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Origin of garnet in aplite and pegmatite from Khajeh Morad in northeastern Iran: A major, trace element, and oxygen isotope approach

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ABSTRACT

Triassic monzogranites and granodiorites of the Khajeh Morad region in northeastern Iran are cut by two types of garnet-bearing intrusive veins: (1) aplite and (2) granitic pegmatite. The former is composed of quartz, feldspar, muscovite, with minor garnet, biotite, and ilmenite. The latter contains quartz, plagioclase (±quartz and muscovite inclusions), alkali feldspar, and muscovite, with minor amounts of garnet, tourmaline, beryl, columbite, and ilmenite. Garnet in both rock types has MnO > 12 wt.% and CaO < ~2 wt.% with spessartine-rich cores, and a core-to-rim increase in Fe, Mg, and Ca. Garnet cores are enriched in Y, REE, Zr, Nb, Ta, Hf, and U. The Y, HREE, and Mn concentrations show strong positive correlations in both types of garnet associations and decrease from core-to-rim. These core-to-rim elemental variations can be explained by increasing fluid content and H_2O activity in magma, together with decreasing Mn contents of an evolved host melt. Aplite and pegmatite garnet $\delta^{18}O$ values are nearly identical (~10.3‰, $n = 7$, SD = 0.09) and are similar to magmatic garnets in granitoids elsewhere. On the basis of calculated $\delta^{18}O$ values for magma (~12.5 and 12.6‰) and quartz (~13.6‰, $n = 7$, SD = 0.08) as well as the major and trace element characteristics, we suggest that the Khajeh Morad garnets crystallized from a variably fractionated S-type monzogranitic magma.

1. Introduction

Garnet is a common accessory mineral in metamorphic rocks and less frequent in igneous rocks (e.g. London, 2008; Muller et al., 2012). It is potentially useful for magmatic studies because of slow diffusion rates for cations and anions, and resistance to alteration. Compositional zonation in garnet may preserve the compositional changes and temperature–time histories of the magma in which they grew. However, few data are available from garnet in aplite and pegmatite (e.g. Arredondo et al., 2001; Baldwin and Von Knorring, 1983; Gadas et al., 2013; Manning, 1983; Whitworth, 1992), which are generally regarded as having magmatic origins (e.g. Deer et al., 1992; Leake, 1967; Manning, 1983). Thomas and Davidson (2012) suggested that granite and pegmatite melts differ significantly with regard to the dissolved H_2O content in the magma and viscosity at comparable temperatures and pressures, with pegmatite formation involving low viscosity, melt-fluid immiscibility, and extremely evolved melts. Although garnets of granitoids and granitic pegmatites are commonly Fe^{2+}-rich, garnet in granitic aplite and pegmatite commonly has higher Mn and lower Ca contents (e.g. Baldwin and Von Knorring, 1983; London, 2008; Macleod, 1992; Manning, 1983); although Gadas et al. (2013) reported grossular garnet in a leucotonalitic pegmatite. Mn, Fe^{2+} and Ca concentrations in garnet can be used to interpret the origin of this mineral (e.g. Harangi et al., 2001; Samadi et al., 2014b and references therein). For example, garnet xenocrysts in granitoids and metapelites typically exhibit normal zoning, with Mn-rich and Fe-poor cores and core-to-rim decrease of Mn whereas phenocrysts and magmatic garnet in plutonic rocks tend to show reversed zoning with core-to-rim increase of Mn, with increasing differentiation in a melt (e.g. Abbott, 1981a, 1981b; Allan and Clarke, 1981; Day et al., 1992; Green and Ringwood, 1968; Harangi et al., 2001; Harris and Vogeli, 2010; Kawabata and Takafuji, 2005; Koepke et al., 2003; Lackey et al., 2008, 2011, 2012; Leake, 1967; Miller and Stoddard, 1981a, 1981b; Mirnejad et al., 2008; Patranabis-Deb et al., 2008; Samadi et al., 2014b; Schwandt et al., 1996; Spear and Kohn, 1996; Vielzeuf et al., 2005). In contrast, garnets within zoned pegmatite bodies are often characterized by Mn-rich cores and Fe^{2+}-rich rims (Arredondo et al., 2001; Baldwin and Von Knorring, 1983; Manning, 1983; Whitworth, 1992). Knowledge of trace element zoning patterns in garnet is useful for characterizing the

