

COMSOL CONFERENCE CAMBRIDGE 2026

Thermo-Poroelastic Modeling of Channelized Melt Fingers in Crystal-Rich Magma Reservoirs

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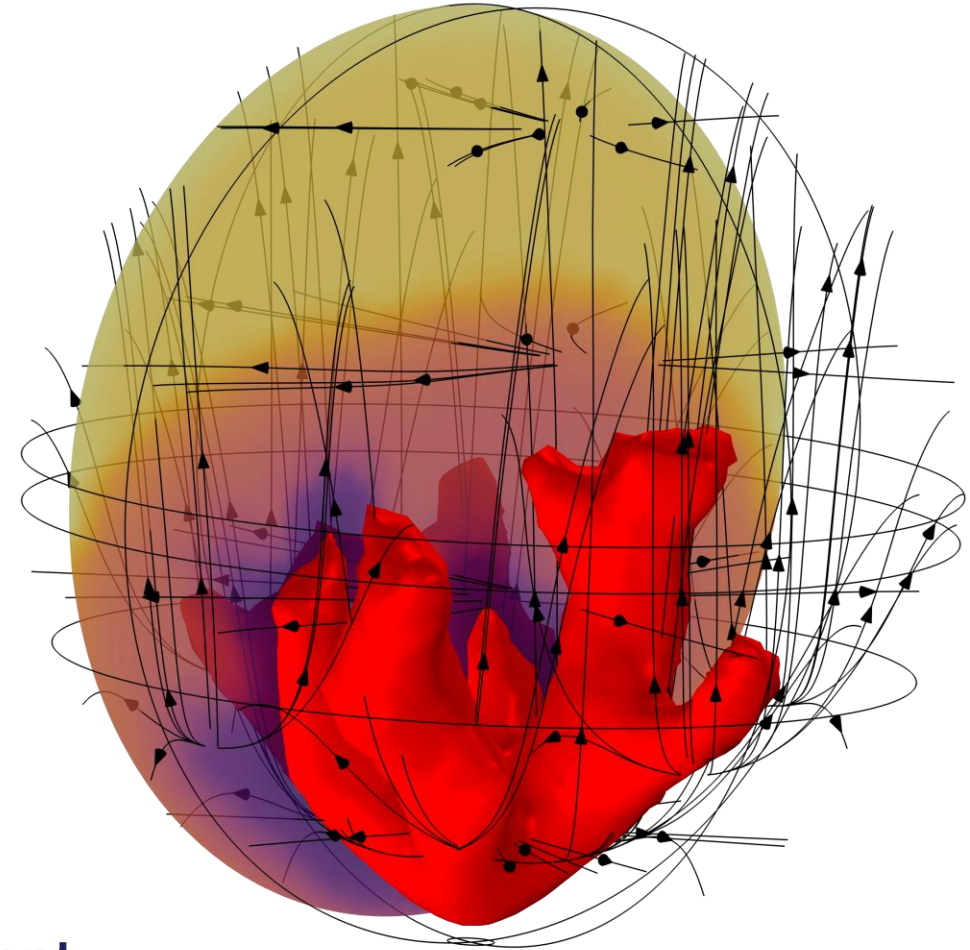
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University
of Exeter



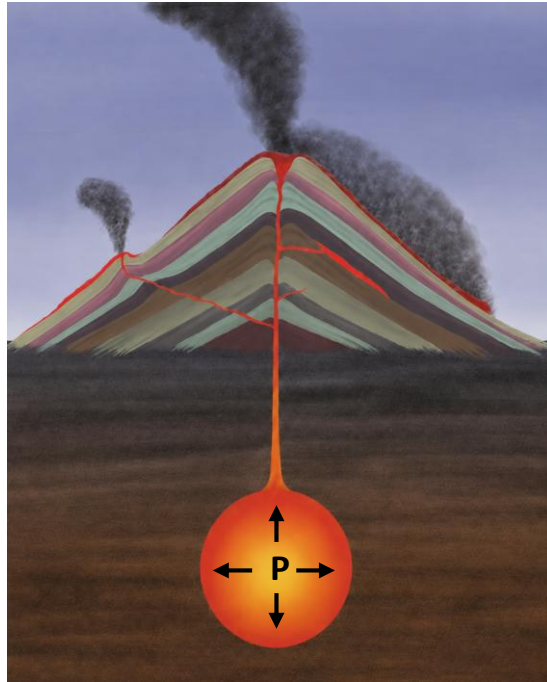
Natural
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The mush paradox

