

**MODELING THE FORMATION OF MENRVA IMPACT CRATER IN TITAN: IMPLICATIONS FOR A POTENTIALLY HABITABLE HYDROCARBON WORLD.** A. P. Crósta<sup>1,2</sup>, E. A. Silber<sup>3</sup>, R. M. C. Lopes<sup>2</sup>, B. C. Johnson<sup>3</sup>, M. J. Malaska<sup>21</sup> Geosciences Institute, State University of Campinas, P.O. Box 6152, 13083-970, Campinas, SP, Brazil [alvaro@ige.unicamp.br](mailto:alvaro@ige.unicamp.br), <sup>2</sup>Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA. 91109, USA <sup>3</sup>Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI, USA, 06912.

**Introduction:** Titan exhibits unique characteristics when compared to other planetary bodies in our solar system: it is an ocean world, an icy world and an organic world. In Titan's dense atmosphere organic molecules are synthesized and then follow a path down to the surface. From the surface, it may be possible that organic molecules were delivered to the deep subsurface ocean [1 and refs. therein]. Among the geological processes that could potentially deliver organic molecules to the aqueous environment at the contact of the ice shell and the subsurface ocean are large cosmic impacts. Hypervelocity impacts can release enough energy to breach through the external ice shell and reach Titan's subsurface ocean. In addition, they could also provide the conditions for liquid water to remain ephemerally at or near Titan's surface. This scenario, combined with hydrothermal fluid circulation cells produced by large impacts, could create transient habitable environments.

The aim of this study is to model the formation of large impact craters on Titan, using the case of the largest one known on its surface, Menrva Crater, and then analyze the implications and potential contributions of impact cratering for providing conditions for the development of life on Titan.

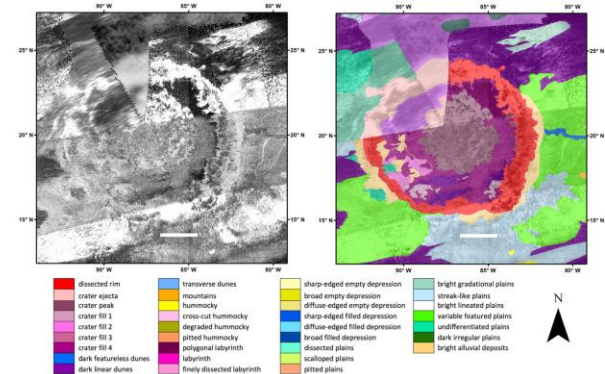
**Menrva Crater:** Differently from other solid planetary bodies, impact craters are not a landform commonly found on Titan. Crater identification is challenging due to the limited and low spatial resolution of the radar and optical imaging data on Titan, coupled with erosional and depositional processes that alter crater morphology leading, in the long term, to the partial or total obliteration of the impact record. Viscous relaxation can also contribute for the limited impact record [2]. Only a relatively small number of impact craters (49) were initially identified in Titan's surface by [3], who divided them into three categories: certain, nearly certain and probable. A more recent appraisal [4] raised this number to 75, this time with a fourth category: possible.

Among Titan's known impact craters, Menrva Crater stands out due to its large 425 km diameter making it at least three times larger than the next largest crater (Forseti, ca. 140 km diameter).

We have chosen Menrva for the modeling exercise, based on the fact that such a large impact event would

potentially create favorable conditions to put the organic molecules in contact with liquid water from the subsurface ocean and also potentially provide enough thermal energy to create the conditions for a transient habitable environment.

Menrva is a complex, double-ring crater, still exhibiting its main characteristic features despite its advanced degradation mostly by erosion: crater rim, crater fill, crater rings and central peak, as well as partially preserved ejecta deposits (Fig. 1).



**Figure 1:** Left: Synthetic Aperture Radar (SAR) image from Cassini RADAR instrument over a 0.93 micron infrared image showing Menrva Crater (ca. 425 km diameter); Right: Updated geomorphological map of Menrva Crater [5]. The white bar for scale has a 100 km length.

