The Plausibility of Silicate Volcanism at Europa's Seafloor

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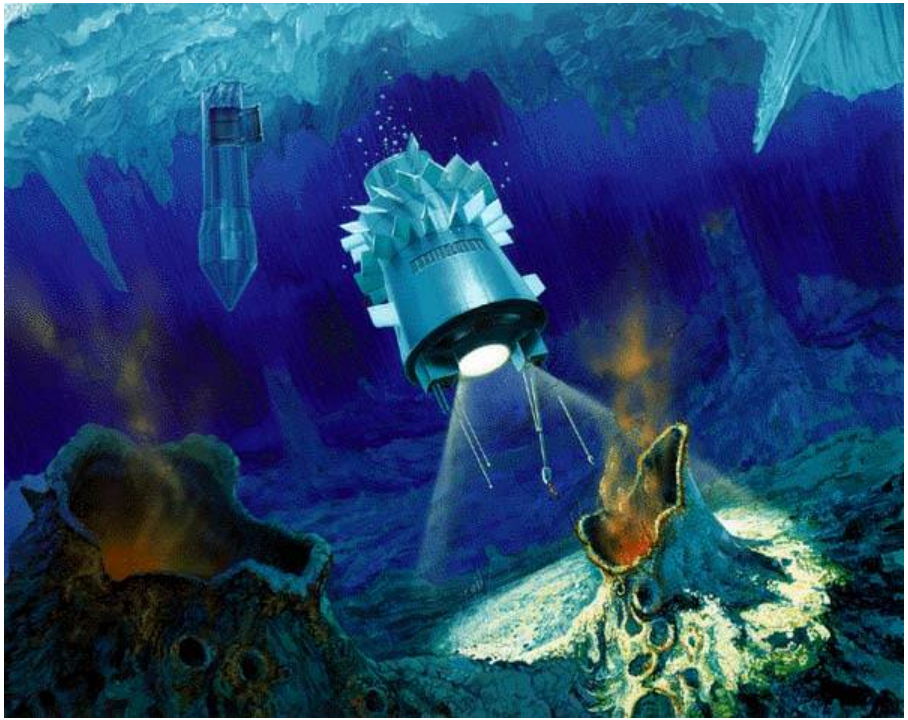
Why study Europa's silicate mantle?



Artist's depiction of a hypothetical Europa mission.
Credit: NASA

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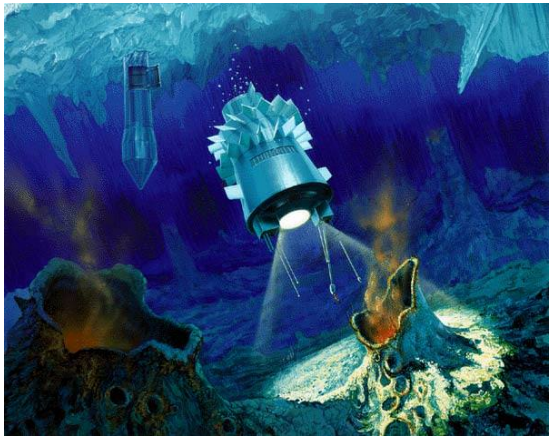
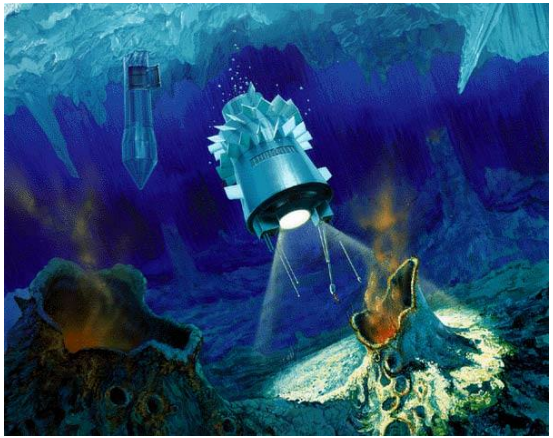


Artist's depiction of a hypothetical Europa mission. Credit: NASA

- Multiple metabolic pathways and biogeochemical cycles *if new rock is delivered to the seafloor* (Zolotov and Shock, 2004)
- "Thermodynamics-driven extinction" / "Specter of entropic death" (Gaidos et al., 1999; Chyba and Hand, 2001)

Why study the silicate mantle?



Artist's depiction of a hypothetical Europa mission. Credit: NASA

Is there volcanic activity at the seafloor today?

- Multiple metabolic pathways and biogeochemical cycles *if new rock is delivered to the seafloor* (Zolotov and Shock, 2004)
- "Thermodynamics-driven extinction" / "Specter of entropic death" (Gaidos et al., 1999; Chyba and Hand, 2001)

Convection

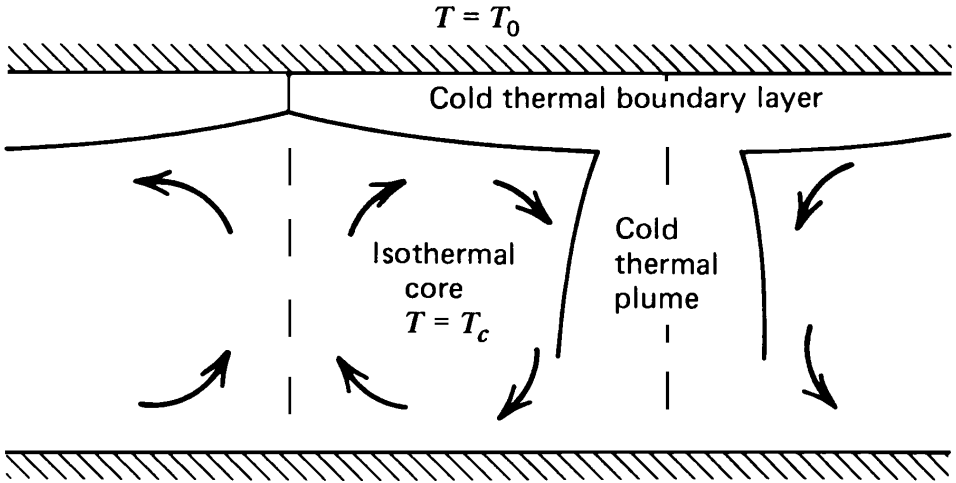


Image credit: Turcotte and Schubert (2002)

