Constraints on shallow magma storage and eruption-triggering mechanisms from zoning profiles in olivine populations from historic lavas (1640-2009 AD) at Volcán Llaima, 38.7° S, Chilean Andes

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Llaima has erupted frequently in historic time, the growth of its late Holocene cone is dominated by mafic magmas (~51-56 % SiO2), many eruptions begin as violent Strombolian events followed by weeks to years of lava extrusion, and many of the mafic lavas are crystal-rich (35-55%) with plag/oliv ~10:1. Summit and flank vents are controlled by intersections of three fault trends. Llow melt inclusion entrapment pressures of compositionally diverse glasses indicate that magmas are stored in shallow conduit-like reservoirs as crystal mushes (up to 70% solids) that are maintained in an 'eruptible state' by low levels of water-rich magma recharge between eruptions. Erupted magmas are heterogeneous for major and trace elements, and U-Pa-Th-Ra activity ratios, and they are the products of multi-component open systems. Plagioclase typically records many cycles of recharge followed by pre-eruptive growth in sub-volcanic mushes. Hundreds of olivine core-rim traverses from 35 samples (3-8 thin sections from 8 historic eruptions) generally show that each thin section contains olivines with variably diverse crystallization histories: (1) Core compositions are Fo84-68, almost irrespective of magma composition or eruption. (2) Olivines in single thin sections have diverse zoning profiles, some of which feature substantial high-Fo shoulders at or near their rims. (3) Outer rim compositions are almost as variable as cores, although many in lavas record steep, late zoning trends to Fo65-50. (4) Outermost rim compositions in some samples converge on intermediate Fo-values, particularly in tephra. These observations are explained as the consequences of distributed magma intrusion into multiple dike-like reservoirs containing crystal-rich residues of variable bulk composition, residence times, crystallinity, and magmatic history (degree of fractional crystallization and amount of assimilation). Explosive eruptions usually occur when recharge is sufficiently vigorous to break through to the surface, thereby remobilizing diverse mush bodies, which then are entrained and mixed with recharge magma to generate lavas.