THE CHEMICAL COMPOSITION OF IMPACT CRATERS ON TITAN.

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Introduction: After 13 years of Cassini-Huygens exploration, Titan was shown to possess unique properties, such as its Earth-like atmospheric structure and composition, in addition to its surface geology. Geomorphological features commonly found on Earth, such as mountains, drainage networks, dunes, and lakes, were observed on Titan by the Cassini spacecraft and the Huygens probe [e.g. 1]. One additional similarity with Earth's geology is the limited number of impact craters on Titan's surface, unlike the heavily cratered surfaces of the other Saturnian satellites. It is thought that erosional processes similar to those on Earth have obscured the majority of impact craters that have hit the surface in the past, especially in the polar regions, leaving only 90 potential features that could be craters [e.g. 2].

In our study [3], we investigate the spectral behavior of nine Titan impact craters in order to constrain their surface composition using Visual and Infrared Mapping Spectrometer (VIMS) data and a radiative transfer code (RT) [e.g. 4] in addition to emissivity data. Past studies have looked at the chemical composition of impact craters either by using qualitative comparisons between craters [e.g. 5;6] or by combining all craters into a single unit [7], rather than separating them by geographic location or degradation state. Here, we use a radiative transfer model to first estimate the atmospheric contribution to the data, then extract the surface albedos of the impact crater subunits, and finally constrain their surface composition by using a library of candidate Titan materials.

Data and Observations: From the nine certain or nearly certain impact craters we have selected for this study, six of them are found in the equatorial dunes fields (up to 20◦N–S) and three of them are found in the midlatitude plains (≥20◦N-S) (Fig. 1). We call the former "dune craters" (Selk, Ksa, Guabonito, and the crater on Santorini Facula) and the latter "plain craters" (Afekan, Soi, and Forseti – along with Menrva and Sinlap) [3]. We study two impact crater subunits, the 'crater floor' (which refers to the bottom of a crater depression) and the 'ejecta blanket' (which is the material ejected from the transient crater during an impact event) [e.g. 8].

Figure 1 includes maps of the different views of Titan's surface taken from different instruments at different wavelengths, with the locations of the nine craters we analyzed in this study marked.

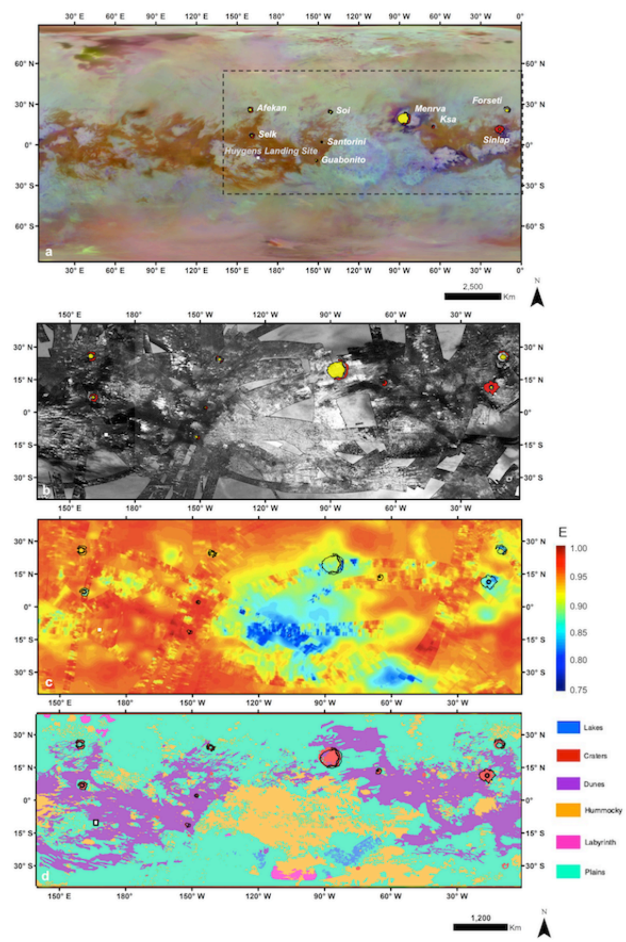

Fig. 1. Dune and plain impact craters on Titan's sur-

face with (a) VIMS RGB color map background (R:1.59/1.27, G: 2.03/1.27, and B: 1.27/1.08 µm ratios) [9]; (b) SAR background (NASA/JPL/Cassini RADAR team) [10]; (c) Microwave emissivity map background [11]; (d) Titan's major geomorphological units [1]. For (a) and (b), yellow selections correspond to the crater floor, and red selections to the ejecta blanket. The black dashed rectangle in (a) corresponds to the zoomed areas shown in b, c, and d. The Huygens landing site is marked with a white box.

