A technique for measuring 3D crystal-size distributions of prismatic microlites in obsidian

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ABSTRACT

We describe a technique for determining the 3D size, shape, and number density of prismatic microlites in obsidian. The procedure involves collecting a series of optical photomicrographs at successive levels in a transparent thin section with a petrographic microscope and digital camera. These images are combined to form 3D stacks with NIH Image software. The number, position, orientation, and projection length of each microlite in the stack are then determined, and these data are used to calculate the true length and number density. Crystal-size distribution (CSD) based on direct measurements exhibit asymptotic, lognormal, and near-lognormal profiles. These forms, in addition to broad variations in crystal aspect ratio suggest that microlites experienced a range of growth rates. Textural parameters (e.g., total crystal number density and volume) determined from regressions of linear CSDs under the assumption of constant growth rate compare well with directly measured parameters.

We compared CSDs based on 3D measurements with those based on 2D measurements of intersection length and area number density. Stereological conversions of 2D data are necessary owing to the cut-section effect and intersection probability problem. We performed corrections with three widely used algorithms and, thus, our comparisons test the accuracy of these correction methods as applied to prismatic microlites in obsidian. CSDs based on 3D measurements are linear over most of the size range. In contrast, conversion programs produce kinked CSDs, with large positive errors in population density at small crystal size. Errors in population density are caused by shape (aspect ratio) variability in the sample population. Conversion programs, which assume a constant shape, overestimate the number of small crystals owing to a large number of intersections along the short crystal dimension. In the real population, these intersections correspond to a wide range of true lengths. Consequently, CSDs constructed from intersection lengths are kinked rather than linear. Kinked and curved CSDs have been interpreted to result from mixing of distinct crystal populations, sharp variations in growth and/or nucleation rate, or from crystal settling. Our results suggest that nonlinear CSDs in some cases may also arise as an artifact of shape variability in the natural population.

INTRODUCTION

Crystal-size distributions (CSDs) are widely used to interpret magmatic processes from the textures preserved in volcanic and plutonic rocks (Cashman and Marsh 1988; Waters and Boudreau 1996; Zieg and Marsh 2002). In igneous rocks, CSDs may provide information on the cooling history (Armienti et al. 1994; Cashman et al. 1999), crystal growth rates (e.g., Cashman 1992, 1993; Wilhelm and Worner 1996), and magmatic processes such as crystal settling and resorption (Marsh 1998). CSDs also have been used to infer magma chamber dynamics (Mangan 1990) and detailed eruptive histories (e.g., Higgins 1996; Hammer et al. 1999). At the core of CSD analysis is a semi-logarithmic plot of the population density ($n$)—the number of crystals of a given size per unit volume, vs. size (commonly apparent crystal length; Randolf and Larson 1971). Textural parameters, such as the dominant crystal size, crystal number density, and crystal volume fraction, can be derived from regressions of linear CSDs (e.g., Marsh 1988; Cashman 1990), however, interpreting magmatic processes from CSDs may not be so straightforward (e.g., Pan 2001, 2002; Eberl et al. 2002; Higgins 2002a, 2002b; Marsh and Higgins 2002; Schaeben et al. 2002).

The accuracy of CSD-derived textural parameters depends largely on the manner in which CSDs are constructed, and on the extent to which the crystal population conforms to a CSD model (e.g., Marsh 1988; Eberl et al. 2002). Direct 3D measurements of crystal size provide the most accurate description of the population (e.g., Armienti et al. 1994; Dunbar et al. 1994; Bindeman 2003). However, because of the time and difficulty associated with making accurate measurements in 3D, most published CSDs of igneous rocks are based on 2D measurements of crystal intersection size and area number density. Conversion of 2D data to 3D requires a number of stereological corrections to account for: (1) modification of crystal shapes during sectioning (cut-section effect); (2) skewing of size distributions to larger diameters due to higher intersection probabilities for large than small particles; and (3) the dependence of the apparent (2D) crystal number density on the orientation distribution of particles (Peterson 1996). Most early studies...