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Factors controlling propagation of a dyke filled with gas-saturated magma

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We present mathematical and numerical model of the propagation of a dyke filled with volatile-saturated magma and a gas cap at its upper part. The magma flows due to its buoyancy and the overpressure at the dyke origin. The model solves for the elastic stresses in the host rocks, the shape of the dyke, the rate at which the tip of the dyke propagates, and for the two-phase (gas and melt) channel flow. The numerical code allows studying various regimes of dyke propagation and the importance of the controlling parameters. Following a sudden increase in the pressure at the dyke origin, the pressure wave propagates until it reaches the magma front. Then the dyke front propagates at a rate that depends on the sub-critical crack propagation of the tip, the gas mass in the cap cavity, the gas flux from the bubbly magma to the cap and on other physical parameters of the system. Pressure decrease in the magma during the flow leads to nucleation and growth of gas bubbles and gas filtration. When pressure variations are small, we neglect gas transport, assuming a constant gas mass in the cap. In this case the propagation of the dyke is self-similar. The rate of propagation is controlled by the rate of fracturing at the tip, and the rate of magma flow in the dyke. In the case of relatively low magma viscosity and high energy needed to fracture the host rock, the rate of the dyke propagation is controlled by the rate of fracturing at the dyke tip (fracture-controlled regime). The dependence of the dyke propagation rate on the amount on the gas in the cap is very weak. When the energy to fracture the host rock is small, the rate of dyke propagation is controlled by the rate of the magma flow (magma-controlled regime). In this case the propagation rate is very sensitive to the gas mass in the cap cavity. The gas-filled cap cavity opens the dyke in front of the magma and leads to higher propagation rates than predicted by models ignoring the existence of a gas cap. The maximal rate of propagation is obtained at the transition between these regimes. The propagation of the dyke with a small amount of gas in the gas cap, the rate of propagation is fracture-controlled. At later stages, the amount of gas in the gas cap increases, the crack growth is faster than magma channel flow and the dyke propagation is in the transitional or magma-controlled regime. If the gas mass is high enough, the cap may separate and form a distinct unconnected balloon that propagates on its own.