STEREO TOPOGRAPHY AND SUBSURFACE THERMAL PROFILES ON ICY SATELLITES OF SATURN. Cynthia B Phillips, Noah P Hammond, James H Roberts, Francis Nimmo, Ross A. Beyer, Simon Kattenhorn, Carl Sagan Center, SETI Institute, Mountain View, CA, United States; phillips@seti.org Brown University, Providence, RI, United States; Applied Physics Lab, Johns Hopkins University, Laurel, MD, United States. Earth & Planetary Sciences, University of California, Santa Cruz, CA, United States. NASA Ames Research Center, Moffett Field, CA, United States. University of Idaho, Moscow, ID, United States.

Introduction: Stereo topography can be used in combination with numerical modeling to study the subsurface structure and thermal history of icy satellites. We construct digital elevation models (DEMs) of Saturn’s icy satellites from stereo images taken by the Cassini ISS instrument using the software programs Ames Stereo Pipeline and SOCET SET. We have extracted topographic profiles of craters on Rhea, Dione, and Tethys, and compared our measured crater relaxation with predictions from coupled thermal and viscoelastic models. We also created topographic profiles of tectonic features on Dione and compared them with models of flexure.

This combination of DEM measurement and theoretical and numerical geophysical models allows us to estimate subsurface thermal profiles early in the histories of these satellites. We find compelling evidence for the presence of liquid water ocean layers beneath the icy surfaces of the satellites at the time of impact crater and tectonic feature formation, with particularly strong evidence for Dione.

Crater Relaxation: After creating DEMs using techniques discussed previously in [1], we extracted topographic profiles of impact craters on the satellites Dione and Rhea. Using the current crater depths, we then estimated the initial crater depth and calculated the viscous crater relaxation for each crater (Figure 1). Our results show that 100 km diameter craters on Rhea range from about 10-50% relaxed, while craters with diameters greater than 200 km have relaxations of 40-50%. In comparison, craters with diameters of less than 100 km on Dione are 30-50% relaxed, while craters with diameters greater than 100 km were 60-75% relaxed. We are currently completing similar measurements for Tethys.

We then compared these observations with the results of a combined thermal and visco-elastic relaxation model based on the work of [2] and [3]. The model for Rhea (Figure 1) predicts a maximum crater relaxation that ranges from about 10% for smaller craters to 40% for larger craters. In the case of Dione (Figure 1), which is modeled as differentiated, the maximum relaxation is even less: about 5% for a smaller crater and about 10% for a larger crater. Our results thus indicate that our model underpredicts the observed relaxation on Rhea and especially on Dione. We therefore require a warmer interior early in the history of the satellites to produce the observed relaxation. Since our initial thermal models reached a maximum temperature using only warm convecting ice, in order to increase the temperature even further we need to add a layer of subsurface liquid water.

Tectonic Flexure: We have also studied the topographic profiles of tectonic features in order to use flexure to estimate the elastic thickness and therefore the heat flux. From fitting our observations of the height and distance to observed flexural bulges at two sites on Dione to theoretical models of flexure, we found that the elastic thickness ranged between 2-5 km. This is consistent with work published by [4] that suggests an elastic thickness of 1.5-5 km based on long-wavelength topography, and is roughly consistent with elastic thicknesses published for other icy satellites.

With our measurement of average strain of 0.03, we estimate a heat flux of between 25-60 mW/m². This is far higher than the heat flux of about 4 mW/m² expected from radiogenic heating, and is consistent with our crater studies which also require an elevated heat flux to explain the observed relaxation on Dione.

We suggest that tidal heating is one way to create the inferred heat flux. A model with a 50 km thick ocean for Dione (at the time these features were formed) can produce this heat flux with an eccentricity value that is fairly close to the current eccentricity value of 0.0022. Without an ocean, an eccentricity of 0.01 or higher is required to obtain sufficient tidal heating. These results are illustrated in Figure 2, and are presented in detail in [5].

Thermal models: We present two lines of evidence that suggest that a subsurface ocean was present on Dione, and perhaps also Rhea, early in their histories. We are currently working on new thermal models that incorporate subsurface oceans, and will report on the results from these models. Preliminary results suggest that if the shells are conductive, the ice will be too stiff to permit the observed degree of relaxation, even if the ice shells are relatively thin (100 km). These results further suggest that the ice shells on Dione and Rhea were convecting at the time of crater formation. Subsurface oceans beneath convective ice shells may not have been long-lived, however, as convection cools the interior far more rapidly than it is heated by radioactive decay. Additional heat sources such as tidal dissipation or shock heating by the impacts themselves may be
required for relaxation to occur prior to the oceans freezing.


**Figure 1:** Crater relaxation vs. diameter for craters on Rhea (orange) and Dione (black). Squares and diamonds, with error bars, indicate estimated crater relaxation percentage from measured crater diameters and estimate of initial crater depth, as described in the text (and in [1]). Solid orange, and dashed black, lines indicate maximum modeled crater relaxation for craters of a particular diameter, assuming that the crater formed at the earliest time possible in the geologic history of the appropriate satellite. Most measured crater relaxations are above (Rhea) or significantly above (Dione) the modeled relaxations, indicating that the model requires the introduction of a subsurface liquid water layer to be consistent with our results.

**Figure 2:** Eccentricity vs. heat flux for Dione. This plot explores the parameter space for orbital eccentricity $e$ vs. heat flux for various values of the geophysical ratio $k_2$ (tidal Love number) / $Q$ (dissipation factor). The horizontal blue dashed line marks the current eccentricity of Dione (0.0022), and the red shaded area marks the range of our heat flux. Without a subsurface liquid ocean, we need a very high eccentricity to produce the required heat flux (dashed curve at top). With a subsurface ocean layer, however, the heat flux can be obtained with a much lower, and thus more physically reasonable, eccentricity value (curve at bottom). See [5] for a more detailed discussion of the implications of this work.