Numerical modelling of a cooling magma chamber

Vít Beran
Charles University, Prague

September 12, 2026

Research gap

Magma bodies represent a complex intersection of fluid mechanics, geochemistry, petrology, and geological processes.

1. Is convection in magma reservoirs longevous or short-lived?
2. Equilibrium crystallisation or fractional crystallisation?
3. Which mechanisms of fractional crystallisation prevail (in-situ vs. crystal settling)?
4. Do magma chambers even exist in the classical sense (big-tank vs. mushy lenses)?

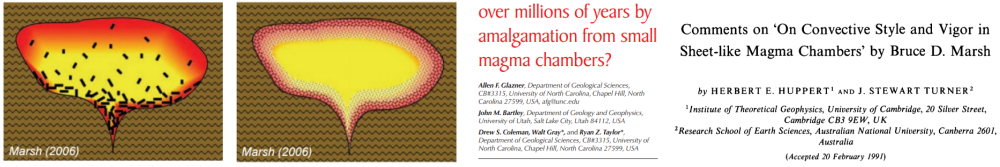


Figure: Selection of the open questions.

Research gap

Magma bodies represent a complex intersection of fluid mechanics, geochemistry, petrology, and geological processes.

1. Is convection in magma reservoirs longevous or short-lived?
2. Equilibrium crystallisation or fractional crystallisation?
3. Which mechanisms of fractional crystallisation prevail (in-situ vs. crystal settling)?
4. Do magma chambers even exist in the classical sense (big-tank vs. mushy lenses)?

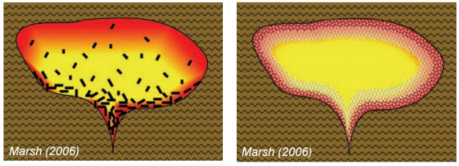


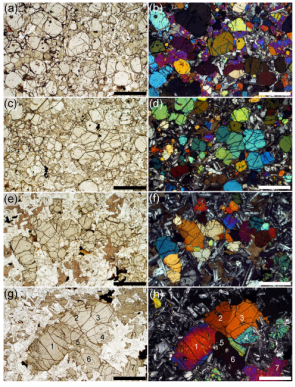
Figure: Selection of the open questions.

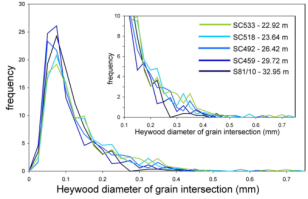
Clues about crystal settling

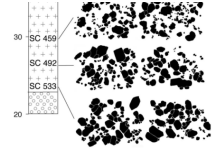


1989, 1991). The disagreement could be resolved if consensus could be reached over the interpretation of features preserved in exposed examples of fully solidified intrusions. Evidence used to argue for convection includes: the preservation of depositional and erosional structures in the floor cumulates of the Skaergaard intrusion, indicative of significant flow of magma across the floor (Irvine et al. 1998); the development of identical mineral assem-

Holness (2017)





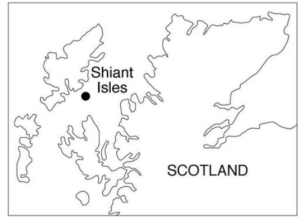


Olivine cargo

Crystal settling and convection in the Shiant Isles Main Sill

Marian B. Holness[1] · Robert Farr[2] · Jerome A. Neufeld[1,3,4]



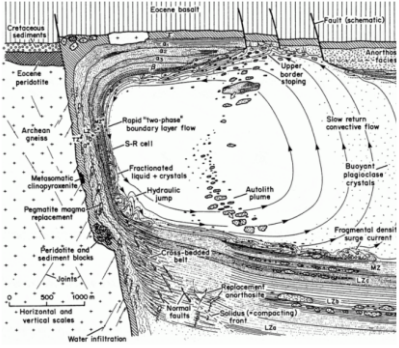


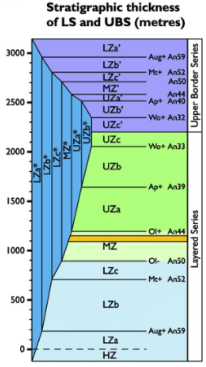
1989, 1991). The disagreement could be resolved if consensus could be reached over the interpretation of features preserved in exposed examples of fully solidified intrusions. Evidence used to argue for convection includes: the preservation of depositional and erosional structures in the floor cumulates of the Skaergaard intrusion, indicative of significant flow of magma across the floor (Irvine et al. 1998); the development of identical mineral assem-

