Crystal habit (tracht) of groundmass pyroxene crystals recorded magma ascent paths during the 2011 Shinmoedake eruption

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ABSTRACT

The morphologies and size distributions of groundmass crystals record conditions of magma ascent through volcanic conduits. However, morphological information (such as crystal shapes) has not been incorporated into crystal size distributions (CSDs). Here, we focused on the crystal habit, especially the shape variation due to the combination of (hk0) faces (hereafter “tracht”) of pyroxene microlites and nano-crystals, and measured CSDs for each crystal habit (tracht) to more comprehensively characterize the crystallization kinetics. We refer to the CSDs measured for each tracht as “tracht-specific CSDs.” Pyroclasts from the 2011 eruption of Shinmoedake (Kirishima volcano group, Japan) were examined by field-emission scanning electron microscopy, electron backscatter diffraction analysis, synchrotron radiation X-ray computed nanotomography, and transmission electron microscopy. The samples contain groundmass pyroxenes of two main trachts: octagonal prisms consisting of {100}, {010}, and {110} faces and hexagonal prism lacking {100} faces. The pumice clasts formed by different eruption styles showed different trends of tracht-specific CSDs. Sub-Plinian pumice clasts were characterized by octagonal microlites (1–10 μm wide) and numerous hexagonal nano-crystals (0.2–2 μm wide), and a Vulcanian pumice clast with the same glass composition showed the same characteristics. In contrast, Vulcanian pumice clasts with more evolved glass compositions contained mostly octagonal pyroxenes. The tracht-specific CSDs and growth zonations indicate a change from octagonal-dominant to hexagon-dominant growth conditions during syneruptive ascent. We infer that the hexagonal tracht resulted from a large degree of effective undercooling due to rapid decompression in the shallow conduit. Moreover, the texture of the less-evolved Vulcanian pumice indicates that a portion of the magma erupted on the Vulcanian eruption followed almost the same ascent paths just prior to the fragmentation as those during the sub-Plinian eruptions, and thus the Vulcanian eruption may have involved the rapid ascent of deeper magma. We propose that tracht analyses of groundmass pyroxenes provide detailed information about time-evolution of magma conditions during syneruptive ascent.

Keywords: Pyroxene, crystal habit, crystal-size distribution, nanolite, magma ascent

INTRODUCTION

Degassing mechanisms within volcanic conduits involve interrelated magmatic properties and processes, and affect both the eruptive style and evolution of volcanoes (Cassidy et al. 2018). One of the most important parameters affecting the various magmatic feedbacks is magma ascent rate. The evolution of ascent rate in conduits is related to syneruptive processes such as volatile exsolution, crystallization, and rheological evolution of magmas (e.g., Gonnermann and Manga 2007; Cassidy et al. 2018; La Spina et al. 2016, 2021) and thus is important for elucidating the depths where transitions in eruptive style originate and the mechanisms of those transitions. Magma ascent paths are preserved in the properties of groundmass crystals, such as their number densities and morphologies (e.g., equant, tabular, acicular, euhedral, swallowtail, and dendritic).

Groundmass crystallization kinetics (i.e., nucleation and growth) have been investigated both experimentally and in natural samples (e.g., Cashman 1992; Hammer and Rutherford 2002; Couch et al. 2003; Brugger and Hammer 2010a). Recent studies have focused on constraining nucleation and growth rates (Shea and Hammer 2013; Arzilli et al. 2015, 2016a; Giuliani et al. 2020), nucleation events through time (Arzilli and Carroll 2015; Polacci et al. 2018; Le Gall et al. 2021; Arzilli et al. 2022), nucleation delay (Arzilli et al. 2020; First et al. 2020; Rusiecka et al. 2020; Rusiecka and Martel 2022), and crystal growth in real time (Polacci et al. 2018; Arzilli et al. 2019, 2022; Le Gall et al. 2021). These contributions have deepened our understanding of the crystallization kinetics under disequilibrium conditions. The kinetics of disequilibrium crystallization results in various crystal textures. Crystal habits are controlled by the degree of effective undercooling ($\Delta T_{\text{eff}}$) imposed from cooling and decompression-induced dehydration, and are thus important clues to investigate magma ascent and/or solidification histories.