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A simple analytical solution for the transient dike volume change and dike velocity for the chamber - dike coupled problem

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In the past decades volcano seismologists and geodesists have collected many observations on the transient regime of dike emplacement that current models of dike propagation do not explain. The cause of this failure has been already identified by several authors in the common assumption that magma chambers can maintain their pressure constant while feeding dikes. This assumption collides e.g. with the convex upward shape of the volume evolution during the 1997 dike intrusion at KIlauea, as noted by Owen et al. [2000] and Segall et al. [2001]. Segall et al. [2001] described the flow of the magma from a chamber to a dike with an ordinary differential equation for the unknown pressures of chamber and dike. The feeding of dikes is then associated to a pressure drop in the magma chamber, controlled by magma bulk modulus and elastic compressibility of surrounding rock. Here I present a model developing on that intuition, which makes use of mass conservation (instead of volume conservation) as a constraint for pressure, as magma flows from the chamber to the dike. This ansatz allows to solve the problem analytically. The model predicts that chamber and intrusion volume change exponentially with time as $V(t) = V_\infty[1 - \exp(-t/\tau)]$. Intrusion velocity is found to change as $v = v_0 \exp(-t/\tau)$, where v_0 is the initial dike velocity. The asymptotic volume V_∞ and the time scale τ can be expressed in terms of rock, magma, chamber and dike parameters and of the initial pressure conditions. Fitting volume or velocity curves can provide independent constraints on parameters difficult to retrieve otherwise. I validate my model with data from the 2000 Miyakejima intrusion (Japan), the 1978 Krafla event (Iceland) and from some intrusions following the 2005 event in Afar (Ethiopia). The fit between model and observations is excellent. This paper confirms and extends the results of a previous study [Rivalta and Segall , 2008] that explained the volume imbalance found during some dike intrusions. The final ratio between dike volume and the volume withdrawn from the chamber was found to be $r_V = 1 + 4\mu\beta_m/3 > 1$, where μ is the host rock rigidity and β_m is the magma compressibility. This invalidates the most intuitive assumption on magma exchange that the volume gained by the intrusion equals the volume lost by the chamber(s). Here, I demonstrate that the formula for r_V holds at any time, not just at equilibrium. My model confirms that some magma chambers behave as stiff magma-tanks, able to inflate large dikes as balloons, and demonstrates that this is unlikely to occur if the chambers are simply shaped as sills.