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Magma ascent in planetesimals: control by grain size

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Abstract

Rocky planetesimals in the early solar system melted internally and evolved chemically due to radiogenic heating from ^{26}Al. Here we quantify the parametric controls on magma genesis and transport using a coupled petrological and fluid mechanical model of reactive two-phase flow. We find the mean grain size of silicate minerals to be a key control on magma ascent. For grain sizes larger than $\sim$1 mm, melt segregation produces distinct radial structure and chemical stratification. This stratification is most pronounced for bodies formed at around 1 Myr after Ca,Al-rich inclusions. These findings suggest a link between the time and orbital location of planetesimal formation and their subsequent structural and chemical evolution.

According to our models, the evolution of partially molten planetesimal interiors falls into two categories. In the *global magma ocean* scenario, the whole interior of a planetesimal experiences nearly complete melting, resulting in turbulent convection and core-mantle differentiation by the rainfall mechanism. In the *magma sill* scenario, segregating melts gradually deplete the deep interior of the radiogenic heat source. In this case, magma may form melt-rich sills beneath a cool and stable lid, while core formation would proceed by percolation.

Our findings [1] suggest that grain sizes prevalent during the internal-heating stage governed magma ascent in planetesimals. Regardless of whether evolution progresses toward a global magma ocean or segregated magma sills, our models predict that temperature inversions due to rapid ^{26}Al redistribution are limited to bodies formed earlier than $\sim$1 Myr after CAIs. We find that if grain size was smaller than $\sim$1 mm during peak internal melting, only elevated solid-melt density contrasts (such as found for enstatite chondrite compositions) would allow substantial melt segregation to occur.

Melt segregation regimes

We define the non-dimensional *melt segregation number* to quantify the propensity of a planetesimal to undergo substantial melt segregation,

$$R_{\mathrm{seg}} = \log_{10}\left(\frac{k_\phi \Delta\rho g_0 c_{\mathrm{p}} \Delta T_0}{R_{\mathrm{P}} \mu H_{0,^{26}\mathrm{Al}}}\right) , \qquad (1)$$

with rock permeability, k_ϕ, solid-melt density contrast, $\Delta\rho$, planetesimal surface gravity, g_0, specific heat of silicates, c_{p}, temperature difference between planetesimal accretion temperature and silicate solidus, ΔT_0, planetesimals radius, R_{P}, silicate melt viscosity, μ, and the decay power of ^{26}Al, $H_{0,^{26}\mathrm{Al}}$.

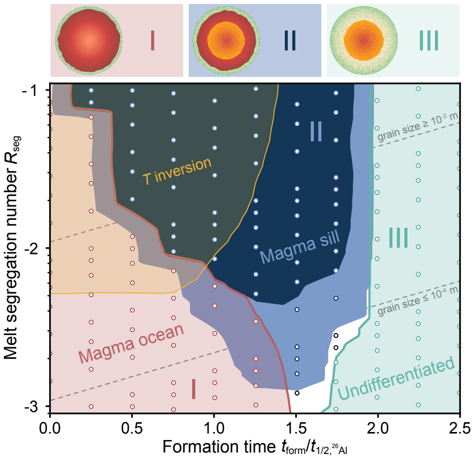

Figure 1: Melt segregation regimes and potential temperature inversions during planetesimal evolution [1].

References

[1] Lichtenberg, T., Keller, T., Katz, R. F., Golabek, G. J., and Gerya, T. V., arXiv:1802.02157.