Introduction: Advances in 3D imaging and analysis of geomaterials

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The advent of the petrographic microscope in the last quarter of the nineteenth century (e.g., Johannsen, 1922) transformed the study of geomaterials, opening a new window into the characterization of materials and the investigation of geological processes at the microscopic scale. With the development of the electron microscope, it became possible to push the limits even further, to submicroscopic scale with the scanning electron microscope, and to the atomic scale with transmission electron microscopes. Despite the tremendous advances brought by the application of optical and electron microscopy in geosciences, the perspective derived from their use suffers from the rather severe limitation that three-dimensional (3D) objects are observed using two-dimensional (2D) sections or surfaces, and the third dimension has to be inferred.

This limitation is particularly acute given our ever growing desire for quantitative characterization. In particular, the application of the theoretical foundations underpinning crystal size distributions to igneous and metamorphic rocks (e.g., Marsh, 1988) led to a surge in the interest to quantitatively characterize crystals and vesicles in particular, and textures in general (see Higgins, 2006). As a natural response, sophisticated methods to convert 2D data to three dimensions using stereology emerged (e.g., Sahagian and Proussevitch, 1998; Higgins, 2000; Morgan and Jerram, 2006). However, such correction procedures have significant limitations and impose additional errors in the measurements. Further, many geomaterials (e.g., pumice) are not well suited for study using thin sections. Because of these problems, techniques that allow direct imaging and quantification in 3D are of great interest.

Early efforts to derive 3D reconstructions of geological samples included techniques such as creating insoluble casts of porous materials (e.g., Zapasnik and Johnston, 1984; Sahagian et al., 1989) and serial sectioning (e.g., Bryon et al., 1995; Mock and Jerram, 2005). These techniques are limited, however, to very particular materials, or are so time-consuming that only very few samples can be studied. Beginning in the 1970s, the availability of computers led to the development of procedures for computer-assisted acquisition and reconstruction of 3D tomographic data, in particular using X-rays. X-ray tomography is now a mature technique that is used routinely (e.g., Rivers et al., 1999; Ketcham and Carlson, 2001; Stock, 2008). It has been applied to a wide array of geomaterials, from rocks to fossils to diverse experimental charges, to name a few.

The ability to create 3D maps with millions to billions of volume elements (voxels) created the challenge of processing and analyzing such large amounts of data. While qualitative observations in 3D yield significant insights into the nature of geomaterials and geological processes, it is in the pursuit of quantitative data that 3D imaging shows its greatest potential. The continued improvements in computer capabilities have led to ever more sophisticated procedures for 3D image analysis (e.g., Proussevitch and Sahagian, 2001; Ketcham, 2005).

This themed issue was inspired by a session entitled Advances in 3-D Imaging and Analysis of Rocks and Other Earth Materials, at the American Geophysical Union Joint Assembly, held in Toronto, Canada, in May 2009. Several of the contributions in this themed issue derive from presentations at the meeting, but others were submitted in response to a call for papers. A total of 13 contributions have been accepted for publication at the time of the writing of this introduction, with additional manuscripts currently under review. Of these, four articles appear in this issue, and others will appear in future issues of Geosphere. All articles that are part of this themed issue are listed at http://geosphere.gsapubs.org/site/misc/geos_themes.xhtml.

The contributions encompass a wide range of topics, from applications of established techniques to a variety of materials, the development of new imaging techniques, and the description of improved imaging and analysis techniques. Much of the work presented focuses on the application of X-ray tomography to investigate a variety of materials in 3D: Kos Plateau pumice (Degruyter et al., 2010); Strombolian, Campi Flegrei, and Vanuatu pumice and scoria (Zandomeneghi et al., 2010); and products of analogue experiments of volcano deformation (Kervyn et al., 2010). X-ray tomography is also used to investigate the mechanical properties of composites under large shear deformation, with potential relevance for mantle processes (Wang et al., 2010).

Boone et al. (2010) use a combination of X-ray tomography, X-ray microfluorescence, and X-ray diffraction for phase identification and characterization in granite. Pamukcu and Gualda (2010) present a procedure to combine tomographic data obtained at a variety of resolutions, exemplified with data from pumice of the Bishop Tuff. Finally, Gualda et al. (2010) introduce differential absorption X-ray tomography as a tool to study accessory minerals, using Peach Spring Tuff and Mount St. Helens pumice as examples.


Heath et al. (2010) use a dual beam focused ion/scanning electron microscope to study...
quantitatively the 3D pore networks in three mudstones from different parts of the USA. Finally, Greenberg and Ebel (2010) successfully apply laser scanning confocal microscopy to image samples from the Stardust comet return sample mission, and illustrate that this technique can be used for 3D imaging of optically transparent materials.

ACKNOWLEDGMENTS

We would like to express our gratitude to participants of the special session Advances in 3D Imaging and Analysis of Rocks and Other Earth Materials at the 2009 AGU Joint Assembly, to authors and reviewers of articles that are part of this themed issue, and to Science Editor Dennis Harry and the editorial staff of *Geosphere* for making this issue possible.

REFERENCES CITED