Holness (2017)

Clues:
- fining / coarsening
- layering
- symmetry of upper and lower zones

Skaergaard (aka petrological laboratory)



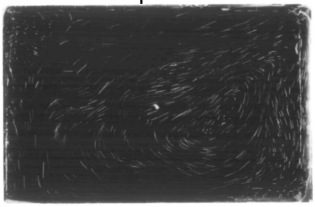


McBirney 1996



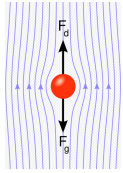
Crystal settling

Dust-like particle



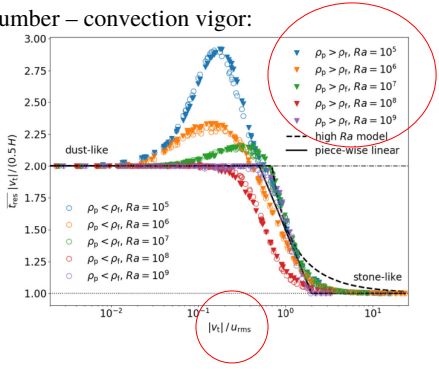
Martin & Nokes (1989)

Stone-like particle



$$|v_t|(a) = \lambda a^2, \quad \lambda = \frac{2g\,\Delta\rho}{9\,\nu\,\rho_f}$$

Rayleigh number – convection vigor:





J. Mungall - Howard Street Robinson Lecture

Residence time of inertial particles in 3D thermal convection: Implications for magma reservoirs

Vojtěch Patočka [a,*], Nicola Tosi [b], Enrico Calzavarini [c]

[a] Faculty of Mathematics and Physics, Department of Geophysics, Charles University, Prague, Czech Republic
[b] Institute of Planetary Research, German Aerospace Center (DLR), Berlin, Germany
[c] Univ. Lille, ULR 7512 - Unité de Mécanique de Lille - Joseph Boussinesq (UML), F-59000 Lille, France



Patočka et al. (2022)

The CSD theory



Crystal size distribution (CSD) in rocks and the kinetics and dynamics of crystallization

I. Theory

CSDs aka MICROSTRUCTURE

Bruce D. Marsh
Department of Earth and Planetary Sciences, The Johns Hopkins University, Baltimore, MD 21218, USA

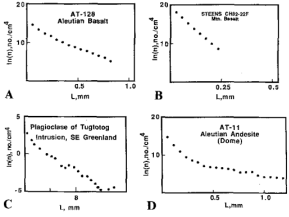
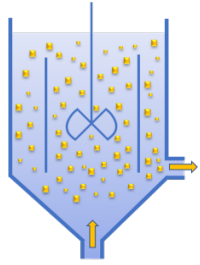


Fig. 1 A–D. Examples of fairly typical plagioclase crystal size distributions (CSDs) of volcanic rocks from the Aleutian Islands (*AT*) Steens Mtn., Oregon, and the Tugtotog intrusion of southeast Greenland. Population density (n, actually $\ln(n)$) in units of numbers of crystals per size (L) per volume (i.e. no. per cm^4) is plotted against crystal size L (mm)

