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3D crystal size distributions of pyroxene nanolites from nano X-ray computed tomography: Improved correction of crystal size distributions from CSDCorrections for magma ascent dynamics in conduits

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Abstract

Groundmass crystals indicate syneruptive magmatic conditions, and thus their crystal size distributions (CSDs) are used to infer magma ascent histories. Three-dimensional (3D) CSDs are most commonly estimated from two-dimensional (2D) observations and plotted against long-axis length, *L* (hereafter referred to as "*L*-plot CSDs"). However, *L*-plot CSDs have two significant problems: the error because of the conversion from 2D to 3D and a lowered sensitivity to changes in the degree of effective undercooling (ΔT_{eff}), which arises because a crystal's growth rate varies with ΔT_{eff} most strongly along its long dimension. Although these problems can result in false interpretations of magma ascent dynamics, there has been little discussion of the influence of the size criteria on CSDs.

In this study, we investigated which 3D size criterion [i.e., long (*L*), intermediate (*I*), or short (*S*) axis length] is optimum for 2D-estimated CSDs of groundmass crystals from two perspectives: (1) conformity with the actual distributions, and (2) the sensitivity of CSD slopes to the magma ascent conditions in the conduit. We observed groundmass pyroxene crystals in pumice clasts from sub-Plinian and Vulcanian eruptive phases during the 2011 eruption of Shinmoedake (andesitic volcano, Japan) by using synchrotron radiation-based X-ray computed nanotomography (SR-XCT) and field-emission scanning electron microscopy (FE-SEM) and reinvestigated the crystallization kinetics of pyroxene nanolites ranging in width from a few hundred nanometers to 1 μm. The SR-XCT observations provided the detailed 3D shapes and 3D CSDs (CT-CSDs) of these nanolites directly. The FE-SEM observations allowed us to estimate 3D aspect ratios (*S*:*I*:*L*) and CSDs (SEM-CSDs). *L*-plot SEM-CSDs, acquired using the program CSDCorrections, were used to calculate *S*-plot SEM-CSDs and *I*-plot SEM-CSDs. We compared the data from FE-SEM with those from SR-XCT to evaluate the accuracy of 3D aspect ratios and CSDs estimated from 2D data.

The *L*-plot SEM-CSDs from the sub-Plinian pumice sample showed significant inconsistencies with the CT-CSD, a result of the difficulty in estimating representative 3D aspect ratios from 2D observations for elongated groundmass crystals. In contrast, the *S*- and *I*-plot SEM-CSDs kept the effect of aspect ratio to a minimum and preserved their actual slopes, except for a vertical discrepancy between the CSDs. Moreover, the slopes of *S*- and *I*-plot CSDs of the nanolites differed more markedly between the two eruptive styles (by ~20% more) than those of *L*-plot CSDs. For estimating magma ascent dynamics, we propose that the optimum method for acquiring SEM-CSDs is to measure the cross-sectional widths of crystals and convert the resulting 2D data set into *S*-plot CSDs.

Our new finding that the 3D shapes and CSDs of pyroxene nanolites differ according to eruptive style means that nanolites indicate distinct differences in ascent histories at the shallow conduit: increasing ΔT_{eff} just before sub-Plinian eruptions and decreasing ΔT_{eff} before Vulcanian eruptions. Given the similarity in CSDs of microlites, our results suggest that eruptive style was determined in the shallow conduit. Monitoring the condition of the shallow conduit may contribute to predicting the time evolution of eruptive activity.

Keywords: Crystal size distribution, morphology, nanolite, X-ray computed tomography, pyroxene, magma ascent