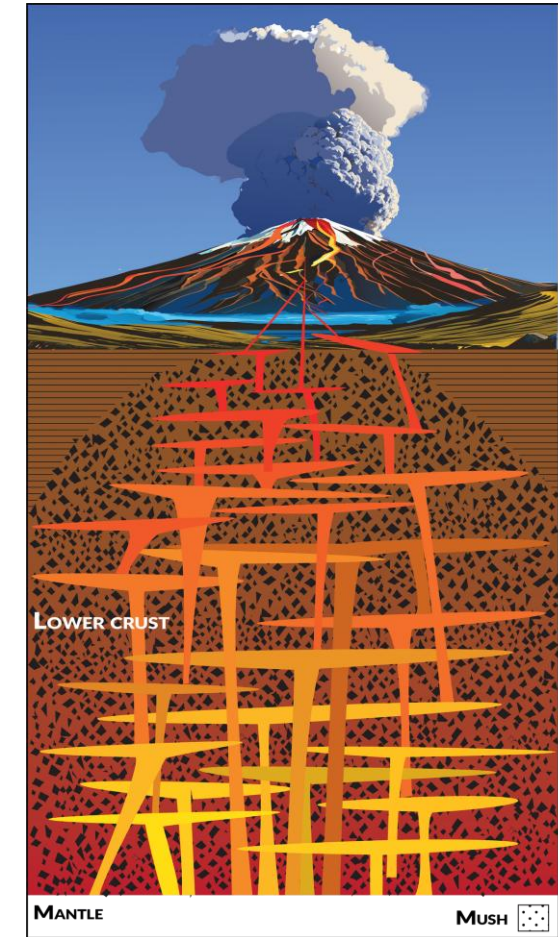
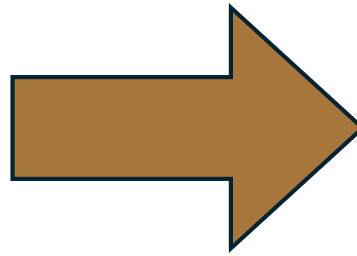
CLASSICAL VIEW

Magma Chamber



MODERN VIEW

**Vertically extensive
crystal-mush zone**



Soufriere Hills Volcano (SHV). - (3 – 10 %) (Paulatto et al. 2012)
- (3-28 %) (Annen et al. 2014) (Paulatto et al. 2019)

