Lifestyles of magma chambers: Towards dynamic typology and interpretations of plutons

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Magma chambers are fundamental features of the Earth's crust. Their lifestyle - internal dynamics and longevity - have profound implications for the crustal heat and fluid fluxes as well as for the eruptive behavior. We developed a simple one-dimensional numerical model of cooling and crystallization of a horizontal melt sheet emplaced into the cold crust. The model incorporates convective and conductive cooling coupled with crystallization evolution, which is further linked to gravitational settling of crystals in the magma. We have employed this model to study the solidification behavior of a melt sheet as a function of the sheet thickness and melt viscosity. In highly viscous (granitic) magmas the solidification regime ranges from zoned symmetrical evolution to homogeneous but rapidly freezing systems as a function of the sheet thickness. Simulation results indicate that sills with the thickness on the order of meters develop both-sided solidification fronts while the sill's interior remains stagnant. By contrast, kilometer-sized granitic plutons establish rapid convection, which keeps their crystal content homogeneous and facilitates effective heat dissipation from the crystallizing magma. The crystallinity increases gradually until the effective viscosity of the magma terminates the convection regime and further crystallization proceeds by propagation of solidification fronts. Characteristic times for convection regime positively scale with the magma chamber size: the larger the magma body, the longer the convection, followed by accelerated solidification of the crystal mush. As a result, large magma batches may crystallize to chemically and texturally homogeneous plutons. Additional processes operate in more fluids (basaltic) magmas: crystals are efficiently dragged by gravitation forces from the upper solidification front and accumulate on the lower front. With increasing chamber size the crystal accumulation becomes dominant mechanism by which the lower solidification front grows. The effect of chamber size overrides the opposing effect of viscosity and makes crystal accumulation important even in highly viscous magmas. Our results suggest a new typology of magma chambers and allow us to identify the principal processes operating during the solidification of magma chambers mainly as a function of the chamber size and melt viscosity.