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# A comparison of new, old and future densiometic techniques as applied to volcanologic study.

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The density of any material imposes a primary control upon its potential or actual physical behaviour in relation to its surrounds. It follows that a thorough understanding of the physical behaviour of dynamic, multi-component systems, such as active volcanoes, requires knowledge of the density of each component. If we are to accurately predict the physical behaviour of synthesized or natural volcanic systems, quantitative densiometric measurements are vital. The theoretical density of melt, crystals and bubble phases may be calculated using composition, structure, temperature and pressure inputs. However, measuring the density of natural, non-ideal, poly-phase materials remains problematic, especially if phase specific measurement is important.
Here we compare three methods; Archimedes principle, He-displacement pycnometry and X-ray micro computed tomography (XMT) and discuss the utility and drawbacks of each in the context of modern volcanologic study.
We have measured tephra, ash and lava from the 934 AD Eldgjá eruption (Iceland), and the 2010 AD Eyjafjallajökull eruption (Iceland), using each technique. These samples exhibit a range of particle sizes, phases and textures. We find that while the Archimedes method remains a useful, low-cost technique to generate whole-rock density data, relative precision is problematic at small particles sizes. Pycnometry offers a more precise whole-rock density value, at a comparable cost-per-sample. However, this technique is based upon the assumption pore spaces within the sample are equally available for gas exchange, which may or may not be the case. XMT produces 3D images, at resolutions from nm to tens of $\mu$m per voxel where X-ray attenuation is a qualitative measure of relative electron density, expressed as greyscale number/brightness (usually 16-bit). Phases and individual particles can be digitally segmented according to their greyscale and other characteristics. This represents a distinct advantage over both Archimedes and pycnometry, since each phase, and its context, may be investigated.
However, greyscale brightness is not solely determined by material density. Polychromatic beam characteristics, drift of these characteristics between scans, digital artifacts (both material- and instrument-induced) and absolute size of each particle all impose uncertainty. We demonstrate that by combining beam-characterisation and matrix-matched density standards (phantoms) these issues are largely overcome, and the results are quantifiable, phase-specific, 3D, densiometric measurements of the entire sample. With streamlined sample preparation and analysis workflows demonstrated here, we anticipate XMT will become as cost effective as conventional densiometic measurement in the near future.