Melt Migration

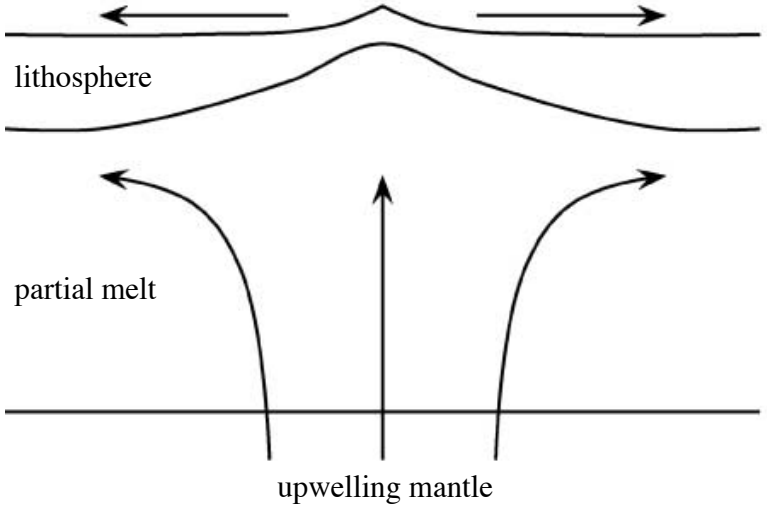


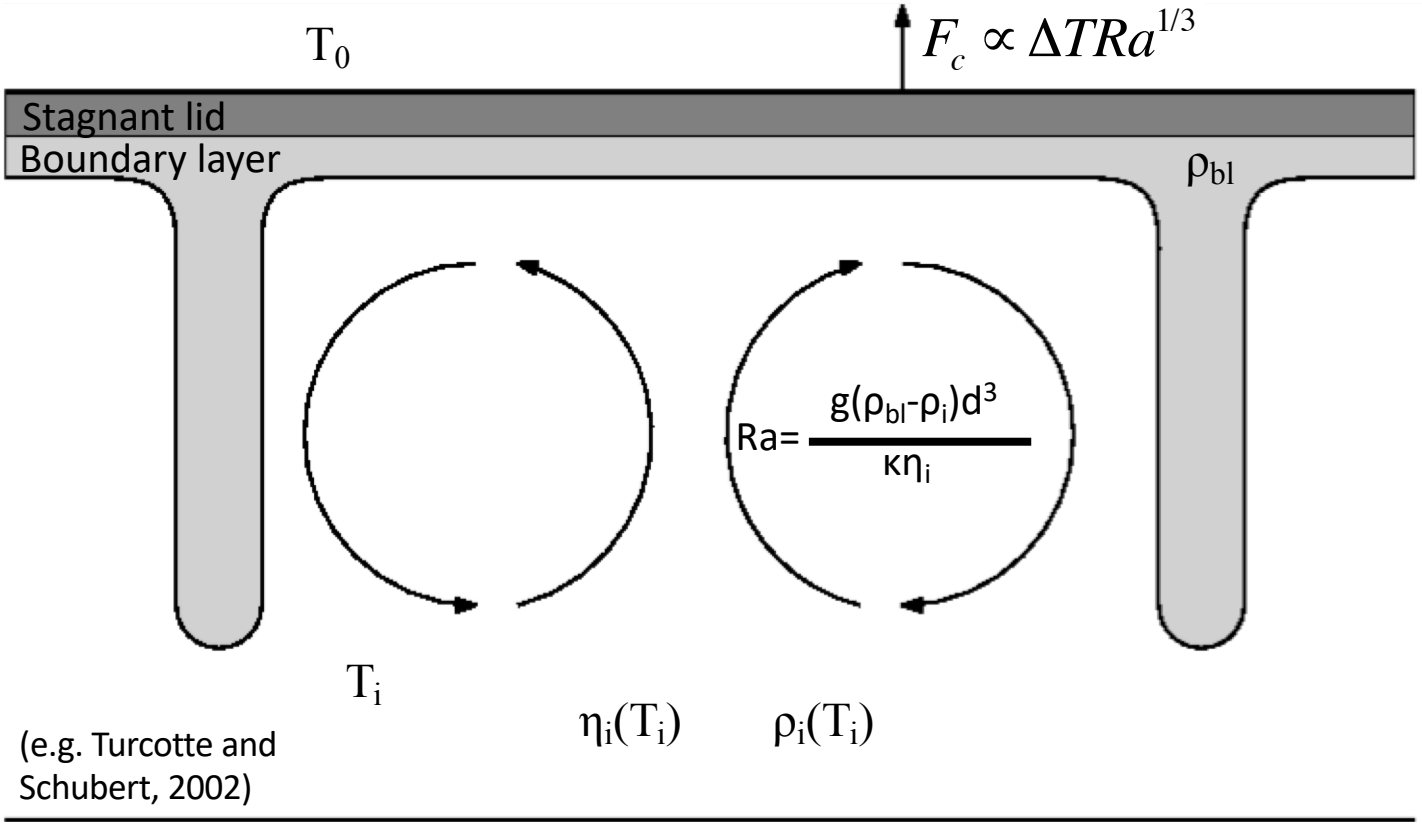
Image credit: Hewitt and Fowler (2008)

(figures not to scale)

This work

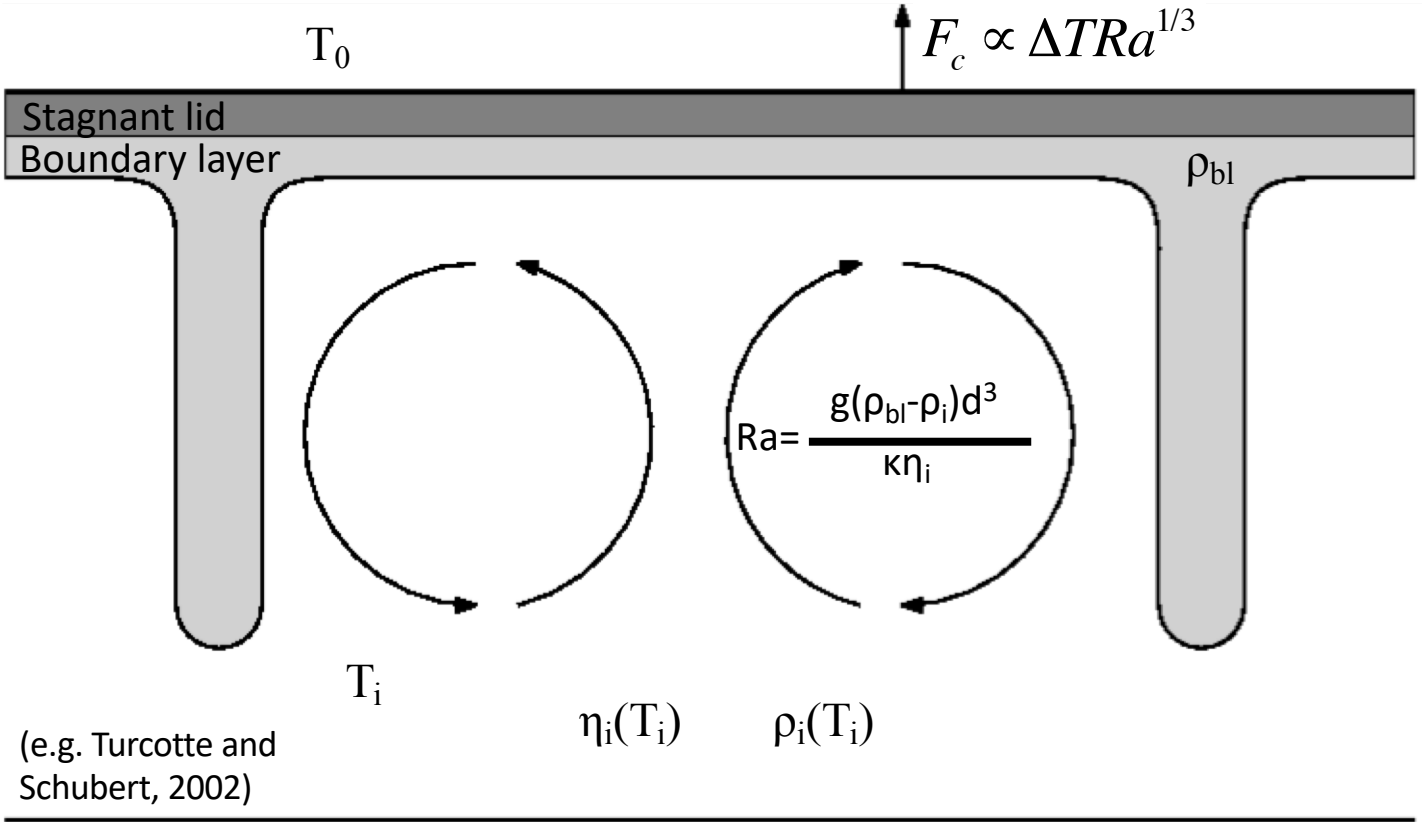
Derive scaling laws for convection that include the effects of partial melting and couple with a 1D melt migration model

