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# High magma flow rates during the emplacement of shallow felsic laccoliths

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Magma flow through the crust is typically directed vertically, although lateral emplacement had been documented during shallow magma reservoir construction in both volcanic and plutonic environments. We present a new numerical model to constrain magma flow conditions of shallow magma reservoirs that emplaced laterally by horizontal magma flow. The main goal is quantifying cooling rates to be compared with U-Pb zircon crystallization ages and temperatures. We apply these simulations on two case studies: La Gloria Pluton and San Gabriel Pluton, central Chile. Both are northwestward elongated plutons of 20 km in length and 4-6 km in width. They present ages between 10 to 13 Ma, and intrude volcanic sequences. Within-pluton age progression and subhorizontal mineral and magnetic lineations in these case studies suggest a southeastward horizontal propagation of the magma during the reservoir emplacement.

Assuming continuous lateral magma propagation, thermo-mechanical numerical simulations indicate that the minimum injection rate needed to preserve a liquid-dominated reservoir (i.e. <50 vol% crystals) for hundred thousand years is a few times larger than that obtained by dividing the estimated pluton volume by the age range. This indicates that most of the magma that flowed through the magma reservoirs was evacuated away from the site of emplacement, implying that injection rates inferred from the plutonic record are underestimated with respect to the actual magma fluxes. An advective transfer of magma through plutonic bodies, particularly in shallow systems with a horizontal flow component such as La Gloria pluton, can partly explain why the averages of pluton-filling rates are lower than the injection rates obtained in volcanic systems or by numerical simulations of incremental magma emplacement. Magma advection rates necessary to maintain reservoirs' temperature above solidus are typically inverse to their preserved volume, because the faster cooling of relatively small reservoirs. The higher advection of smaller reservoirs could be favored by their ability for reaching a critical overpressure to evacuate magma, with respect to more voluminous reservoirs.

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