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Quantitative 3D petrography using x-ray tomography: Application to Bishop Tuff pumice clasts ☆

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Abstract

Textures are traditionally studied using the petrographic microscope, which limits observations to 2D sections of 3D objects. Given the difficulty in retrieving information on shapes, sizes and spatial distribution of objects in 3D from random sections, a method that can yield observations in 3D is highly desirable.

X-ray tomography yields a 3D map of the linear X-ray attenuation coefficient, which is a function of the atomic number and density of the material, and the X-ray energy used. Based on the compositional contrasts between different phases, various phases can be identified in a rock.

Pumice clasts, characterized by isolated crystals surrounded by a low-density matrix, are ideal for the application of this technique. We present our first results obtained using X-ray tomography for pumice clasts from the Bishop Tuff. Samples studied are from units F7 and F8, and are representative of the variability in density and crystal contents observed in the early erupted Bishop Tuff.

Data were collected on the GeoSoilEnvironCARS beamline at the Advanced Photon Source, Argonne National Laboratory, using a 22 keV monochromatic X-ray beam. Image analysis was performed using the software Blob3D.

Brightness contrasts in the resulting images allow the separation of magnetite, sanidine, quartz (including minor plagioclase), glass and vesicles. Crystals smaller than 5 voxels in diameter cannot be quantified properly, mostly due to noise in the images. This constrains the spatial resolution of the resulting images, such that there is a trade-off between sample size and spatial resolution. We employed two runs with samples of varying sizes (5 and 10 mm) to obtain adequate resolution (voxel sizes, ca. 8 and 17 μm).

We have previously studied quartz size distributions in Bishop pumice clasts using a crushing, sieving, and winnowing procedure. The agreement between our new and previous results is excellent. Quartz size distributions obtained using the tomography data are concave-upward on (population density vs. size plots) and resemble the size distributions for all quartz crystals (including both whole crystals and fragments). These size distributions were probably generated by fragmentation, through which large crystals were converted in a larger number of small crystals; petrographic observations suggest fragmentation occurred mostly under magmatic conditions. Sanidine size distributions are similar to those observed for quartz. Magnetite size distributions are typically linear, indicating a simple magmatic history, in contrast with the tektosilicates.
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Keywords: textures; crystal size distribution; X-ray tomography; Bishop Tuff; Rhyolite

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1. Introduction

In simple terms, a rock can be described based on two main aspects: (1) a chemical aspect, manifested as the chemical composition of the rock and of its mineral phases; and (2) a physical aspect, revealed by the physical arrangement of the different phases present in the rock, usually referred to as texture. While the study of the chemistry of rocks has experienced tremendous advances resulting from improvements in analytical techniques, the study of textures has been essentially qualitative in nature and it was only after the pioneering works of Marsh (1988) and Cashman and Marsh (1988) that a more quantitative approach started to develop.

Traditionally, textures are studied using the petrographic microscope, which, indeed, provides observations of yet unsurpassed quality. However, such observations are intrinsically limited to 2D sections of 3D objects. And it is this aspect that poses the main challenge to the quantitative study of textures. The example in Fig. 1, in which we show a section through a simple arrangement of spheres of same size, should suffice to convince the reader that retrieving information on the shapes and spatial distribution of objects in 3D from random sections of a volume constitutes a formidable task.

In recent years, considerable effort has been put into developing methods that yield adequate stereological corrections and permit the transformation of quantitative data obtained in 2D into true measures of the 3D arrangement in the rock (Sahagian and Proussevitch, 1998; Higgins, 2000). Despite the advances, difficult assumptions regarding the shapes of the grains are necessary, and the uncertainties resulting from the application of these methods are largely unconstrained and have only now begun to be evaluated (Mock and Jerram, 2005).

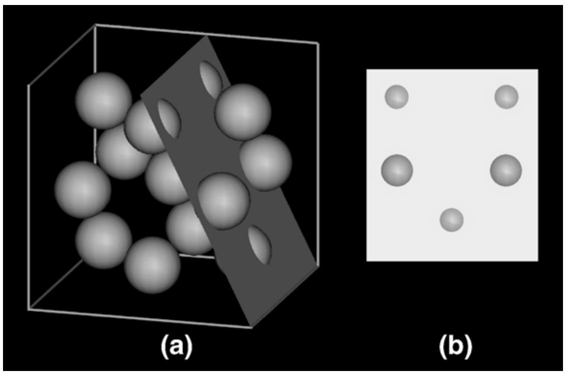

Fig. 1. (a) Hypothetical ordered arrangement of spheres of equal radius; arrangement has face-centered cubic symmetry; an oblique section parallel to the (021) plane is indicated. (b) Plan view of the section indicated in (a). Note the difficulty in retrieving information on the 3D arrangement based on this or any other arbitrary section.

Hence, the necessity of a technique that can yield observations in 3D becomes evident, and we suggest here that X-ray tomography is a suitable choice. Pumice clasts are typically characterized by isolated crystals surrounded by a porous, low-density matrix, and, as such, are ideal for the application of this technique.

In this paper, we present crystal size distributions obtained using X-ray tomography for 3 pumice clasts from the Bishop Tuff (Wilson and Hildreth, 1997). We compare these results to those obtained previously for the same samples (Gualda et al., 2004) using a crushing, sieving, and winnowing procedure. The agreement between the two methods is encouraging. Efforts to expand the application of X-ray tomography to other kinds of silicic rocks (e.g. rhyolite flows, granites) is now being undertaken, and a summary of the results will be the subject of a future contribution.

2. Motivation and sample description

The pumice clasts used in this study are part of the collection used by Gualda et al. (2004). We studied three samples from two stratigraphic units of the early erupted Bishop Tuff. Samples are from fall units F7 (our samples F7-12 and F7-14) and F8 (F8-15), some of the earliest erupted fall units of the whole deposit (Wilson and Hildreth, 1997). The samples span a density range from 0.499 to 0.902 g/cm^3 and the crystal contents are between 5% and 13% in mass (Gualda et al., 2004), representative of the variability observed in much of the early erupted Bishop Tuff (Hildreth, 1979; Wilson and Hildreth, 1997).

The original goal of Gualda et al. (2004) was to verify a possible scarcity of small quartz crystals (<200 μm), suggested by qualitative petrographic observations. One of the difficulties in quantifying the crystal size distributions is that processing of the sample tends to cause significant loss of small crystals, which strongly affects our results and interpretations. Gualda et al. (2004) extensively discuss ways to combine optical microscopy observations to yield reliable results for the whole spectrum of crystal sizes present in pumice clasts.

Another problem faced by Gualda et al. is that processing leads to breakage of crystals, which clearly affects the crystal size distributions. The tomography data was used to show that many crystals in the pumice clast are already broken, but the fragments are in close proximity to each other (see Section 5.2; also, Fig. 7e

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