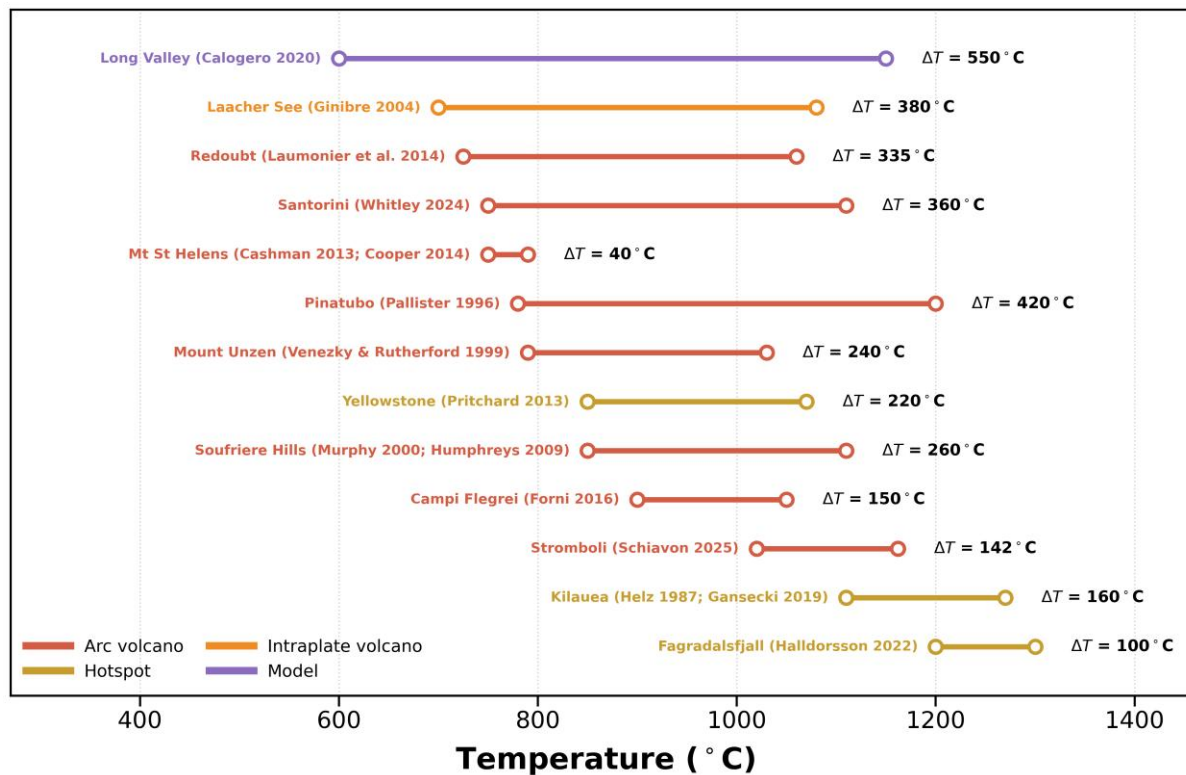
The mush paradox

- Most stored magma is too crystalline to erupt, yet eruptions of remobilized mush are common
- Yet repeated eruptions imply that recharge can remobilize melt locally

How does hot melt injection reorganize a locked mush into eruptible magma?
and what controls when this happens?



