Exsolution lamellae in volcanic pyroxenes as an indicator of cooling times and sizes of magma reservoirs

Fidel Costa[1], Jason S Herrin[2]

[1]Earth Observatory of Singapore, Nanyang Technological University, Singapore, [2]Facility for Analysis, Characterisation, Testing, and Simulation, Nanyang Technological University, Singapore

E-mail: fcosta@ntu.edu.sg

Magma residence times below active volcanoes are crucial for understanding the processes of magma evolution and for proper assessment of volcano related hazards. Major progress has been made in the last decades by a combined approach of modeling zoning patterns of crystals, bulk-rock and single mineral analyses of U-Th disequilibria isotope series, and in-situ determination of crystallization ages of zircon. Here we explore another approach that can potentially lead to new insights into the, sizes, residence times and internal processes of magma bodies that is based on the existence of solvus relations in several mineral groups. Clino- and orthopyroxenes for example may start crystallizing at high magmatic temperature, and new compositions will grow with decreasing the temperature. But once the system intercepts the solvus, early-formed pyroxenes will tend reequilibrate through formation of exsolution lamellae. The size, spacing, and composition of the lamellae depend on the initial temperature, cooling rate, and bulk composition. This means that the characteristics of exsolution lamellae are potentially a record of the cooling history which can be related to the size, growth styles (single batch vs. pulses), and cooling rates of the magma. This type of information has been exploited in several studies of plutonic bodies. However, exsolution lamellae have been rarely documented in volcanic pyroxenes (except for plutonic xenocrysts), probably because of faster cooling rates and shorter magma residence times. Using a new Field Emission Gun Electron Microprobe (EM), and electron backscattered diffraction we have found micro to submicron exsolution lamellae subparallel to the [001] plane (e.g., high-T exsolution) on clinopyroxene from dacites and andesites from volcanoes in Chile and Indonesia. The size of the lamellae is too small to fully characterize with the EM so we have used the Focused Ion Beam technique to extract cross-sectional slices of lamellae in clinopyroxenes perpendicular to the 001 plane. We obtained element maps and traverses using energy dispersive spectrometry and electron energy loss spectroscopy with an Analytical Transmission Electron Microscope. We found that the width of the lamellae vary from about 50 nm to a few hundred nm, and thus near the resolution of backscattered electron maps produced by the EM. Using experimentally calibrated growth rates of exsolution lamellae in clinopyroxene, and simplified cooling models of magma reservoirs of various sizes, we find that the observed lamellae require time scales of formation of a few thousand years from a reservoir of a few to tens of km^3. Given the small sizes of the lamellae that we observed, it seems likely that they have been overlooked in other volcanic systems, but the information they could provide is difficult to obtain by other approaches and should lead to better understanding of the growth rates and sizes of subvolcanic magma reservoirs.