How Robust Are Our Assumptions in Using Crystal-Hosted Melt Embayments to Estimate Magma Ascent Rate?

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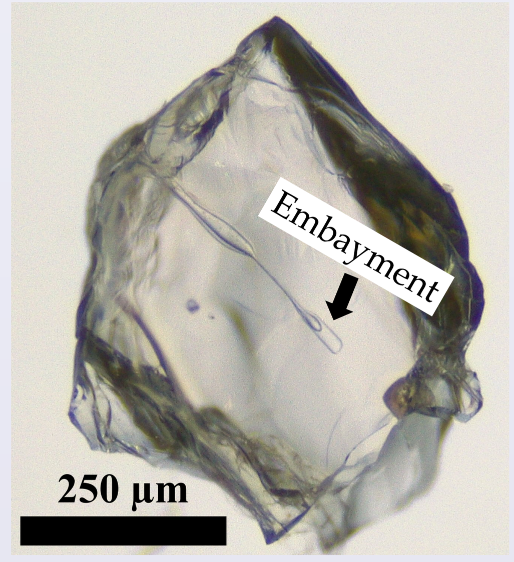
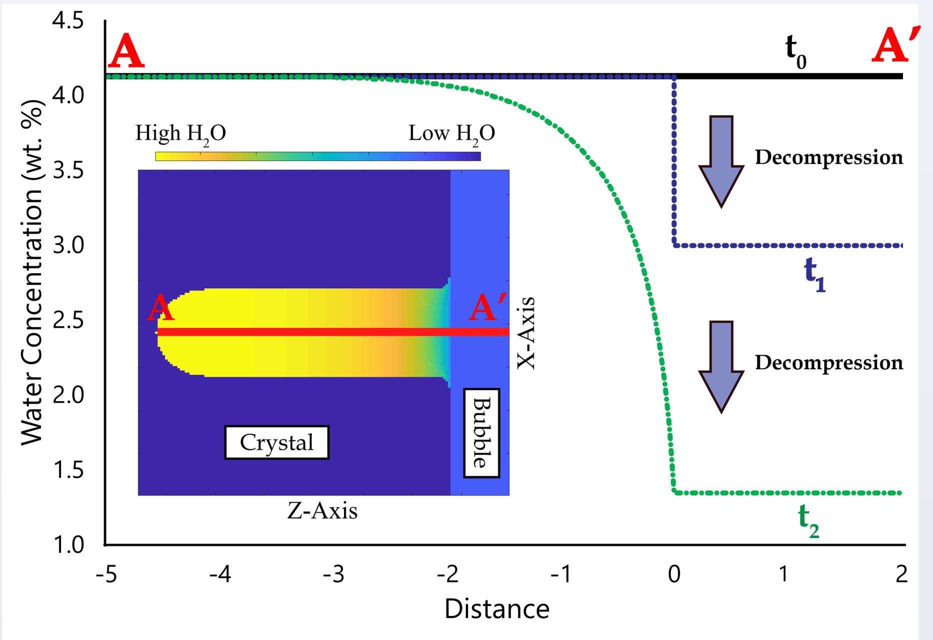
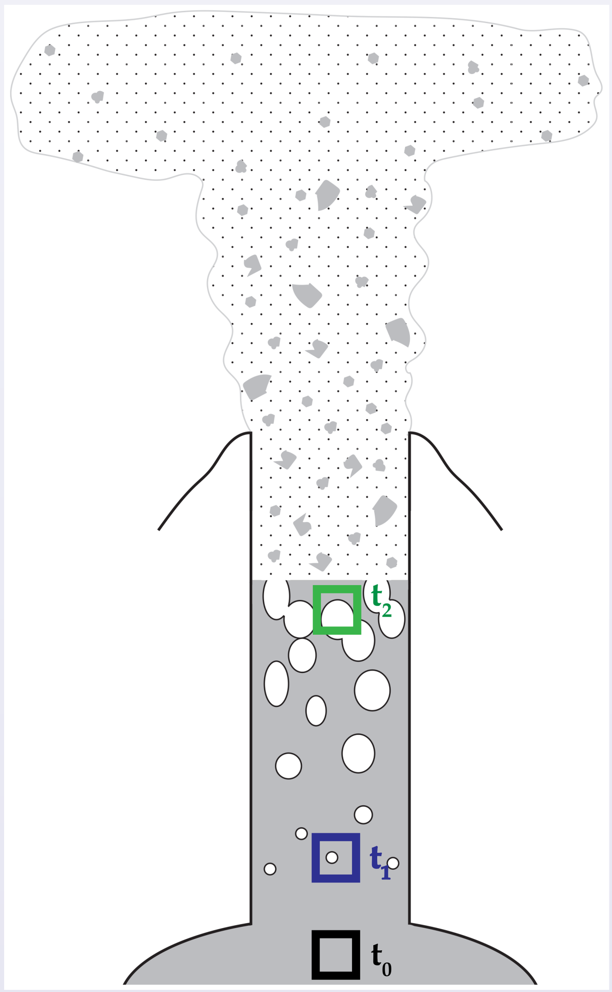
Melt Embayments and Calculating Magma Ascent Rate

