EPSC Abstracts
Vol. 7 EPSC2012-161 2012
European Planetary Science Congress 2012

Can Large Icy Moons Accrete Undifferentiated?

J. Monteux (1), G. Choblet (1), M. Le Feuvre (2), G. Tobie (1)
(1) Laboratoire de Planétologie et de Géodynamique de Nantes, U.M.R. CNRS, FRANCE. (julien.monteux@univ-nantes.fr)
(2) IFSTTAR, LCPC, Nantes

Abstract

To explain the dichotomy in the degree of differentiation that seems to exist among various icy satellites of the Solar System, we characterize the early thermal evolution of an icy moon growing by km-size impacts. For each impact, we account for the topographic deformation, the deep impact heating and the ejecta heating. For that purpose, we have modified the 3D convection code Oedipus and we monitor the temperature and melt fraction evolution within the growing icy satellite. By exploring the accretionary parameter space, we determine the degree of differentiation of a growing icy moon.

1. Introduction

Differences in composition and internal structure exist between the major icy satellites of Jupiter and Saturn and suggest distinct accretionary histories [1][2][3]. Callisto's accretion was probably slower than Ganymede's [1][4], reducing the internal temperature increase and the volume of melted ice while Ganymede's differentiation may be the result of a catastrophic event following a thermal runaway a few hundred million years after its accretion [2]. Gravity measurements performed by the Cassini Radio Science Experiment [5] suggest that Titan's internal structure is probably intermediate between Ganymede and Callisto. The moment of inertia inferred from the gravity field suggests either that the segregation of rock and ice is not complete in the deep interior or that the rocky core is mostly composed of highly hydrated minerals [6][7]. Whatever the exact degree of ice-rock segregation, melting of outer icy layers is expected to have occurred during the late stage of the accretion [8][9]. The most recent models even suggest that a second melting process via impacts may have occurred during the late heavy bombardment 700 Myr after the system's formation [10].

For a better understanding of the thermal evolution of a growing icy satellite and of the conditions under which melting may occur, we developed a three-dimensional numerical model based on the Oedipus code, initially developed to solve the equations of thermal convection in a spherical geometry [11]. This numerical model characterizes the thermal evolution of an icy satellite during its accretion from a variety of plausible impactor population (Fig.1).

2. Method

2.1 Satellite growth

After a large impact, the formation of a crater occurs with lengthscales (diameter, depth and ejecta thickness) that depend on several impact parameters (impactor radius, impact velocity and angle, rheology and size of the moon). We use the relations between the crater lengthscales and the impact parameters inferred from observations of simple and complex craters on icy satellites [12]. After each impact we calculate the topography modification and take into account the pre-impact topography using the method developed by Howard [13]. We consider the growth of an icy satellite by 100 $\%$ accretive impacts meaning that neither material from the satellite nor the impactor escape from the growing object. We consider that the impactor diameters range between d_{min} and d_{max}. Each impact diameter is chosen within a population using a Monte-Carlo sampling method. We assume that the accretion rate σ is constant during the whole accretion duration τ and that the population of impactor is infinite with a mass distribution slope deduced from the N-body simulations of [14].

2.2 Thermal evolution

After a large impact, temperature locally increases deep within the impacted growing moon. Part of this heated material is excavated and deposited in a shallow ejecta blanket. As the icy moon grows, gravitational forces increase and impacts become more and more energetic. As the temperature increase below the impact site is proportional to the impact velocity, melting events are expected to occur at the end of the accretion once the icy moon reaches a critical size. For each impact, we consider the thermal effects due to the dissipation of the impactor's kinetic energy [15]. In our models, thermal equilibration within the satellite occurs via diffusion of heat. At the satellite surface, heat is efficiently radiated away. We impose a surface heat flux $\sigma(T_{eq} - T)$ with σ the Stefan-Boltzman constant and T_{eq} the temperature of equilibrium typically varying between 50 and 150 K.

