Granulite Xenoliths from the Sumikawa Granite Body, Niigata Prefecture, Japan : Finding of Spinel+Quartz Assemblage from the Japanese Islands

Toshiaki Shimura*, Toshiko Kawai** and Shin-ichi Kagashima***

Received August 29, 2001
Accepted March 7, 2002

* Department of Geology, Faculty of Science, Niigata University, 8050, Ikarashi-2, Niigata 950-2181, Japan
** Hitachi INS software co., Nihon-ohdori 5-2, Naka-ku, Yokohama, Kanagawa 231-0021, Japan
*** Graduate School of Science and Technology, Niigata University, 8050, Ikarashi-2, Niigata 950-2181, Japan

Abstract : Spinel + quartz assemblage is one of the indicators of ultrahigh-temperature (UHT) metamorphism. Metamorphic xenoliths of granulate facies occur in the Sumikawa Granite, Niigata Prefecture. We found the spinel + quartz assemblage from a pelitic metamorphic xenolith in the granite body. The metamorphic textures show a clockwise P-T-t path and the metamorphic reactions follow the order : Grt + Sil = Spl + Qtz, and Spl + Qtz = Crd.

According to thermodynamic model, the spinel + quartz assemblage in this rock is thought to be stable at T > 660°C and P > 600 MPa. This assemblage was presumably generated by metamorphism in the lower crust in the Uetsu area.

Key words : ultrahigh-temperature (UHT) metamorphism, spinel + quartz, granulate, xenolith, Sumikawa Granite, Uetsu area

Introduction

Recently metamorphic rocks, which formed above the temperature of 900°C and the pressure of 700 MPa, have been reported from various localities (Harley, 1998 ; Motoyoshi, 1998). The spinel + quartz assemblage is one of the indicators of ultrahigh-temperature (UHT) metamorphism, and has been reported from various localities, such as Peekskill (Caporuscio and Morse, 1978), Napier (Ellis et al., 1980 ; Motoyoshi et al., 1990), Tallante (Vielzeuf, 1983), Rundvåghetta (Motoyoshi et al., 1986), Paderu (Lal et al., 1987), Labwor Hills (Sandiford et al., 1987), Eastern Ghats (Sengupta et al., 1991 ; Dasgupta et al., 1995 ; Shaw and Arima, 1997 ; Bose et al., 2000), Nova Scotia (Owen and Greenough, 1991), Taltson (Chacko, 1994), Brattstrand Bluffs (Fitzsimons, 1996), and Lace (Dawson et al., 1997).

Additional components such as Zn, Cr, and Fe³⁺ in spinel broaden the spinel + quartz stability field to low-temperature side (Bohlen et al., 1986 ; Hensen, 1986 ; Nichols, 1992). Therefore this assemblage does not mean UHT metamorphism directory (e.g. Ishihara, 1971 ; Plimer, 1977 ; Ikeda, 1998). However we found this assemblage from a granulate xenolith in a Tertiary granite body of the Uetsu area. Because Zn, Cr, and Fe³⁺ contents in the spinel are very low, this rock thought to be formed by UHT metamorphism. The present paper describes mode of occurrence and chemical characteristics of the minerals concerned, and discusses the P-T condition of the metamorphism. Mineral abbreviations in this paper follow Kretz (1983).

Geological setting

Plutonic and volcanic rocks of Cretaceous to Tertiary age are widely distributed in the Uetsu area, northeastern Japan (Fig. 1). The plutonic bodies have been emplaced in the Ashio Belt, a pre-Cretaceous accretionary complex. Peraluminous Iwafune Granite (biotite granite, two-mica granite, and garnet two-mica granite) occurs in the western part of this area, and is classified as the S-type granitoid of Chappell and White (1974) by the petrochemical criteria (Kagashima and Shimura, 2001). The Sumikawa Granite (mainly massive hornblende-biotite granodiorite) intrudes into the Iwafune Granite as a small stock (Tsuchiya et al., 1999). The isotopic age of the Iwafune Granitoid ranges from some 80 to 100 Ma (Rezanov et al., 1999 ; Kagashima, 1999), whereas that of the Sumikawa Granite is about 20 Ma (Agency of Natural Resources and Energy 1982 ; Kawai et al. 1999).

A variety of metamorphic rocks occur as xenoliths in the Sumikawa Granite (Otsuka and Shimazu 1981 ; Kawai et al. 1999). They are divided into petititic-pirammitic rock, mafic-intermediate rock, and calc-silicate rock. Pelitic metamorphic xenoliths are dominant and can be grouped to the following sub-types by the mineral paragenesis ; Bt-gneiss, Grt-Bt-Sil gneiss, Spl-Opx-Bt gneiss, Spl-Crd-Bt gneiss, and Grt-Crd-Spl-Sil gneiss. The spinel + quartz assemblage has been found in the Grt-Crd-Spl-Sil gneiss (sample SUM77).

