LREE-redistribution among fluorapatite, monazite, and allanite at high pressures and temperatures

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ABSTRACT

The REE enrichment process in fluorapatite and the REE redistribution among fluorapatite, monazite, and allanite were studied in a series of three sets of experimental runs at P-T conditions of 0.5 to 4 GPa and 650 to 900 °C. The first two sets of experimental runs utilized fluorapatite as a P-source, synthetic monazite or allanite as the REE sources, albite, quartz, and NaF-H2O or NaCl-H2O. The third set of runs was carried out with powdered Ca4(PO4)2, allanite, quartz, (±Al2O3), and a NaF-H2O solution. In all runs REE-bearing fluorapatite with up to 28 wt% ΣREE2 formed at the expense of monazite or allanite; either as narrow zones at the margin of synthetic fluorapatite in runs 1 and 2 or as discrete grains in run 3. The REE-enrichment of fluorapatite in melt-bearing runs is explained in terms of the high solubility of monazite in the presence of alkali-rich melts together with the high partitioning values for REEs among fluorapatite and alkali-rich melts. The formation of REE-enriched fluorapatite in melt-absent runs implies that the solubility of monazite and the REE-uptake of fluorapatite are similarly high in both alkali-rich melts and fluids and depends foremost on the activity of alkalis in fluids or melts.

The results from this study show the importance of fluorapatite as a REE-carrier in rocks whose petrogenesis involved alkali-bearing fluids/melts. In metamorphic rocks, alkali-enriched fluids or melts will likely form under higher-grade conditions, explaining the preferential occurrence of REE-enriched fluorapatite in granulite and eclogite-facies rocks.

Keywords: Fluorapatite, monazite, allanite, experimental petrology, alkali-rich fluids

INTRODUCTION

Monazite and allanite are commonly treated as the major LREE carrier minerals in metasediments and granitoids. However, recent studies have shown that during metamorphism at high pressures and high temperatures a considerable transfer of LREEs into apatite takes place. Conversely, monazite-growth from REE-rich fluorapatite is multiply documented in nature (Pan et al. 1993; Liou et al. 1998; Harlov and Förster 2002b; Hansen and Harlov 2007) and has been confirmed experimentally (e.g., Harlov and Förster 2003; Harlov et al. 2005).

Finds of intact REE-rich fluorapatite in nature are rare and mainly restricted to monazite-absent, alkaline-peralkaline magmatic (volcanic), metasomatic or hydrothermal rocks (e.g., Roeder et al. 1987; Rønsbo 1989; MacDonald et al. 2006). In most allanite- or monazite-bearing metapelites fluorapatite rarely has REE contents much greater than 1%. This is also valid in the case of those fluorapatite grains, which formed directly from the breakdown of monazite (e.g., fluorapatite-allanite coronas surrounding monazite; Finger et al. 1998; Broska and Siman 1998; Grapes et al. 2005). Either the fluorapatite in these rocks was never enriched in REEs, or the fluorapatite was enriched in REEs at high P and T, but lost them somewhere along the retrograde metamorphic P-T path.

At least in some cases, there is evidence that fluorapatite was enriched in REE during some stages of the metamorphic P-T cycle. This earlier enrichment in REE is not only evidenced by the formation of retrograde monazite grains associated with fluorapatite but also through the existence of peak P-T monazite with a La/Nd ratio different from that of secondary monazite as well as the bulk rock (Finger and Krenn 2007; Krenn et al. 2009). The latter authors also showed that REE-loss in fluorapatite had already occurred during isothermal decompression and not during cooling. Krenn et al. (2009) speculated that the REE-uptake capacity of fluorapatite as well as the REE-partitioning among fluorapatite and monazite is probably pressure dependent as has already been assumed by Spear and Pyle (2002). This assumption is further strengthened by the observed occurrences of fluorapatite-monzonite intergrowths in other high- to ultrahigh-pressure rocks (e.g., Liou et al. 1998, Zhang and Liou 1999; Janoušek et al. 2007; Chen et al. 2009).

In this study, a series of piston-cylinder and hydrothermal autoclave experiments have been carried out to test if and under which conditions fluorapatite becomes enriched in REE’s at the expense of monazite and allanite. Since the chemical systems represented by the minerals under study are very complex, this work should be seen as a first attempt in understanding the REE-enrichment process in fluorapatite based on textural observations and mineral chemistry.