What are melt embayments?

- Pockets of melt trapped within crystals
- Remain open to the host melt and can exchange elements (e.g., H, S, C, F)
- Some embayments contain bubbles, but unclear as to why







Melt Embayment Modeling (MEM)

- Concentration gradients of volatile elements within embayments preserve the timescale of magma ascent
- Gradients can be used as output constraints for diffusion models
- t_0 - during storage, embayment and melt are in equilibrium
- t_1 - at some supersaturation, bubbles nucleate and decrease water in outside melt; diffusion out of embayment starts at this point
- t_2 - at fragmentation, diffusion stops as the sample is quenched

Research Question

What is the error introduced to modeled ascent timescales by 3 common simplifications?

1. 1D vs 3D models and embayment geometry
2. Equilibrium vs disequilibrium degassing
3. Isothermal vs isentropic ascent

Symbol	Parameter	Units
C	water concentration	weight percent
C_m	modeled water concentration	weight percent
C_r	real water concentration	weight percent
D	diffusivity	$\mu m^2 s^{-1}$
α	weighting factor	unitless
N	number of elements	unitless
P_i	initial pressure	MPa
P_f	final pressure	MPa
T	temperature	°C
t	time	s
x, y, z	position	µm

Modeling Parameters - General

General Workflow

1 Run model with non-simplified conditions - produce profile → **2** Treat previous profile as the "real" profile a model with simplifying assumptions needs to fit → **3** Run model with simplified conditions - coarse search of decompression rates → **4** Run model with simplified conditions - fine, targeted search of decompression rates

Running the Models

- Solve Fick's 2nd Law in either 1D or 3D using centered finite differences approach
- For 3D model, add terms for y-dimension and z-dimension

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial C}{\partial x}\right)$$

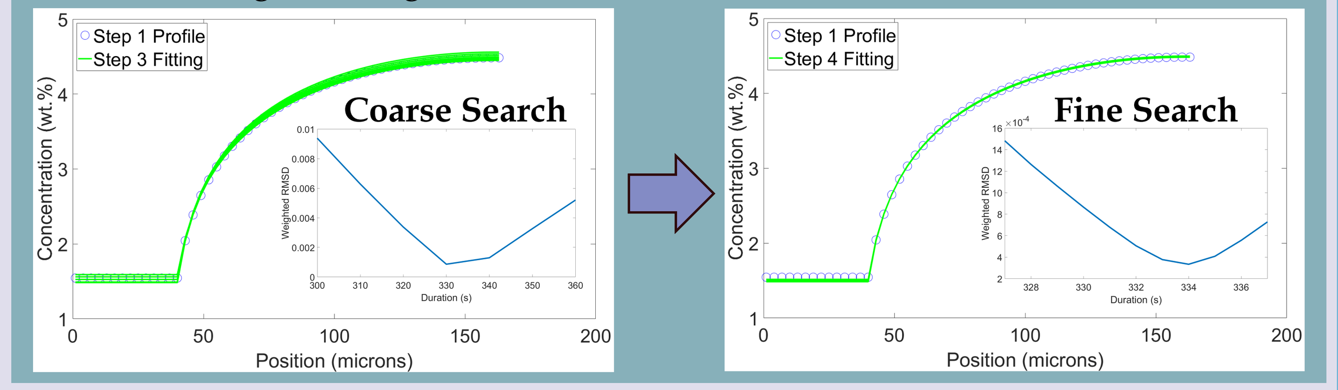
- Use water solubility model of Liu et al. (2005) and water diffusivity model of Ni and Zhang (2008)

