INSIGHTS INTO THE FORMATION OF MENRVA CRATER ON TITAN AND IMPLICATIONS FOR HABITABILITY. A. P. Cróstal, E. A. Silber, R. M. C. Lopes, B. C. Johnson, M. J. Malaska, Geosciences Institute, State University of Campinas, P.O. Box 6152, 13083-970, Campinas, SP, Brazil alvaro@ige.unicamp.br. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA. 3Department 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 epithermally 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 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-like crater, we use the iSALE2D hydrocode [6,7]. The model is set up with an icy projectile vertically striking a 2-layered target at 15 km/s. The target is comprised of an ocean overlaid by a conductive-convective ice shell (Fig. 2). To test a wide parameter space [8], we vary the temperature of the warm convective ice, the total thickness of the ice shell and the thickness of the conductive (stagnant) lid (Fig. 2). Examples of thermal profiles are shown in Fig. 3.

Figure 2: Diagram depicting the 2-layered target structure representing the Titan-like conditions. A wide parameter space was tested by varying the conductive lid and ice shell thickness, and temperature of warm convective ice as shown in the diagram (not to scale).

The impactor diameter is 45 km, which is appropriate for producing a Menrva-like impact crater. The model inputs are consistent with the earlier model-
ing study that examined the formation of impact craters on Europa [9]. To represent the ocean layer and ice Ih, we implement the ANEOS [10] and Tillotson [11] equations of state, respectively. The grid resolution is 20 cells per projectile radius, which is sufficient for estimating the final crater dimensions, and evaluating the surface-ocean material exchange during the crater collapse process.

**Results:** Only some model scenarios lead to the formation of an impact crater with the dimensions and morphology consistent with that of Menrva, which helps in constraining the conditions present at the time this crater came into the existence. In particular, only those ice shells with a 60 and 36 km stagnant lid and warm convective ice at 245 K lead to a discernable impact structure, but only the latter reproduces Menrva’s relatively low depth. Conversely, the ice shells with a stagnant lid <36 km thick yield conditions that are too warm for any impact features to be retained upon completion of the crater collapse process. This is expected, considering that thermal gradient plays an important role in impact cratering process on icy bodies [9 and refs therein].

The surface-ocean communication is possible only in the thinnest ice shell scenario, which is 75 km. In the 100 km thick ice shell, some breaching occurs but only during the later stages of impact crater collapse, which is more likely due to the vertical geometry rather than a real effect. The 125 km and 150 km thick ice shells remain intact; however, there is significant amount of impact induced heating. Figure 4 shows the time series of the crater collapse process for the 75 km thick ice shell with the 36 km thick stagnant lid.

**Conclusions:** We modeled the formation of a Menrva-size impact crater in a Titan-like target using iSALE hydrocode. Our results suggest that at the time this crater formed, Titan’s ice shell had a 36 km thick stagnant lid overlying warm convective ice with the likely temperature of 245 K. The surface-ocean pathway is entirely possible, allowing the uppermost organ-

**Acknowledgements:** Part of this work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. Government sponsorship is acknowledged. A.P. Crôsta acknowledges funding received from the São Paulo Research Foundation (FAPESP).