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A finite-element marker-in-cell simulation code for thermo-chemically coupled magma dynamics in a visco-elasto-plastic host rock

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Many prominent geodynamic scenarios such as subduction zones, plate collision and orogeny formation, mid-ocean ridges, continental rifting, etc. involve a significant amount of active magmatism. However, many numerical simulations used to address related questions focus on the deformation of the solid rock phase only, sometimes taking into account the magma dynamics in the form of some parameterized weakening mechanism. On the other hand, simulations specifically developed for magma dynamics problems have largely been restricted to the context of mantle dynamics and are not designed to deal with brittle tectonic deformation of the rock matrix as it occurs in the lithosphere and crust. Here, a 2-D finite-element marker-in-cell numerical method is presented capable of simulating thermally and compositionally coupled two-phase flow problems in a realistically deforming mantle, lithosphere and crust. The modeling approach is based on a set of well accepted equations for the conservation of mass, momentum, energy and composition, completed by constitutive laws for visco-elasto-plastic shear and compaction stresses and a much simplified yet thermodynamically consistent melting model depending on temperature, pressure and composition. The simulation code is written in Matlab and is capable of solving up to 500k degrees of freedom (requiring 2m marker particles) within few minutes per time step on a standard desktop computer. Long-term simulations of that size require run times of one to three weeks. The non-linear system of equations is solved using a Picard iterative scheme, where the linearized system of equations is solved directly during each iterative step. Sufficient convergence is usually obtained within less than 10 non-linear iterations. Generally, this numerical method is versatile, accessible and efficient enough for a wide range of 2-D problems.