TEM investigation of potassium-calcium feldspar inclusions in Bøggild plagioclase

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ABSTRACT

Potassium-calcium feldspar inclusions in a Bøggild plagioclase were investigated by analytical high-resolution transmission electron microscopy (HRTEM), and the formation process of these inclusions is considered based on the Al-Si ordering scheme in ternary feldspar system. Nanometer-scale chemical analyses and selected-area electron diffraction (SAED) patterns show that the rims of the inclusions consist of lamellar intergrowths of potassium feldspar (CT symmetry) and anorthite (PI symmetry), whereas the core is unexsolved potassium feldspar (CT symmetry). Potassium feldspar and anorthite in the inclusions share the crystallographic orientation of the host Bøggild plagioclase. High-resolution lattice images indicate coherent interfaces between the inclusions and the host Bøggild plagioclase and the phases in the inclusions. The results indicate a unique formation process of potassium-calcium feldspar inclusions in a ternary feldspar: crystallization of host labradorite → precipitation of potassium feldspar → decomposition of Bøggild exsolution lamellae → growth of anorthite on the rims of potassium feldspar inclusions. Potassium-calcium feldspar inclusions may be found in Bøggild and other plagioclase, and they have the potential to give constraints on thermal histories of K-rich plagioclase.

INTRODUCTION

Microstructural observations of potassium-sodium-calcium feldspars provide information about the feldspar ternary. These phase relationships have the potential to constrain the thermal histories of metamorphic and igneous rocks. For this reason, synthetic potassium-calcium feldspars have been studied extensively to estimate thermodynamic properties and structural information (Nekvasil 1994; Kroll et al. 1986; Fuhrman and Lindsley 1988; Nekvasil and Carroll 1993). Kay (1978) investigated microtextures of experimentally ion-exchanged potassium-calcium feldspar using transmission electron microscopy (TEM). The author determined the orientation of exsolution lamellae and discussed the formation of potassium-calcium feldspar lamellae with respect to antiperthite textures and Bøggild exsolution lamellae of a plagioclase from an anorthosite complex (Kay 1977). It is known that Bøggild exsolution lamellae occur in plagioclases with An contents ranging between An$_{30}$ and An$_{55}$ and with Or components greater than 1.6 mol% (Nissen et al. 1967). They have also been reported in An$_{50}$Ab$_{50}$Or$_{50}$ (Carpenter et al. 1985). Most feldspars showing Bøggild exsolution lamellae are derived from high-grade metamorphic environments, typically of Precambrian age (Smith 1983). Fuhrman and Lindsley (1988) stated that exsolved K-rich feldspars in plagioclases, which affect the original composition of plagioclase, should be taken into account when we consider thermal histories of plagioclases.

Several phases are known in plagioclase and alkali feldspar. In feldspar, the reflections in the diffraction patterns from these phases are conventionally named a, b, c, d, and e (see Smith 1974). The following notation for reflections is commonly used:

- **a reflections**: $h + k = \text{even}$, $l = \text{even}$
- **b reflections**: $h + k = \text{odd}$, $l = \text{odd}$
- **c reflections**: $h + k = \text{even}$, $l = \text{odd}$
- **d reflections**: $h + k = \text{odd}$, $l = \text{even}$
- **e reflections**: satellites around b reflections

The a reflections are observed in all feldspars and are related to the average structure with space-group symmetry C1. The b reflections are observed in calcic plagioclase and are related to P1 anorthite. The c and d reflections can only be observed in the range An$_{0.5}$-An$_{10}$ and belong to P1 anorthite. The e reflections, satellite reflections of b reflections, are characteristic of intermediate plagioclase (An$_{0.5}$-An$_{10}$) and are divided into $e_1$ ($> \text{An}_{10}$) and $e_2$ ($< \text{An}_{10}$).

Tagai and Hoshi (1995) showed that K in plagioclases from Ylämma, Finland, is segregated into inclusions of potassium-calcium feldspar that are several hundreds of nanometers in diameter. SAED patterns generated from the inclusions and the host plagioclase suggested that the crystallographic orientations of the potassium-calcium feldspar inclusions and the host Bøggild plagioclase were common and that inclusions show structure similar to that of P1 anorthite.

In this study, the microtextures of the inclusions were investigated using HRTEM combined with nanometer-