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origin of garnet and its host rock. Although trace element zoning of garnets in granitoids, skarns, pelitic and ultramafic rocks is well studied (e.g. Čopjaková et al., 2005; Heimann et al., 2011; Irving and Frey, 1978; Koepke et al., 2003; Lackey et al., 2011; Schwandt et al., 1996; Smith et al., 2004), garnets in granitic pegmatites and aplites have received much less attention (e.g. Gadas et al., 2013; Muller et al., 2012). Trace element zoning in garnets arises from the partitioning of incompatible trace elements into the garnet (relative to more compatible major elements) that accompanies changes in composition of melt, temperature and pressure (e.g. Schwandt et al., 1996 and references therein). The oxygen isotope composition of garnet is a potential useful tracer of the parent magma (Lackey et al., 2006, 2008) because garnet has a high closure temperature to oxygen diffusion (e.g. Farquhar et al., 1996) and does not change its $\delta^{18}O$ value once crystallized (e.g. Harris and Vogeli, 2010).

Numerous garnet-bearing aplite and pegmatite veins cut across the Triassic monzogranite–granodiorite bodies in the Khajeh Morad area, in southeastern Mashhad city (Fig. 1). To understand the origin of these garnets, and how they may relate to the time–composition and temperature histories of the rocks in which they grew, we employed LA-ICP-MS, EPMA, and IRMS to establish major and trace element zoning patterns and oxygen isotope compositions of garnet grains from these aplite and pegmatite associations. We then compare Khajeh Morad garnet from aplite–pegmatite associations with similar garnet associations studied elsewhere around the world in order to further understand the origin and petrogenetic implications of garnets. Abbreviations of minerals were adopted from Kretz (1983) and Whitney and Evans (2010).

2. Geological background

Iran is located in the middle of the Alpine-Himalayan orogenic system. The latter forms a continuous suture zone from the eastern Mediterranean area to the northwest Himalayan belt. The study area, located in southeastern Mashhad city, northeastern Iran, forms the eastern portion of a northwest-southeast trending granitoid batholith within the Paleo-Tethys suture zone (Fig. 1). This suture zone includes meta-ophiolites and meta-flysch sequences, representing Paleo-Tethys Ocean closure in the Jurassic period (Alavi, 1991). The meta-ophiolites, meta-flysch and granites are surrounded by metamorphosed marginal continental sediments, consisting of well-layered slate, phyllite, schist, hornfels, marble, quartzite, and skarn (Samadi et al., 2012). Silurian opening of the Paleo-Tethys in northern Iran was followed by its northward subduction beneath the Kopeh Dagh zone (Turan Plate in the southern part of Laurasia) in the Late Devonian, culminating in late Triassic collision between the Iranian Microcontinent and Turan Plate (Alavi, 1991; Natalin and Sengor, 2005). Emplacement of the Mashhad granitoid batholith occurred during the final stages of Paleo-Tethys subduction and early stages of Turan–Iran Plate collision (Mirnejad et al., 2013; Samadi et al., 2014a). The Mashhad batholith consists of granodiorite, monzogranite, and diorite–tonalite–granodiorite suites that were intruded into the metamorphic complex.

In the Khajeh Morad area, granodiorite and monzogranite bodies are cut by aplite and pegmatite veins (Fig. 1). The granodiorites are largely quartz, feldspar, and biotite, whereas monzogranite intrusives contain quartz, feldspar, muscovite, and lesser amounts of biotite. Mirnejad et al. (2013) reported that granodiorite and monzogranite intrusions of Mashhad batholith were emplaced at 212 ± 5.2 Ma and 199.8 ± 3.7 Ma, respectively. Aplite veins were emplaced first, as they are cross-cut by pegmatite veins (Fig. 2). Pegmatite veins consist of quartz, plagioclase, K-feldspar, muscovite, garnet, tourmaline, beryl, columbite, and opaque minerals. The finer grained aplite veins consist of quartz, plagioclase, muscovite, garnet, biotite, and opaque minerals.

