Linking magma chamber evolution to eruptive history using a simplified numerical model

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The eruptive history of a volcano is controlled by the non-linear interplay between mass recharge, crystallization and volatile exsolution modulated by the heat loss and outgassing out of the chamber to the surrounding crust which ultimately affect the stress field in and around the magma chamber. The complexity and coupling between these processes is a formidable challenge to our understanding of the response of volcanic systems to different forcing acting over different time scales. Here we propose a simplified model to capture, to a first order, how the coupling between the stress field and the thermodynamical state of the chamber (temperature, volume fraction of exsolved volatiles, crystals and melt) evolve during the injection of fresh magma into the chamber. In a first time, we impose that the influx of new magma scales linearly on the pressure difference between the magma chamber and a fixed imposed pressure at depth. In a second time, we use the results of Karlstrom et al. (2009) and assume a constant influx at depth but that the pressure in the chamber increases the lensing of feeder dikes towards the chamber (i.e. higher recharge flux as the pressure in the chamber increases, opposite of the first scenario). In our model we solve for the coupled non-linear mass balances for three phases (melt, crystals and exsolved volatiles) as well as a heat conservation equation for the multiphase system. In these governing equations we account for volatile exsolution, crystallization/melting, the visco-elastic relaxation of stresses around the chamber and passive degassing through a permeable crust. We allow for dikes to initiate from the chamber when it reaches a critical overpressure, if the overpressure remains large enough during the dike propagation to reach the surface, then an eruption of volume controlled by the excess pressure in the chamber occurs. The ability of the magma to erupt is also controlled by its crystallinity, with a threshold crystallinity set at 0.5 above which the magma is considered uneruptible (Marsh, 1981).

Using this simple model, we study the effect of the two scenarios for the magma recharge on the periodicity (or chaotic behavior) of eruptions and the volume of magma erupted (and its crystallinity and bubble content). The modularity and the simplicity of the model allow for rapid calculations and offer the flexibility to add different and sometimes competing processes and test their influence on the outputs.