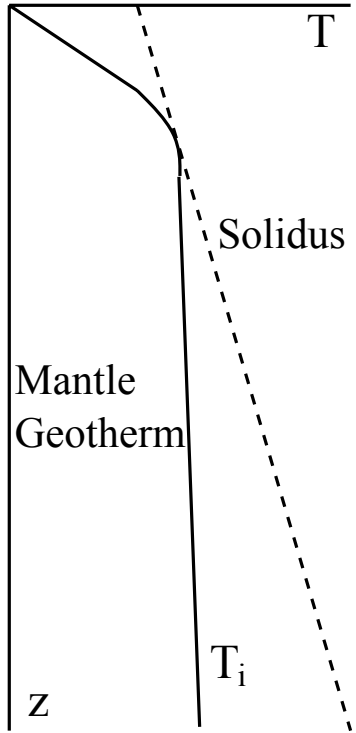
Scaling laws for convection



(e.g. Turcotte and Schubert, 2002)

Scaling laws for convection





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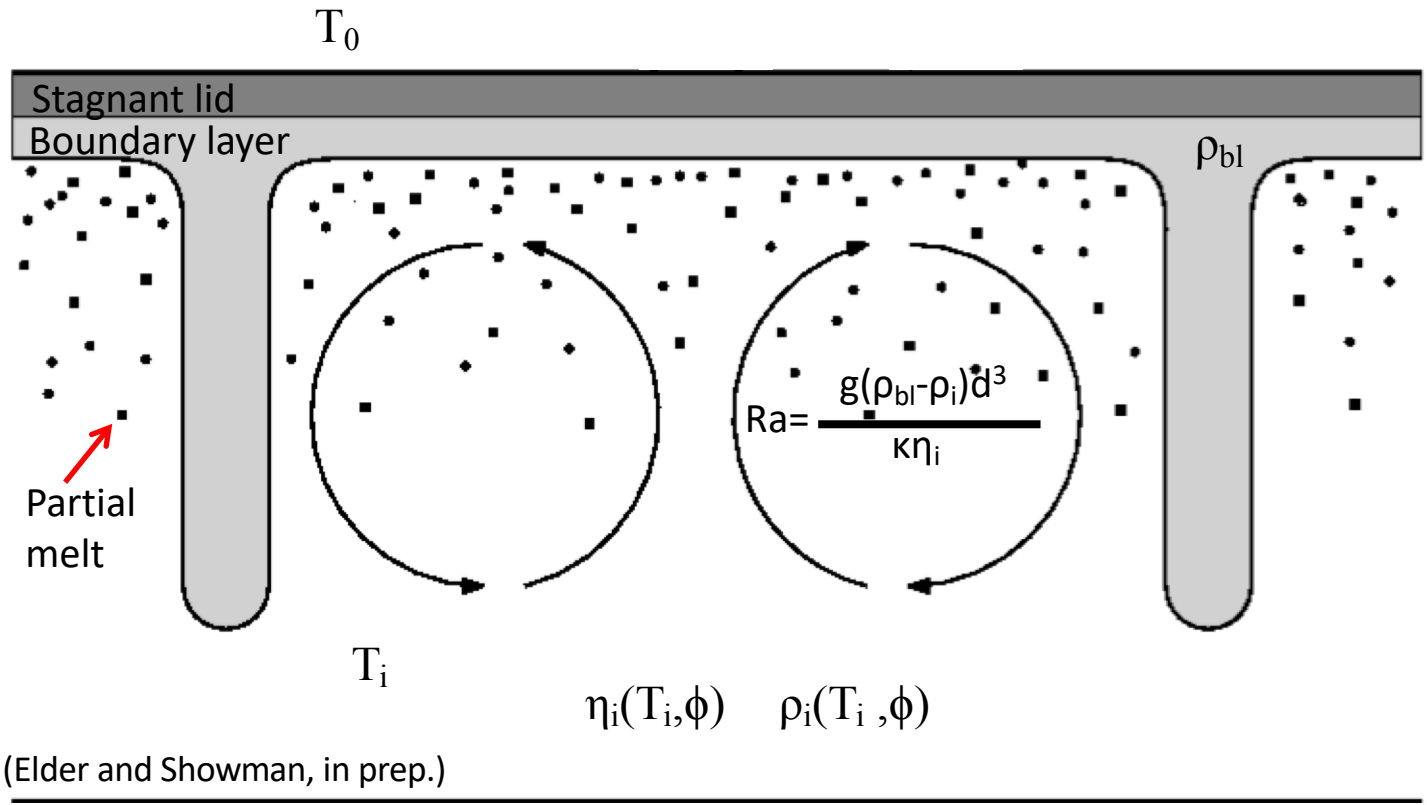
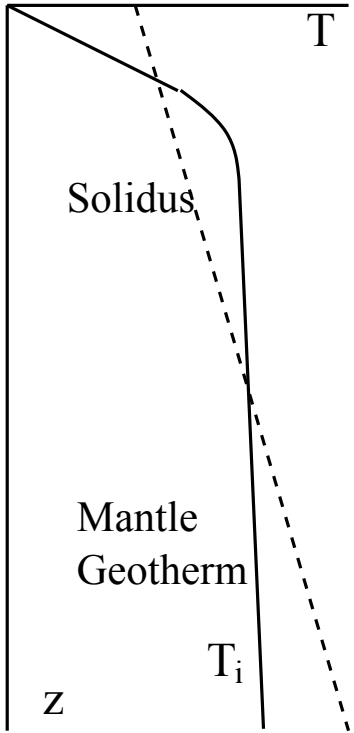


(Elder and Showman, in prep.)



