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Composition and genesis of garnet in the rocks of Paleoproterozoic gneiss–migmatite complex (*Sharyzhalgai uplift, southwestern Siberian craton*)

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Abstract

We present the results of study of garnet-bearing paragneisses, migmatites, and vein granites of migmatite–gneiss complex of the Irkut terrane (Sharyzhalgai uplift, southwestern Siberian craton), major- and trace-element zoning of the garnet, and the age and trace-element composition of zircon. The migmatite–gneiss complex of the Irkut terrane formed in the Paleoproterozoic, at 1.85–1.86 Ga. The maximum temperatures of metamorphism and partial melting evaluated with the Ti-in-zircon and Zr-in-rutile thermometers are 790–830 and 830–860 ºC, respectively. Three generations of garnet have been recognized according to texture and zoning: metamorphic, peritectic, and magmatic. Metamorphic generation forms the core of garnet in paragneisses and migmatites, contains numerous fine inclusions, and has the highest contents of grossular (Grs) component, HREE, and Y decreasing from core to rim, which agrees with the Rayleigh fractionation of compatible components. Peritectic garnet with large inclusions of quartz and feldspar is predominant in diatexites and in gneisses in contact with leucosome. It has almost constant low contents of Grs, HREE, and Y slightly increasing in the rim. Garnet in vein melanocratic granites is similar in composition zoning to garnet in diatexites. Magmatic garnet in leucocratic granites is characterized by a decrease in the contents of Grs, HREE, and Y from core to rim and by a strong negative Eu anomaly. It seems to have resulted from the dissolution/precipitation of peritectic garnet in the melt. According to mineral and chemical compositions, the gneisses and migmatites are subdivided into high- and medium-alumina series produced through the metamorphism and melting of two source rocks, pelitic and graywacke, which is confirmed by their different REE patterns. The FeO and MgO enrichment of the granites relative to the melts experimentally produced of pelites and graywackes, the inherited contents of HREE in the diatexites and granites from paragneisses, and the presence of peritectic garnet in melanocratic granites evidence that the formation of granite was not accompanied by the effective segregation of garnet from the melt.

Keywords: garnet; major- and trace-element zoning; paragneisses, migmatites, *S*-granites

Introduction

Migmatite–gneiss complexes and *S*-type granitoids in which garnet is a persistent rock-forming mineral are widespread in deeply eroded collisional orogens. Garnet forms in these rocks through metamorphism, partial melting, and/or crystallization from melt. The high rate of diffusion at high temperature is responsible for unzoned garnet or garnet with regressive zoning showing a decrease in pyrope component toward the rims. Rare-earth elements and Y in garnet, on the contrary, show a clear zonal distribution and thus are informative in petrological research. Study of the trace-element zoning showed that the contents of HREE and Y in metamorphic garnet decrease from core to rim of its grain, following the Rayleigh fractionation of these compatible elements during the garnet growth (Otamendi et al., 2002; Spear and Kohn, 1996). Garnet in migmatites is more diverse in REE and Y zoning. It can be nonzonal, or some of its zones can be depleted or enriched in these elements (Dorais et al., 2009; Jiao et al., 2013; Jung et al., 2014; Otamendi et al., 2002), which indicates the complicated formation of the mineral through partial melting and crystallization from melt. Garnet in granites usually shows depletion in HREE and Y from core to rim, as a result of its crystallization from melt, or zoning similar to that of garnet from associated migmatites

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(Taylor and Stevens, 2010; Villaros et al., 2009; Xu et al., 2013). Thus, study of the composition and trace-element zoning of garnet gives an insight into the sequence of metamorphism and partial-melting processes and helps to assess the mineral origin during the formation of migmatite–granite complexes.

S-type granitoids containing garnet, muscovite, and cordierite usually differ from experimental melts produced during melting of metapelites and metagraywackes (Montel and Vielzeuf, 1997; Patiño Douce and Harris, 1998) in having higher contents of FeO, MgO, and Al_2O_3 (Clemens and Stevens, 2012). This specific composition of *S*-type granites is explained by the restite unmixing model suggesting different degrees of melt separation from residual phases, first of all, garnet (Chappell et al., 1987; Clemens and Stevens, 2012; Stevens et al., 2007). Hence, analysis of the origin of garnet is of crucial importance for understanding the genesis of the above rocks.

