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Propagation velocity of magma intrusions, a new 2D numerical approach

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The tortuous travel of magma through the crust may sometimes result in volcanic eruptions at the surface. In the brittle crust, magma propagation usually occurs by fracturing the rock and opening its own way through them. This process of diking is controlled by the interaction of many complex physical processes including rock fracture, flow of compressible fluids, phase transitions, heat exchange. Current models of dikes consider either a fracturing-dominated approach, that neglects the viscous flow and allow to estimate the trajectory of dike propagation, or a viscous-dominated approach that neglects the fracturing at the dike tip allowing to infer the propagation velocity of the dike. Here we propose a new numerical approach aiming at modeling both the magma path and velocity. We start from a two-dimensional Boundary Element model solving for the trajectory of a quasi-static crack in an elastic medium subjected to external stress (Maccaferri et al, 2011), and implement the effects of the viscous fluid flow assuming a Poiseuille flow. We build on the previous work by Dahm (2000) but relaxing the assumption of stationarity, and thus allowing to take into account heterogeneous crustal stresses, complex dike paths, and dike velocity variations. The fluid flow results in a viscous pressure drop applied to the crack wall, which modifies the crack shape and contributes to the energy balance of the propagating dike. In fact, the energy dissipated by viscous flow is linearly dependant on the viscosity of the fluid and the crack velocity. It follows that the velocity can be inferred from the total energy budget by imposing that the viscous energy dissipation and the energy spent to fracture the rocks equals the strain-plus-gravitational energy release. However, the viscous dissipation strongly depends on the opening of each dislocation element, causing numerical instabilities in the calculation of the dike velocity due to the fracture closure at the dike tail. We will present first results of velocities derived with this approach considering only a static crack shape (that is to say neglecting the modification of the crack shape induced by the flow). We will discuss the influence of various parameters (crack size, Young's modulus value...), and will compare the numerical velocities obtained with observations, first considering velocities measured in analogue experiments when injecting fluids of various viscosity (air and oils) in gelatin tanks, and secondly using diking events documented at basaltic volcanoes (such as Piton de la Fournaise (Réunion) and Mount Etna (Sicily)).