Effect of fluid composition on growth rate of monazite in quartzite at 1.0 GPa and 1000 °C

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ABSTRACT

The dependence of monazite coarsening rate on fluid composition was evaluated by performing growth experiments in a piston-cylinder apparatus at 1.0 GPa and 1000 °C. Results show that the rate of monazite coarsening in quartzite + fluid is strongly sensitive to fluid composition. Although other studies have shown that monazite solubility is higher in acidic fluid, addition of 2 m HCl to H2O decreased the growth rate. Textural observations and modeling indicate that monazite growth in 2 m HCl occurs through a combination of Ostwald ripening and coalescence. Addition of 2 m NaCl to H2O should have increased monazite aqueous solubility and made the fluid interconnected, but the expected increase in monazite growth rate did not occur, with monazite size distributions showing no change between 0 and 165 h and no measurable growth. Ion adsorption on the surface of monazite may have slowed the rate of monazite growth on addition of HCl and stopped growth on addition of NaCl. The strong dependence of monazite coarsening rate on fluid composition suggests that the size of crystals produced by metamorphic coarsening may not be a reliable indicator of duration of metamorphism, and that adsorption of ions on mineral surfaces may be significant even at 1000 °C.

Keywords: Monazite, mineral growth, growth kinetics, metamorphism, coarsening, textural development, Ostwald ripening

INTRODUCTION

Textural development during metamorphism affects the measured size and age distributions of, and therefore the growth history recorded by, dateable minerals (Eberl et al. 1990; Ayers et al. 1999). Recrystallization can reset mineral isotopic clocks, so that measured ages correspond to recrystallization events. According to Evans et al. (2001), the three driving forces of recrystallization, in decreasing order of driving force magnitude, are reduction in system energy through heterogeneous chemical reactions (chemical recrystallization involving multiple phases), reduction of energy stored in defects (mechanical recrystallization), and reduction of interfacial energy by reduction of surface area through grain growth (coarsening). Only heterogeneous reaction leads to new growth of a phase. Existing grains may shrink by heterogeneous reaction or mechanical recrystallization, and can grow by heterogeneous reaction or coarsening. While the decrease in system energy caused by coarsening is relatively small, the driving force is always present and so the process is common. Coarsening causes mean grain size and sphericity (ratio of the surface area of a sphere of equal volume to the surface area of the particle) to increase with metamorphic grade even in the absence of heterogeneous growth, as shown for quartzites and marbles (Joesten 1991).

For dispersed phases such as monazite or other accessory minerals coarsening occurs by the process of Ostwald ripening. Although the rare earth phosphate mineral monazite often grows by heterogeneous reaction during prograde metamorphism (Kohn and Malloy 2004; Finger and Krenn 2007), studies have provided natural and experimental evidence of Ostwald ripening of monazite during metamorphism (Kingsbury et al. 1993; Ayers et al. 1999).

Ostwald ripening can produce homogeneous metamorphic rims on larger grains that grow at the expense of smaller grains. These rims can be used to date the coarsening event (Ayers et al. 1999). The thickness of rims and the final size of grains should depend on the duration of metamorphism and on the rate of coarsening. Since crystal growth is a thermally activated process, crystal growth rates increase exponentially with temperature so that most crystal growth will occur at the maximum metamorphic temperature, and grain size will depend on the duration of peak metamorphism. If the rate of coarsening at peak metamorphic conditions is known, the duration of metamorphism theoretically can be estimated from the maximum thickness of metamorphic rims or size of unzoned grains. However, estimates will be accurate only if all factors that affect monazite coarsening rate are quantified and accounted for.

LIMITING FACTORS ON GROWTH RATE

Ostwald ripening has been shown to affect clays and metamorphic minerals, causing grain size distributions to broaden and mean grain radius to increase with time or increasing metamorphic grade (Eberl et al. 1990). Evidence of Ostwald ripening is also preserved in the shapes of grain size distributions: they are self-similar, meaning that reduced grain size profiles (frequency/max frequency vs. radius/mean radius) do not change during Ostwald ripening, so it is a steady-state process. Theoretically, thermodynamic equilibrium is not fully achieved until only one grain