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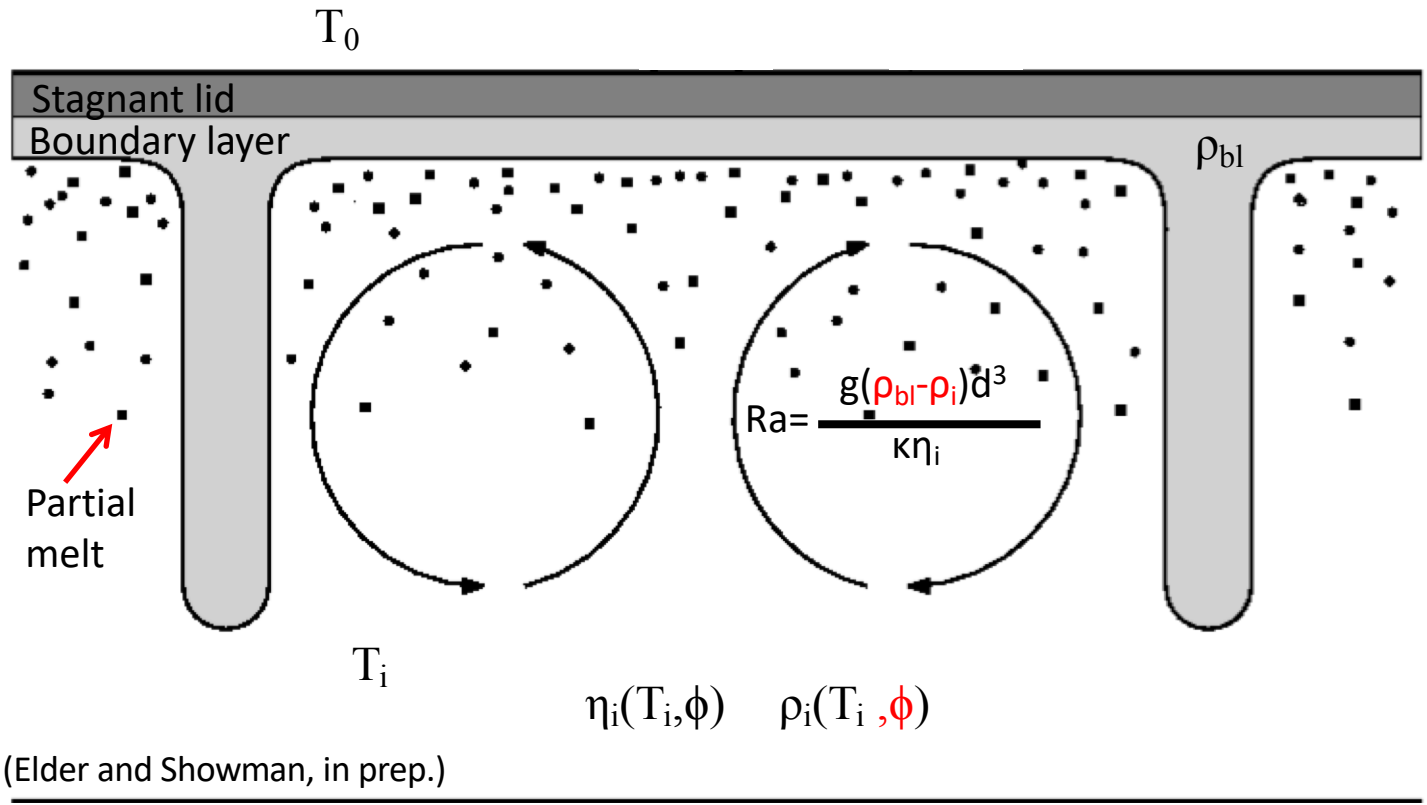

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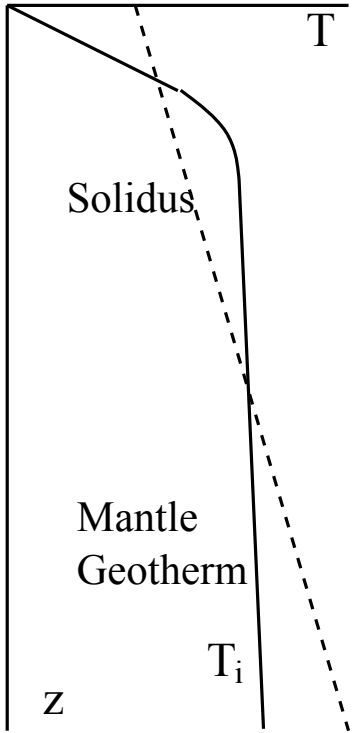

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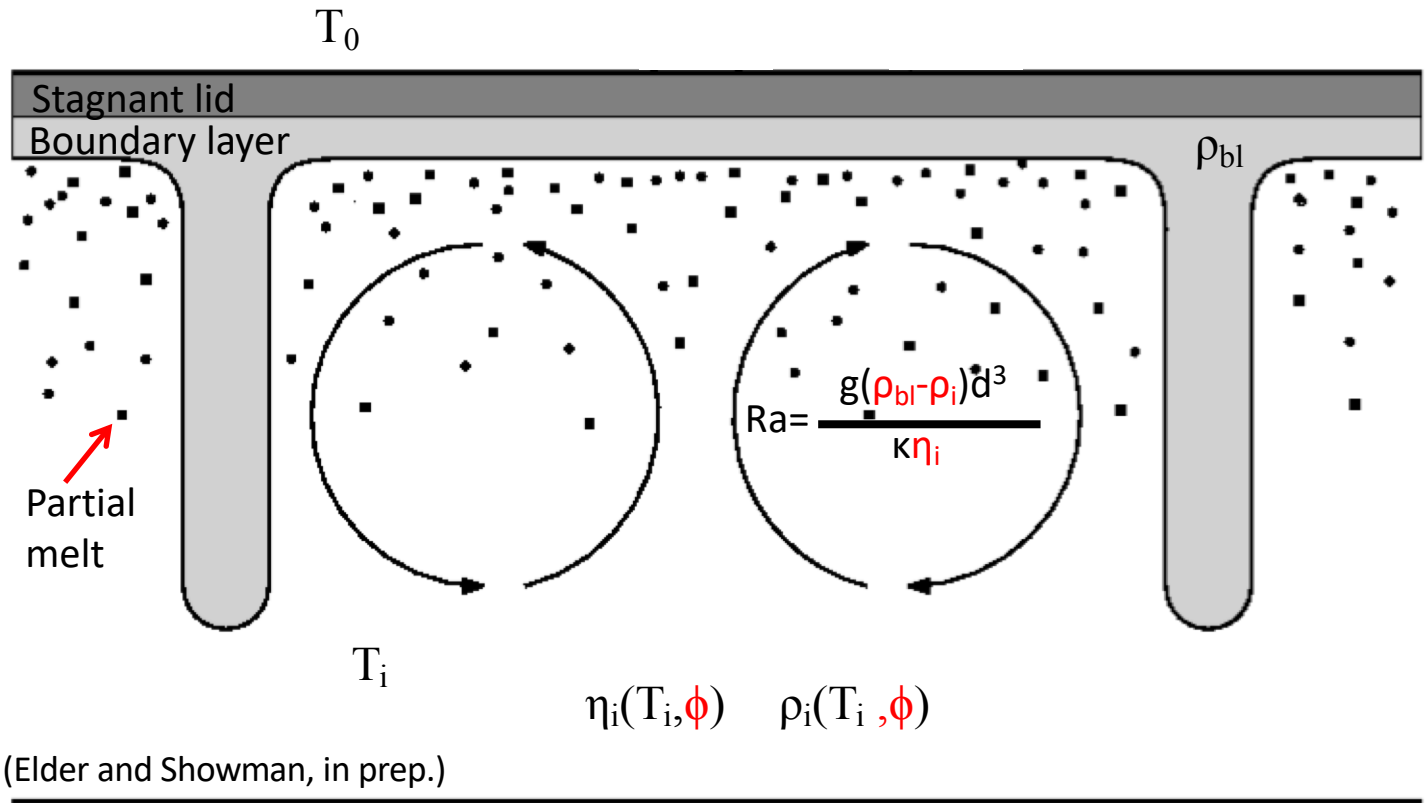

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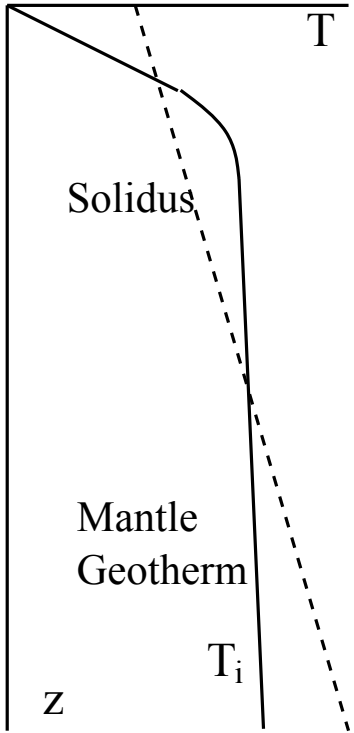