	Geometry	Disequilibrium	Isentropic
P_i (MPa)	200	200	200
P_f (MPa)	20	10	20, 10, and 5
T (°C)	800	850	800
Embayment Length (µm)	242 or 268	165	165

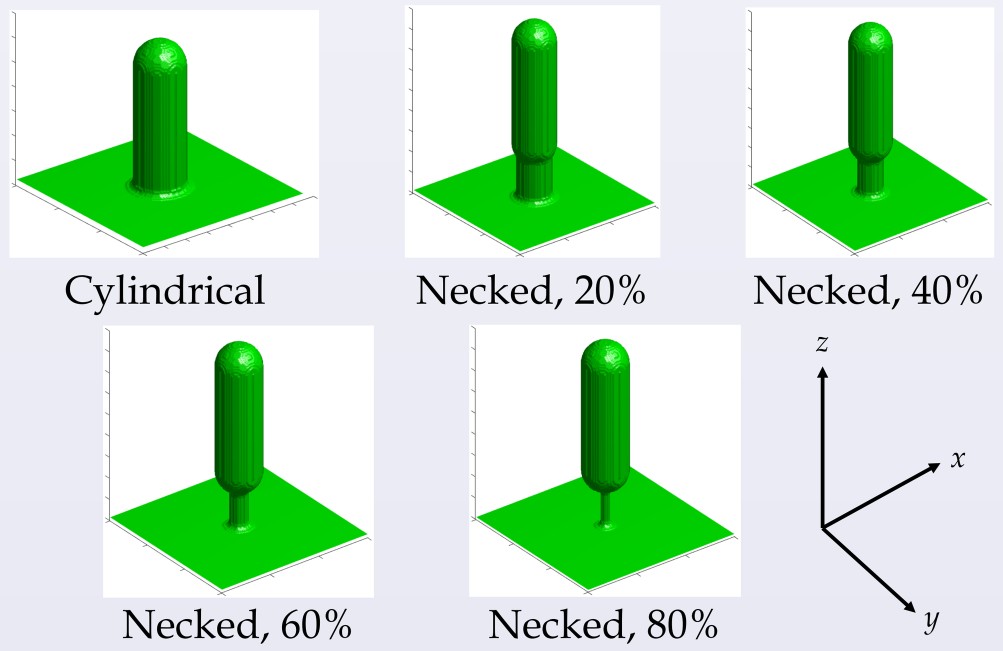
Fitting the Profiles

- Use weighted RMSD - high weight given to position at mouth of embayment, forces best solution to fit final pressure
- Iteratively search decompression times from broad to targeted range to find best fit

