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Using Mantle Xenoliths as Recorders of Magma Acceleration

TERRY PLANK[1] AND HENRY TOWBIN[2]

[1]Lamont-Doherty Earth Observatory, Columbia University
[2]Lamont Doherty Earth Observatory, Columbia Univ.

Presenting Author: tplank@ldeo.columbia.edu

Magma decompression rate is a first order control on the explosivity of eruptions. Here we use mantle xenoliths as timekeepers of deep and shallow ascent of the carrier magma. The Sullivan Ranch cone in the Western US (~100ka) erupted alkali basalt as scoria and lava that contain abundant mantle xenoliths. We study lherzolite xenoliths ejected as bombs and their interaction with the host magma. Olivines at the xenolith exterior have core compositions that are typical of primary xenolith olivines (~Fo90), while rims reflect host magma equilibrium, with Fo~82, similar to phenocrysts in the host magma. Modeling of the diffusion timescale results in 6 +/- 2 days from below the Moho, at 40 km (~0.002 MPa/s), similar to timescales derived from olivines in the interior of the xenolith in contact with melt veins that formed during decompression (6-18 days). These timescales are consistent with minimum xenolith settling velocities of 40 km in 10-20 days. We also model H_2O zonation profiles in orthopyroxene (opx) and clinopyroxene (cpx) at the xenolith exterior. NanoSIMS traverses reveal H_2O loss within ~150 microns of opx rim and ~50 microns of cpx rim, yielding decompression rates that agree with those calculated for an olivine phenocryst in the host scoria (of 0.2 +/- 0.05 MPa/s). A fifth diffusion clock comes from estimates of grain boundary H^+ diffusion, modeled from opx rim H_2O concentrations across the xenolith, which yields consistent decompression rates. Taken together, these decompression rates chart a path of acceleration: ascent velocities increase from 0.08 m/s, during initial xenolith entrainment (40 km to ~6 km), to 8 m/s when the host magma begins major water exsolution at ~6 km, a 100-fold increase. This acceleration of the magma logically results from the increased buoyancy due to increasing vapor fraction. These rates are likely relevant to other monogenic cones that erupt in violent strombolian eruptions, and are consistent with previous work that documents seismic unrest weeks prior to eruption [Albert et al., Geology, 2016].