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Magma ascent in planetesimals controlled by grain size

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In the early solar system, internal heating by short-lived radiogenic nuclides led to significant melting of rocky planetesimals. This altered their physical and chemical interior structure on a time scale comparable to disk-stage accretion processes. Two hypotheses for the evolution of heated planetesimal interiors are prevalent in the literature. In the *global magma ocean* scenario, the whole interior of sufficiently early-formed planetesimals experienced nearly complete melting, resulting in turbulent convection and core-mantle differentiation via the rainfall mechanism. In the *magma sill* scenario, ascending buoyant melts gradually depleted the deep interior of the radiogenic heat source. In this case, core formation may have proceeded via percolation; erupted lavas buried the primitive lid and chemically stratified the body.

To investigate the parameter controls that separate the *magma ocean* and *magma sill* end-member scenarios, we study the genesis and segregation of silicate melts in early solar system planetesimals using a novel computational method for reactive, disequilibrium, multi-component melting and two-phase fluid flow. We find that for planetesimals with rapid magma transport, melt segregation produces distinct radial structure. A key control on this segregation is the mean grain size of silicate minerals, suggesting that the time scale of grain growth – either before or after planetesimal accretion – governed internal magma flow. Furthermore, the formation time of the body sets the total amount of energy available for melting. As a result of this, our models indicate a peak in the propensity for melt segregation in bodies formed at around $\sim$1 Myr after CAI formation. Regardless of whether a planetesimal evolves toward a global magma ocean or melt-segregated sill structure, temperature inversions due to rapid aluminum-26 redistribution are limited to bodies formed earlier than $\sim$1 Myr after CAIs. In general, if grains did not grow beyond sizes of $\sim$1 mm before the peak of internal melting, only strongly reducing environments, such as found for enstatite chondrite compositions, could generate substantial magma segregation due to their elevated solid-melt density contrast.

Our findings suggest a link between the time and orbital location of planetesimal formation and their subsequent structural and chemical evolution. The results have implications for the mode of core formation and the redistribution of planetary materials in the crustal stripping paradigm of planetary accretion.