3D crystal size distributions of pyroxene nanolites based on nanoX-ray CT analyses

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Groundmass texture of pyroclasts, such as crystal shapes and population density, reflects physical condition during crystallization and thus is important to understand ascent conditions in conduits. For instance, Castro et al. (2003) have confirmed crystal elongation with decreasing size, which means a change of physical condition. Besides, crystal size distributions (CSDs), which are the numbers of crystals per volume per each size-range, are used to infer magma dynamics, such as mixing and syneruptive ascent (e.g., Marsh, 1998). However, most of these studies are based on 2D analyses (SEM observations): CSDs are acquired through stereological corrections from 2D to 3D (Higgins, 2000). On the other hand, some researches have aimed to acquire true 3D texture through serial sectioning, X-ray computed tomography with pixel size of 3–30 μm (Jerram et al., 2018), and optical transmission microscopy (e.g., Castro et al., 2003). However, few 3D observations for pyroclasts have spatial resolution of smaller than μm-scale necessary for analyses of groundmass crystals; that is, their 3D dataset is insufficient. It is necessary to present their true 3D data and test accuracy of the stereological corrections of 2D data for CSDs. We aimed to infer the ascent conditions based on the true 3D data.

Recent researches on extraterrestrial samples have used synchrotron radiation-based X-ray computed nanotomography (SR-nanoXCT) at BL 47XU of SPring-8, a synchrotron radiation facility in Japan, with effective spatial resolution of ~100 nm (e.g., Tsuchiyama et al., 2012; Matsumoto et al., 2019). We applied this SR-nanoXCT to pyroxene nanolites (< 1 μm in width; Mujin et al., 2017) in pumices and acquired their 3D data and directly measured CSDs (CT-CSDs). We analyzed two pumices from the 2011 eruption of Shinmoedake, the Kirishima volcano: one is from a sub-Plinian eruption and the other is from a Vulcanian explosion. Two equant specimens (ca. 25 μm on a side) for the SR-nanoXCT were extracted from each pumice using a focused ion beam system (Quanta 200 3DS, FEI). We also acquired CSDs of pyroxene crystals in 2D with a field-emission SEM (JSM-7001F, JEOL) (SEM-CSDs) in addition to the CT-CSDs.

We found that the shapes of pyroxene nanolites exhibit different features between the two pumice samples, although the degree of elongation varies greatly from crystal to crystal even in each specimen: elongate prisms with swallowtail ends in the sub-Plinian pumice, and slightly thicker prisms with flat ends in the Vulcanian pumice. In the sub-Plinian pumice, smaller nanolites tend to become more elongate. However, such a tendency is not found in the Vulcanian pumice. As for CSDs, the CT-CSDs and the SEM-CSDs correspond well with each other. They show a log-linear figure for the Vulcanian pumice. On the other hand, for the sub-Plinian pumice, the SEM-CSD exhibits a kink at 1 μm of crystal width and a steeper slope in the finer size-range, and the CT-CSD also exhibits such a steep slope.

Because crystals become elongated with large undercooling (Shea and Hammer, 2013), the difference in degree of crystal elongation indicates that the sub-Plinian magma batch has undergone larger undercooling than the Vulcanian one. Besides, this elongation can affect figures of CSDs. There are cases where elongated small crystals generate a falsely-high population density of the small crystals (e.g., Castro et al., 2003). For the sub-Plinian pumice, however, this effect appears to be insignificant, although the small nanolites become elongated. The concave upward curvature of the CSD is interpreted as an accelerated increase in population density and nucleation rate of small crystals, which results from increasing undercooling. These results are considered to reflect a difference in ascent rate for the eruption styles: the sub-Plinian magma batch ascended acceleratedly but the Vulcanian one was in a steady condition in the shallow conduit.

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