EXPLORING HABITABILITY CONDITIONS IN TITAN'S IMPACT RECORD: THE FORMATION OF MENRVA CRATER

A.P Crósta[1], E.A. Silber[2], R.M.C. Lopes[3], M.J. Malaska[3], A. Solomonidou[4], B.C. Johnson[5], S.D. Vance[3], C. Sotin[6], E. Bjonnes[7], J.M. Soderblom[8] [1]Geosciences Institute, State University of Campinas, P.O. Box 6152, 13083-970, Campinas, SP, Brazil crosta@unicamp.br; [2]Western University, London, ON, Canada; [3]Jet Propulsion Laboratory, California Institute of Technology; [4]California Institute of Technology; [5]Purdue University; [6]University of Nantes, France; [7]Brown University; [8]Massachusetts Institute of Technology

Introduction: Titan is unique in our Solar System: it is an ocean world, an icy world, an organic world, and has a dense atmosphere. It is also a geologically active world, with ongoing exogenic processes, such as rainfall, sediment transportation and deposition, erosion, and possible endogenic processes, such as tectonism and cryovolcanism. This combination of an organic and an ocean world makes Titan a prime target for astrobiological research, as pre-biotic and biotic lifeforms may have developed in its deep ice and water ocean underneath the outer ice shell [1].

Impact craters are important sites in this context, as they may have allowed exchange of materials between the surface, the near subsurface and the ocean, and possibly even created conditions for the development of primitive lifeforms.

The formation of Menrva crater: To investigate possible exchange pathways between the subsurface water ocean and the organic-rich surface, we model the formation of the largest crater on Titan, Menrva, with a diameter of ca. 425 km. Menrva is a complex impact basin, with a peak-ring-like structure in its central area [2,3,4]. Despite degradation, the crater still exhibits morpho-structural features with typical characteristics of this type of large impact crater: rim, two inner annular rings, crater fill, and possible peak-ring central elevations, as well as partially preserved ejecta deposits (Fig. 1).

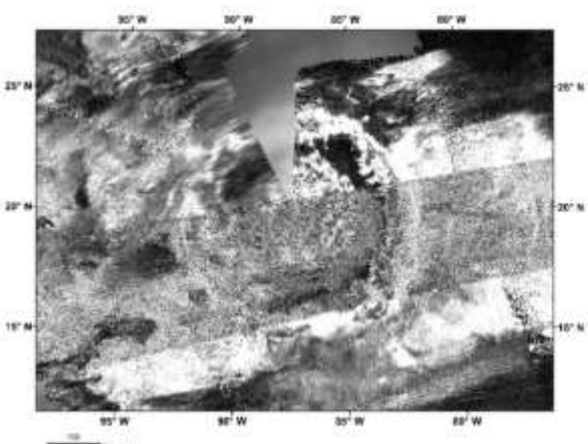

Figure 1. Menrva crater depicted in a combination of Synthetic Aperture Radar (SAR) and Imaging Science Subsystem (ISS - 0,93 µm) images, taken by Cassini.

Herein we test the hypothesis that a Menrva-like impact event is sufficiently large to breach Titan's ice shell and reach the subsurface ocean, creating path-ways connecting the organic-rich surface and the sub-surface water ocean. Even more important, during such an impact, materials from the deep subsurface ocean, including salts and potential biosignatures of putative subsurface biota, could be emplaced on the surface — likewise, atmospherically derived organic surface materials could be directly injected into the subsurface ocean, where they could undergo aqueous hydrolysis and form potential astrobiological building blocks, such as amino acids.

To study the formation of a Menrva-like impact crater, we performed numerical simulations using the iSALE-2D shock physics code, employing different scenarios. These scenarios used current estimates of Titan's ice shell's thickness, constrained by the minimum and maximum values of 50 and 125 km, respectively, based on geophysical data [5,6]. We analyze the implications and potential contributions of impact cratering as a geological process able to provide conditions for the development of life on Titan.

Results and Discussion: Menrva straddles Titan's equatorial dunes and midlatitude plains, in contrast to other large craters, that are located in one or the other terrain types [7]. As such, Menrva's surface exhibits some particular characteristics, as shown by the analysis of the crater's surface using VIMS data (Table 1).

Table 1. Major constituents and emissivity results for the ejecta blanket and the crater floor of Menrva.

	Menrva	
Unit	*Floor*	*Ejecta*
H_2O	15%	15%
Tholin	85%	85%
Dark	-	-
Total organic	**85%**	**85%**
Emissivity	0.90	0.87
Degradation state	Still retains main morpho-structural features	

Mixing of materials from the organic layer, ice shell and underlying ocean: Significant deformation and mass movements occur in the 110 km-wide central area right before the complete breach of the ice shell, at ca. 6100 s, as shown in Figure 2.