Recharge-reservoir contrasts span an order of magnitude



< 40 °C

MT ST HELENS

~ 420 °C

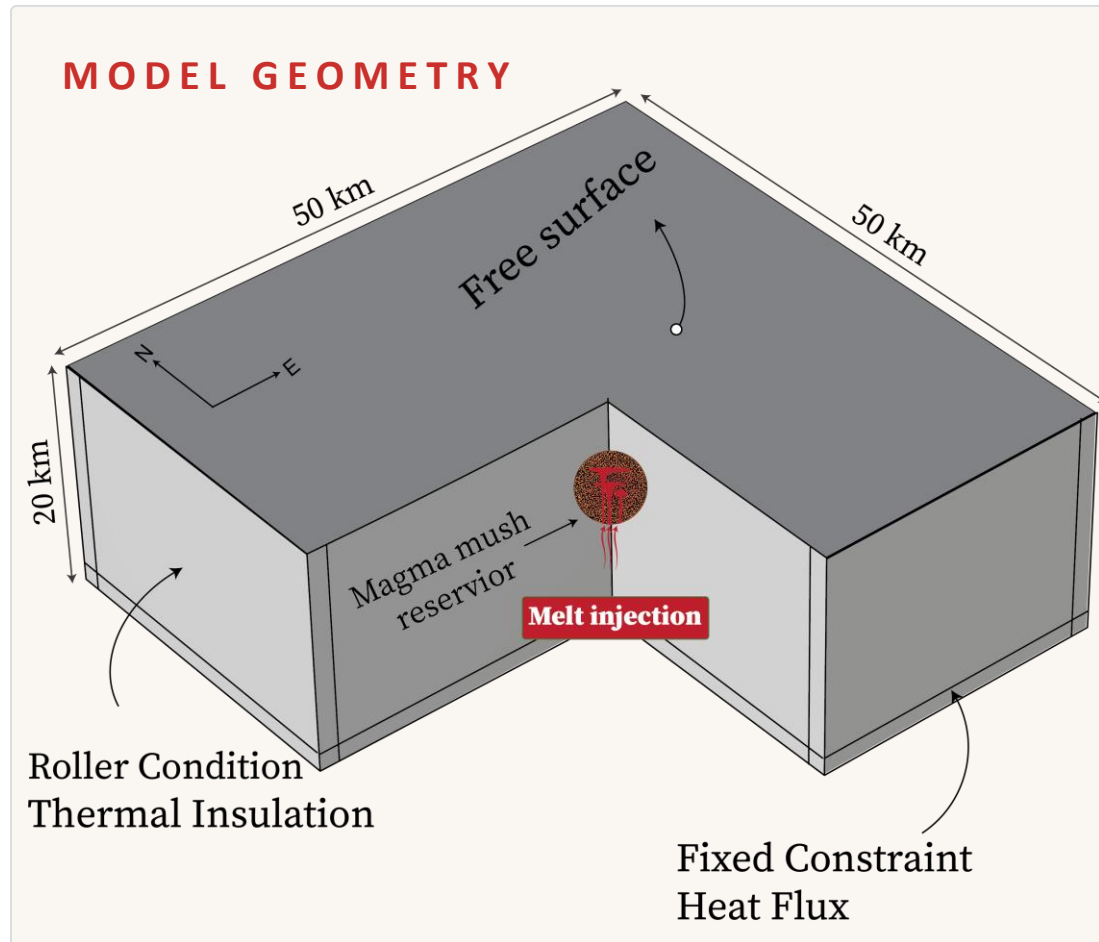
PINATUBO

100 - 550 °C

NATURAL RANGE OBSERVED

Even small changes in ΔT modify melt fraction, viscosity (orders of magnitude), and permeability - a generalized framework is needed.

