Interface coupled dissolution-reprecipitation in garnet from subducted granulites and ultrahigh-pressure rocks revealed by phosphorous, sodium, and titanium zonation

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ABSTRACT

Garnet zonation provides an unparalleled record of the pressure-temperature-time-fluid evolution of metamorphic rocks. At extreme temperature conditions >900 °C, however, most elements preserve little zonation due to intracrystalline diffusional relaxation. Under these conditions, slowly diffusing trace elements including P, Na, and Ti have the best chance of recording metamorphic histories. Here we map dramatic zoning patterns of these elements in subducted high-pressure felsic granulite (Saxon Granulite Massif) and ultrahigh-pressure diamondiferous “saidenbachite” (Saxonian Erzgebirge, Bohemian Massif). The results show that garnet replacement via interface coupled dissolution-reprecipitation can strongly affect garnet compositions in subduction zones and that P, Na, and Ti record burial and exhumation histories that are otherwise lost to diffusion. In these samples, P diffuses the slowest, and Ti the fastest.

Keywords: Metamorphic petrology, garnet, trace elements and REE, diffusion, major and minor elements, kinetics

INTRODUCTION

Chemical zonation in garnet is widely used to reconstruct the pressure, temperature, time, and fluid histories of mountain belts. Most documented chemical zonation in garnet is the result of changing pressure-temperature-fluid conditions during growth as well as post-growth intracrystalline diffusion. In addition to diffusion, interface coupled dissolution-reprecipitation (ICDR) is another important process that can modify mineral compositions (e.g., Putnis and Austrheim 2010; Putnis and John 2010; Harlov et al. 2011). During ICDR, a disequilibrium fluid reacts with mineral surfaces, replacing the pre-existing composition with a new one that is likely to be in equilibrium with the fluid, although kinetic effects are also possible (e.g., Geisler et al. 2010). The interface between the old and new portions of the mineral is extremely sharp and propagates inward, leaving a zone of fluid-filled micro- or nano-porosity in its wake. Fresh reactants are transported to the reacting interface through the fluid-filled porosity, normally by diffusion, whereas products are transported out. In this way, the interface can advance until the entire crystal is replaced, commonly with little or no overall change in volume. Because diffusional transport occurs through a fluid phase, ICDR is in general much faster than intracrystalline diffusion. Successive episodes of ICDR can crosscut or replace earlier-formed replacement zones.

ICDR has been well documented in minerals such as feldspar (e.g., replacement of albite by K-feldspar; Niedermeier et al. 2009) and zircon (Geisler et al. 2007; Rubatto et al. 2008). A growing body of evidence demonstrates that it can also play a significant role in garnet, as revealed by chemical and/or oxygen isotope zonation (e.g., Hames and Menard 1993; Whitney 1996; Alvarez et al. 2005; Pollok et al. 2008; Faryad et al. 2010; Martin et al. 2011; Page et al. 2013; Xu et al. 2013; Centrella et al. 2015; Chen et al. 2015). Nonetheless, the potential for trace element zonation to reveal ICDR processes remains relatively little explored.

Regardless of how garnet acquires zonation, at ultrahigh-temperature (UHT) conditions >900 °C, intracrystalline diffusion for most elements is rapid and, thus, growth and recrystallization histories are largely erased. To have some chance of reconstructing these histories, the most slowly diffusing elements must be identified. We focus on phosphorous, sodium, and titanium. Their concentrations in garnet generally increase with P and T, making their measurement via electron-probe microanalysis (EPMA) feasible (e.g., Hermann and Spandler 2008; Auzanneau et al. 2010). Phosphorous, which substitutes mainly for Si4+ on tetrahedral sites, has been shown to preserve zoning in magmatic olivine (e.g., Mallmann et al. 2009) and garnet from amphibolite facies, near-UHT, UHT, and >900 °C ultrahigh-pressure (UHP) rocks (e.g., Spear and Kohn 1996; Vielzeuf et al. 2005; Kawakami and Hokada 2010; Kobayashi et al. 2011; Ague and Eckert 2012; Axler and Ague 2015a, 2015b; Jedlicka et al. 2015). Sodium substitution is linked to P substitution in garnet by mechanisms such as NaP2+Si4- (e.g., Hermann and Spandler 2008), and complementary Na-P zonation patterns are documented for UHP rocks (e.g., Axler and Ague 2015b). Titanium zonation tends to be somewhat smoother than that for P, but well-defined retrograde Ti-depletion halos surrounding rutile or ilmenite precipitates in garnet can be preserved in UHT and UHP garnets (e.g., Ague and Eckert 2012; Axler and Ague 2015b).

In this study, we use chemical maps to examine P, Na, and Ti zonation in subduction-related high-pressure (HP) eclogite facies granulate from the Saxon Granulite Massif (e.g., O’Brien 2006; Rötzlzer et al. 2008) and UHP diamondiferous saidenbachite from the Saxonian Erzgebirge (e.g., Massonne 2003). Our goals are to determine: (1) the nature and extent of zoning preservation and (2) what the implications of the zoning are for metamorphic processes. EPMA analyses were done using the JEOL-JXA8530F at Yale...