EPSC Abstracts
Vol. 10, EPSC2015-104, 2015
European Planetary Science Congress 2015

Consequences of large impacts on Enceladus' core shape

J. Monteux (1), G.S. Collins (2), G. Tobie (3) and G. Choblet (3)
(1) Laboratoire Magmas et Volcans, Université Blaise Pascal, CNRS, IRD, Clermont-Ferrand, France, (2) Impacts and Astromaterials Research Centre, Department of Earth Science and Engineering, Imperial College London, (3) Laboratoire de Planétologie et de Géodynamique, CNRS, Nantes, France (j.monteux@opgc.univ-bpclermont.fr)

Abstract

The intense activity on Enceladus suggests a differentiated interior consisting of a rocky core, an internal ocean and an icy mantle. However, topography and gravity data suggests large heterogeneity in the interior, possibly related to significant core topography. In the present study, we investigated the consequences of collisions with large impactors on the core shape. We performed impact simulations using the code iSALE2D considering large differentiated impactors with radius ranging between 25 and 100 km and impact velocities ranging between 0.24 to 2.4 km/s, which are representative of impact events during the end of Enceladus' accretion. Our results show that if enough energy is available, part of the Enceladus' core is excavated which leads to a negative topography anomaly surrounded by a small positive anomaly. Among the icy mantle and the rocky core porosities, only the second one influences the post-impact rocky core shape. However, its influence as well as the influence of a thick sub-surface water ocean is less significant compared to the impact velocity or the impactor radius. Hence, constraining precisely the rocky core morphology is more likely to inform on the late accretionary conditions (i.e. impact velocity and impactor size) than on the internal structure and mechanical behaviour of Enceladus.

1. Introduction

Despite its small size (R=252 km), Saturn's moon Enceladus is one of the most geologically active body of the Solar System. This activity, concentrated at the south pole [1], implies a warm interior, consistent with a liquid water layer underneath the ice shell and a differentiated interior [2, 3]. The global shape data show a depression at the south pole [4]. It has been proposed that the dichotomy between the north and south hemispheres may be the result of asymmetry in core shape [5]. [5] proposed three hypotheses to explain the possible irregularity of Enceladus' rocky core: accretional melting of the outer region of the icy moon associated with the degree-one instability; accretion of icy protomoons around irregular rock chunks; and collisional merger of two previously differentiated protomoons. Here we test the latter hypothesis by investigating the consequences of the collision of a large differentiated impactor on the shape of Enceladus' core.

2. Impact modeling

To constrain the consequences of large-scale impacts on Enceladus, we simulated head-on collisions of differentiated impactors with size ranging between 50 and 200 km using the iSALE2D shock physics code [6]. From these simulations, we tracked the evolution of rock fragments coming from the impactor and the impact-induced modification of Enceladus's core shape. In particular, we quantified the sensitivity in these outcomes to key model parameters, such as impactor velocity and radius, as well as structure and mechanical properties of Enceladus' interior (porosity, strength, temperature profile, core size, presence of an internal ocean).

3. Results

Fig. 1 shows characteristic simulations with (vimp=10 vesc, Rimp=25 km), (vimp=10 vesc, Rimp=75 km) and (vimp= vesc, Rimp=75 km). After such events, a large volume of Enceladus' mantle is displaced or escapes the orbit of the icy moon. To get a quantitative measure of deformation induced by the impact event, we monitor the plastic strain experienced by the impacted material. As represented in Fig. 1, the icy material is highly disturbed by the impact and most of the plastic deformation occurs in this layer. For the largest impact velocities (Fig. 1, left and middle), deformation also occurs at the top of the rocky core and leads to the formation of a depression. The material removed from the depression is displaced in a very small uplift of the core, surrounding the depression.