3. Analytical techniques

Samples were selected from Khajeh Morad aplite and pegmatites veins for petrographic studies. The garnet grains sampled were sufficiently representative to ascertain geochemical zoning trends within the respective vein associations. Major oxide analyses of core and rim of garnets were carried out by wavelength dispersive electron probe microanalysis (EPMA), using a JEOL JXA-8800 at the Japan Agency for

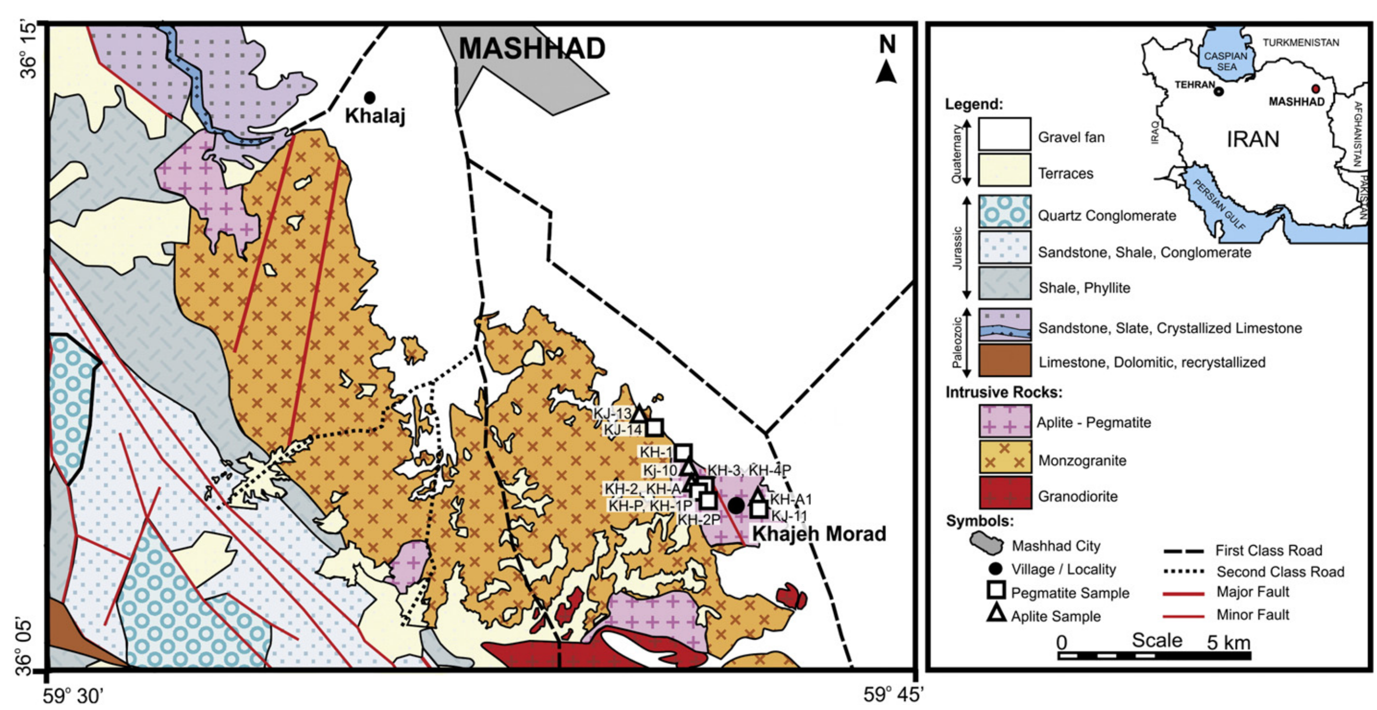

Fig. 1. Geological map of Khajeh Morad in southeastern Mashhad, northeastern Iran (modified after Samadi, 2014).