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Hydrogen diffusion in quartz: a new tool to unravel the last instants of unrest of felsic volcanism

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Understanding the timescales between beginnings of magma unrest and volcanic eruptions is of great importance for populations living on and around volcanoes. Mafic to intermediate systems provide various determinations of very short processes (minutes to days via hydrogen diffusion chronometry in olivine, pyroxenes), whereas timescales for felsic systems often rely on slow diffusing elements (e.g. Ti in quartz, Ba, Sr in feldspar), which, given our current analytical limitations, are inappropriate for inspecting any process occurring over human timescales at low temperatures (700-800 °C). Hydrogen loss from quartz hosted melt inclusions (e.g. Myers et al., 2018) is more appropriate for short timescales, but requires complex sample preparation and analyses.

Here we propose hydrogen diffusion in quartz as a new chronometer for determining very short timescales (minutes to hours at 700-800 °C) of unrest of relatively cool and viscous felsic magmas that experience changes in water fugacity (e.g. liberation of water from silicate melt caused by magma decompression during or prior to eruption).

Oriented cubes were cut from various optically perfect quartz crystals (from Brazil, Arkansas, Tibet, Pakistan, plus two synthetic hydrothermal), all of which contained some structurally bound OH groups. These crystals were then dehydrated in air at 1 bar, in either Au or Pt containers, either alone or packed into a lithium disilicate-quartz powder (to explore charge-balancing mechanisms during H-loss). Experiments were conducted for minutes to weeks at 350-1000 °C, then doubly polished to 300-500 μm thickness, and analysed using Fourier transform infrared spectroscopy (both polarised and unpolarised). Total absorbance (in the OH stretching wavenumber region of $\sim$3000-3650 cm-1) versus distance from the crystal interface follows simple error function shapes, but profiles deconvoluted into contributions from individual bands show diffusion-induced OH band fractionation. This band fractionation may provide a simple tool for distinguishing between intra-crystal variations in OH concentration induced by diffusive loss versus crystal growth in natural samples. In line with previous data (Kats, 1962, and others), the Arrhenius relationship is kinked, with a high activation energy region at $>\sim$700 °C, and a lower Q region at lower temperatures. Li profiles were also measured using laser ablation inductively coupled plasma mass spectrometry, Li appears to be anti-correlated to H in experiments where an Li source was used.

The H diffusivities are sufficient that profiles several hundred μm long form in <1 hour at 750 °C – this, and the utility of the new diffusion chronometer will be demonstrated using very well-preserved deposits from the Lauca ignimbrite, Chile.

Kats, A. (1962). Hydrogen in alpha-quartz. Philips Research Repository 17: 133-195.

Myers, M. L., Wallace, P.J., Wilson, C.J.N. (2019). Inferring magma ascent timescales and reconstructing conduit processes in explosive rhyolitic eruptions using diffusive losses of hydrogen from melt inclusions. Journal of Volcanology and Geothermal Research 369: 95-112.