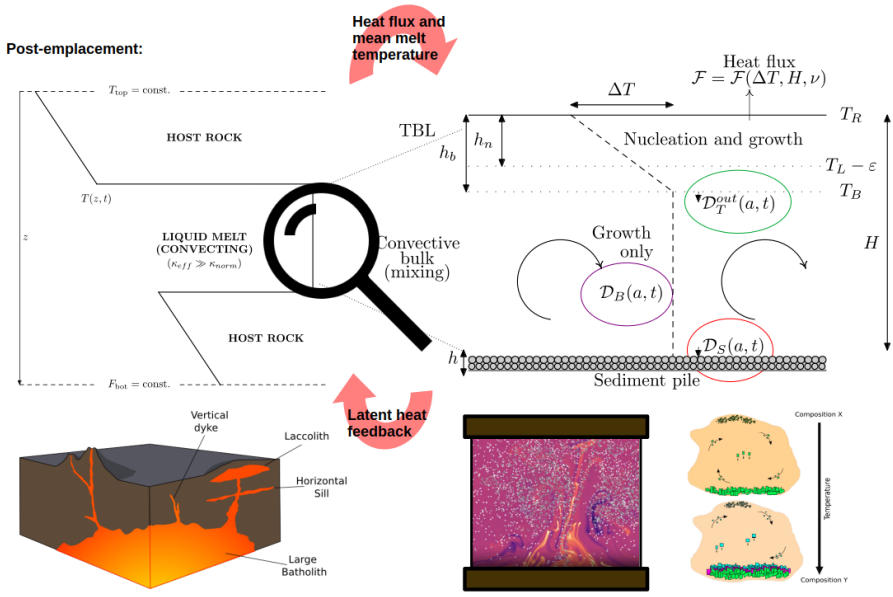
Marsh 1988



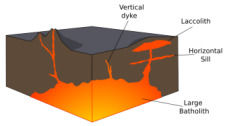
Marsh (1988): often predicts log-linear distributions, modified by further processes.

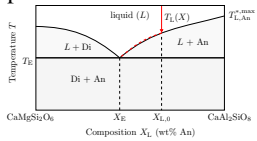
Log-linear CSD, however, implies the process is not size-selective!

ParMaCH: Parameterised model of a cooling magma chamber

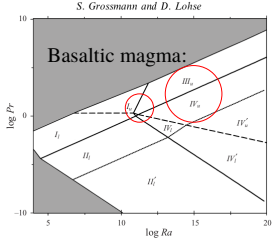


Petrological component:
- melt evolution





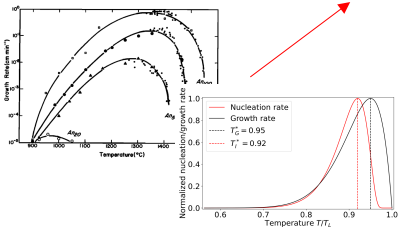
Grossmann-Lohse theory.



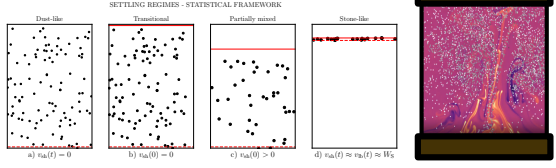
Chamber coupled to the host rock via 1D heat equation.

ParMaCH components

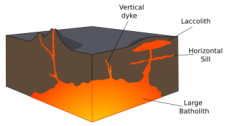
Realistic crystallisation kinetics.

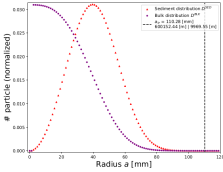


Crystal population dynamics.



Petrological component:
- melt evolution etc.





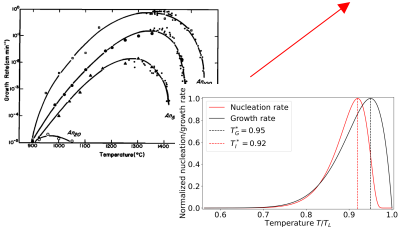


Chamber coupled to the host rock via 1D heat equation.