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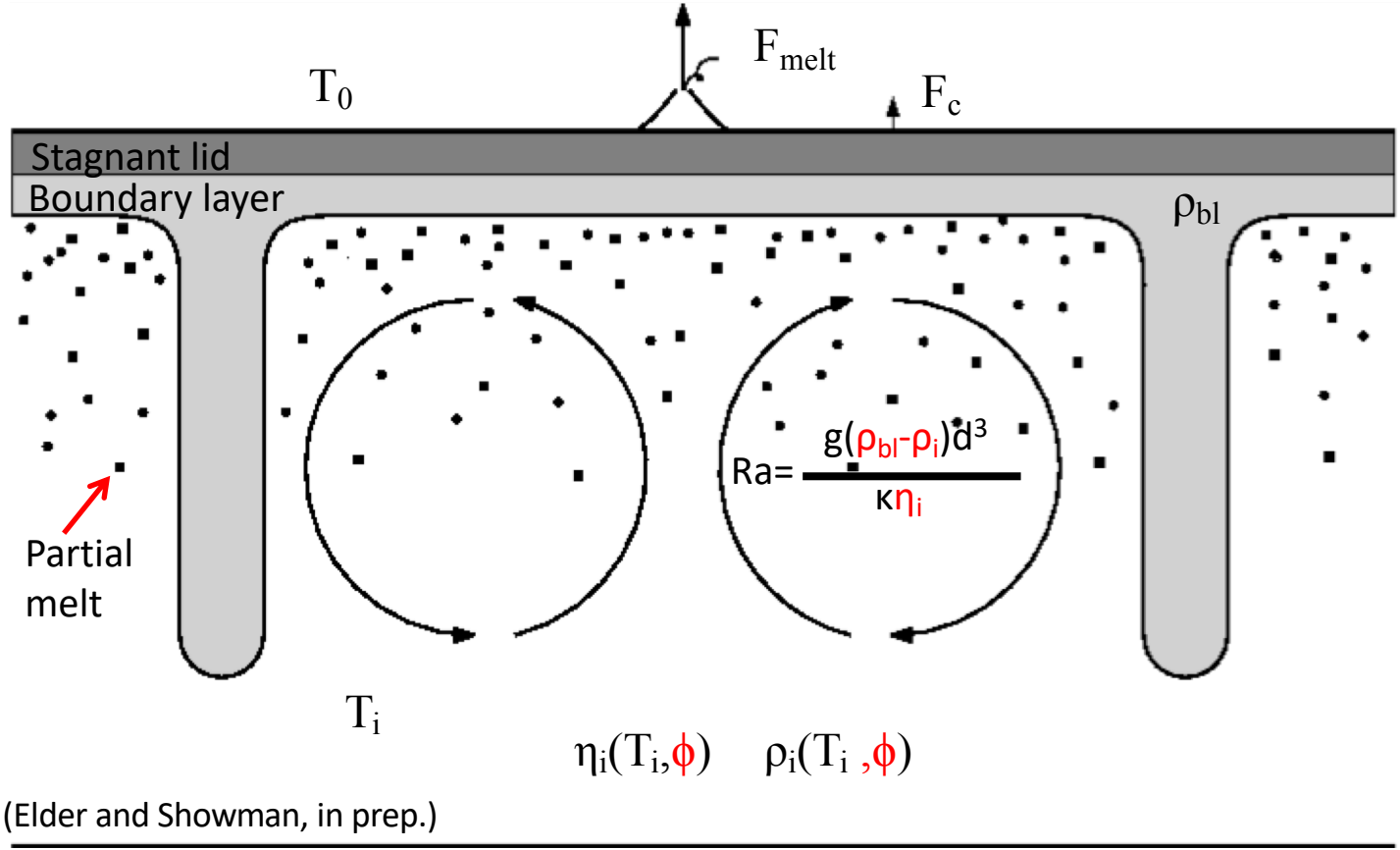

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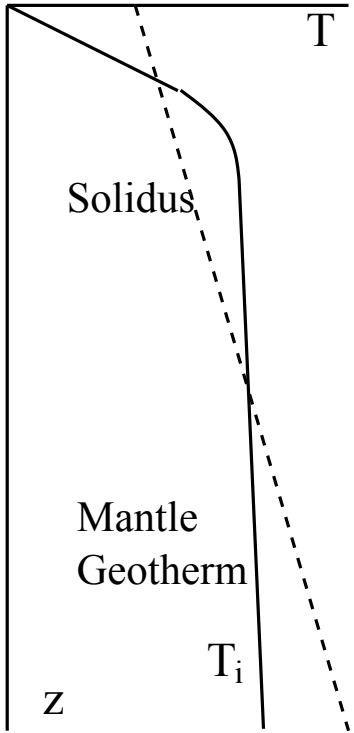

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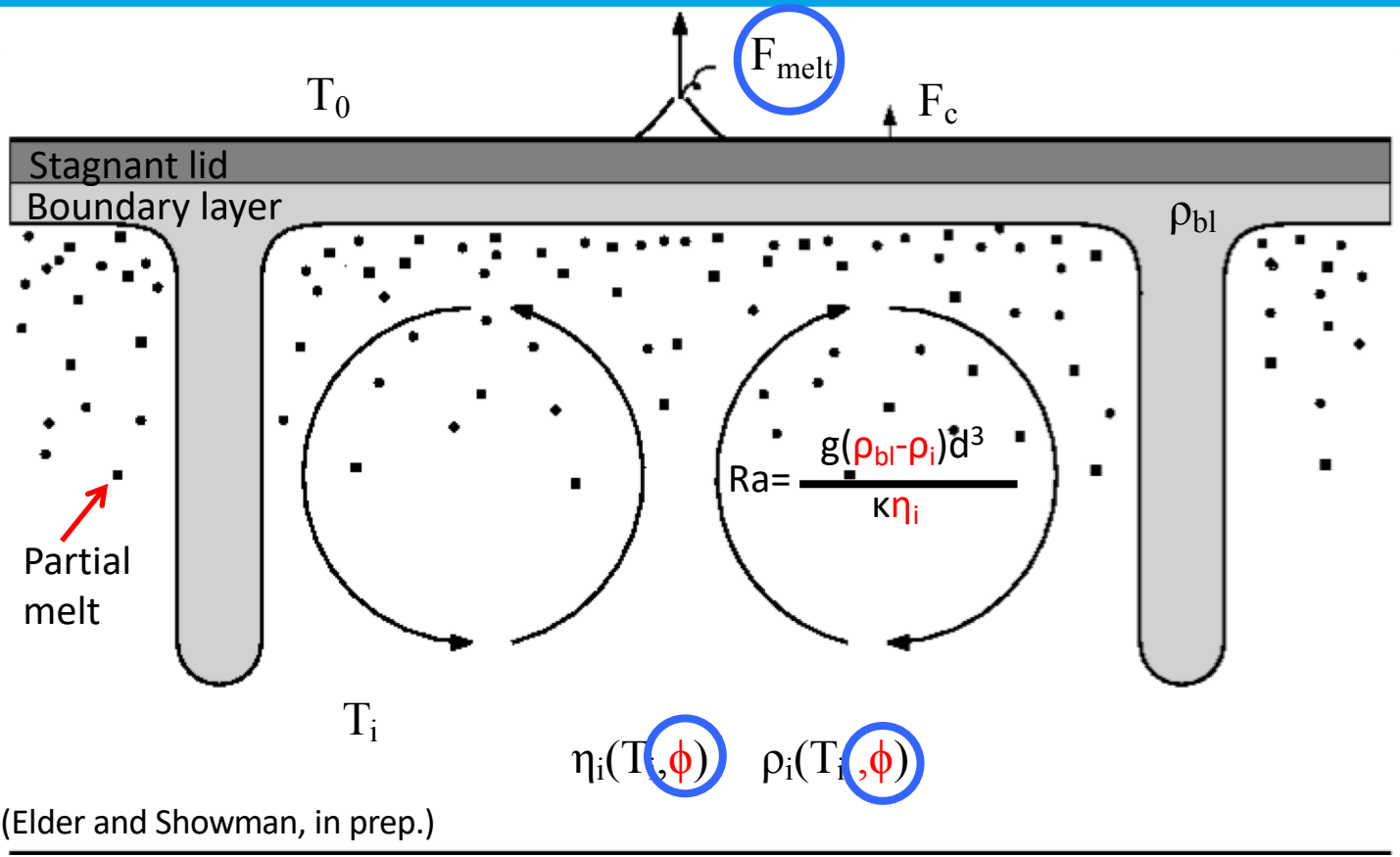

