Tourmaline growth in the border and wall zones of the Emmons pegmatite (Maine, U.S.A.): Evidence for disequilibrium crystallization and boundary layer formation

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ABSTRACT

The anisotropic textures, including unidirectional solidification textures and graphic intergrowths, characteristic for pegmatites, are interpreted to result from disequilibrium crystallization at high degrees of undercooling. Experimental studies have revealed the existence of thin boundary layers surrounding the rapidly growing crystals. Here, tourmaline-bearing samples from the outer zones of the Emmons pegmatite (Maine, U.S.A.) are used to examine if a boundary layer can also occur in natural samples. Crystal morphology is linked with geochemistry to understand the evolution of pegmatite melts and to constrain disequilibrium conditions at large degrees of undercooling. Petrographic studies and semiquantitative micro-X-ray fluorescence element mapping were conducted to identify crystal morphology and zonation, complemented with electron microprobe analyses to determine major and minor element compositions and LA-ICP-MS analyses of selected trace elements. Three textural groups were identified: comb-like tourmaline, quartz-tourmaline intergrowths, and radiating tourmaline. The intergrowths are optically coherent and are split into three different morphologies: central, second tier, and skeletal tourmaline. Most tourmaline is schorl, but chemical variation occurs on three different scales: between textural groups, between different morphologies, and intracrystalline. The largest scale geochemical variation is caused by the progressive evolution of the melt as it crystallized from the borders inwards, while the intracrystalline variations are attributed to sector zoning. A model is suggested where the systematic variation of Mg, Mn, and Fe within individual intergrowths is proposed to be the result of crystallization from a boundary layer, rich in water and other fluxing elements (e.g., Li, P, B), formed around the rapidly growing central tourmaline. Here, we show the first examples of boundary layers in natural pegmatites. Furthermore, the results bring into question whether boundary layer tourmaline can be used as a bulk melt indicator in pegmatitic melts.

Keywords: Tourmaline, graphic intergrowths, pegmatite, boundary layer, µXRF, EMPA

INTRODUCTION

The most striking characteristic of granitic pegmatites is their extremely coarse (up to tens of meters) grain size. A wide range of grain sizes can, however, occur within the pegmatite. Often occurring as dikes, the contact with the host rock, is usually fine-grained, with an inwards coarsening to the core that mostly consists of large, blocky grains (Simmons and Webber 2008; London 2018). Pegmatite dikes take between a few days up to tens of years to cool completely, depending on their size (Webber et al. 1999; Simmons and Webber 2008; Phelps et al. 2020), challenging the traditional view that large crystals in igneous rocks are always the product of long crystallization and cooling times. Another distinctive characteristic is the anisotropic textures often found in the outer zones of pegmatites (London 2009), including unidirectional solidification textures (UST), with crystals growing directly away from the contact and graphic intergrowths between different minerals (London 2008, 2018). These textures are assumed to be the result of disequilibrium crystallization (Simmons and Webber 2008). The morphology of growing minerals is controlled mainly by nucleation and growth rates, and these are controlled by the H2O content and liquidus undercooling of the melt (Swanson 1977; Nabelek et al. 2010; Sirbescu et al. 2017). Sirbescu and Nabelek (2003) showed that melts far below the granite solidus can exist in the crust, likely due to a high number of fluxing elements such as H2O, Li, P, and B decreasing the crystallization temperatures. Additionally, these elements decrease the viscosity of the melt and the nucleation rate and increase the diffusion of elements through the melt (Fenn 1977; Sirbescu and Nabelek 2003; Simmons and Webber 2008). This causes rapid growth of large crystals toward the center of the dike (London 2008), leading to preferential uptake of previously incompatible elements in the growing crystals. An evolution from euhedral to skeletal morphologies occurs as the degree of undercooling increases (Swanson 1977; Longfellow and Swanson 2011). In experimental studies (London 2005; Sirbescu et al. 2017), and natural studies (Honour et al. 2019),