Compositional zoning within quartz ejected before, during and after a supervolcanic eruption at 1.256 Ma, Valles Caldera, New Mexico, USA

Jack Wilcock ¹, William Minarik ¹, Fraser Goff ², John Stix ¹

¹ Earth & Planetary Sciences, McGill University, Montreal, Quebec H3A 2A7, Canada
² Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, USA

We have examined individual quartz crystals from a large caldera-forming eruption (CFE) at Valles caldera to highlight the potential role of magmatic recharge during the evolution of large-volume, high-silica rhyolite systems. Valles represents the type example of a resurgent caldera erupting 250 km³ of Upper Bandelier Tuff (UBT) at 1.256 ± 0.010 Ma. Following this eruption, central resurgence of >1000 m proceeded for the next c. 27 ka, contemporaneous with emplacement of small-volume rhyolitic and rhyodacitic lavas and tuffs. Dating of the initial, undeformed ring fracture rhyolite at 1.229 ± 0.017 Ma (Cerro del Medio rhyolite) places an upper time constraint on the duration of resurgence at Valles (Phillips et al., 2007).

Quartz crystals from the UBT, resurgence-related volcanic rocks and Cerro del Medio lavas were analyzed by cathodoluminescence (CL) and $\text{TitaniQ}$ geothermometry techniques (Wark & Watson, 2006). Titanium concentrations were determined using LA-ICP-MS and ranged from 30 to 110 ppm. A crystallisation temperature based upon Ti concentration in quartz can be calculated using $\text{TitaniQ}$, given an estimate of TiO₂ activity. Rutile was not found in these samples, hence the TiO₂ activity was less than unity. Several lines of evidence suggest $a_{\text{TiO}_2}$ to be either relatively constant (~0.4) or even decreasing (0.75-0.5) during the caldera-forming eruption. CL imaging of quartz from the initial plinian fallout unit of the UBT indicates isothermal conditions (i.e., no apparent compositional zoning) at temperatures of ~700 º C using a TiO₂ activity of 0.4. Similar thermal conditions are implied during eruption of the early ignimbrite flow units, which also exhibit unzoned quartz. These units represent 80-90 % of the total 250 km³ erupted volume (Dense Rock Equivalent, DRE).

An important observation is the abrupt appearance of zoned quartz crystals exhibiting Ti-rich rims within mid to late-erupted ignimbrite units, indicating thermal disequilibrium during the waning stages of the eruption. The titanium concentrations of these bright CL rims on the quartz suggest temperature increases of 70-100 º C compared to the darker core regions, which show Ti concentrations hence temperatures similar to the plinian unit. Quartz crystals from earliest-erupted resurgence-related lava units show multiple high-temperature rim overgrowths and dissolution events as shown by quartz embayments, again with core-to-rim temperature increases of 80-100 º C compared to thermal conditions prevalent during the initial plinian stage. A return to isothermal but hotter conditions (>820 º C, using $a_{\text{TiO}_2}$ of 0.4 ) is indicated by quartz crystals from the Cerro Del Medio rhyolite.

A working hypothesis

Regardless of temperature uncertainties induced by possible variations of $a_{\text{TiO}_2}$, an important temperature increase appears to be recorded by rim overgrowths on quartz crystals from the mid-to-late ignimbrite units. Additionally, new experimental results on the effect of pressure on Ti solubility in quartz pose interesting and poignant questions to this study:

(a) What control does the dynamic pressure regime of a caldera-forming eruption have on quartz growth?
(b) Is the zoning observed a product of pressure and/or temperature fluctuations during eruption?
The occurrence of dacitic pumices within the initial air-fall deposit of the UBT demonstrates the input of relatively primitive and genetically unrelated magma into the Bandelier system at some point prior to eruption. We envisage that this magma underwent differing degrees of mixing within the Bandelier chamber to a) provide an eruptive trigger and b) cause thermal and chemical heterogeneity within lavas erupted following the cataclysmic UBT eruption.