In situ measurements of plagioclase growth using SIMS depth profiles of $^7\text{Li}/^{30}\text{Si}$: A means to acquire crystallization rates during short-duration decompression events

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ABSTRACT

Numerous petrologic studies have attempted to determine crystal growth rates in volcanic systems through several methods, including analyses of crystal size distributions in natural samples and decompression experiments on hydrous magmas. Experiments have revealed that rim growth on existing crystals will occur under a wide range of decompression conditions and is favored under conditions of low to moderate undercoolings over microlite nucleation, which has typically been the focus of decompression-induced crystallization studies. For this study, samples of eruptive clasts were collected from a Vulcanian explosion that occurred following the July 12–13, 2003 dome collapse of Soufrière Hills volcano, Montserrat. Plagioclase phenocrysts were extracted and examined with secondary ion mass spectrometry (SIMS) depth profiling. Lithium inflection depths within the profiles, along with the observed time interval between the peak in the collapse decompression and the explosion that ejected the examined samples, were used to calculate the growth rates as a result of magma devolatilization, with an average of $8.3 \times 10^{-4}$ mm/s. Anorthite content of the plagioclase rim growth indicates an average decompression magnitude of 40 MPa, inducing an undercooling of ~45 °C that favors crystal growth over microlite nucleation. However, variability in the final anorthite contents suggests that not all phenocrysts recorded an equilibrium composition reflecting accurate pressure conditions. In such events occurring over short timescales (<10 h), lithium is a more reliable indicator of decompression-induced growth than changing anorthite content due to lithium’s rapid diffusivity.

Keywords: Plagioclase, lithium, decompression, SIMS, Soufrière Hills

INTRODUCTION

Crystallization rates, and the kinetics that control them, have been extensively studied as a means to interpret the dynamics of igneous systems, including those systems that exhibit volcanic activity. Quantifying the rates of in situ decompression-induced crystal growth has been restricted by an inability to constrain accurate time intervals over which growth occurs and the length scale of that growth in natural phenocryst samples. For this reason, microlites have typically been the focus of studies concerning crystallization as a result of magma devolatilization during ascent from magma chamber to surface. However, the growth of phenocrysts may also occur and contribute to increases in crystal volume fraction, which will result in further devolatilization, affect magma rheology, and cause shifts in eruption intensity. Thus, to model accurately the processes occurring during silicic magma ascent, a constraint of phenocryst growth rates is vital.

Decompression-induced crystallization

Because silicic volcanic eruptions are partially driven by the effects of exsolved volatiles, dominantly H$_2$O, the response of anhydrous minerals to degassing has been a primary focus of petrologic experiments as a means to understand the physical dynamics that influence explosive events (Geschwind and Rutherford 1995; Hammer and Rutherford 2002; Couch et al. 2003b; Martel and Schmidt 2003). During episodes of decompression, exsolution of H$_2$O from a saturated silicic melt will cause the liquidus temperatures of anhydrous mineral phases to shift toward higher values (Moore and Carmichael 1998; Cashman and Blundy 2000; Hammer and Rutherford 2002), resulting in an undercooling within the system (Cashman and Blundy 2000; Hammer and Rutherford 2002; Couch et al. 2003b). Decompression-induced crystallization of plagioclase feldspar has been used in various studies to examine the response of hydrous magmas to decompression, the resulting textures of mineral phases, and the response of magma rheology to variable decompression paths (Geschwind and Rutherford 1995; Hammer et al. 1999; Cashman and Blundy 2000; Hammer and Rutherford 2002; Couch et al. 2003b; Martel and Schmidt 2003; Clarke et al. 2007; McCanta et al. 2007). Studies that involve experimental examinations of crystallization kinetics and the effect of magma ascent parameters on clast textures stress the importance of developing analytical methods to compare natural samples to experimental products and to validate or repudiate experimental data and interpretations of syn-eruptive volcanic processes.

Petrologic experiments on the Soufrière Hills magma have revealed key information concerning the effect of decompression style on crystallization kinetics. Couch et al. (2003b) examined the difference between single decompression events (SDEs), similar to the large volume dome collapse at Soufrière Hills in July 2003, and multiple decompression events (MDEs), like those