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Combining machine learning and petrology: application to the magma plumbing structure beneath Klyuchevskoy volcano, Kamchatka, Russia

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Understanding the structure of magma plumbing beneath volcanoes is a fundamental goal of igneous petrology. Changes in compositions of crystals found in lavas have been used to infer different conditions (magmatic environments, ME) experienced by crystals as they traverse the plumbing system present beneath volcanoes. However, this approach requires extensive analysis of many crystals, which is time- and cost-intensive. Here, we show the utility of using machine learning with electron microprobe data (Leichter et al., submitted), in the case of olivine, to quickly and accurately 1) identify olivine in a thin section (trained on quantitative EDS x-ray map references of specific elements – Ca, Mg, Al, Si, and Fe), 2) map, quantitatively, distribution of Mg and Fe in crystals by back-scattered electron intensity (correlated with Mg# (Mg/Mg+Fe*100)), and 3) classify olivines by type of zoning (e.g., normal, reverse, complex).

We use compositions (Mg# and their spatial distribution) of olivines from the Bulochka lava flow (~3 ka) on Klyuchevskoy to infer that there were four MEs experienced by the material that fed the eruption: ME1 - Mg# 70-75, ME2 - Mg# 76-82, ME3 - Mg# 83-85, and ME4 - Mg# >86. Olivine core Mg# plateaus are typically from MEs 1, 3, or 4, and rim Mg# plateaus for majority of olivines are from ME2. Complexly zoned olivines show two patterns of Mg# variation from core to rim: 1) oscillating Mg# within one or two MEs or 2) steadily decreasing Mg#, typically ME4 to ME3 to ME2. Combined, this indicates a relatively simple magma plumbing structure, with three MEs that produce the olivine cores that are primarily filtered through ME2 prior to eruption (Figure 1). The rapid acquisition of important petrologic data, here over the course of a few weeks, has exceptional utility for petrologic monitoring of ongoing eruptions.

Figure 1