Magma Properties Evolve Dynamically with Pressure and Temperature



COUPLED PHYSICS

01 Heat transfer

Conduction + Darcy advection + latent heat

02 Darcy flow

Pressure-driven melt transport; k evolves with ϕ

03 Solid mechanics

Elastic crust + Biot poroelastic mush

04 Dynamic porosity

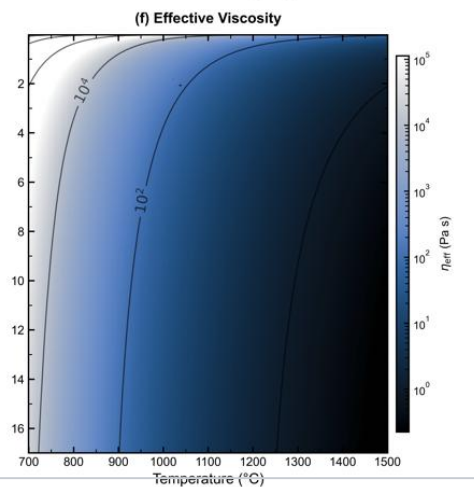
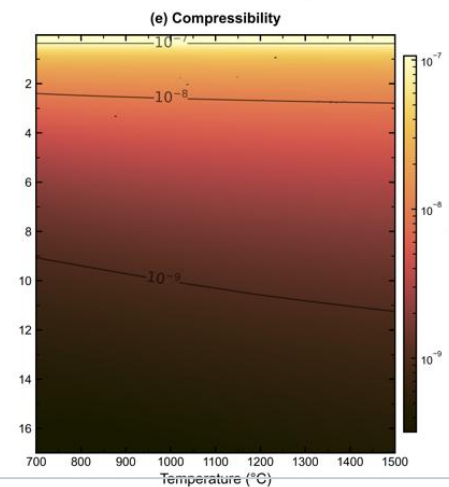
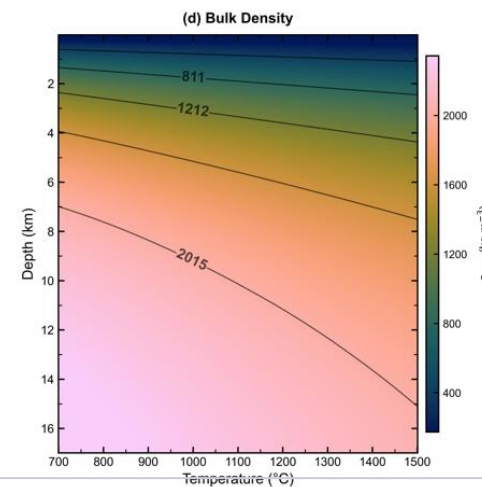
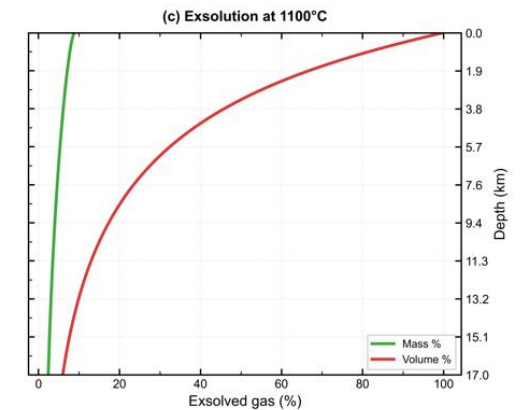
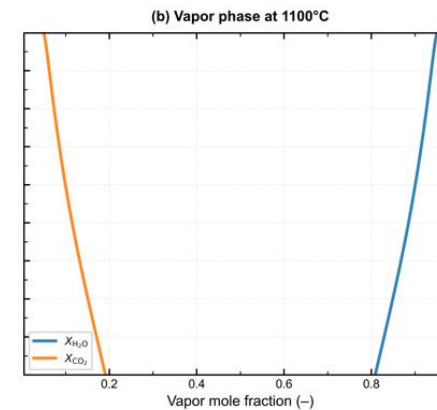
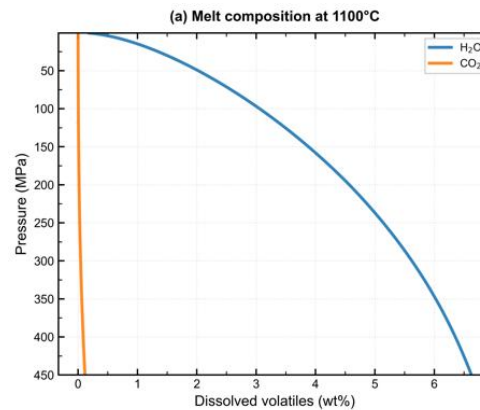
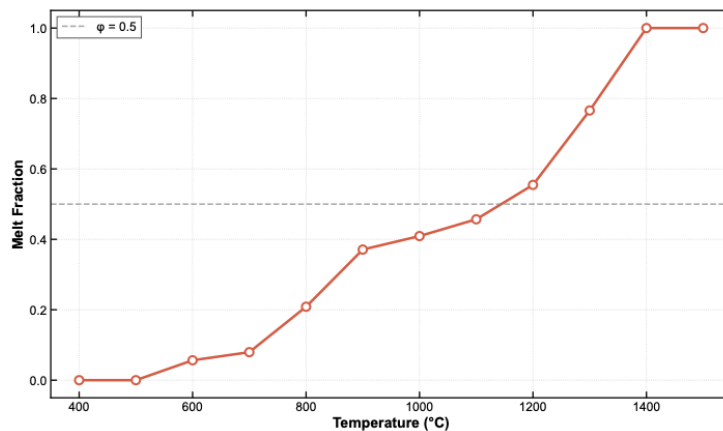
ϕ responds to temperature, pressure and strain