In this work we present results of study of garnet from paragneisses, migmatites, and garnet-bearing vein granites of an Early Precambrian granulite complex in the southeastern Sharyzhalgai uplift of the Siberian Platform. The goal of the study was to elucidate microstructural and geochemical indicators of garnet formation during high-temperature metamorphism, partial melting, and crystallization of melt. Data on major- and trace-element contents in migmatites and granites and on the origin of garnet helped to assess the influence of garnet on the composition of granitoids.

Methods

The contents of major elements were evaluated by XRF analysis on an VRA-20R X-ray spectrometer at the Analytical Center of the Institute of Geology and Mineralogy, Novosibirsk; the analysis error was ≤5 rel.%. The contents of trace and rare-earth elements were determined by ICP-MS on an ELEMENT (Finnigan Mat) high-precision mass spectrometer with a U-5000AT+ ultrasonic spray at the same Analytical Center. The detection limits of REE and HFSE were 0.005 to 0.1 ppm. The average analysis accuracy was 2–7 rel.%.

The contents of major components in garnet and other rock-forming minerals were measured with a Camebax-Micro probe at the above Analytical Center. Analysis of garnet for trace elements was performed along the same profiles as for major elements or at two points in the grain core and rim. Trace elements in garnet, zircon, and rutile were determined by secondary-ion mass spectrometry (ion probe) with a Cameca IMS 4F in the Yaroslavl Branch of the Institute of Physics and Technology, following the procedure described by Fedotova et al. (2008). The accuracy of determination was <10% for contents of >0.1 ppm and 30–50% for contents of <0.1 ppm.

Geologic location and petrography of paragneisses, migmatites, and granites

The Sharyzhalgai uplift is the southern exposed margin of the Tunguska province in the basement of the Siberian Platform (Fig. 1, inset). The Irkut terrane in the southeast of the uplift is composed of granulite–gneiss complex including associations of metamagmatic and metasedimentary rocks. The paragneiss units are localized mostly in interdomal structures, whereas the domes are formed by charnockites, granites, intermediate–felsic orthopyroxene-bearing and mafic two-pyroxene (± amphibole) granulites. The major- and trace-element composition of the paragneisses evidences that they formed from terrigenous sedimentary rocks of the pelite–graywacke series (Turkina and Urmantseva, 2009). Acording to the mineral composition, the *P–T* conditions of metamorphism of the paragneisses are *T* = 800 ºC and *P* = 6–7 kbar. The mineral microtextures indicate the decompression *P–T* path during retrograde metamorphism, with *P* decreasing to ~3 kbar (Sukhorukov, 2013). The studied samples were taken mostly from migmatite–gneiss section at an extending site near the Ulanovo Station of the Circum-Baikal Railroad (shore of Lake Baikal) (Fig. 1).

The studied paragneisses are predominant garnet–biotite, orthopyroxene–biotite (± garnet), and scarcer high-alumina sillimanite–cordierite–garnet–biotite (± orthopyroxene) rocks (Table 1). All paragneisses are migmatized. The migmatites have a banded structure due to 1 mm to 10 cm thick bands of dispersed quartz–feldspathic material (Fig. 2*a*). There are also migmatites with a massive medium-grained texture, enriched in quartz–feldspathic material. These are rocks rich in leucosome with or without schlieric aggregate of mafic minerals (Fig. 2*b*, *c*), which correspond to diatexites or leucocratic diatexites (Ashworth, 1985; Milord et al., 2001; Sawyer, 1998). Leucocratic garnet-bearing granites form thin (no more than few tens of centimeters) concordant or cutting veins among migmatized paragneisses.

The studied paragneisses and migmatites are divided into two types: varieties bearing high-alumina minerals (Sill, Grt, Crd) and medium-alumina orthopyroxene–biotite and biotite (± garnet) rocks.

Weakly migmatized high-alumina **paragneisses** (**samples 119-87 and 118-87**) are composed of assemblage Grt + Crd + Bt + Sill + Pl + Kfs + Ilm + Rt + (Spl)[1] and are of lenticular-banded structure. They are formed by thin segregations of coarser-grained leucosome with scarce garnet grains and by fine-grained melanosome enriched in garnet and biotite. The cores of coarse garnet grains contain abundant fine inclusions of quartz, biotite, and sillimanite. The rims are of massive texture and contain larger inclusions of biotite, quartz, and feldspar.

High-alumina migmatite (**sample 79-87**) has a thin-banded structure due to leucosome segregation (Fig. 2*a*). The melanosome is composed mostly of Grt + Opx + Bt + Pl +

[1] Mineral symbols after (Kretz, 1983).