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Tidal Dissipation in a Partially Molten Material

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Abstract

Io is the most volcanically active body in the solar system, because orbital interactions due to the Laplace resonance increase its eccentricity causing it to deform and dissipate tidal energy as the distance between Jupiter and Io varies throughout its orbit. This periodic tidal flexing may cause modest periodic motion of melt relative to a solid matrix which could cause dissipation in addition to dissipation in solid rock alone. We solve governing equations for two phase flow to calculate fluid pressure, fluid velocity relative to the solid matrix, and fluctuations in melt fraction. We use these solutions to calculate the dissipation caused by the relative flow of melt and matrix.

1. Introduction

It is well established that tidal dissipation caused by Io's high eccentricity makes it the most volcanic body in the solar system [6, 4, 3]. The presence of widespread volcanism on Io's surface, predictions of Io's internal temperature based on modeling, and magnetometer data collected by the Galileo spacecraft suggest that Io's interior is partially molten [5, 1, 2]. [4] attempted to calculate the amount of dissipation of tidal energy transported to Io's surface by convection of a partially molten material. They found that the heat flux transported by convection in equilibrium with tidal heating is approximately an order of magnitude lower than Io's observed heat flux. This implies that either Io's heat transport is out of equilibrium with heat production or convection is not the only heat transport mechanism. [3] used astrometric observations from 1891-2007 to determine the long term effects of dissipation on the orbits of the Galilean satellites. They calculated a predicted surface heat flux based on the observed changes of Io's orbit and found a heat flux similar to that observed on Io. This implies that Io's interior is close to thermal equilibrium [3]. The likely presence of melt in Io's interior and the inability for convective equilibrium to explain the observed heat loss implies that partial melt may be very important to the generation and transport of heat in Io. In this study, we take steps toward understanding the geophysics of Io by investigating the effect of melt on the total amount of tidal dissipation Io experiences. Periodic flexing of a partially molten Io could cause additional dissipation by forcing the liquid to periodically move back and forth relative to the solid matrix.

2 Approach

Most rocky bodies behave viscously on long time scales and elastically on short time scales. Therefore a viscoelastic model is usually appropriate. To investigate the physics controlling dissipation we are calculating the dissipation due to movement of fluid in the two end-member rheologies: a viscously deforming porous matrix and a poroelastic material (e.g. [7] and [8] respectively). In both cases, the matrix can be thought of as a spongelike crystalline matrix saturated with liquid where the matrix is viscous in one case and elastic in the other [7, 8].

First, we investigate idealized linear tidal-flexing models that assume the strain, stress, and melt fraction fluctuations due to tidal flexing are small which allows us to solve the problem analytically. Follow-on work will explore nonlinear models as well as the general question of how melt segregation interacts with tidal dissipation and convection in Io's interior to shape Io's overall geophysical state. We will present a status report of this research at the conference.

3. Summary and Conclusions

If Io is partially molten, the flow of molten rock through a solid matrix, forced by tidal flexing, could cause more dissipation than tidal flexing of a simple solid body. By assuming the fluctuations in the melt fraction are small, we are able to linearize the problem and solve governing equations for two phase flow to determine the fluid pressure, fluid velocity relative to the solid matrix, and fluctuations of the melt fraction. We will present the volumetric rate of dissipation as a function of porosity, melt viscosity, grain size, and permeability due to flow of fluid relative to the solid matrix expected based on calculated relative velocities.

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