$$RMSD = \sqrt{\frac{1}{\sum\alpha}\sum\alpha\frac{(C_m - C_r)}{N}}$$

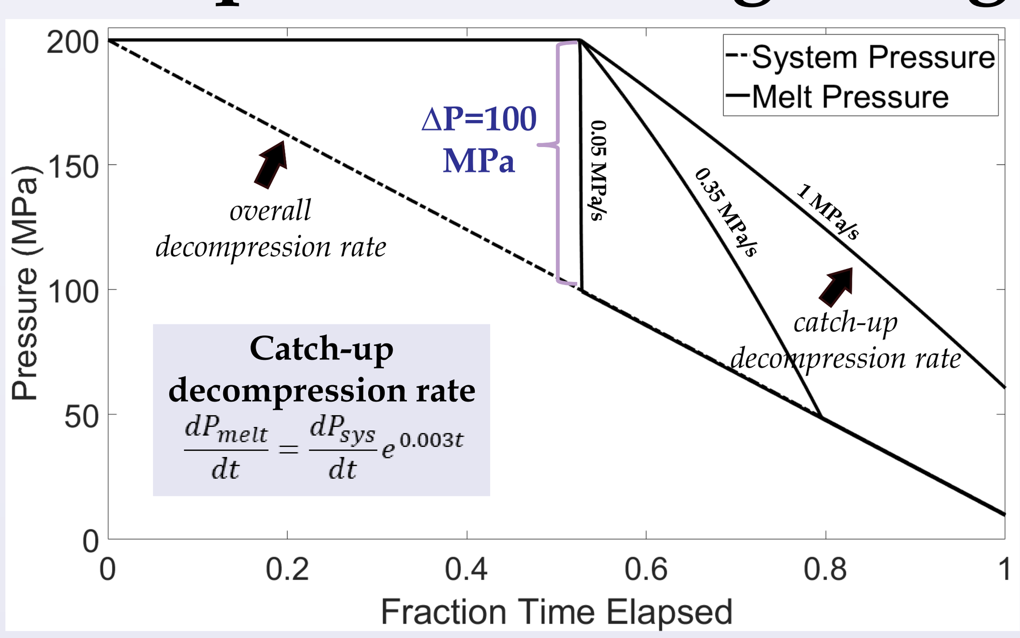


Modeling Parameters - Embayment Geometry



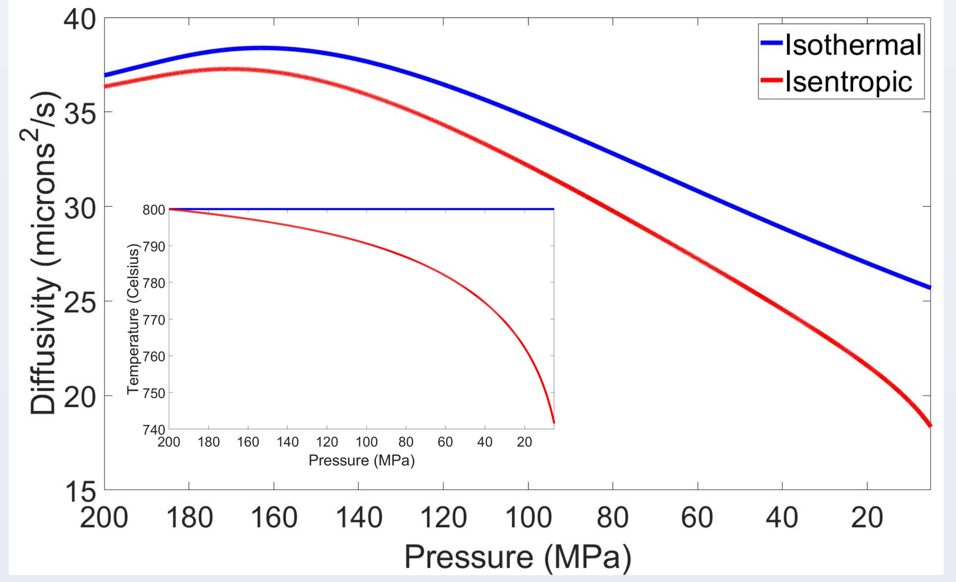
- 3D diffusion model was run for a range of decompression rates with the above geometries
- 1D profile taken along z-axis, through the midpoint of the x- and y-axes

