Magma Thermal Histories from Volcanic Pyroxenes Nano Scale Chemical Profiles

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The thermal histories of magma bodies are important to evaluate the potential hazards of a given volcano and the processes that build up the continental crust. Current methods of estimating the time scales of magma storage and growth are mainly based on zircon geochronology and chemical re-equilibration of phenocrysts. Here we explore the use of elemental exchange between touching pairs of clinopyroxene (Cpx) and orthopyroxene (Opx), plus the formation of exsolution lamellae as an additional means to extract temporal and temperature information. Recent progress and improved availability of nanoscale characterization using NanoSIMS, Analytical Transmission Electron Microscopy (ATEM) and Focused Ion Beam (FIB) sample preparation enables to achieve quantitative analysis of small features and short compositional profile (in order of a nanometer) of a range of elements and concentration levels.

We have collected FIB cross sections and ATEM across several Cpx-Opx pairs, and across exsolution lamellae of Cpx of a range of volcanic rocks. The FIB sections allowed to correct for the slope across Cpx-Opx interface which can significantly deviate from the preferred 90°. We obtained chemical profiles with the SEM and ATEM of the FIB foils. SEM profiles gave a spatial resolution of 0.3µm and good analytical precision of around 0.5% relative. ATEM allow much better spatial resolution (0.3 nm), but analytical precision decreased to about 5 % relative. We constrained pyroxene crystallization temeparture and modeled the profiles (mainly Fe and Mg exchange) using Cpx-Opx-Pigeonite thermodynamic equilibria (QUILF) and a forward model for a range of cooling histories and times. We found that the ATEM data are too noisy to obtain precise time constraints (varying between a few days and a few year of residence), whereas the SEM data suggest maximum times of about 10 years.