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Mechanical interaction between gas bubbles and micro-crystals in magma

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The magnitude of volcanic gas emissions from low viscosity magmas is controlled by many factors. The buoyancy driven ascent of gas bubbles in the volcanic conduit is one of them. During the ascent the bubbles may collide with micro-crystals, slide along the crystal faces, and finally leave the crystal at the crystal tip. We investigate the mechanical consequences of this interaction in a static volume of magma assuming constant pressure, temperature and chemical composition and neglecting thermodynamic processes between bubbles and crystals. Explicitly, we focus on tabular crystals whose extensions are about one order of magnitude larger than the bubbles. The mechanical interaction changes the motion of both the bubbles and the crystals. The buoyancy force of the bubbles results in a torque on the crystal which ultimately orients the long axis of the crystal to the vertical direction. On the other hand, bubbles change their ascent path and velocity if they slide along a crystal face. This change in the bubble motion may have two opposing impacts on the magnitude of volcanic emissions: First, the reduced ascent velocity results in a bubble accumulation and thus enhanced bubble coalescence rate in the proximity of crystals. Second, the crystals align the bubbles in rise channels starting at the crystal tips while no bubbles access the magma volume immediately located above the crystal cross section, which we call "crystal shadow". Now, volatile degassing from supersaturated magma is a diffusive short-distance process which accelerate in the proximity of pre-existing gas bubbles. We thus infer that the orientation of the crystals influences the bulk volatile degassing rate and thus the volcanic gas emission rate due to the crystal shadow.

The mechanical model suggests that all crystals get erected by the bubble-induced torque within time periods in the order of weeks to months. This has to be compared to the crystal nucleation rate in order to obtain a steady state distribution of the crystal orientation. Anyway, crystal orientation is also, and potentially much stronger, influenced by the general magma convection. Accordingly, for the second part of our investigation - a crystal-induced variation of the volcanic gas emissions - we assume a random crystal orientation. We investigate a quantisation of the crystal-induced changes in volcanic gas emissions and its dependency on crystal size and distribution. Finally, we investigate the impact of a periodic variation of the crystal orientation, as exerted by e.g. a Earth tidal forcing.