50 × 50 × 20 km domain · 1 km-radius mush at 7 km depth

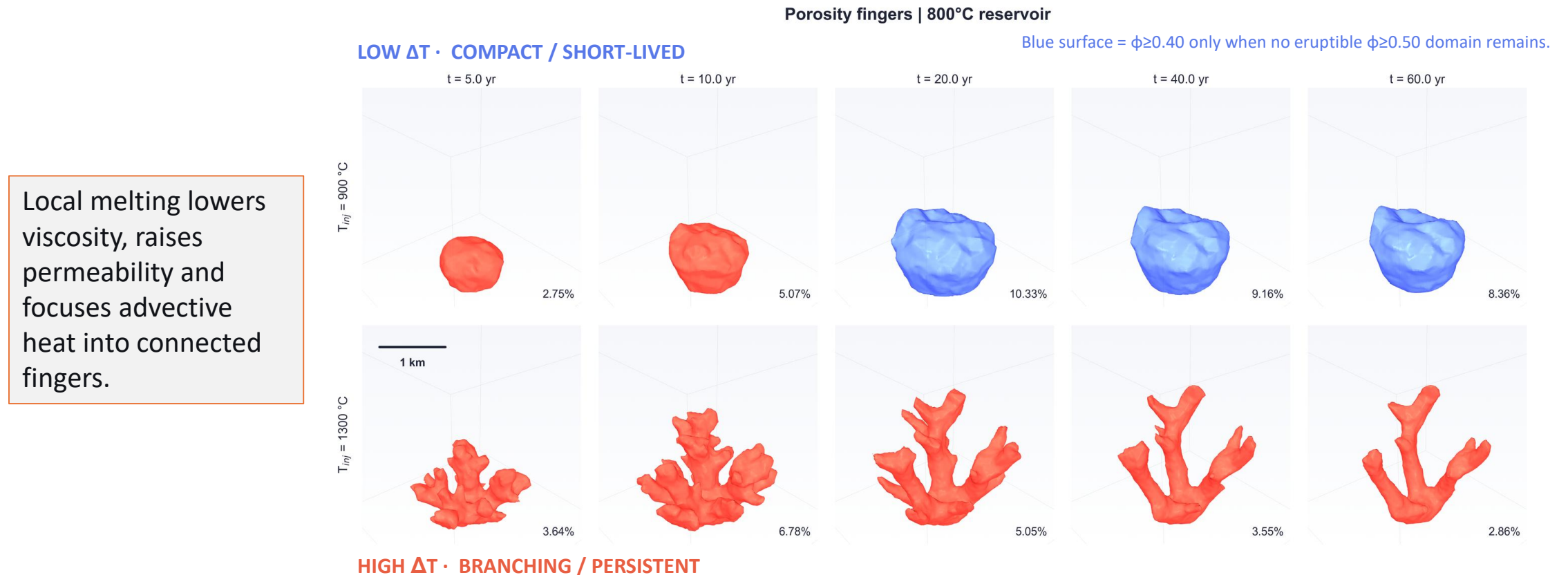
Magma Properties Evolve Dynamically

$$\text{Magma state} = f(T, P, X_{\text{H}_2\text{O}}, X_{\text{CO}_2})$$

- Degassing continuously modifies volatile content, density, compressibility, and viscosity as magma ascends and cools.



