WHY IS ENCELADUS ACTIVE WHEREAS MIMAS IS NOT? M. Neveu1 and A. R. Rhoden1, 1School of Earth & Space Exploration, Arizona State University, Tempe, AZ 85287, USA. Email: mneveu@asu.edu.

Context: Thermal models struggle to sustain an ocean on Enceladus, even with tidal heating [1-5]. In contrast, Mimas, Saturn’s innermost mid-sized moon, is surprisingly geologically inactive, although likely differentiated [6]. An ocean on Mimas would lie below warm ice, subject to tidal dissipation at a rate 30 times higher than on Enceladus [7]. Strong tides would drive surface activity and circularize Mimas’ orbit, regardless of dissipation inside Saturn [7-9]. Yet, Mimas’ orbit is four times as eccentric as Enceladus’, and not in an eccentricity-type resonance with other moons. Previous studies suggested that Enceladus’ lower surface area:volume ratio and higher density (i.e. more abundant radionuclides) may have warmed it enough for tidal dissipation to produce heat and melt, whereas Mimas may never have been warm enough to be sufficiently tidally heated [10-12]. However, none of these studies explicitly modeled tidal dissipation.

Model: We model the thermal evolution of Mimas and Enceladus from formation to the present. We use the 1-D code icyDwarf [13,14] to model partial or full ice-rock differentiation, ammonia antifreeze, parameterized convective heat transfer both in the shell and due to hydrothermal flow, and radiogenic, gravitational, and chemical heating. We have added viscoelastic tidal heating [15-17], as well as porosity (model simplified from [18]) and its effects on thermal conductivity [19,20]. Between simulations, we vary the time of accretion (short- and long-lived radionuclide content), initial temperatures, porosities, and structure (homogeneous or rocky core + icy shell), as well as tidal dissipation models (elastic, Maxwell, Burgers, or Andrade).

Results and discussion: Successful evolution scenarios must yield differentiated moons [6], an extant ocean on Enceladus, but no dissipative interior on Mimas (which likely precludes ocean emplacement or persistence). We have yet to find a set of realistic conditions that satisfies all criteria. Melting is favored in insulating interiors (undifferentiated and/or porous). Ocean sustainability hinges on tidal dissipation, but is also favored by undifferentiated crust and hydrothermal circulation, which efficiently transports heat from the radiogenic core into the hydrosphere. Unlike previous findings [10-12], most sets of initial conditions that yield an ocean on Enceladus also yield one on Mimas, for which the positive tidal feedback on ocean persistence is stronger. This highlights the need to explicitly model tidal effects on thermal evolution.

Our simulations produce an extant ocean on Enceladus if (1) it retains an insulating crust (Fig. 1); or (2) with Andrade-like dissipation, which yields an ice thickness of 50 km, or 25 km if dissipation is ten times higher as suggested by [17]. In scenario (1), Mimas has no ocean, but remains undifferentiated. In scenario (2), Mimas also has an ocean.

Ongoing work: Because differentiation requires ice softening, conducive to runaway dissipation, a scenario in which Mimas accretes rock before ice could explain its present state [21]. It would then never heat up enough for tidal feedbacks to take place, whereas Enceladus would. We are now testing such scenarios.


Fig. 1: Thermal evolution of Enceladus for accretion 7 Myr after Ca-Al-rich inclusions, with initial temperature 100 K and 20% initial porosity. Tidal dissipation follows the Andrade model. Maxwell dissipation yields a thinner ocean and thicker crust.