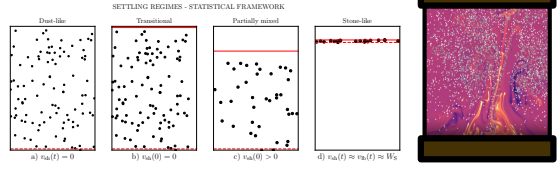
ParMaCH components

Theoretical prediction

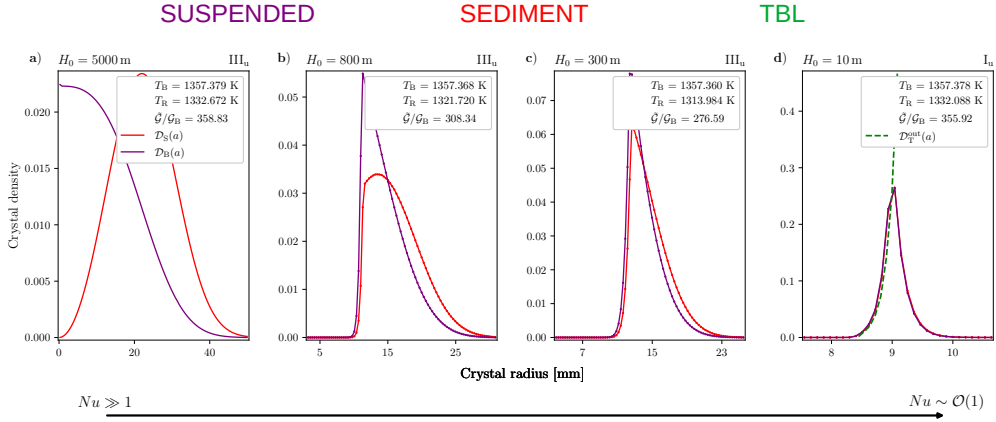
Realistic crystallisation kinetics.



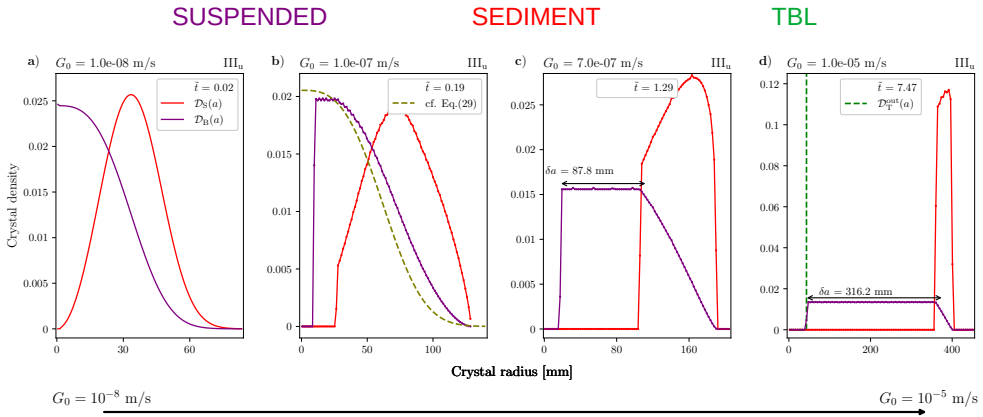
Crystal population dynamics.



Crystal settling signature I (growth in the TBL)

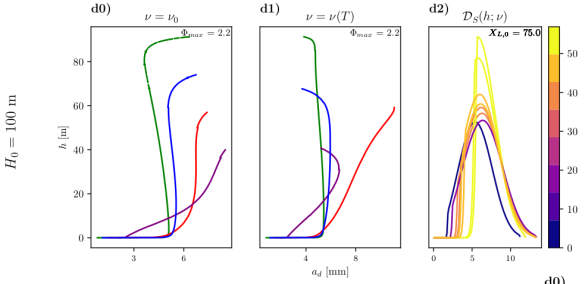


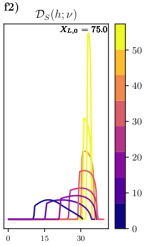
Crystal settling signature II (dust-like — stone-like transition)



Crystal size grading in the cummulate

Model A: immediate nucleation



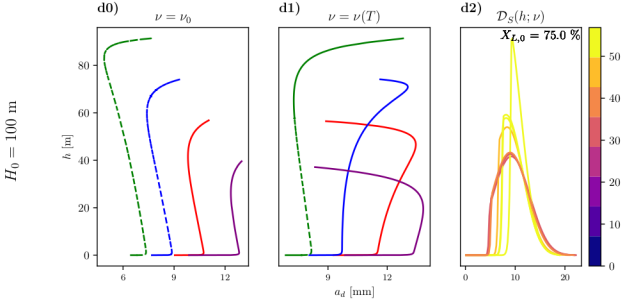


Increased growth rate, check CSDs!

