Chemical Zonation in Olivine-Hosted Melt Inclusions

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During the last few minutes to hours of a volcanic eruption, olivine-hosted melt inclusions (MIs) cool and crystallize olivine on their walls, producing olivine-depleted boundary layers in the melt adjacent to their olivine hosts. Competition between diffusive relaxation of these boundary layers into the centers of the MIs and replenishment of the boundary layers by continued olivine crystallization produces concentration profiles that are preserved in glassy MIs.

Characterization of boundary layers in MIs from pillow rims from the Siqueiros transform fault (26 MIs), a hornito on Santiago Island (8 MIs), and a subaqueous lava flow on Fernandina Island (2 MIs) revealed chemical zonation in all MIs studied. The widths of the boundary layers vary from element to element. The zonation of fast-diffusing elements (e.g., Ca) can extend across the entire diameter of MIs (radii up to ~150 μm). An implication of this chemical zonation is that analyses of zoned MIs, even if made near their centers, can be diffusively fractionated relative to a simple olivine extraction path. Certain elements have similar concentration gradients in the MIs despite large differences in experimentally determined diffusivities (e.g., Al, Si, and Na; and also H_2O and F) suggesting strong coupling of these components in the melt. Uphill diffusion is observed in Ca and Fe profiles.

We have developed a model that uses measured MgO concentration profiles across compositionally zoned, naturally glassy, olivine-hosted MIs to constrain their thermal histories in the last few minutes to hours of an eruption. Most MIs require two-stage, linear cooling histories from liquidus temperatures to ~1000°C with a slower-cooling first stage followed by a faster-cooling second stage, over a time period of a few minutes to just over 1 hour.