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Numerical investigation of permeability models for low viscosity magmas: application to the 2007 Stromboli effusive eruption

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Magma permeability is the most important factor controlling the transition between effusive and explosive activity of a basaltic eruption. Indeed, when low viscosity magmas are not permeable enough, volatiles stay trapped into the melt, expanding and pushing up more and more magma as the pressure decreases. As soon as the volume fraction of the gas, or the overpressure of the bubbles, or the strain rate of the melt becomes too large, magma fragments, generating an explosive eruption. On the contrary, if magma is sufficiently permeable, gas is able to decouple from the melt and fragmentation does not occur, causing, thus, an effusive eruption. A correct modelisation of gas/magma decoupling is, therefore, fundamental to properly understand the ascent dynamics occurring during an eruption. Here we study several permeability models for a low viscosity magma using a 1D steady-state model for magma ascent dynamics, focussing, in particular, on the 2007 effusive eruption at Stromboli volcano, Italy. We compare the numerical solutions computed using respectively Darcy's and Forchheimer's law. We also take into account the different expressions for Darcian permeability introduced by Bai et al. (2010, 2011) for Stromboli volcano, comparing them against a new expression for permeability derived from the data collected by Polacci et al. (2009) on Stromboli scoria. The numerical results show that using the permeability expressions of Bai et al. (2010, 2011) with Darcy's law, magma fragments into an explosive eruption. Using the new permeability model, instead, the decoupling between gas and magma is sufficient to generate an effusive eruption. However, when Forchheimer's law is adopted, fragmentation is always achieved, even with our new permeability. For a broader investigation on permeability, we also adopt the permeability relation introduced by Degruyter et al. (2012) as a function of three parameters: bubble number density, throat-bubble size ratio, and tortuosity factor. Using this parameterisation for permeability, we perform a sensitivity analysis adopting Darcy's law, deriving a set of values for which the corresponding numerical solution generates an effusive eruption. We conclude, finally, that, for low viscosity magmas, permeability models derived from the study of solid products are not adequate to produce an effusive eruption. Indeed, the assumption that the behaviour of gas flowing through solidified magma is the same as when flowing through a hot and fluid melt is not valid for a low viscosity magma. Therefore, the permeability calculated assuming gas flowing through solidified magma is clearly an underestimation of the real permeability of basaltic magmas.

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