of the Kōmori ultramafic body, Kyoto Prefecture. Graduation thesis, Shinshu Univ.
- KURODA, Y., SATO, M., OGURA, Y., and HASHIDA, E. (1964) Two kinds of white mica found in the Kōmori ultrabasic mass, Kyoto Pref., Japan. *J. Japan. Assoc. Min. Pet. Econ. Geol.* **51**, 149–157.
- KURODA, Y. and SHIMODA, S. (1967) Olivine with well-developed cleavages – its geological and mineralogical meanings. *J. Geol. Soc. Japan* **73**, 377–388.
- KURODA, Y., SUZUOKI, T., MATSUO, S. and KANISAWA, S. (1974a) D/H fractionation of coexisting biotite and hornblende in some granitic masses. *J. Japan. Assoc. Min. Pet. Econ. Geol.* **69**, 95–102.
- KURODA, Y., SUZUOKI, T. and MATSUO, S. (1974b) A preliminary study on D/H ratios of hornblendes from granites and ultramafic-mafic rocks, *Geochem. J.* **8**, 135–139.
- KUROKAWA, K. (1975) Discovery of kyanite from epidote-amphibolite in the Ōeyama ultramafic mass, inner zone of southwest Japan, *J. Geol. Soc. Japan* **81**, 273–274.
- OGURA, Y., KURODA, Y. and SHIMODA, S. (1970) Petrology of the Ōeyama (Kōmori) ultrabasic body, Maizuru zone, Japan. *Rep. Resources Res. Inst.* **76**, 1–26.
- SUZUOKI, T. and EPSTEIN, S. (1970) Hydrogen isotope fractionation between OH-bearing silicate minerals and water. *Publ. Div. Geol. Planet. Sci.* California Institute of Technology, Contribution No. 1921 (preprint).
- SUZUOKI, T. and EPSTEIN, S. (1972) Partition of hydrogen isotopes between hydrated silicate minerals and water. *Chikyukagaku*, **5**, 38–44 (in Japanese).