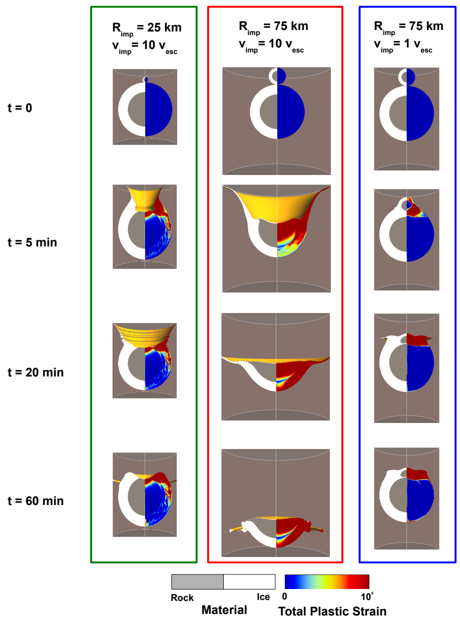

Figure 1: Material repartition (left column) and total plastic deformation (right column) as a function of time (from top to bottom) on Enceladus for 3 impact cases: (vimp=10 vesc, Rimp=25 km), (left), (vimp=10 vesc, Rimp=75 km) (centre) and (vimp= vesc, Rimp=75 km) (right)

We have used numerical impact simulations to examine the behaviour of an Enceladus' rocky core after an impact with a differentiated proto-moon with size ratios ranging between 0.1 and 0.4 and impact velocities ranging between 0.24 to 2.4 km/s. Our results show that depending on these two impact parameters, the post-impact shape of the target body's rocky core can exhibit negative or positive topographical features. If enough energy is available, part of the Enceladus' core is excavated which leads to a negative topography anomaly surrounded by a small positive anomaly. Otherwise the impactor's core spreads above the target body's core and leads to a positive topographic anomaly. Ultimately, for impactors larger than 150 km and/or impact velocities $\geq$ 10 vesc, the target body's core is disrupted and a substantial part of the icy mantle is irreversibly removed from the icy moon.

Among the icy mantle and the rocky core porosities, only the second one influences the post-impact rocky core shape. However, its influence is less significant compared to the impact velocity or the impactor radius. This conclusion also stands for the minimum strength of the impacted material. On the contrary, the presence of a thick sub-surface water ocean tends to reduce deformation of the rocky core during the impact.

4. Conclusions

Constraining precisely the rocky core morphology is more likely to inform on the late accretionary conditions (i.e. impact velocity and impactor size) than on the internal structure and mechanical behaviour of Enceladus. For a better comprehension of the post-impact rocky core shape, more sophisticated (i.e. 3D) simulations are required to include the impact angle effect.

Acknowledgements

We gratefully acknowledge the developers of iSALE, including Kai Wünnemann, Boris Ivanov, Jay Melosh, and Dirk Elbeshausen. We also thank Katarina Miljkovich and Tom Davison for useful discussions.

References

[1] Tobie, G., O. Cadek, and C. Sotin: Solid tidal friction above a liquid water reservoir as the origin of the south pole hotspot on Enceladus, Icarus, 196, 642-652, 2008.

[2] Nimmo, F., J. R. Spencer, R. T. Pappalardo, and M. E. Mullen : Shear heating as the origin of the plumes and heat flux on Enceladus, Nature, 447, 289-291, 2007.

[3] Schubert, G., J. D. Anderson, B. J. Travis, and J. Palguta: Enceladus: Present internal structure and differentiation by early and long-term radiogenic heating, Icarus, 188, 345-355, 2007.

[4] Thomas, P. C., J. A. Burns, P. Helfenstein, S. Squyres, J. Veverka, C. Porco, E. P. Turtle, A. McEwen, T. Denk, B. Giese, T. Roatsch, T. V. Johnson, and R. A. Jacobson: Shapes of the saturnian icy satellites and their significance, Icarus, 190, 573-584, 2007.

[5] McKinnon, W. B.: The shape of Enceladus as explained by an irregular core: Implications for gravity, libration, and survival of its subsurface ocean, Journal of Geophysical Research (Planets), 118, 1775–1788, 2013.

[6] Collins, G. S., H. J. Melosh, and B. A. Ivanov: Modeling damage and deformation in impact simulations, Meteoritics and Planetary Science, 39, 217-231, 2004.