Petrography and mineral composition

Chemical composition of minerals were analyzed by

© The Geological Society of Japan 2002
Fig. 1. Simplified geological map of the Uetsu area, modified from Takahashi (1999).

TTL (Tanagura Tectonic Line) after Omori et al., (1953), (a), (b), and (c) are northern extensions of TTL proposed by (a), Shimazu (1964); (b), Takiguchi and Tanaka (2001); (c), Takahashi (1999).

an electron-probe microanalyzer with wavelength dispersive system (JEOL JXA-8600MX) at Graduate School of Science and Technology, Niigata University. The oxide ZAF method was employed for matrix corrections. Representative chemical compositions of minerals are shown in Table 1. In this paper, we use $X_{Mg} = Mg/(Fe^3+Mg)$. On spinel, Fe$^{3+}$ and Fe$^{2+}$ were calculated by stoichiometry. Spinel $X_{Zn}$ and $X_{Cr}$ represent mole fractions within the related site.

Sample SUM77 is a xenolith which size is about 15 cm in diameter. It is medium-grained (ca. 1-4 mm), dark-colored and gneissic. The rock is composed mainly of garnet, cordierite, spinel (hercynite), plagioclase, sillimanite, and ilmenite, associated with small amounts of biotite, quartz, K-feldspar, rutile, pyrhotite, graphite, apatite, and zircon (Fig. 2).

Spinel (hercynite, $X_{Mg} = 0.14-0.25$) occurs in the following modes (Figs. 2A, 2B, 2C); (1) inclusions in plagioclase or in cordierite (type-1), (2) forming a domain with quartz (type-2), and (3) forming a domain with cordierite (type-3). The type-1 spinel is reddish brown and higher in $X_{Zn}$ (0.02-0.06) and $X_{Cr}$ (maximum 0.015) than the other types. It forms a domain with graphite, ilmenite, and pyrrhotite (Fig. 2A). The type-2 spinel+quartz domain cuts across garnet porphyroblasts (Figs. 2C, 2D). This spinel is dark greenish brown and lower in $X_{Zn}$ (0.006-0.023) and higher in Fe$^{3+}/(Fe^{2+}+Fe^{3+})$ (0.02-0.06) than the other types. This type spinel does not coexist with graphite, but ilmenite. Thin layers of cordierite occur between the spinel and quartz (Fig. 2D). The type-3 spinel occurs around garnet porphyroblasts. It is elongated and forms asymmetrical tail and schistosity around garnet or cordierite porphyroblasts with sillimanite, ilmenite, and cordierite (Fig. 2B). It is dark green and has intermediate in $X_{Zn}$ (0.01-0.04) and lower in $X_{Cr}$ (maximum 0.005).

Garnet forms subhedral to euhedral porphyroblasts as large as 3 mm across (Fig. 2A). The porphyroblasts show a normal zoning from core ($X_{Mg} = 0.19$) to rim ($X_{Mg} = 0.28$). The garnet has a dusty core with numerous inclusions surrounded by clear rim. The enclosed minerals are biotite, quartz, plagioclase, sillimanite, ilmenite, rutile, and pyrrhotite.

Cordierite ($X_{Mg} = 0.60$) mostly occurs as porphyroblasts or forms aggregates with type-3 spinel. They are mostly altered to pinitite.

Biotite mainly occurs as inclusions in garnet and plagioclase (Fig. 2B). It shows a pleochroism of yellowish brown along X axis and reddish brown along Y and Z axes. The $X_{Mg}$ is 0.39-0.42. Biotite rarely occurs in the matrix, but aggregates of biotite+sillimanite occasionally cut across garnet, type-3 spinel, and cordierite. The biotite shows light brown axial color along Y and Z axes, but the axial color changes to light green in the rim toward the host granite.

Plagioclase ($An = 29-33$) encloses type-1 spinel, biotite, quartz, sillimanite, ilmenite, and graphite.

Whole rock $X_{Mg}$ is 0.44 and magnitude of $X_{Mg}$ in coexisting phases are $Sp<Prt<Bt$ the whole rock < Crd.

