Insights into Magma Storage Beneath an Active Arc Volcano (Villarrica, Chile) from Unsupervised Machine Learning Analysis of Mineral Compositions

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Arc volcanoes produce most of the Earth's subaerial volcanic activity and are responsible for some of the largest historic eruptions. However, the structure of the magmatic systems that feed their eruptions is mostly unknown. Recent models suggest that sub-volcanic chemical processing and storage of magmas likely occurs within multiple discrete low-melt-fraction reservoirs that are distributed vertically throughout the crust (i.e. Trans Crustal Magmatic Systems, Cashman et al., 2017). Constraining the architecture and dynamics of these storage systems, and their role in driving eruptive activity, is challenging due to a lack of direct observational constraints.

A key method to investigate magma dynamics is the analysis of the crystal cargoes carried by erupted magmas. These cargoes may comprise autocrysts (from the carrier liquid), antecrysts (from previous batches of magma), xenocrysts (foreign to the magmatic system), or microlites (formed after eruption). While an individual eruption likely provides a partial view of the sub-volcanic plumbing system, compiling data from multiple eruptions builds a picture of the whole magmatic system. In this study we use machine learning techniques to analyse a large (>2000) compilation of mineral compositions from a highly active arc volcano: Villarrica, Chile. Villarrica's post-glacial eruptive activity (14 ka-present) displays large variation in eruptive style (mafic ignimbrites to Hawaiian effusive eruptions) yet has a near constant basalt-basaltic andesite bulk rock composition. Therefore, what is driving explosivity at Villarrica and can differences in storage dynamics be related to eruptive style?

Hierarchical clustering detects previously unseen structure in olivine, plagioclase and clinopyroxene compositions, revealing the presence of compositionally distinct clusters. Using MELTS thermodynamic modelling we relate these clusters to intensive variables. Our results provide evidence for the existence of multiple discrete magma reservoirs beneath Villarrica where melts fractionate and mix with incoming more primitive magma. The compositional diversity of an erupted crystal cargo strongly correlates with eruptive intensity, and we postulate that mixing between primitive and fractionated magma drives explosive activity at Villarrica.