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Mechanisms of formation of lava tubes

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Lava tubes are present on many volcanos. We propose a model to describe lava tubes formation, considering lava as a Newtonian fluid moving downslope in a rectangular channel. A 3D dynamical model is used. We obtain flow velocity using an analytical steady-state solution of the Navier-Stokes equation. Shear stress is also calculated from velocity for a Newtonian, incompressible and isotropic fluid. A 2D model with heat flux assigned at the upper surface is introduced in order to describe lava cooling by radiation into the atmosphere and to obtain a steady state expression of flow temperature. Lava crust is considered as a plastic body, and the yield strength is introduced as a strongly temperature dependent function, describing the capacity of crystalline structure to prevent shear deformation for lower shear stress values. When lava temperature becomes lower than its $solidus$ value, a superficial thin solid layer develops in regions where shear stress is inferior to the yield strength. For typical Etna flow parameters, crust develops in the center of the channel, laterally limited by two crust-free regions. The model analyzes the effect of some typical channel irregularities on crust width growth. We consider channel width and slope variation, finding that tube formation is favored by channel widening or slope reduction. In both cases, the increment of shear stress σ_{xy} and the decrease of yield strength τ produce an increase of the fraction of channel width occupied by solid crust. We determine critical values of channel width and ground slope that allow the passage from a mobile crust to a stationary roof. The effect of different effusion rate on crust development is also studied, with the result that tube formation is favored by low flow rate.