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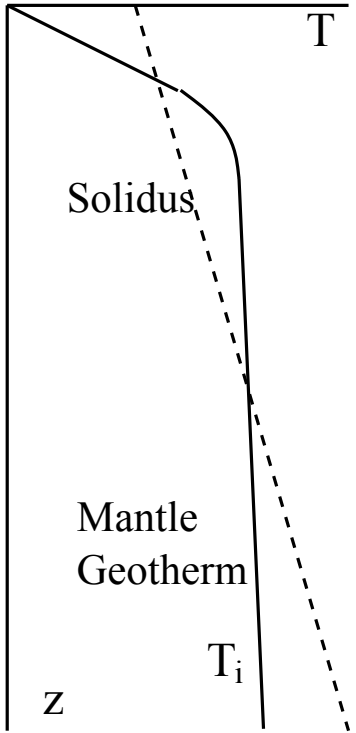
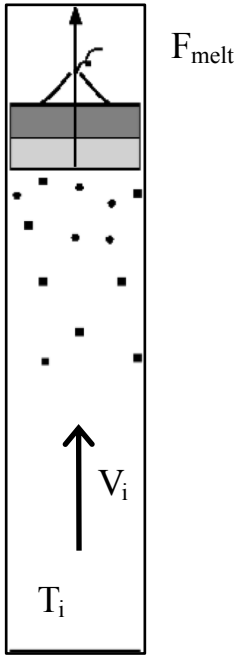
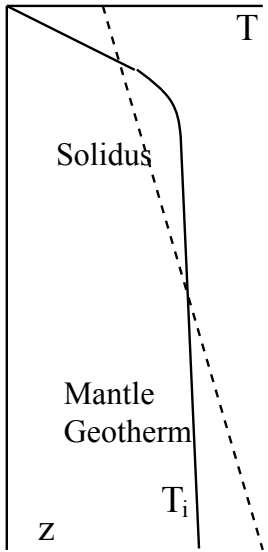


Melt migration





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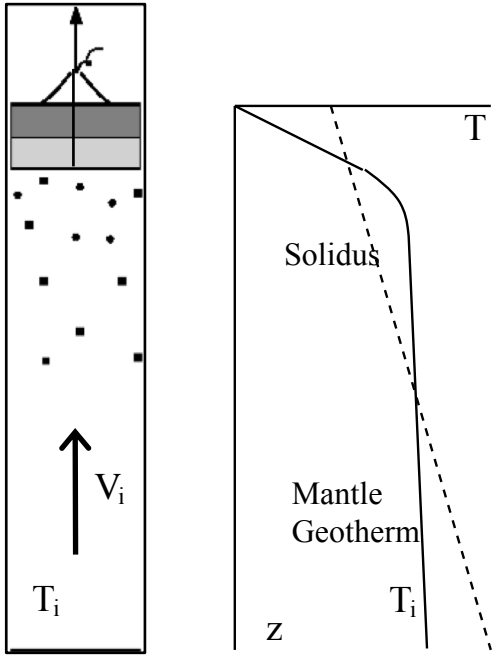
Melt migration

- 1D model of melt generation and migration (Hewitt and Fowler, 2008)
- Conserve mass, momentum and energy, and use Darcy's law to solve for the melt velocity relative to the solid
- Add internal heating term to account for tidal heating (Elder and Showman, in prep.)



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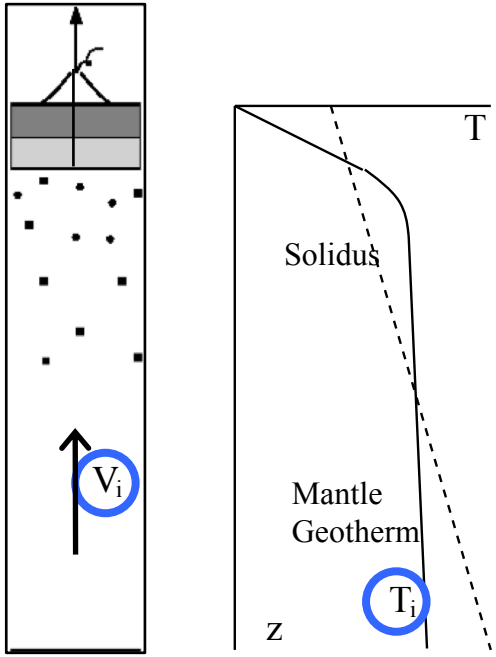
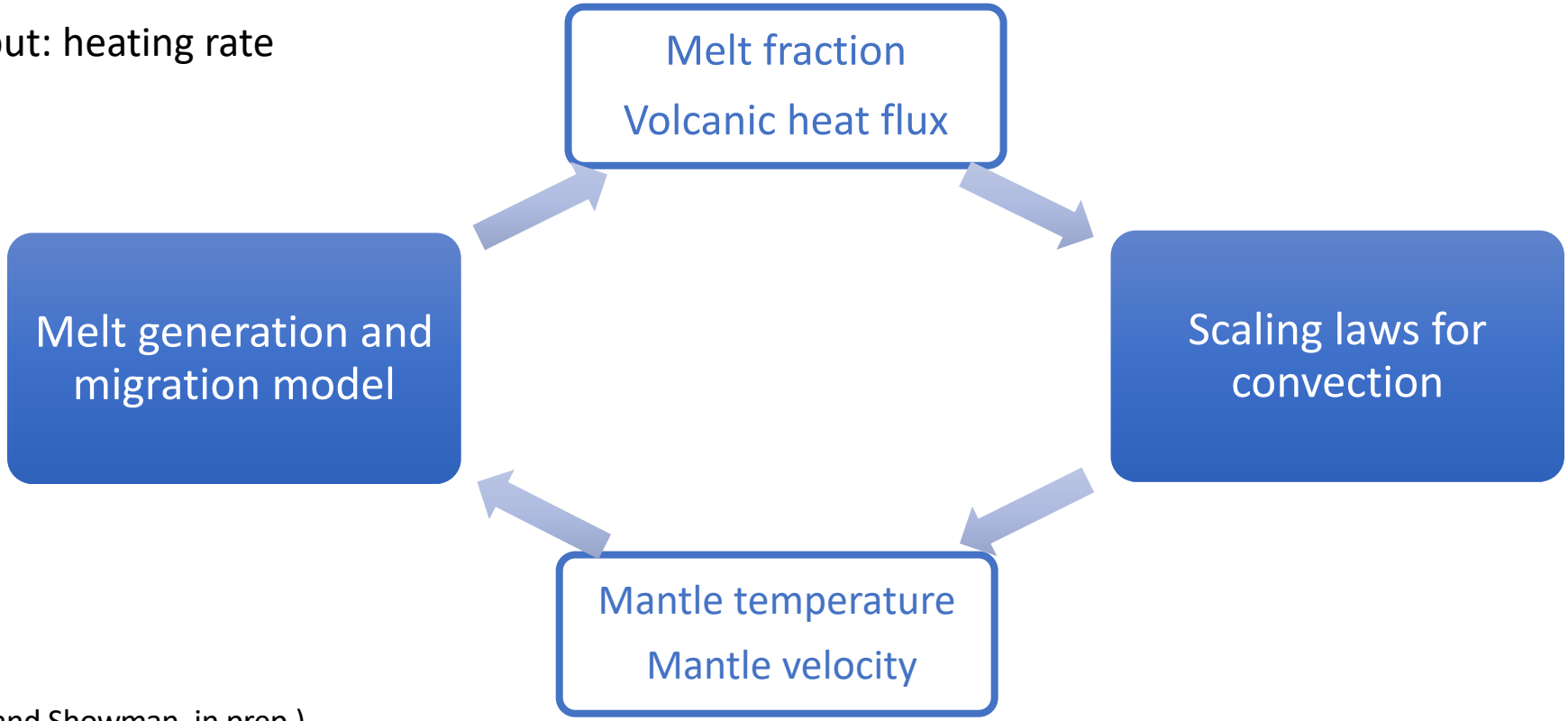


