Texture constraints on crystal size distribution methodology: An application to the Laki fissure eruption

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ABSTRACT

Modeling crystal size distributions often requires the extraction of 2D discrete crystal lengths to calculate 3D volumetric equivalences. These apparent lengths are obtained from digital images that exploit different physical and chemical characteristics of samples, and the choice of image type can affect the interpretation of crystal length measurements, thus affecting crystal size distribution modeling. To examine method- and texture-based effects on extracting crystal size distributions, we obtained plagioclase length measurements from two texturally opposing basaltic lava samples from the well-documented Laki fissure eruptions of 1783–1784. Using approaches that consider inherent texture-based limitations of 2D image types, we employed manual tracing and imaging software to extract plagioclase crystal lengths from three types of images: (1) photomicrographs from polarized-light microscopy, (2) backscatter electron images from scanning electron microscopy, and (3) energy-dispersive X-ray maps from automated mineralogy. Our results demonstrate that (1) phenocrysts ($L \geq 150 \mu m$) and groundmass plagioclase ($L < 150 \mu m$) in our basalt samples appear with multiple aspect ratios, while the latter also display greater nucleation densities as crystal size population are continuously refined over increasingly smaller crystal lengths; (2) complex crystal clusters must be manually dissected into their discrete crystal components to produce meaningful crystal size distributions; (3) localized electron backscatter diffraction analysis reveals mild preferred orientation in complex clusters and groundmass, the latter confirmed by variations in crystal size distributions between orthogonal backscatter electron images; and (4) method-induced variations in both aspect ratio and crystal length determination can produce a wide range of kinetic interpretations that pose challenges for cross-research comparisons. For phenocrysts, compensating for clustering and fracturing through manual tracing remains the most effective method, while groundmass populations can be addressed with high-resolution (micrometer-scale) automated scanning electron microscopy for deciphering late-stage eruptive behavior. A texture-focused protocol should be established, as any kinetic information derived from crystal size distribution analyses across multiple studies employing multiple approaches cannot otherwise be directly compared.

Keywords: Plagioclase, crystal size distributions, aspect ratio, basalt, textural analysis, crystallization kinetics, automated mineralogy, EBSD, Laki; Dynamics of Magmatic Processes

INTRODUCTION

Textural analysis of volcanic rock provides insight into crystallization dynamics and associated magmatic environments. Petrologic studies that focus on geochemistry and phase equilibria as the primary means to explore geologic questions can utilize texture to constrain crystallization histories and the extent to which crystallization reflects dynamic processes such as fractionation or magma mixing. A common textural investigative tool is the use of crystal size distributions (CSDs) that focus on the most conspicuous aspect of texture—the distribution of crystal sizes (Cashman and Marsh 1988; Marsh 1988, 1998; Higgins 2000, 2006).

Crystal size distributions for a purely open, steady-state igneous system display a linear relationship between the natural logarithm of crystal population density and the corresponding crystal size, $L$ (Marsh 1988). Natural lava samples variably mimic this relationship through seriate textures where crystals nucleate and grow through size populations. This is mathematically and graphically represented by the following power law equation:

$$n(L) = n^0G^{-\alpha}$$

where $n(L)$ is the population density for crystals of size $L$ (the 3D length, usually converted from 2D thin section measurements), $G$ is the average crystal growth rate [assumed constant and derived from experimental values (Kirkpatrick 1977; Cashman and Marsh 1988; Cashman 1993)], $\tau$ is the residence time, and $n^0$ is the nucleation density. Other characteristics may be determined from the equation: characteristic length (i.e., average size, $C$), can be calculated as $G\tau$, an associated regression slope as $-1/C$, and nucleation rate ($J$) is equivalent to $n^0G$. Semilogarithmic plotting