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Growth histories and emplacement dynamics of laccoliths and large mafic sills: an evaluation of critical parameters

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Successful mechanical models for shallow igneous emplacement should predict both the observed geometric scaling (i.e. power law slopes and intercepts on logarithmic Thickness, T, versus Length, L, plots) and the first-order morphology of intrusions. Here we explore the behaviour of a mechanical model for shallow igneous intrusion that couples appropriate boundary conditions (interaction with Earth's surface, propagating tip) with the transport properties of magma (density, viscosity) during emplacement (Bunger & Cruden, 2011, J. Geophys. Res., 116, B02203). We focus on modelling laccoliths and large mafic sills (L » 2 km) with a view to placing limits on the growth histories and rates of well-constrained examples. Behaviour of the model is captured by an evolution parameter, G, which is a function of time, magma density, volumetric emplacement rate and depth, and the fracture toughness of the wall rocks. As G increases with time and hence with the magma volume, the intrusion shape evolves from the initial bell-jar form of well-known thin elastic plate solutions to a steep sided-flat top morphology with L/T $\sim$10, characteristic of laccoliths, to a uniform thickness-high aspect ratio shape with L/T >100, typical of large mafic sills. Lower final values of G consistent with laccolithic forms are favoured for deeper levels of emplacement in the upper crust, smaller total magma volumes and high fracture toughness. Higher final values of G leading to large mafic sill morphologies are expected for shallower emplacement depths, larger total magma volumes and lower fracture toughness values. Ignoring the effects of magma cooling and freezing, magma viscosity appears not to be an important factor in controlling the final size and shape of laccoliths and large mafic sills. However, it does play a critical role in determining the flux of magma into a growing dyke-fed intrusion and, together with the emplacement time, the total magma volume, G and ultimately whether a laccolith or sill is formed. Considering the effects of cooling, magma viscosity is an important factor in ensuring that the magma flux is sufficiently large and the emplacement time is sufficiently fast to prevent freezing and stalling of the growth history.