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Eruption triggering by partial crystallization of mafic enclaves at Chaos Crags, Lassen Volcanic Center, California

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Abstract

Magma mixing at arc volcanoes is common, but the manner in which mixing or mafic recharge may trigger volcanic eruptions is unclear. We test ideas of eruption triggering for the 1103 ± 13 years B.P. Chaos Crags eruption at the Lassen Volcanic Center, Northern California. We do so by applying mineral-melt and two-mineral equilibria from mafic enclaves and host lavas from six eruptive units of the Chaos Crags eruption to calculate crystallization conditions. Understanding that Chaos Crags are a type location for magma mixing, we estimate these *P*-*T* conditions by employing some apparently new methods to reconstruct pre-eruptive liquid compositions—which can be independently verified using various mineral-melt equilibria. We find that crystallization of "host" rhyodacite magmas occurs within the upper crust (at pressures of 0–1.7 kbar) over an approximate 300 °C interval (temperatures ranging from 669–975 °C) and that mafic magmas (which occur as enclaves within the host felsic samples) crystallized over an approximate 250 °C temperature interval (ranging from 757–1090 °C), also within the upper crust, though extending to middle-crust depths (0–3.9 kbar). Notably, both host lavas and mafic enclaves contain crystals that are inherited from their opposing end-member, and both magma types contain plagioclase crystals that appear to have equilibrated with the resulting intermediate composition magmas; these intermediate composition plagioclase crystals indicate that some amount of time passed between both the recharge of magma into a felsic reservoir and the mixing event that caused an exchange of crystals before eruption.

We propose that mafic recharge—though it may have been the ultimate triggering event—did not immediately precede any of the eruptive events at Chaos Crags. The most mafic (least mixed) enclaves in our collection are nearly aphyric, indicating that they were likely the first melts to enter the system, and quenched upon intrusion into a cold, upper-crust felsic magma. Many high-*T* olivine grains in enclaves also coexist with clinopyroxene, plagioclase, and amphibole crystals that crystallized from only slightly more evolved liquids, at temperatures that are low enough (e.g., 800–900 °C) to have possibly quenched earlier-formed, high-*T* Ol crystals, perhaps negating the use of Ol diffusion profiles as a record of mixing-to-eruption timescales (at Chaos Crags, at least, they would only provide minimum times, which could be orders of magnitude less than actual times). And more crystalline enclaves record more mixing and more cooling. It thus appears that recharge is required to reinvigorate an otherwise dormant Chaos Crags system, as described by Klemetti and Clynne (2014), but ~250 °C of cooling and crystallization, as recorded by many enclaves, provides the immediate cause of eruption—through increased magma overpressure by the exsolution of a fluid phase and increased buoyancy.

Keywords: Magma mixing, eruption triggering, mafic enclaves, Chaos Crags, Lassen Volcanic Center; Geology and Geo-Biology of Lassen Volcanic National Park