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Fe-Mg diffusion chronometry in orthopyroxene from the Minoan eruption of Santorini, Greece

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Constraining the timescales governing magma ascent and storage prior to ignimbrite eruptions is crucial for understanding the behaviour of caldera volcanoes. Diffusion chronometry provides estimates of the pre-eruptive residence times of crystals at magmatic temperatures, and hence of the longevities of bodies of crystal-bearing magma that are finally discharged. We have used Fe-Mg diffusion chronometry in orthopyroxene (opx) crystals from the Minoan eruption of Santorini in order to calculate the pre-eruptive residence times of these crystals. The Minoan eruption occurred in the late 17^{th} century BCE, and discharged 30-80 km^3 of rhyodacitic magma containing about 10 vol.% of plagioclase, opx, cpx and Fe-Ti oxides. The orthopyroxenes have compositions of $Wo_{2-3}En_{52-70}Fs_{28-45}$ (#Mg = 0.53-0.65) with Al_2O_3 contents typically <0.5 wt.%, and include normally zoned, reversely zoned and unzoned types. Compositional images reveal sector zoned morphologies with Al-rich prismatic zones and Al-poor terminations, possibly indicative of rapid growth. Representative opx crystals were extracted from pumices and mounted in epoxy grain mounts. High-resolution backscattered electron images of zoned crystals with greyscale values calibrated for Mg# were used to identify Fe-Mg gradients across zone boundaries, which were then modelled as diffusion gradients using published diffusion coefficients for Mg-Fe interdiffusion within the a-b plane of opx, a magmatic temperature (855 $\pm$ 25 ˚C) and fO_2 determined from touching magnetite-ilmenite pairs in the same rock. Our models assumed initial step functions in Mg and Fe concentrations, and that any non-zero width is a result of diffusion. The time required for to reach the observed width of diffusion at 855˚C was taken to be a maximum residence time, and was calculated for a total of 22 zone boundaries from 13 crystals. Profiles were taken perpendicular to the crystal length, within the a-b crystallographic plane. Only zone boundaries with bounding plateaus in Mg and Fe concentrations (implicit in the diffusion model) were used.

Resulting timescales ranged from 28 years to <0.1 y, with 70 % less than 1 y. No significant differences of timescale spectra from the four eruptive units were observed. There is some suggestion in the data that timescales from individual crystals are highest near the centre and decrease towards the rim, which would be consistent with crystal growth on the timescales concerned. Placed in the context of published melt inclusion barometry, Mg-in-plagioclase diffusion chronometry and phase equilibria, we infer that the opx crystals grew during the ascent of batches of volatile-saturated rhyodacitic melt from the middle crust, and their subsequent injection into the shallow pre-eruptive magma chamber. The opx timescales are in excellent agreement with those obtained previously using Mg diffusion in plagioclase, reinforcing the conclusion that final assembly of the shallow magma body took place only years to months prior to the eruption.