Convection and partial melting

Input: heating rate



(Elder and Showman, in prep.)

Parameter Space

- Very poorly constrained…
- Internal heating rate
  - Radiogenic heating 1.1-1.9x10^{11} W (chondritic)
  - Tidal dissipation <5x10^{13} -1.7x10^{14} W (Io)
  - Tidal dissipation in Europa's silicate mantle is expected to be lower than radiogenic (Tobie et al., 2003) unless it's partially molten then dissipation increases (Moore and Hussman, 2009)
  - Test 10^{11}-10^{14} W

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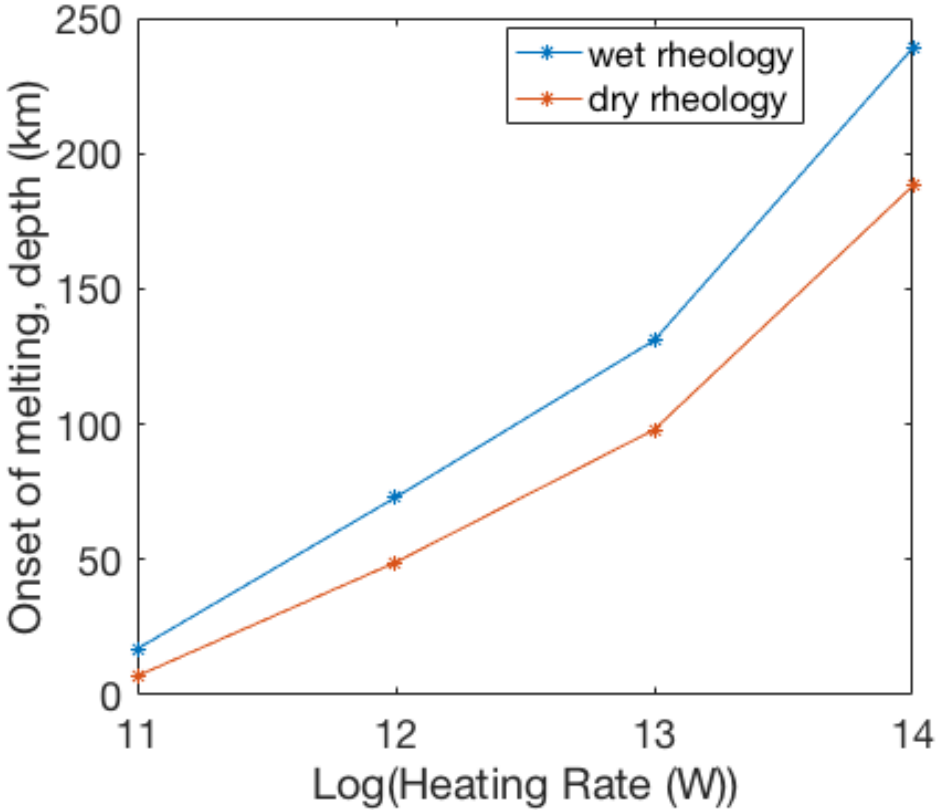
  - Test 10^{11}-10^{14} W
- Mantle rheology
  - 'Wet' – water-saturated, lower viscosity, lower solidus
  - 'Dry' – water free

Europa Preliminary Results



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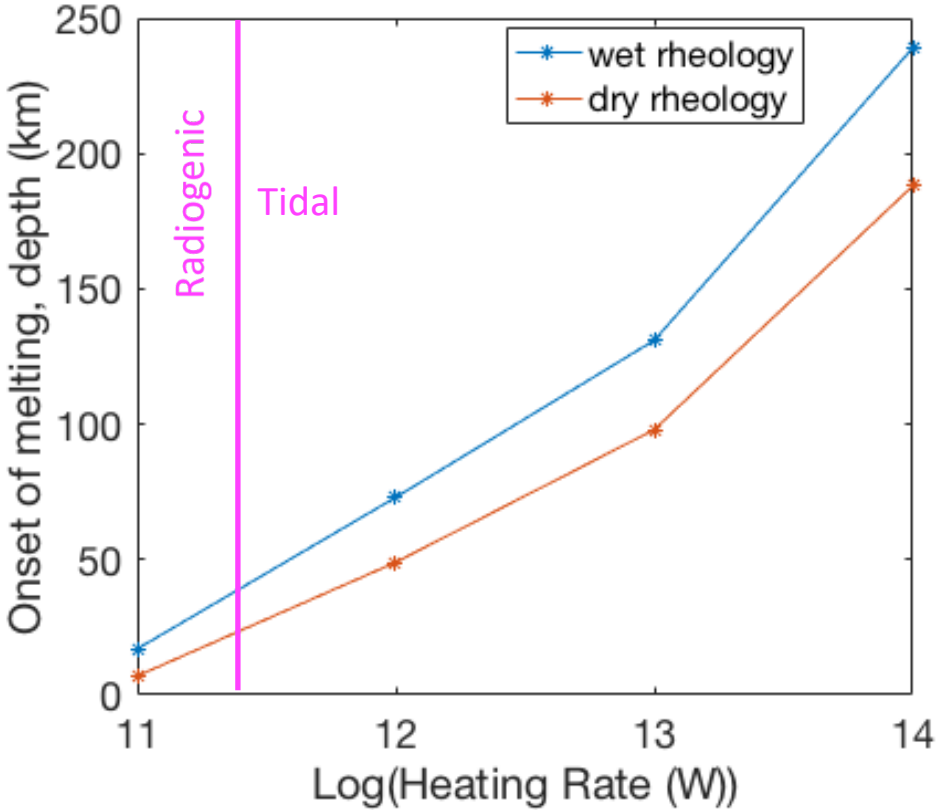

