Synopsis

- Io shows no signs of plate tectonics, but stagnant lid convection cannot produce Io’s observed heat flux [1].
- Io’s mantle is partially molten [2].
- Advection of heat by magma is very important [3, 4].
- We model convection, magma generation, and magma migration in Io’s mantle.
- We find that Io has a partially molten upper mantle and loses the majority of its internal heat through volcanic eruptions.
- The heat flux through volcanic eruptions oscillates with a period of a few thousand years.
- Io is currently the only body in our solar system where heat loss through volcanism dominates, but this could be an important stage of planetary evolution for many planets.

Model

- We model convection, partial melt generation, and melt segregation in Io’s mantle using the code StagYY [5].
- StagYY calculates:
  - The bulk velocity field by solving the Stokes and continuity equations
  - Melting and/or freezing using a simplified petrological model
  - Melt solid segregation according to Darcy’s law.
- It uses finite volume discretization to calculate velocities and variable mass tracer particles to track the advection of melt and composition.
- We approximate eruption by allowing all melt that reaches the base of the lithosphere to erupt if it is less dense than the lithosphere [6].
- We consider a two-dimensional region the full depth of Io’s mantle by a width approximately equal to the distance between Io’s equator and its pole.
- We assume an internal heating rate of 1.4×10² W kg⁻¹ [7].

Interior structure

- Io has a thick lithosphere, a partially molten upper mantle, and a solid lower mantle
- In statistical steady state, our simulations show that Io has a cool solid stagnant lithosphere that is 150–260 km thick depending on the choice of rheological parameters (figures 2 and 3).
- Beneath the stagnant lithosphere, the mantle is adiabatic as in solid-state mantle convection (figure 3).
- The upper mantle is partially molten with an average melt fraction of 2–4% molten depending on the choice of rheological parameters.
- In the partially molten upper mantle, melt fraction increases with decreasing depth.
- The highest melt fraction occurs just beneath the stagnant lithosphere. In the case presented here, this reaches an average value of 8% (figure 3), but locally it can be as high as 40% molten (figure 2).
- The root mean squared mantle velocity is highest in the partially molten upper mantle, but convective velocities in the solid lower mantle are not negligible.

Heat loss

- Our simulations evolve to a statistical steady state.
- Io loses an average of two orders of magnitude more internal heat through volcanic eruptions than conduction through a stagnant lithosphere.
- The heat loss due to volcanic eruptions oscillates around an average value with a period of just a few thousand years.

Conclusions

- Beneath a 150–260 km thick lithosphere, Io has a partially molten upper mantle (2–4% molten), and a solid lower mantle.
- Io loses the majority of its internal heat through volcanic eruptions.
- Heat flux due to volcanic eruptions varies over a period of a few thousand years.

Literature cited


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