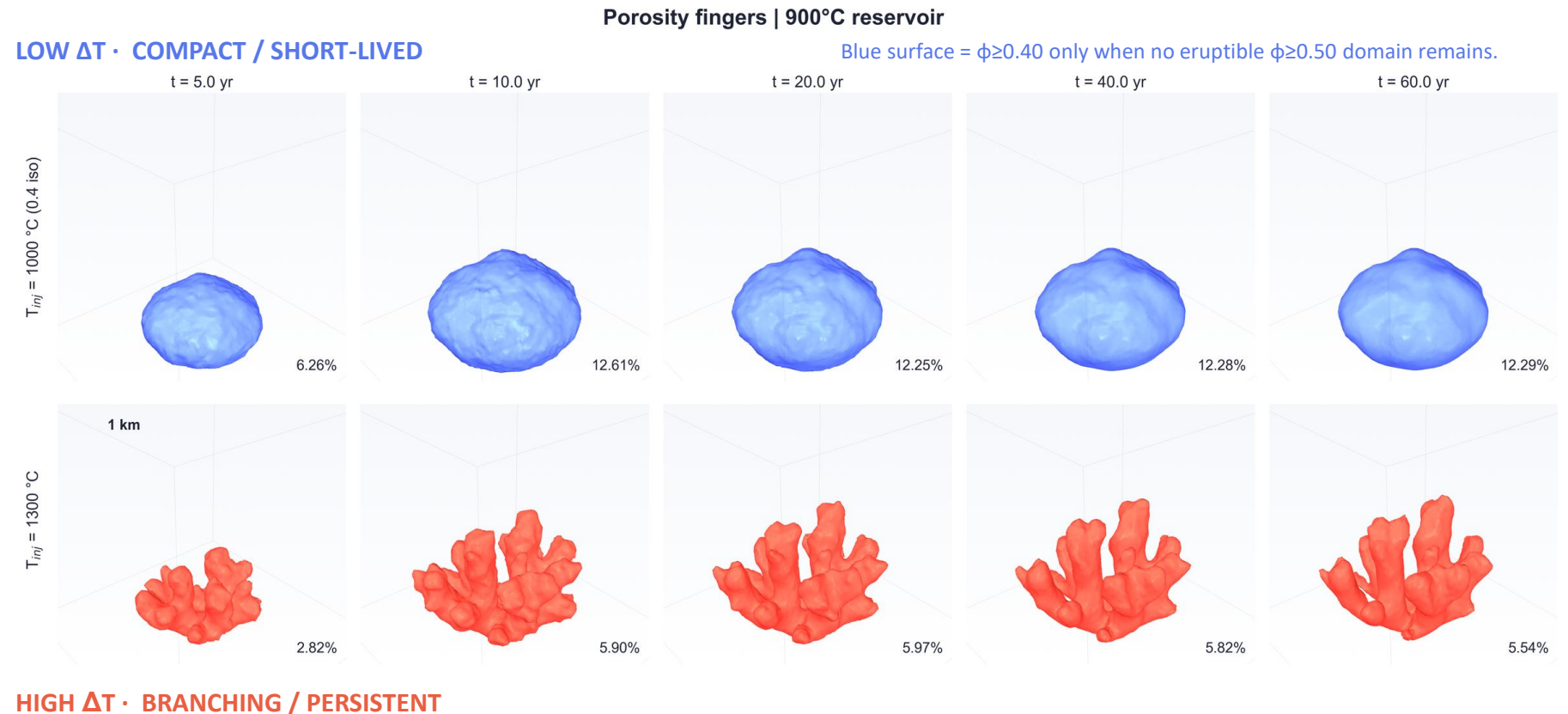
Results: Thermal Contrast Controls Melt Channelization



- Higher injection temperatures promote more strongly channelized melt pathways, but the eruptible melt fraction evolves differently through time.