**Modeling:** To simulate the formation of the Menrva crater, we use the iSALE2D hydrocode [6,7]. The model is set up with an ice projectile impacting a 2-layered target comprised of a fully conductive ice shell with variable thickness overlying a liquid ocean at  $T = 273$  K. Due to the axial symmetry of the model, impacts are vertical, with the impact velocity of 15 km/s and the projectile diameter of 42 km. The surface temperature of the conductive ice shell is set to 94 K. The model inputs are consistent with the earlier modeling study that examined the formation of impact craters on Europa [8], with a few minor adaptations relevant to Titan, such as gravity. To represent the ocean layer and ice Ih, we implement the ANEOS [9] and Tillotson [10] equations of state, respectively. We vary the thickness of the ice shell from 75 to 150 km, in 25 km increments. In our preliminary runs, we set the grid

resolution to 25 cells per projectile radius (CPPR), which is sufficient for estimating the final crater diameter, and evaluating the mixing and movement of the material during the crater collapse process.

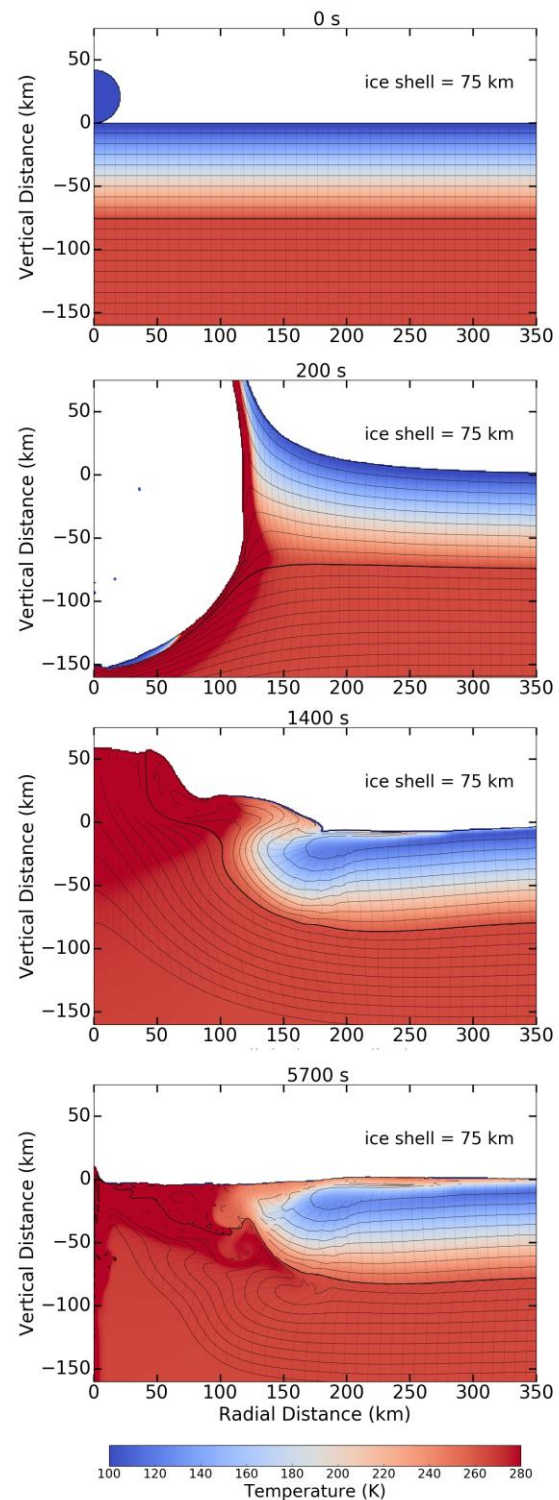
**Preliminary Results:** Our preliminary runs produced an impact crater consistent with the dimensions of Menrva. Higher resolution simulations will be needed to better evaluate the final crater depth and compare to the observed values. The 75 km and 100 km thick ice shell breaks up during the crater collapse, establishing a pathway to the ocean. The 125 km and 150 km thick ice shells remain intact; however, there is significant amount of deformation and heating. Figure 2 shows the time series of the crater collapse process for the 75 km thick ice shell. As seen from top to bottom, the panels show the initial time step, at the moment of impact, followed by time steps at 200, 1400 and 5700 seconds.

**Discussion and Future work:** In our future work, we aim to better characterize and constrain the possible conditions that existed on Titan at the time Menrva formed. Among other things, future work will involve expanding the parameter space to also include a conductive-convective ice shell over ocean, similar to the modeling work done for impact craters on Europa [8]. We also plan to estimate the melt production, and evaluate transport and mixing of the material around the point of impact.

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**Figure 2:** Time series of the Menrva crater produced by a 42 km projectile impacting at 15 km/s into the 75 km thick ice shell. From top to bottom, the panels show the time steps at the moment of impact, and then at 200, 1400 and 5700 seconds.