
Introduction: We investigate the effect of giant planet’s luminosity on the subsurface evolution of its satellites. We focus on some Saturnian medium-sized satellites that are characterized by the absence of long-term heat sources likely to play a significant role in endogenic activity.

Approach: In the early history Saturn’s luminosity determines the surface temperatures of the satellites. This has consequences on properties of the mechanical lithosphere, with implications for geological activity and crater relaxation. This can also have consequences for the onset of convection. The surface temperature increase results in an inverted temperature profile that is not conducive to convection. Parameters involved in the modeling are: Saturn’s luminosity (see [1]), the initial temperature of the satellites, the time of residence of the satellites in the Saturnian subnebula, the mode of heat transfer from Saturn to the satellites’ surfaces, the satellites’ albedos, etc. Surface temperatures are expected to decrease linearly as a function of distance to Saturn. This effect is moderated by the way heat is transferred from Saturn to the satellites (see [2] for a review).

We argue that there should be a link between a satellite’s distance to its planet and its surface age. Satellites closer to their planets should be more affected by luminosity variations which affect geological features. The influence of Saturn’s luminosity can be important for the inner satellites out to and including Tethys, and become negligible for more distant satellites. Thus, Iapetus, the farthest regular satellite of Saturn, should be the least affected by Saturn’s luminosity variations.

At the opposite extreme, Mimas being very close to Saturn should show some expression of Saturn’s luminosity (after dissipation of the subnebula, while the planet’s luminosity is high). The only constraint available for Mimas’ early surface temperatures is that they must be less than the ice sublimation temperature, i.e., 200 K for the conditions in Saturn’s nebula (see also [2]). We model Mimas’ thermal evolution for several cases. Mimas is formed and then resides in the subnebula for 10 My. The subnebula then dissipates and we consider two maximum surface temperatures: 90 K and 190 K. In the latter case, we assume that there is a linear decrease of this temperature over a few hundred million years. The initial porosity profile is assumed, using laboratory measurements as a guide [e.g., 3]. For Mimas, a 150-km thick layer with porosity larger than 0.2 is at the surface. We compute the evolution of porosity as described in [4]. We also consider the presence of absence of short-lived radiogenic species (SLRS) following the model proposed by [5] for Iapetus, i.e., a formation time of ~2.5 My after the formation of Calcium-Aluminum Inclusions. Results are presented in Figure 1.

The first major difference between the different cases is the evolution of porosity. Models of Mimas in which the surface temperature is 90 K keep a thick high-porosity outer layer over the long run. Models in which surface temperature reaches 190 K lose most of their porosity. We note that if the body is made of pure water, a similar decrease in the porosity occurs if the surface temperature is larger than 160 K. This threshold temperature can be even less if the ice is rich in ammonia and other contaminants. While Saturn’s cooling time scale is not well constrained, the time scale for porosity to decrease, once the temperature gets above the ice creep temperature is less than one hundred million years.

The other major difference between the cases is the capacity of the mechanical lithosphere to record and support geological features over the long run. Depending on whether or not the body is highly porous [6], and the maximum internal temperature reached inside the satellite due to radionuclide heating, conditions are suitable for crater relaxation and even reset of the surface a few hundred years after formation.

Conclusion: We expect to derive constraints on some of the parameters involved in the modeling, especially Saturn’s luminosity, by comparing crater morphology, distribution, etc. as a function of distance to the planet (e.g., as an extreme, Mimas vs. Iapetus). Different time scales need to be considered for better characterizing these processes: time scale for endogenic activity to start and become significant, time of residence in the subnebula, Saturn’s cooling, bombardment history, crater relaxation time-scale, as well as despinnning.

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Figure 1. Temperature and porosity evolution models for Mimas. (a,b) Models with no short-lived radiogenic species; (c, d) Models with short-lived radiogenic species for a formation time of 2.5 My after CAIs. For each category, we consider two cases for the upper boundary conditions: (a, c) the maximum surface temperature $T_e = 90$ K (assumes that Saturn’s luminosity is low); (b, d) $T_e = 190$ K (upper bound, slightly lower than ice sublimation temperature). In both cases, the maximum surface temperature is reached at ~10 My after satellite’s formation, after dissipation of the Saturnian subnebula.