Modeling Parameters - Disequilibrium Degassing



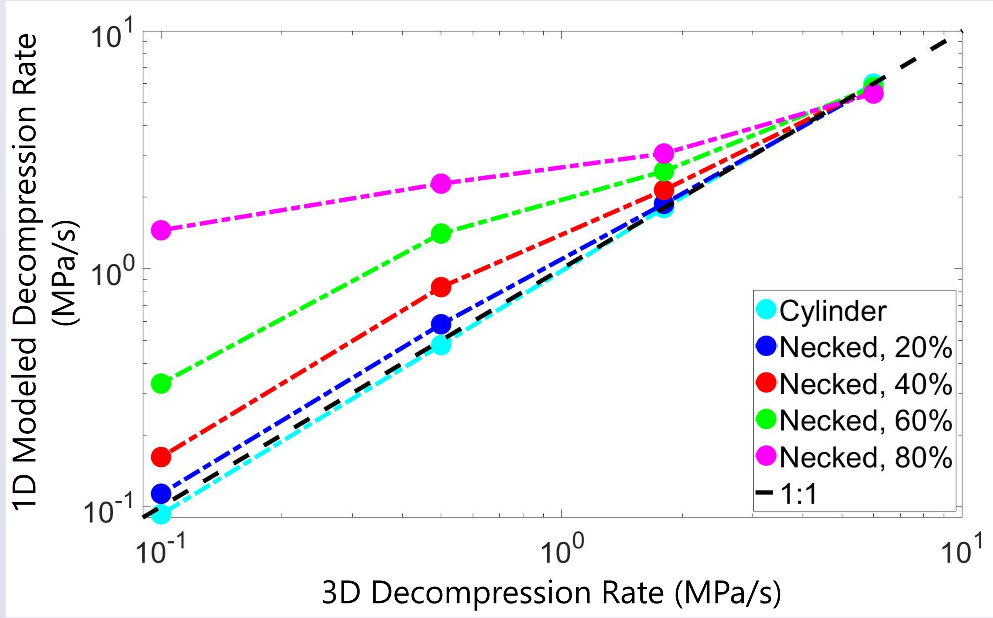
- Bubble nucleation (and thus diffusion) not allowed to start until 100 MPa supersaturation
- Supersaturation pressure in the melt decreased at an exponential rate to produce curves similar to Mangan and Sisson (2000)

Modeling Parameters - Isentropic Ascent



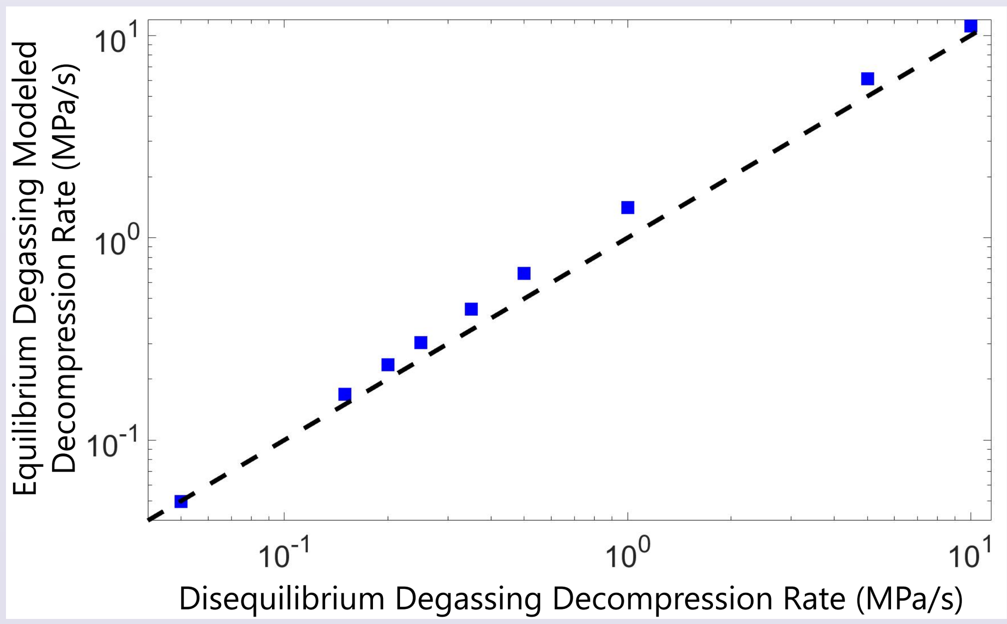
- T-P path, water saturation determined via rhyolite-MELTS (Gualda et al., 2012; Ghiorso and Gualda, 2015), using Glass Mountain, CA composition (Grove et al., 1997)
- 3 different quench pressures were tested for each decompression rate - 20, 10, and 5 MPa

