Fluid-induced nucleation of (Y + REE)-phosphate minerals within apatite: Nature and experiment. Part I. Chlorapatite

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ABSTRACT

This study investigates chlorapatite [ideally Ca10(PO4)6Cl2] from two spatially separated locations in the Ødegårdens Verk apatite mine, Bamble Sector, SE Norway, which was partially metasomatized under amphibolite-facies conditions. Relative to the original chlorapatite, metasomatized areas in sample DL136 are enriched in OH and F, depleted in Na, Si, and (Y + REE) and contain numerous inclusions (1–15 μm) of monazite and xenotime. In contrast, metasomatized areas in sample TN174 are enriched in F and Si, depleted in Na, show (Y + REE) abundances similar to the original chlorapatite, and host only a few monazite and xenotime grains.

In order to define the role of fluids in the formation of (Y + REE)-phosphate minerals associated with apatite, a series of experiments covering wide ranges of temperature (900–300 °C) and pressure (1000–500 MPa) for a series of fluid compositions (pure H2O, a 50/50 molar mix of H2O and CaF2, and CO2 with 1–2 wt% H2O) were conducted on unaltered chlorapatite from the Ødegårdens Verk. In the H2O experiments, features due to metasomatic alteration [depletion in Na, Si, and (Y + REE) as well as numerous monazite and xenotime inclusions], as observed in the natural sample DL136, were fully reproduced. Monazite and xenotime grains were also observed growing on the surface of the apatite in dissolution embayments in metasomatized areas. In the 50/50 CaF2-H2O experiments, metasomatized regions are strongly enriched in F and Si, depleted in Na, show unchanged (Y + REE) abundances, and host only a very few, small monazite and xenotime grains similar to what was observed in sample TN174.

Natural and experimental observation imply the presence of two coupled substitutions: Na+ + (Y + REE)3+ = 2 Ca2+ and Si4+ + (Y + REE)3+ = P5+ + Ca2+. In the case of DL136 and H2O–fluid experiments, Na+ and Si4+ went into solution, whereas the released (Y + REE) contributed to the growth of monazite and xenotime within the metasomatized apatite structure. For sample TN174 and the 50/50 CaF2 + H2O–fluid experiments, Na in apatite became depleted but Si was enriched thereby stabilizing the (Y + REE) in the now recrystallized fluor-hydroxylapatite structure, which retarded the growth of monazite or xenotime inclusions. The basic conclusion of this study is that nucleation of monazite and xenotime in the metasomatized chlorapatite is principally a function of the composition of the infiltrating fluid and, to a much lesser extent, temperature and pressure.

INTRODUCTION

Chlorapatite [ideally Ca10(PO4)6Cl2], either as a near end-member phase or as a significant component in fluorapatite [ideally Ca10(PO4)6F2], is a common accessory mineral in layered mafic intrusions such as the Stillwater Complex, Montana (Boudreau and McCallum 1989, 1990; Meurer and Boudreau 1996), the Munni Munni Complex, Western Australia (Boudreau et al. 1993), the Merensky Cyclic Unit, Western Bushveld Complex, South Africa (Boudreau and Kruger 1990), and the Great Dyke, Zimbabwe (Boudreau et al. 1995). However it has also been described as minor phase in marbles (Hounslow and Chao 1970), as inclusions in iron meteorites (McCoy et al. 1994), as a major component in magmatic magnetite-apatite ores from Chile (Treloar and Colley 1996) in addition to being a significant component in a mafic intrusion from the Ødegårdens Verk, Bamble Sector, SE Norway (Liefink et al. 1994). Although chlorapatite possesses the same hexagonal symmetry (P63/m) as fluorapatite at temperatures >350 °C, at temperatures <350 °C, chlorapatite has a monoclinic symmetry (P21/b) (Bauer and Klee 1993).

Chlorapatite from the Stillwater Complex and the Ødegårdens Verk possesses the additional feature of having inclusions of monazite-Ce [(Ce, LREE)PO4], and/or xenotime-(Y) [(Y, HREE)PO4] in areas where the original apatite has been hydrothermally altered into a hydroxyl-fluorapatite (Boudreau and McCallum 1990; Liefink et al. 1994). In chlorapatite from the Stillwater Complex, trails of monazite inclusions are observed along healed fractures and low temperature (100–300 °C) micro-veins of CO2-bearing hydroxylapatite. In contrast, chlorapatite from the Ødegårdens Verk contains both trails and patches of monazite and xenotime grains in areas altered to a