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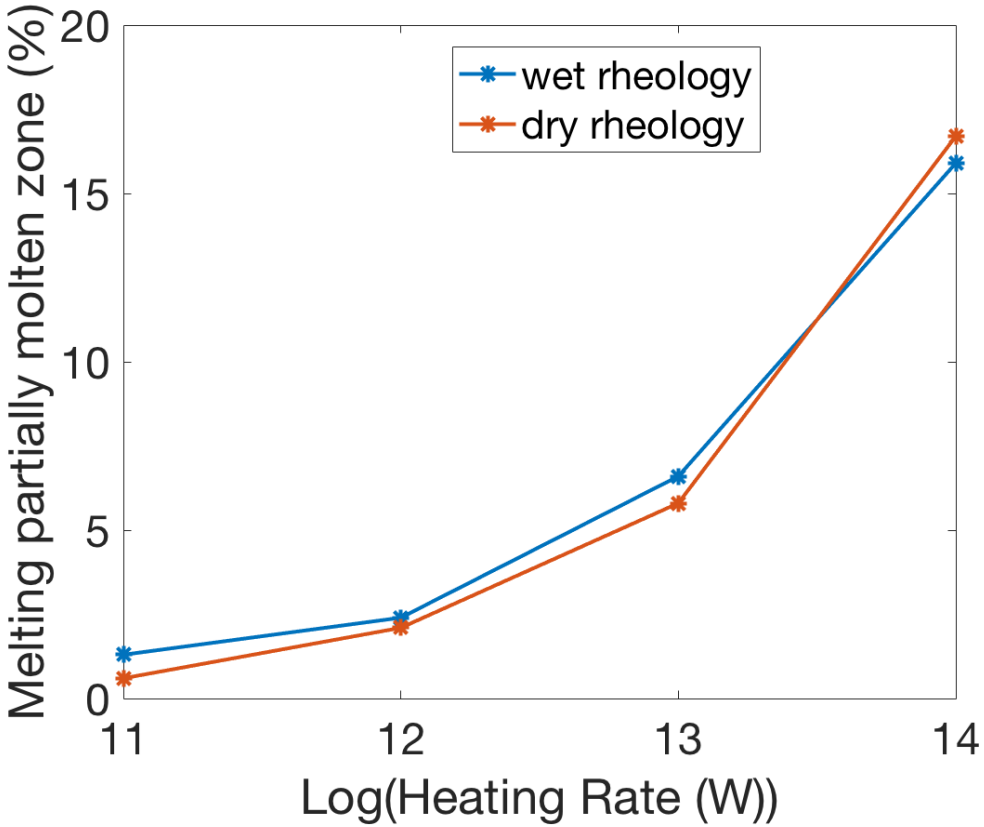

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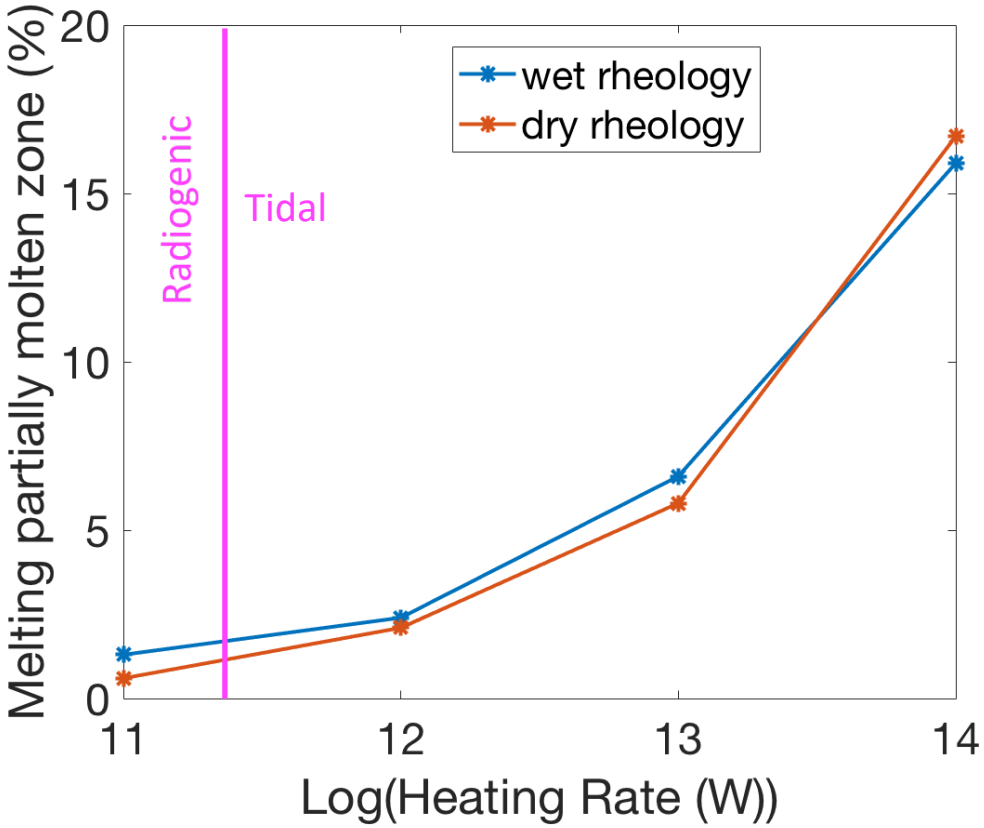
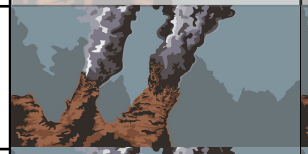
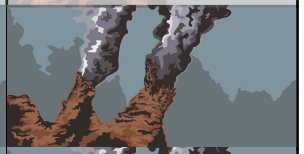
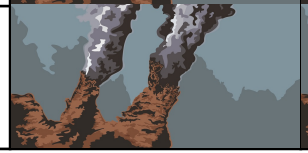
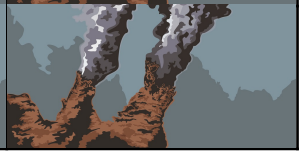


Europa Preliminary Results

	H (W)	Wet rheology	Dry rheology
Radiogenic	10^{11}	??	??
Tidal	10^{12}	?	?
Tidal	10^{13}		
Tidal	10^{14}		

Disclaimers

- We don’t know intrusive/extrusive ratio
- We don’t know depth of intrusion
- We don’t know if radiogenic elements were concentrated in a crust early in the evolution of the silicate mantle
- Tidal dissipation also varies with rheology
- Europa’s silicate mantle properties are even more uncertain than Io (will test a range of values in future work)

Discussion and Conclusion

- Small amounts of melting are possible in Europa's silicate mantle
  - But would resulting eruption rates be enough to maintain chemical disequilibrium in the ocean?
- At high tidal heating rates, significant melting is expected on Europa

Discussion and Conclusion

- More work is necessary to evaluate fraction of melt that can erupt
  - Earth has ~5 times more intrusion than eruption
  - Shallow intrusion could still cause hydrothermal vents at Europa's seafloor

Convection, partial melting, magma migration, and eruption are closely coupled processes