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Quantitative measurement of olivine composition in three dimensions using helical-scan X-ray micro-tomography

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Abstract

Olivine is a key constituent in the silicate Earth; its composition and texture informs petrogenetic understanding of numerous rock types. Here we develop a quantitative and reproducible method to measure olivine composition in three dimensions without destructive analysis, meaning full textural context is maintained. The olivine solid solution between forsterite and fayalite was measured using a combination of three-dimensional (3D) X-ray imaging techniques, 2D backscattered electron imaging, and spot-analyses using wavelength-dispersive electron probe microanalysis. The linear attenuation coefficient of natural crystals across a range of forsterite content from ~73–91 mol% were confirmed to scale linearly with composition using 53, 60, and 70 kV monochromatic beams at I12-JEEP beamline, Diamond Light Source utilizing the helical fly-scan acquisition. A polychromatic X-ray source was used to scan the same crystals, which yielded image contrast equivalent to measuring the mol% of forsterite with an accuracy of <1.0%. X-ray tomography can now provide fully integrated textural and chemical analysis of natural samples containing olivine, which will support 3D and 3D+time petrologic modeling. The study has revealed >3 mm domains within a large crystal of San Carlos forsterite that varies by ~2 Fo mol%. This offers a solution to an outstanding question of inter-laboratory standardization, and also demonstrates the utility of 3D, non-destructive, chemical measurement. To our knowledge, this study is the first to describe the application of XMT to quantitative chemical measurement across a mineral solid solution. Our approach may be expanded to calculate the chemistry of other mineral systems in 3D, depending upon the number, chemistry, and density of end-members.

Keywords: Micro-computed tomography, densitometry, olivine, chemical composition