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Convective melting in a magma chamber: theory and numerical experiment.

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We present results of the numerical modeling of convective melting in a magma chamber in 2D. Model was pointed on the silicic system approximated with Qz-Fsp binary undersaturated with water. Viscosity was calculated as a function of the melt composition, temperature and crystal content and comprises for the pure melt $10^{4.5}$–$10^{5.5}$ Pas. Lower boundary was taken thermally insulated in majority of the runs. Size of FEM (bilinear elements) grid for velocity is 25x25 cm and for the integration of the density term 8x8 cm. Melting of the chamber roof proceeds with the heat supply due to the chaotic thermo-compositional convection and conductive heat loose into melted substrate. We compare our numerical data with existing semi-analytical models. Theoretical studies of the assimilation rates in the magma chambers usually use theoretical semi-analytical model by Huppert and Sparks (1988) (e.g., Snyder, 2000). We find that this model has strong points: 1) Independence of the melting rate on the sill thickness ($Ra>>Ra_c$) 2) Independence of the convective heat transfer on the roof temperature 3) Determination of the exponential thermal boundary layer ahead of the melting front

and weak points: 1) Ignoring the possibility of the crystallization without melting regime for narrow sills and dykes. 2)Neglecting of two-phase character of convection. 3)Ignoring of the strong viscosity variation near the melting front.

Independence of convective flux from the sill size (at $Ra>>Ra_c$) allows reducing of computational domain to the geologically small size (10-15 m). Concept of exponential thermal boundary layer is also rather important. Length scale (L_0) of this layer is related to the melting rate and thermal diffusivity coefficient k_T as $L_0=k_T/u_m$ and at the melting rate 10 m/yr becomes about 2 m. Such small scale implies that convective melting is very effective (small conductive heat loss) and part of the numerical domain filled with roof rocks can be taken small. In the H&S model conditions for the intruded magma to crystallize first and then switch to the roof melting or only crystallize were not defined. We did this in our numerical experiments in terms of the initial magma and roof rocks temperatures for particular sill size. Neglecting strong viscosity variation in the boundary layer at the melting front leads to the overestimation of the melting rate by H&S model on approximately 70% at T_m=940^{o}C. At T_m =800^{o}C effect of the crystals present in descending plumes compensates viscosity increase and numerical Um practically coincides with theoretical one (difference 8%).

Some researchers (Huber et al., 2010) use empirical and scaling results obtained from stagnant-lid convection (Davaille and Jaupart, 1993). We find that the later model is not applicable to the melting problem since super-exponential dependence of the viscosity from temperature is valid providing full solidification below eutectic temperature T_s. “Melting temperature” at the stagnant-lid style of convection is defined by Arhenius rheological parameters and bulk melt temperature and can be less than T_s. Our numerical study was applied to the estimation of the possible time frame and efficiency of the remelting of the silicic pyroclastics by superheated rhyolites in the caldera environment (Simakin and Bindeman, 2012).

Literature.

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