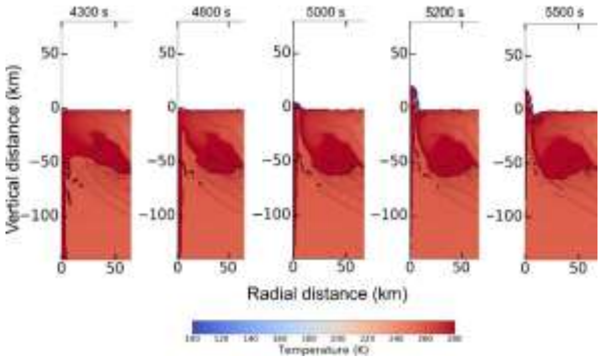

Figure 2. Displacements of the crustal layers of Titan, right before the complete breach of the ice shell, at ca. 6100s. As a consequence of these movements, water from the subsurface ocean raise to the surface in considerable volume and mix with ice. The lines in each figure represent the depths of the layers prior to impact.

Near the center of the basin, our simulations show the displacements of the different crustal layers taking place in Menrva's central area, during the time interval between 4300 and 5500 s, right before the total breach of the ice shell. They also suggest the entirety of the ice shell is melted. In such a melt through scenario, substantial mixing between ocean and melted ice shell is likely [8].

Provenance of materials: Intense upward displacement of materials occurs within a zone extending out to ~1/3 radius and down to depths of 80 km (Fig. 3). These movements result in optimal conditions for materials from the ice shell+organics and the water ocean to mix together, thus promoting an active interchange of materials from these media.

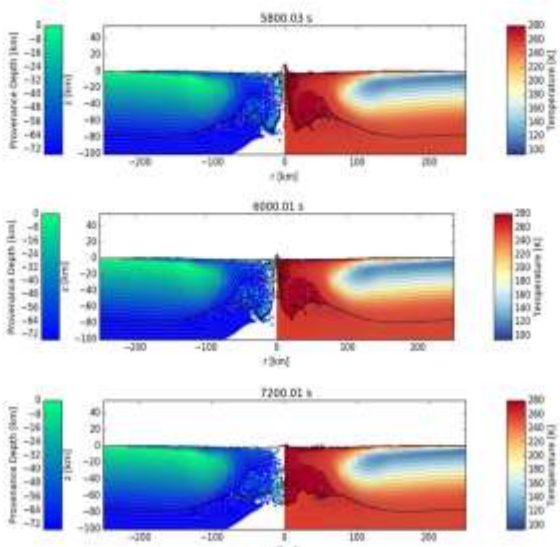

Figure 3. Provenance depths of the materials that undergo mixing (left) x temperature conditions (K) (right).

Conclusions: Large hypervelocity impacts can have an important and beneficial role in creating habitable environments or niches. When viewed from the perspective of a geobiological process, impact cratering can influence the biological evolution of planetary bodies and control planetary habitability [9].

Our findings include the occurrence of significant exchange of materials from the surface (organics and ice) and the subsurface (water ocean) in the central area of Titan's Menrva crater. We argue that a combination of these processes, in an environment containing organic compounds and water, heated to ca. 280 K by the transfer of thermal energy from the impact to the crust, would result in a near-optimal habitable ecosystem or a habitable zone on Titan. Thus, Menrva crater and its immediate surrounding terrains, such as the ice-rich regions to the south, southeast and east of the crater [10] offer a potentially favorable location for future exploratory missions in search for biosignatures.

References:

[1] Lopes et al 2018 AGU Fall Meeting, abstract # P21E-3401. [2] Collins et al. 2002 *Icarus*, 157, 24-33. [3] Morgan and Bray 2014 *Nature*, 390, 472-476. [4] Melosh 2015 Bridging the Gap III. Abstract #1003. [5] Sotin et al. 2010. In: Brown, R.H.; Lebreton, J-P, Waite, J.H., 61-73. Springer. [6] Vance et al. 2018 *JGR: Planets*, 123, 180–205. [7] Solomonidou et al. 2020 *Astronomy & Astrophysics*, 641, A-16. [8] Turtle and Pierazzo 2001 *Science*, 294, 1326-1328. [9] Osinski et al. 2020 *Astrobiology*, 20, 1121-1149. [10] Griffith et al. 2019 *Nature Astrono*my, 3, 642-648.

Acknowledgements: This research was supported partly by the JPL-led NASA Astrobiology Institute team "Habitability of Hydrocarbon Worlds: Titan and Beyond". Part of this his work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. Government sponsorship is acknowledged. A.P. Crósta acknowledges the financial support from the São Paulo Research Foundation (FAPESP, grant 2017/27081-1) and the State University of Campinas (Unicamp), that allowed part of this research to be developed during his stay at JPL as a visiting scientist. We gratefully acknowledge the developers of iSALE-2D, including Gareth Collins, Kai Wünnemann, Dirk Elbeshausen, Tom Davison and Boris Ivanov. Some plots in this work were created with the pySALEPlot tool written by Tom Davison.