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Why are plutons dry? Outgassing mechanisms of crustal magmatic bodies

andrea parmigiani (1), Christian Huber (2), Olivier Bachmann (1), and Sébastien Leclaire (3)

(1) ETHZ, Earth Sciences Department, CH, (2) GeorgiaTech, School of Earth and Atmospheric Sciences, US, (3) University of Geneva, Computer Science Department, CH

Magma bodies crystallizing to completion within the crust (i.e. forming plutons) typically undergo significant amounts of second boiling (i.e. cooling and crystallization of dominantly anhydrous minerals lead to volatile saturation and bubble nucleation/growth). The low water content (< 1 wt % H_2O) and vanishing residual porosity of most plutons, despite the high volatile concentrations of their magma sources (commonly > 6 wt % H_2O for evolved compositions in subduction zones), testify that outgassing from crystalline mushy reservoirs must be an efficient and widespread process. Understanding this outgassing mechanism is key to understand how volatiles are transferred from mantle depths to the surface.

From the hydrodynamics point of view, the mass balance of exsolved volatiles in these plutonic bodies is controlled by the difference between the rate of degassing (formation of bubbles by 2nd boiling) and outgassing (transport of gas out of the magma body). In this study, we use pore-scale multiphase modeling to constrain these rates as function of the crystal and volatile contents in the magma. Because second boiling is a slow process, one can consider equilibrium degassing as a valid assumption. Outgassing, on the other end, is controlled by the competition between buoyancy, capillary and viscous forces. Our numerical simulations are used to determine the most efficient setting for gas to escape its magmatic trap. The high viscosity of interstitial melts and capillary forces (due to the non-wetting nature of the gas phase with most of the mineral phases in magmatic systems) strongly limits gas transport until vertically extensive gas channels are generated. We show that channels can readily form in volatile-rich coarse-grained mush zones in the upper crust, and allow efficient outgassing at crystallinities around 50-75 vol%, when millimetric bubbles can still win capillary resistive forces.