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Time scales of magma recharge and crystal growth rate determined from Mg and Ti zoning in plagioclase phenocrysts from the Upper Toluca Pumice, Mexico

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Major and trace element zoning in plagioclase phenocrysts has the potential to stores information on the temporal evolution of the chemical environment during crystal growth, i.e. the surrounding melt composition as well as the intensive parameters temperature (T) and pressure (P), provided that equilibrium partitioning accompanies growth. However, the problem is complicated by the fact that diffusion of mobile elements changes their initial concentrations due to re-equilibration with the surrounding melt at later stages, making estimation of the pre-diffusive element profiles fraught with uncertainty. Here we present a new approach that combines the information from immobile (e.g., Ca, Ti) and mobile (e.g., Mg) elements in plagioclase to unravel the growth history and time scales of magma recharge events from the 10.5 ka Upper Toluca plinian eruption of Nevado de Toluca volcano, Mexico.

Since trace elements are less sensitive to intensive parameters their variations in plagioclase phenocrysts have been used to identify open-system processes in silicic systems [1]. These phenocrysts preserve complex element patterns, such as oscillatory zoning and overgrowths, indicating multiple magma recharging events. Based on available diffusion data major elements and, for example, the trace element Ba, are effectively unchanged since crystallization, but the mobility of Mg [2] is large enough to alter the initial concentration at later growth stages. We made attempts to model the Mg zoning using two endmember cases for the growth history of the plagioclase. In the model the growth rate can either be constant until the final crystal diameter is reached or involve various short growth stages with diffusion relaxation breaks in-between. The corresponding moving boundary problem of the diffusion equation was solved numerically using the method of finite differences and a front-tracking method [3]. A particular challenge of the modelling is to estimate the initial Mg concentration after an incremental growth step since the melt composition is unknown during each growth stage. We have tried two different approaches: In each case three calculation steps are involved, which are based on the assumption that Ti and the anorthite (An) content were not affected by diffusion and both correlated linearly with Mg in the plagioclase during growth. Both methods give a very similar result for the initial Mg profile, provided that the plagioclase-melt Mg partition coefficient is constant (independent of T and An) and of the order of 0.03 +/-0.01, which is consistent with the data of Bindeman et al. (1998) [4] and unpublished data of Blundy & Wood [5], and with the fact that the predicted MgO contents in the melt are consistent with observed melt inclusions in UTP rocks [1].

Our first modelling results are, in general, able to simulate the final observed Mg concentration profiles, but the time scale obtained is actually less sensitive to the choice for the growth history (constant or one-step growth). The time scales are on the order of hundred years to several thousand years subject to the assumption of Costa et al (2003) [6] that the diffusion coefficient of Mg has the same dependence on An as Sr, which has to be experimentally validated. Temperature was taken from two-oxide thermometry (830 °C). Other factors of uncertainty for the modelling are less significant (e.g., anisotropy) and lower than an order of magnitude. Our estimated magma residence times are consistent with steady refilling of the Toluca magma chamber since the previous eruption $\sim$12 kyr at a rate of $\geq$ 6.e6 m3/yr.

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