Results: Thermal Contrast Controls Melt Channelization

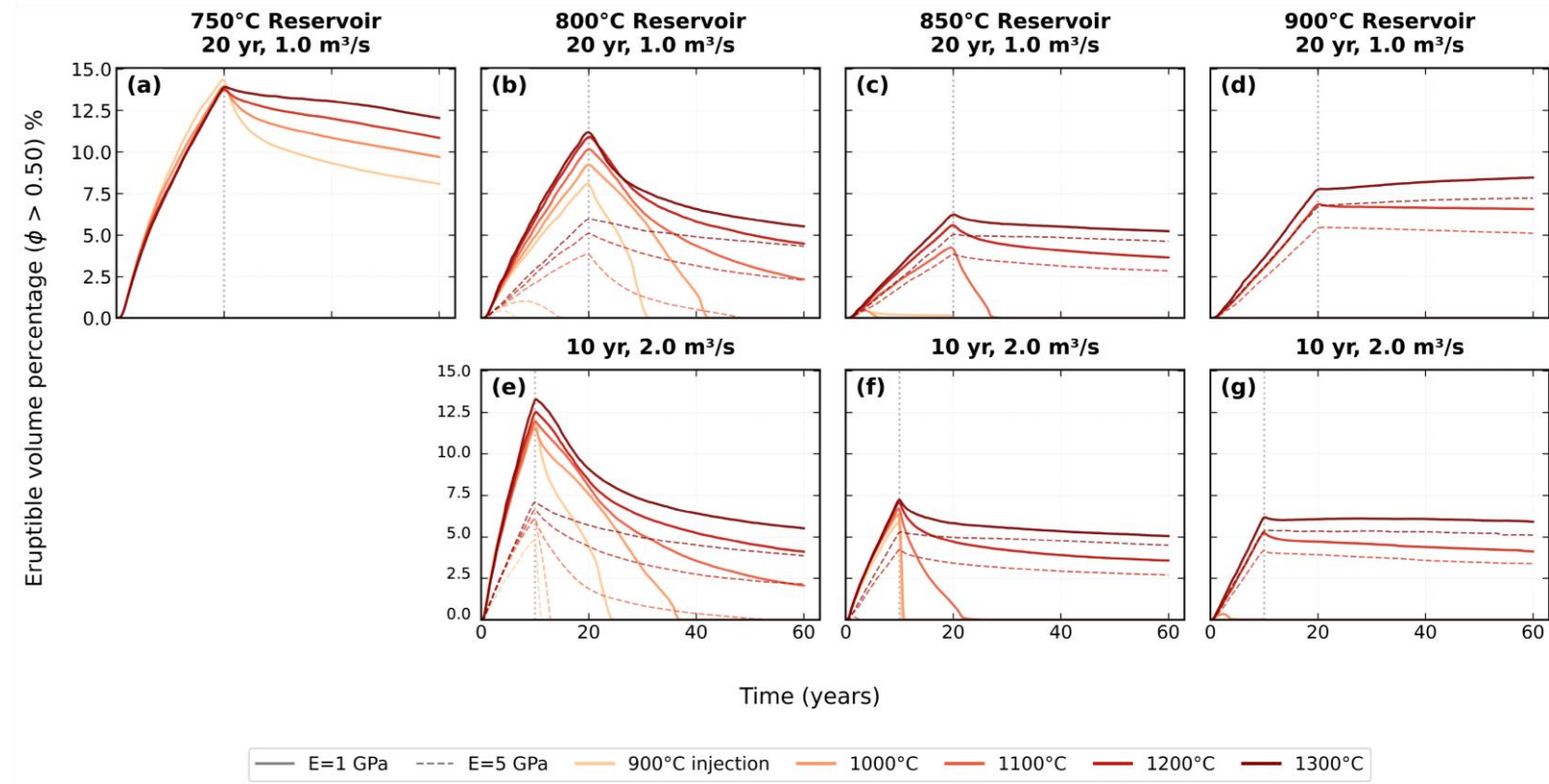
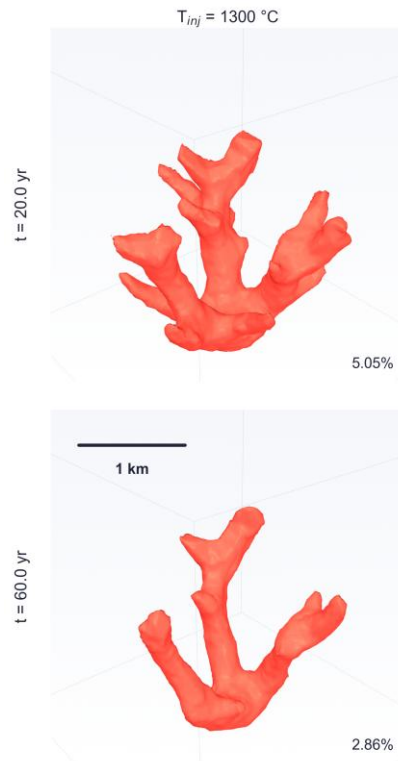
Local melting lowers viscosity, raises permeability and focuses advective heat into connected fingers.



- Higher injection temperatures promote more strongly channelized melt pathways, but the eruptible melt fraction evolves differently through time.

How much eruptible melt forms and for how long?

Peak usually forms near
shutoff
→ cooling drives decay



12-14 %

PEAK ERUPTIBLE MELT

Cold reservoirs (750-800 °C) with hot recharge

~ 5 %

SUSTAINED ERUPTIBLE MELT FOR DECADES

Hot reservoirs led to eruptible state for long after injection ends

IMPLICATIONS & OUTLOOK

Take-home messages

- 01 Hot recharge generates eruptible melt as branching fingers/channels.
- 02 Finger geometry controls both eruption-pathway potential and geodetic signals.
- 03 Eruptible magma can form within realistic surface-uplift budgets.

Forward links: *The results point toward some open questions on dyke nucleation, multi-pulse recharge memory, and critical-metal enrichment in mushes.*

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