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Evolution of magma bodies and mush zones: Insight from two-phase flow modelling of partially molten continental crust

Harro Schmeling (1), Gabriele Marquart (2), Roberto Weinberg (3), Herbert Wallner (1), and Sandy Cruden (3)

(1) Goethe University Frankfurt, Institute of Geoscience, Frankfurt/M, Germany (schmeling@geophysik.uni-frankfurt.de), (2) Institute for Applied Geophysics and Geothermal Energy, E.ON Energy Research Center, RWTH Aachen University, Germany, (3) School of Earth, Atmosphere and Environment, Monash University, Clayton, Vic 3800, Australia

The physics of formation and evolution of magma bodies, and particularly of mush zones and eruptible melt caps within the continental crust is not well understood. We approach this problem by a thermo-mechanical-compositional two-phase flow formulation based on the conservation equations of mass, momentum, and energy for melt and solid. The approach includes compaction of the solid matrix and melting, melt segregation, melt ascent and freezing. We assumed meta-greywacke as the initial rock type and use a simplified melting law of a binary solid solution system to track chemical composition, i.e. the enrichment or depletion in SiO_2 of the advected silicic melt and solid. The rheology is based on dislocation creep of quartzite or granite, and includes plasticity and the effect of melt porosity. As initial condition, one model series assumes supersolidus temperatures within the lower part of the crust. In this case melt separates from the solid matrix and accumulates in high melt porosity magma bodies within 10's ka. During and after this separation phase magma ascends by the newly discovered CATMA mechanism, which stands for Compaction/decompaction Assisted Two-phase flow Melt Ascent. This mechanism is associated with significant chemical separation of depleted versus enriched composition, resulting in significant spatial variations in solidus temperatures. Melt - solid separation together with chemical separation result in a dual melt porosity distribution with melt rich magma bodies (> 60% melt) collected in a cap on top of low melt fraction mushes (< 20 %). The melt volume ratio of mush to cap is less or of the order of one, i.e. significantly less than estimates from natural examples such as the Altiplano-Puna magma body. This discrepancy may be due to instantaneous heat input condition in our models, which produces large amounts of melt at the model starting time. Alternative models with time-distributed heat input are shown in which the mush/cap melt volume ratio rises to values significantly larger than 1 (i.e. smaller cap volumes). In some of these models a fingering instability near the top of the magma body is observed, allowing melt to leave the magma body. We further address the question of possible melt fractions in mush zones and their lifetime. Estimating compaction times with effective solid matrix viscosities shows that several Ma lifetimes of >10% mushes are not stable for most wet and dry granite rheologies. Thus, the mechanical lifetime of high melt fraction mushes is limited and would rapidly evolve into a bimodal melt porosity distribution with 5 – 15% mushes and > 60% – 80 % magma caps. Therefore, high porosity mush zones (> 10 %) are ephemeral and to be long-lived the heat source must be replenished on longer time scales.