Metamorphic reactions

Pelitic system can be described chemically by $K_2O·FeO·MgO·Al_2O_3·SiO_2·H_2O$ (KFMA) system. Projection of the KFMASH system from H_2O and K-feldspar onto a plane (FeO+MgO)-(Al_2O_3-K_2O)-(SiO_2-6K_2O) is employed for our sample (a triangle in the Fig. 3). This system is very useful to analyze silica-saturated and silica-undersaturated mineral assemblages (Hiroi et al., 2001).

Biotite and quartz occur as inclusions in garnet porphyroblasts, but are rare in the matrix (Fig. 2B). It
Fig. 2. Photomicrographs (A, B, and C) and back scattering image (D) of a sample SUM77. (A) Type-1 spinel enclosed in the plagioclase or cordierite. (B) garnet porphyroblast and type-3 spinel. (C) a spinel+quartz domain cuts a garnet porphyroblast. (D) Back scattering image of part of the Fig. 2C. Note thin layer of cordierite between spinel and quartz.

Fig. 3. Petrogenetic grids for the KFMAH system, projected from H₂O and K-feldspar of KFMAH system onto a plane (FeO+MgO)(Al₂O₃·K₂O·(SiO₂−6K₂O).

Squares and a star in a triangle diagram indicate mineral composition and whole rock composition of SUM77, respectively. Reactions 1, 2, 3, 4, and 5 are described in the text. Dashed univariant reactions are not stable owing to the whole rock composition. An arrow indicates P-T-t path of the SUM77. Mineral assemblage of the divergent fields are also shown.

can be ascribed the following reaction of the system,

\[ \text{Bt} + \text{Sil} + \text{Qtz} = \text{Grt} \]  \hspace{1cm} (1)

Spinel+quartz domains cutting across garnet porphyroblasts (Figs. 2C and 2D) developed by the reaction

\[ \text{Grt} + \text{Sil} = \text{Spl} + \text{Qtz} \]  \hspace{1cm} (2)

Thin layers of cordierite sandwiched between the spinel and quartz (Fig. 2D) formed by the reaction

\[ \text{Spl} + \text{Qtz} = \text{Crd} \]  \hspace{1cm} (3)

Light brown biotite and sillimanite domains cutting across spinel and cordierite suggest the following reaction,

\[ \text{Spl} + \text{Crd} = \text{Bt} + \text{Sil} \]  \hspace{1cm} (4)

or

\[ \text{Crd} = \text{Bt} + \text{Sil} + \text{Qtz} \]  \hspace{1cm} (5)

Reactions (1), (2), (3), (4), and (5) can be described as the univariant reactions in the P-T grid of this system (Fig. 3). The invariant point [Spl] is the same as that of [Kfs, Ms, Opx] in Fig. 5 given by Vielzeuf and Holloway (1988). The invariant point [Bt] corresponds to the low-P-T side invariant point in Fig. 5(a) given by Sengupta et al. (1991). The observed petrogenetic features suggest that the reactions (1), (2), (3), (4), and (5) took place along a clockwise P-T-t path (Fig. 3). Type-3 spinel and cordierite domains formed around garnet porphyroblast (Fig. 2B), suggesting that the relict garnet porphilooblasts are replaced by the spinel and cordierite, within the “Spl+Crd+Sil” field (between the reactions (3) and (4)) of Fig. 3.

Discussion and Conclusion

The four univariant reactions around an invariant point [Bt] were calculated on the sample SUM77 in the FMASHZn system on the basis of the thermodynamic model of Nichols et al. (1992) (ΔH, ΔS, and ΔV in table 5 and spinel activity model of equations (17) and (18)). As a result, it was proven that the spinel+quartz
assemblage in this rock is stable at $T > 860^\circ$C and $P > 600$ MPa (system $X_{\text{Me}} = 0.44$ and spinel $X_{\text{sp}} = 0.02$) (Fig. 4).

The type-3 spinel formed with simple shear deformation (Fig. 2B), and this event is later than the reaction (3). Light green biotite are thought to have grown by contact metamorphism of the Sumikawa Granite, which subsequent to the reactions (4) or (5). Therefore, the spinel + quartz assemblage formed prior to the contact metamorphism of the host Sumi- kawa Granite magma. This granite xenolith might be a constituent rock of the lower crust in the Uetsu area.

Acknowledgments

We are grateful to Prof. B. J. Hensen, Dr. Y. Osanai, and other JAGAR members for fruitful discussions. The critical comments by Prof. M. Arima and Dr. T. Ikeda were very helpful in improving the manuscript. This work was supported by the Grant-in-Aid for Scientific Research (No. 12640441, T. Shimura and No. 12440134, K. Shuto) from JSPS.

References


Ikeda, T., 1998, Phase equilibria and the pressure-temperature path of the highest-grade Yokoite metamorphic rocks in the Yanai dis-