HEAT LOSS THROUGH VOLCANISM ON IO. C. M. Elder, P. J. Tackley, and A. P. Showman, Lunar and Planetary Laboratory, University of Arizona, 1629 E. University Blvd. Tucson, AZ 85721, USA (cmelder@lpl.arizona.edu), ETH Zurich, Institute of Geophysics, Sonneggstrasse 5, 8092 Zurich, Switzerland.

Introduction: Tides induced by Jupiter and a high forced eccentricity lead to a large internal heating rate in Io’s mantle [1]. Previous work has shown that solid mantle convection beneath a stagnant lid is insufficient to remove this internal heat [2]. Although tidal heating does lead to significant geologic activity, Io does not show any signs of plate tectonics like Earth. Instead of plate tectonics or stagnant lid convection, Io may lose the majority of its internal heat via volcanic eruptions through a stagnant lithosphere [3, 4]. We model both convection and partial melting to show that Io does lose the majority of its internal heat through volcanic eruptions [5]. Although Io is currently the only body in our Solar System where volcanism contributes significantly to global heat loss, heat loss through volcanism could be an important stage in planetary evolution for many planets.

Model: To model convection, partial melt generation, and melt segregation in Io’s mantle, we use the code StagYY [6]. StagYY calculates the bulk velocity field by solving the Stokes and continuity equations, melting and/or freezing using a simplified petrological model, and melt solid segregation according to Darcy’s law. It uses a combined Eulerian-Lagrangian method with finite volume discretization for calculating velocities and variable mass tracer particles to track advection of melt and composition. We do not model the movement of magma through the lithosphere which is not fully understood even on Earth. We approximate eruption by allowing all melt that reaches the base of the lithosphere to erupt if it is less dense than the lithosphere [5].

In this initial study, we use two-dimensional Cartesian geometry and consider a region the full depth of Io’s mantle by a width approximately equal to the distance between Io’s equator and its pole. We use 256x64 grid cells and 4 million tracer particles. We assume an average internal heating rate of \(1.4 \times 10^{-9}\) W/kg [7]. The spatial distribution of tidal heating in Io’s mantle is expected to be non-uniform [8], so we assume the internal heating rate decreases from left to right [5]. We run our calculations to a statistical steady-state.

Results and Discussion: We find that Io loses two orders of magnitude more heat through volcanic eruptions than conduction through the stagnant lid. This shows that instead of stagnant lid convection or plate tectonics, Io is losing its internal heat through volcanism. Beneath Io’s cold stagnant lithosphere is a partially molten upper mantle and a solid lower mantle (Figure 1). In the partially molten layer, the peak horizontally averaged melt fraction is 5–9% for most parameters we test [5]. For most parameters we test, our simulations predict an average eruption rate of approximately 1 cm/yr [5]. However, the eruption rate oscillates around this average suggesting that current observations may not be representative of Io’s longer term behavior.

![Figure 1: The steady state temperature (T) field (top) and the steady state melt fraction (f) field (bottom). The domain is 880 km deep and 2772 km wide.](image)

Although Io is currently the only body in our Solar System losing the majority of its internal heat via volcanism through a stagnant lithosphere, this type of planetary heat loss could be important on exoplanets or on other bodies in our Solar System earlier in their history. Further work is needed to understand what conditions lead to heat loss by volcanism rather than plate tectonics and whether a body can transition between these two heat loss mechanisms. It would also be interesting to consider whether the two heat loss mechanisms could be distinguished through observations of an exoplanet’s atmosphere.


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