Magma ascent in planetesimals: control by grain size

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arXiv:1802.02157
Thermal inversions due to melt segregation?

- Early-accreting planetesimal
- Efficient volatile loss via Darcy flow
- Positively buoyant melts; achondritic crust formed
- Negatively buoyant melts; chondritic crust preserved
- CV and CM carbonaceous chondrite bodies

Progressive radiogenic heating

e.g., Wilson & Keil 17
Steady-state melt ascent scaling

Melt segregation number

\[ R_{\text{seg}} = \log_{10} \left( \frac{\tau_{\text{heat}}}{\tau_{\text{segr}}} \right) = \log_{10} \left( \frac{k_\phi \Delta \rho g_0 c_p \Delta T_0}{R_P \mu H_{0,26\text{Al}}} \right) \]

Permeability:

\[ k_\phi = \frac{a_0^2 \phi^n}{b (1 - \phi)^m} \]

- \( \Delta \rho \): Solid-melt density contrast
- \( \Delta T \): Temperature contrast
- \( H_{0,26\text{Al}} \): \( ^{26}\text{Al} \) decay power
- \( \phi \): Melt fraction (porosity)
- \( a_0 \): Grain size
- \( c_p \): Specific heat
- \( \mu \): Melt viscosity
- \( R_P \): Planetesimal radius
- \( g_0 \): Surface gravity
- \( \phi = 0.4 \)
- \( t = 0 \)
- \( \Delta \rho = 1200 \text{ kg/m}^3 \)
- \( \Delta \rho = 120 \text{ kg/m}^3 \)
Two-phase magma dynamics + multi-component thermo-chemistry

- Split up planetesimal rock body into multiple components, follow individually

- **Two-phase, thermo-chemical** evolution in 1D column setup (*Keller & Katz 16*)

- ‘Dry’ compositional setup:
  - Olivine/\textit{olv} (~50%, refractory)
  - Pyroxene/\textit{pxn} (~35%, fertile)
  - Feldspar/\textit{fsp} (~15%, $^{26}$Al)

- Parameter study of solid-melt density contrast, grain sizes (permeability), formation time
Melt segregation regimes

\[ R_{\text{seg}} = \log_{10} \left( \frac{\tau_{\text{heat}}}{\tau_{\text{segr}}} \right) \]
\[ = \log_{10} \left( \frac{k_{\phi} \Delta \rho g_0 c_p \Delta T_0}{R \mu H_{0,26}\text{Al}} \right) \]

I Magma ocean
Global interior magma ocean
Chemical & isotopic equilibration
Shallow chondritic lid at surface
Adiabatic interior \( T \)

II Magma sill
Efficient magma segregation
Chemical differentiation
Shallow chondritic lid at surface
Potential \( T \) inversion

III Undifferentiated
Zero to partial silicate melts
Primordial chemical signature
Thick chondritic lid
Inside-out \( T \) decrease

Lichtenberg, Keller, Katz, Golabek, Gerya (E&PSL, in revision, arXiv:1802.02157)
Summary & Conclusions

- Two melting regimes:
  - Control: grain size, formation time, $fO_2/\Delta \rho$
    - (i) global magma ocean ($t_{\text{form}} < t_{26,\text{Al}}$)
    - (ii) magma sill ($t_{\text{form}} \sim 1 \text{ Myr} + \text{grain size} > 1 \text{ mm}$)
- Temperature inversions limited in parameter space (< 250 K)
  - Questions use of simple thermal models for age dating
- Constrains possible core formation regimes
- Consistent with/implications for:
  - Paucity of olivine on Vesta’s surface; ‘missing olivine’
  - Time gap between basalts and CAIs/youngest irons

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