Using the lack of relaxation on Mimas to test for an ocean. J. P. KAY[1], A. R. RHODEN[2], M.E. WALKER[3], [1]Dept. of Ocean & Earth Science Old Dominion University, 406 Oceanography & Physical Sciences Building Norfolk, VA 23529 (jkay@odu.edu), [2]Southwest Research Institute, Boulder, CO, [3]Planetary Science Institute, Tucson, AZ

Introduction: Mimas is the smallest and innermost of Saturn's major moons (r = 197 km), with a bulk density of 1150 kg m^{-3}, which is about 40% lower than Enceladus. It is heavily cratered, which suggests that there has not been enough heat to drive geologic activity [1-2]. When compared to Enceladus, Mimas has a larger eccentricity and should experience larger tides, but it is currently believed that Mimas remained frozen and has a more rigid lithosphere that is not easily deformed [3].

Measurements of the libration of Mimas suggest that it has a either a non-hydrostatic core or a global, liquid water ocean [5], either of which challenge our previous assumptions about the formation and evolution of Mimas. The excess triaxiality that is measured in the libration implies that the libration is more consistent with an ocean [6]. Recent work that used a Andrade ice rheology found that tidal heating within the ice shell of Mimas could maintain a present-day ice shell thickness of somewhere between 24-29 km [7], consistent with the librations. If Mimas has a subsurface ocean today, the magnitudes of tidal stresses would be comparable to Europa or Enceladus but are still well below that of the tensile strength of ice measured in the lab [4].

The thicknesses allowed by tidal heating correspond to a narrow range of heat flows of 22 – 29 mW/m^{-2}. Similar heat flows have craters to relax (e.g., modify their shapes as a result of heat flow) on Tethys and Dione [8]. Crater relaxation is thought to be quite limited on Mimas, but a lack of topographic data could obscure the overall amount [9].

In this study, we use the heat flux estimates provided by [7] to build a model of Mimas that has high enough heat flow to sustain an ocean of the desired thickness, and determine whether the heat flow is low enough to prevent global relaxation of craters.

Methods: We use the commercially available MSC.Marc finite element package, which has been well vetted in the study of the thermal and mechanical properties of the lithospheres of icy satellites [e.g., 10, 11]. The code employs a composite rheology that describes the general behavior of geologic materials: elastic on short time scales and viscous on long time scales, with brittle failure (continuum plasticity) for high enough stresses. We use material, thermal, and rheological parameters for water ice that have been measured in the laboratory [see 10-12].

Our simulated domain is one radial slice in an axi-symmetric, planar Mimas crater. The radius of this crater is 10 km. The thickness of the domain is 25 km, the approximate depth of the ice shell on Mimas. To minimize the effects of the far edge boundaries on the crater evolution, the side boundaries are placed three crater radii away. We use a simplified shape for the surface topography, with a 4th order polynomial depression (eq 1). and an ejecta blanket exterior to the rim following an inverse 3rd power law (eq. 2). Here, C_r is crater radius, C_{rim}, is crater rim, which we are calculating as 25% of the crater radius, and C_d as crater depth which we are using 25.9% if the crater radius.

$$F(x) = (C_{rim} + C_d) * \left(\frac{x}{C_r}\right)^4 - C_d \qquad \textbf{(1)}$$

$$F(x) = \left(\frac{C_{rim}}{7}\right) * 8 * \left(\frac{C_r}{x}\right)^3 - 1 \qquad \textbf{(2)}$$

We start with a surface temperature of 90 K in a conductive heat flow profile. We simulate five different basal heat flows (5, 10, 20, 30, 40 mW m^{-2}) for this initial case. The results of the thermal simulation are piped into a mechanical simulation. We assume a density of 950 kg m^{-3}, a gravity of 0.064 m s^{-2}, and an ice grain size of 1 mm. Free-slip boundary conditions are applied to the two sides of the mesh, whereas the nodes at the bottom of the mesh are fixed.

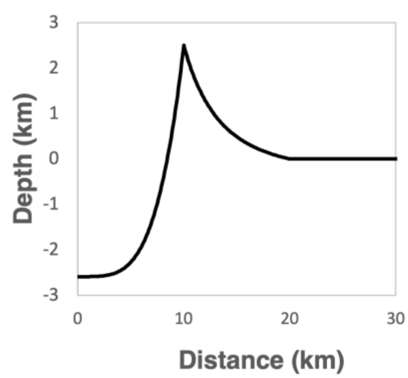

Figure 1: Plot of the initial surface topography for a crater with a radius of 10 km.

Results: In our low heat flow simulations (5 and 10 mW m^{-2}), the thermal structure is mostly isothermal and therefore these simulations run quickly and display a max displacement of 0.1 meter after 1 billion years (Table 1). The higher heat flows take longer to run, which is why a limited subset of data is presented here. They show that there is very little displacement during the initial simulations. These are a snapshot but show almost no displacement after 3 million years.

Table 1: Maximum positive displacement at center of crater.

Heat Flow (mW m^{-2})	Max Displacement (m)
5	0.1 (1 billion years)
10	0.1 (1 billion years)
20	0.11 (1 million years)
30	0.15 (2 million years)
40	0.24 (3 million years)

Discussion and Conclusions: With our preliminary simulations, we have demonstrated that for the initial 3 million years, that there is almost zero relaxation for any of the simulations. For simulations with a lower heat flow (5 & 10 mW m^{-2}), there is zero relaxation. Given the empirical evidence presented in previous work [7], this is consistent with the presence of an ocean on Mimas.

Further work is needed to explore the amount of relaxation that is hypothetically possible on Mimas in a higher heat flow environment.

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