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Non-isothermal diffusive analysis: experimental validation and application

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Diffusion chronometry serves as an essential tool in constraining magmatic evolution and storage. Diffusion rates vary significantly for a small change in temperature. For crystals growing in natural conditions in a dynamically evolving magma reservoir, time-scales of diffusion are difficult to precisely constrain using isothermal diffusion modelling. In such cases, the "Non-Isothermal Diffusion Incremental Step model", proposed by Petrone, et al., 2016, can be a very effective tool to constrain pre-eruptive time-scales. In this study, we experimentally test the model and after validation, apply it to the compositionally zoned sanidines in the dacites from an eruption ($\sim$33 Ka) of Taapaca volcanic complex, Chile to investigate their pre-eruptive history.

For the experiments, we prepared an anhydrous homogenous glass of the composition similar to Montana Blanca phonolite. Cl and F were used as the diffusing components due to their high diffusivities. The experimental set-up was designed to involve multiple diffusive interfaces that denote multiple zoning. The range of starting temperatures was between 975 and 1150 ^{o}C and each set of experiment included a temperature change of 85 to 150 ^{o}C, which accounts for the non-isothermal nature of diffusion. The experiments were performed in internally heated pressure vessel at 1 kbar and the total duration of each experimental set was kept in between 8-12 hours. The rapidly quenched samples were analyzed under the electron microprobe and measured Cl and F concentration profiles were analyzed using the model to estimate the experimental time-scales. The estimated values matched perfectly with the actual experimental conditions, thus confirming the validity of the model by Petrone, et al., 2016. The model was then applied to the multiple compositional zonings in the sanidines of dacite samples from Taapaca volcano. Ba-profiles obtained from quantitative analyses and element maps, and grey-scale (as a proxy for Ba) profiles from accumulated back-scattered images were modelled to obtain diffusion time-scales. The temperature range was estimated to be $\sim$700-800 ^{o}C based on amphibole-plagioclase thermometry applied to inclusions in the sanidines. Based on the modeling of non-isothermal diffusion with multiple time-steps with different temperatures per individual crystal, the pre-eruptive growth and residence histories of these crystals were interpreted.

Reference:

Petrone C. M., Bugatti G., Braschi E., Tommasini S. (2016) Pre-eruptive magmatic processes re-timed using a non-isothermal approach to magma chamber dynamics. Nat. Commun. 7, 12946 doi: 10.1038/ncomms12946.