Results - Embayment Geometry



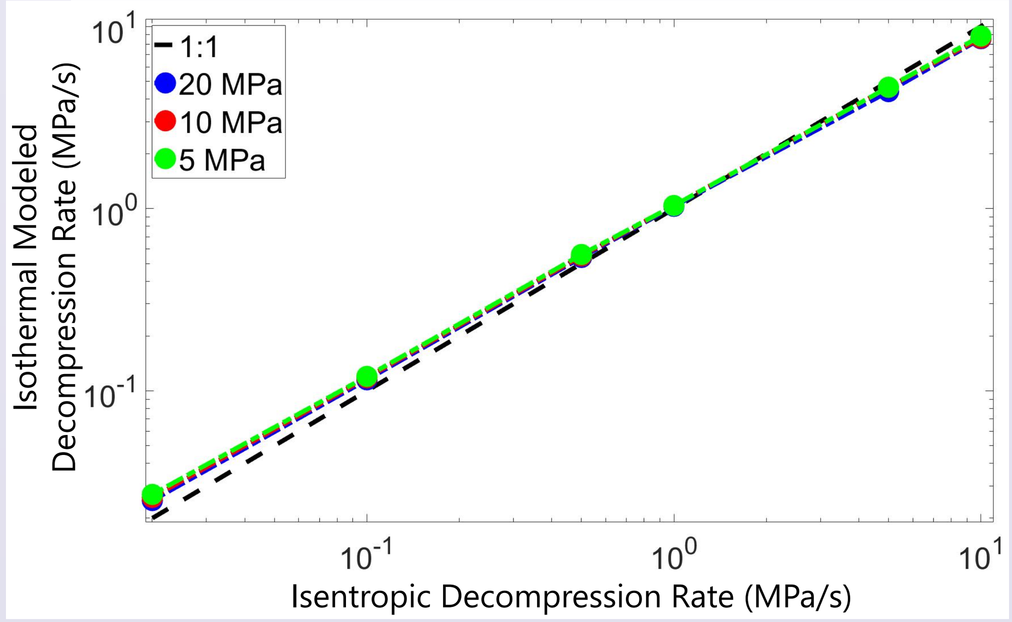
- Cylindrical geometry generally has good agreement between 1D and 3D models
- 1D models of necked geometries deviate more from the 3D timescale the more restricted the opening and the slower the decompression rate

Results - Disequilibrium Degassing



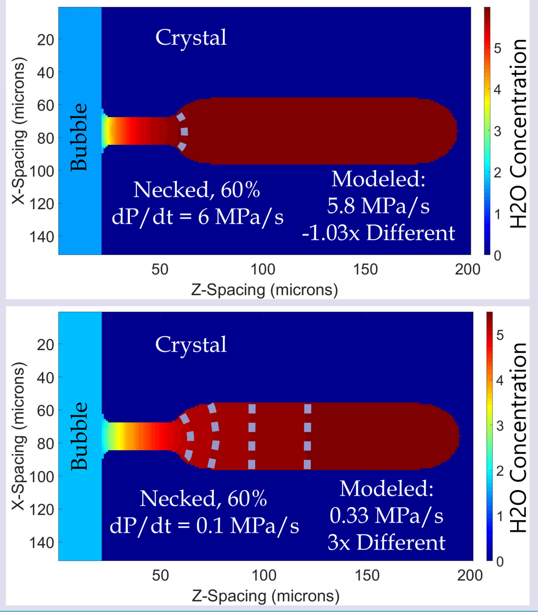
- Equilibrium degassing timescales generally agree well with disequilibrium degassing timescales
- Biggest deviation occurs for mid-range decompression rates, and little deviation for very fast and very slow decompression rates

Results - Isentropic Ascent



- Isothermal models generally in good agreement with isentropic models
- For fast decompression rates, isothermal models slightly undercalculate the rate applied during isentropic ascent
- For slow decompression rates, isothermal models slightly overcalculate the rate applied during isentropic ascent

Summary



Effect of Geometry

- Necked embayments produce deviations between 1D and 3D models once the diffusion front moves beyond necked region
- Water flux converges to pass through narrower region, resulting in increased water content that 1D models cannot account for
- Increased water content makes it appear like less diffusion has occurred, resulting in longer 1D modeled timescales

Effect of Disequilibrium Degassing and Isentropic Ascent

- These two assumptions appear to have a minimal influence on modeled ascent timescales, so are "safe" simplifications
- These factors cannot be the cause of unexpected calculated ascent rates

Acknowledgements

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References

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