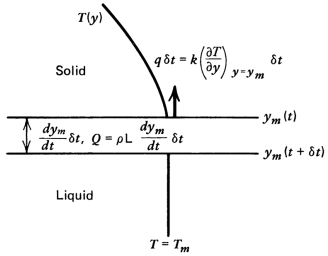
Crystal size grading:

$$\vec{a}'_{\mathrm{d}} \sim \left(\frac{\nu'}{\nu} + \frac{\mathcal{G}'_{\mathrm{B}}}{\mathcal{G}_{\mathrm{B}}} + \frac{H'}{H} \right)$$

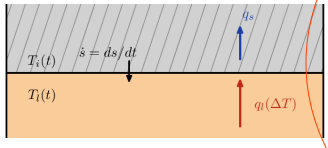
Model B: delayed nucleation



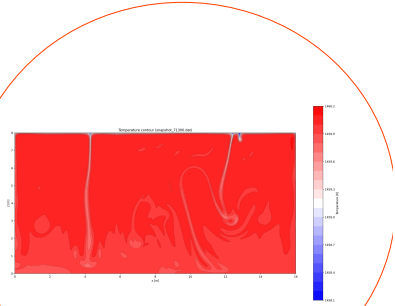
Convective vigor & latent heat



Classic Stefan problem.



Moving phase boundary with a convecting fluid underneath.

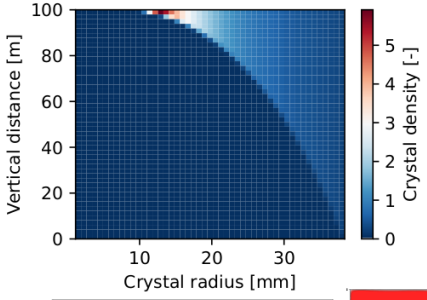


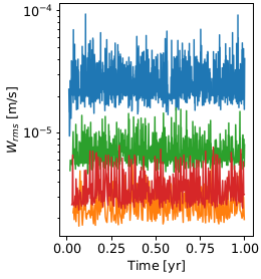
Internally heated convection (IHC).

$$\rho_f c_p \frac{\mathrm{d}T}{\mathrm{d}t} = -\mathscr{F} + \rho_f L \frac{\mathrm{d}\Phi}{\mathrm{d}t},$$

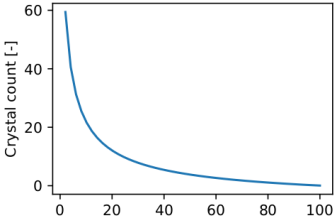
$$\rho L \dot{s} = k_s \left.\frac{\partial T}{\partial z}\right|_{s^-} - \underbrace{k_l \left.\frac{\partial T}{\partial z}\right|_{s^+}}_{\mathscr{F}(\Delta T = T_l - T_i)},$$

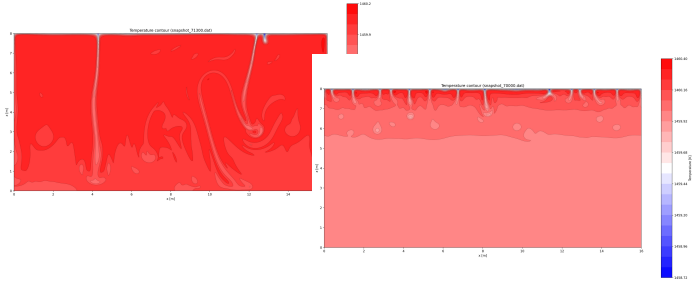
Latent heat is generally spatially variable!





UNIFORM
TBL-DOMINATED






Thank you for your attention!