Metasomatic thorite and uraninite inclusions in xenotime and monazite from granitic pegmatites, Hidra anorthosite massif, southwestern Norway: Mechanics and fluid chemistry

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ABSTRACT

Thorite and uraninite inclusions are documented in metasomatized regions in three xenotime crystals and one monazite crystal collected from three granitic pegmatites hosted within an anorthosite intrusion located on the island of Hidra, southwestern Norway. Formation of these inclusions is demonstrated to be the result of dissolution-reprecipitation processes that occurred in an effectively closed chemical system. The reaction was initiated by interaction between the early crystallizing orthophosphate minerals and the evolving pegmatite fluid. This fluid was dominated by H2O, but also contained F and minor amounts of Cl, and significant quantities of dissolved Na+ and K+. This is an example of auto-metasomatism and highlights a natural case where Th-U-Si-enriched orthophosphate minerals have been partially altered such that the Th, U, and Si have been converted to secondary inclusions within the now Th-U-Si-depleted orthophosphate via reaction with fluids rich in alkali elements.

Keywords: Monazite, xenotime, thorite, uraninite, dissolution-reprecipitation, pegmatite, alkali-rich fluids

INTRODUCTION

Xenotime [(Y,HREE)PO4] and monazite [(Ce,LREE)PO4] are relatively common accessory minerals in both igneous and metamorphic rocks. Their role in mineralogy, petrology, and geochemistry from the standpoint of geochronology (Williams et al. 2007), temperature estimation (Gratz and Heinrich 1997, 1998; Andrehs and Heinrich 1998), and secondary involvement in metasomatic processes such as alteration of apatite (Harlov et al. 2002, 2005; Harlov and Förster 2003), have already been well documented. However, metasomatic alteration of xenotime or monazite, although described in the literature (e.g., Bingen et al. 1996; Townsend et al. 2000), is poorly understood with respect to the mechanics of how it occurs as well as with respect to the fluid chemistry.

In this study, backscattered electron (BSE) imaging and electron probe microanalysis (EPMA) are used to describe and interpret textures in three xenotime crystals and one monazite crystal from granitic pegmatites that are themselves hosted by an anorthosite intrusion on the island of Hidra, southwest Norway (Fig. 1). The euhedral crystals of xenotime and monazite have extensive altered regions, which contain numerous thorite ± uraninite inclusions. Unaltered regions do not contain these inclusions. Textural, crystal-chemical, and crystallographic evidence suggest that formation of the thorite and uraninite inclusions occurred as the result of fluid-mineral interaction within a closed chemical system, i.e., all the components necessary for the nucleation and growth of the inclusions were already present in the host xenotime and monazite.

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ANALYTICAL METHOD

Electron probe microanalysis (EPMA) was done using the Cameca SX50 electron microprobe at the University of Massachusetts (Amherst). The electron microprobe is equipped with 4 wavelength-dispersive spectrometers. Individual spot analyses were made using a focused electron beam having a diameter of 1 µm, an accelerating voltage of 15 kV, and a beam current of 15 nA. Counting times for Th and U were 30 s on the peak and 10 s on each background position. For all other elements, counting times on the peak and the background positions were 20 and 10 s, respectively.

The measured peak and background positions are based on evaluation of detailed wavelength scans run on natural monazite, similar, in principle, to the approach of Scherrer et al. (2000). Techniques have been established for the accurate determination of Pb and U in actinide-bearing phosphates such that the effects of peak and background interferences and background curvature are accounted and corrected for during analysis (Jercinovic and Williams 2005; Pyle et al. 2005; Williams et al. 2007). An overview of peak and background positions is provided in the electronic depository (Item A). To reduce the possible contribution from micro- to nano-scale phase inclusions or phase boundaries that are not seen because of orientation effects, the activation volume of each analysis is minimized using a 15 kV accelerating voltage, while still providing sufficient energy for excitation of all measured lines (Pyle et al. 2005). This also avoids additional complications from efficient L-level ionizations in high-Z elements (e.g., actinides). Higher beam currents are also avoided during major-element analysis to avoid beam damage to the specimen and conductive (carbon) coat that may lead to unpredictable and unquantifiable effects to the X-ray emission (Jercinovic and Williams 2005). An additional benefit of the low beam current is that the heating of the sample during prolonged exposure to the electron beam is reduced, thereby lowering the possibility of diffusion and volatilization of elements in the measured volume, and subsequently, erroneous totals.

Each element was calibrated using well-characterized natural and synthetic standards (electronic depository, Item A). The Cameca PAP correction procedure was used for all data reduction (Pouchou and Pichoir 1985). Calculated absolute detection limits for each element are provided in Item A in the electronic depository. Note that analytical errors for Y, the REE, and other heavy elements depend on the absolute abundances of each element. Relative 1σ errors are estimated to be <0.5% at the >10 wt% level, 15% at the 10 wt% level, 10–20% at the 0.2 to 1