Implications of tidal stresses on global ocean models of mid-sized icy moons. A.R. Rhoden¹ W. Henning², T.A. Hurford³, M. Bland⁴, G. Collins⁵, and R. Tajeddine⁶. ¹School of Earth and Space Exploration, ASU, Tempe, AZ 85287. ²Alyssa.Rhoden@asu.edu; ³Department of Astronomy, University of Maryland – College Park, College Park, MD 20742; ⁴NASA Goddard Space Flight Center, Code 693, Greenbelt, MD 20771; ⁵USGS Astrogeology, Flagstaff, AZ 86001; ⁶Physics and Astronomy Department, Wheaton College, Norton, MA 02766; ⁷Centre for Astrophysics and Planetary Science, Cornell University, Ithaca, NY 14850.

Introduction: Cassini ISS observations have revealed a great deal of diversity among the surfaces of Saturn’s mid-sized icy moons. Enceladus is currently, and dramatically, active. Tectonic activity is widespread on Dione and Rhea, while Tethys has limited tectonic activity, and Mimas has an ancient, heavily cratered surface, nearly devoid of fractures. The reason for the geologic diversity of the moons is unknown.

Eccentricity-driven tidal stresses have been invoked to explain activity on Enceladus [e.g. 1], especially due to the presence of subsurface liquid. This mechanism has not been seriously considered for the other icy moons because their eccentricities are low (with the exception of Mimas) and they were not expected to have oceans, which inhibits tidal response. However, more recent work has provided evidence for subsurface global oceans within Mimas [2], Enceladus [3,4], Dione [5,6], and Rhea [5,7], and some new models for the formation of the Saturnian satellites predict periods of past higher eccentricities [e.g. 8,9], which could have allowed for increased tidal activity. We compute tidal stresses on each of these moons for a variety of interior structure models and presumed eccentricities to determine which are most likely to have been tidally active in the past. We can then use the tectonic records of the moons to constrain possible interiors and histories.

We focus first on Mimas, which lacks widespread tectonic activity, and determine the conditions under which it could possess a global ocean and avoid both tidal activity and circularization of its eccentric orbit. We will then discuss tidal stresses on Enceladus in an attempt to address the hemispheric dichotomy in its tectonic activity. Finally, we will present calculations of tidal stress using a preliminary suite of interior models for Dione and Rhea and discuss the overarching implications for the presence of oceans within these worlds as well as their failure properties.

Methods: We use a 5-layer model, based on [10], to calculate tidal stresses on each moon for a suite of interior structure models. The models all include ice shells with both brittle and ductile layers overlying global oceans. To explore a large range of possible interior structures, we vary the whole ice shell thickness, the depth of the upper brittle ice layer, and the viscosities of the brittle and ductile ice layers. For Mimas and Enceladus, we further constrain our models to be consistent with the observed librations [2,3]. We compute global peak tidal stresses for each moon and interior model. For those models that can produce tidal stresses comparable to Europa’s, we also create histograms of peak daily stresses at thousands of locations across the surface. We then compare our results across all four Saturnian moons and Europa.

Because Mimas is not currently in an eccentricity-pumping resonance and maintains an eccentricity twice that of Enceladus, we also compute circularization timescales and tidal heating rates for each interior model, following the approach of [11].

Results: Our results show that it is challenging to reconcile a global ocean within Mimas with its lack of tectonic activity and large present-day eccentricity. On Enceladus, the challenge lies in achieving high stresses in the south polar region, where tectonic activity is abundant, but low stresses in the north polar region, which displays limited fracturing. We were able to identify models for Dione that produce tidal stresses within the range of magnitudes on Europa; Rhea will be the subject of our future work. Given the similar magnitudes of stress involved and the high heat flows inferred for Dione and Enceladus, it seems more likely that some tidal-tectonic activity has occurred on Dione and Enceladus, perhaps even in the north polar region, and that Mimas does not possess a global ocean.


Acknowledgements: This work was supported by NASA’s Cassini Data Analysis Program.