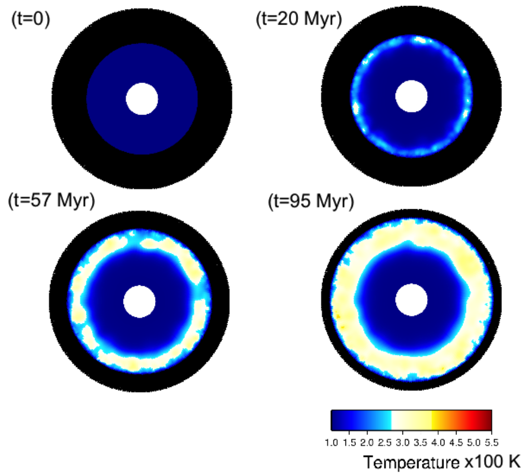

Figure 1: Temperature evolution within a growing icy satellite.

3. Preliminary results

In order to constrain the critical size above which melting is no longer negligible, we simulate the growth and thermal evolution of icy bodies from a 1000 kilometer-size initial undifferentiated body to a size of order 2500 km from various populations of undifferentiated icy impactors and by assuming different orbital configurations for the growing body and different accretion rates. During the accretion, we monitor IN 3D the radius of the growing satellite, the maximal and mean temperature (Fig.2) and the melt fraction (Fig.3). We show here some preliminary results with an unrealistic impactor population that emphasizes large impact effects ($d_{min} = 10$ km, $d_{max} = 100$ km) and with $\tau = 100$ Myr. We choose $\sigma \sim 10^{16}$ kg yr^{-1}. We characterize the inner thermal evolution of an icy satellite with an initial radius $R = 1000$ km to $R = 1500$ km.

Our preliminary results show that melting and differentiation is almost certain for an icy body growing only by km-size impacts and suggest that small scale

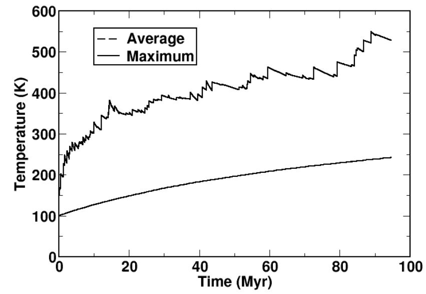

Figure 2: Normalized temperature evolution within a growing icy satellite.

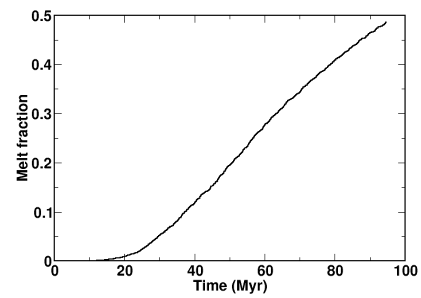

Figure 3: Melt fraction during the accretion.

deposits have probably played a key role during accretion and thermal evolution of icy moons. This effect will be presented.

Acknowledgements

J. Monteux is funded by ANR ACCRETIS. G. Tobie and G. Choblet are funded by ERC EXOWATER.

References

[1] S. Mueller, W.B. McKinnon, *Icarus* **76**, 437-464, 1986.
[2] R.L. Kirk, D.J. Stevenson, *Icarus* **69**, 91-135, 1987.
[3] I. Mosqueira, P.R. Estrada, *Icarus* **163**, 232-255, 2003.
[4] K.D. Nagel, *et al.*, *Icarus* **169**, 402-412, 2004.
[5] L. Iess, *et al.*, *Science* **327**, 1367-1369, 2010.
[6] F. Sohl, *et al.*, *Space Sci. Rev.* **153**, 485-510, 2010.
[7] J. Castillo-Rogez, J.I. Lunine, *GRL* **37**, L20205, 2010.
[8] K. Kuramoto, T. Matsui, *JGR* **199**, 21183-21200, 1994.
[9] G. Tobie, *et al.*, *Nature* **440**, 61-64, 2006.
[10] A. Barr, R. Canup, *Nature Geo.* **3**, 164-167, 2010.
[11] G. Choblet, *et al.*, *G. J. Int.* **170**, 9-30, 2007.
[12] K. Zahnle, *et al.*, *Icarus* **163**, 263-289, 2003.
[13] A. Howard, *Geomorphology* **91**, 332-363, 2007.
[14] E. Kokubo, S. Ida, *Icarus* **143**, 15-27, 2000.
[15] J. Monteux, *et al.*, *GRL* **34**, 24201-24205, 2007.