Methods of analysis: For this work, we use VIMS data, an RT code, and a library of candidate Titan constituents.

VIMS pixel selection: The pixel selections made using overlapping images of SAR and VIMS data, which helped in locating the pixels corresponding to the specific crater floor and ejecta blanket areas. The method of VIMS-SAR superposition and pixel selection we used is described in detail [7] and [12].

VIMS analysis: We use our RT code whose characteristics, methodology, and several applications on VIMS data are presented in [3, 4,7, 12, 13]. We can estimate the atmospheric contribution to the VIMS data and extract meaningful surface information (surface albedos) by using Huygens and Cassini inputs and other parameters, such as laboratory data, that simulate Titan's conditions.

Compositional constraints: We use the extracted surface albedos to examine the compositional properties of the craters. We specifically looked for differences between the crater floors and ejecta blankets, as well as differences based on geographic location and degradation state. In order to constrain the composition of the craters using VIMS data, we tested their spectral properties against a spectral library of various constituents: water ice (H_2O) at 15 grain sizes (10 - 1,000 µm), laboratory tholins produced at 6 different grain sizes (1-100 µm) and dark materials such as bitumens and amorphous carbon (aC) at three different grain sizes. In addition, we have included in our model simulations carbon dioxide ice (CO_2), ammonia ice (NH_3) and a methane-like ice, also at 15 grain sizes.

Results and interpretations: The results show that Titan's midlatitude plain craters: Afekan, Soi, and Forseti, in addition to Sinlap and Menrva are enriched in an OH-bearing constituent (likely water-ice) in an organic based mixture, while the equatorial dune craters: Selk, Ksa, Guabonito, and Santorini, appear to be purely composed of organic material (mainly unknown dune dark material). This follows the pattern seen in [7], where midlatitude alluvial fans, undifferentiated plains, and labyrinths have surface spectra consistent with a mixture of tholin-like spectral features and water ice-like spectral features, while the equatorial undifferentiated plains, hummocky terrains, dunes, and variable plains appear to have spectra similar to a dark material and tholin-like mixture in their very top layers. These observations also agree with the evolution scenario proposed by [6] wherein the impact cratering process produces a mixture of organic material and water-ice, which is later "cleaned" through fluvial erosion in the midlatitude plains. This cleaning process does not appear to operate in the equatorial dunes, which seem to be quickly covered by a thin layer of sand sediment (with the exception of the freshest crater on Titan, Sinlap). Thus, it appears that active processes are working to shape the surface of Titan, and it remains a dynamic world in the present day while the impact craters and their processes might play an important role on Titan's habitability potential [14].

Acknowledgments: All Cassini data used in this article can be accessed in the Planetary Data Systems (PDS). This research was partly supported by the NASA Astrobiology Institute through its JPL-led project entitled ability of Hydrocarbon Worlds: Titan and Beyond. This research was partly supported by the Cassini Data Analysis and Participating Scientists Program (CDAPS) grant #NH16ZDA001N to R.L. A.S. was supported by a European Space Agency (ESA) Research Fellowship at the European Space Astronomy Center (ESAC), in Madrid, Spain. A.S. and Y.M. are supported by the Czech Science Foundation (grant no. 20-27624Y).

References: [1] Lopes, R., et al. (2020). Nat. Astron., 492, 4, 228-33. [2] Hedgepeth, J., et al. (2020). Icarus, 344, 113664. [3] Solomonidou, A., et al. (2020a), A&A, 641, A16. [4] Hirtzig, M., et al. (2013). Icarus, 226, 470–486; [5] Neish, C.D., et al. (2015), Geophys. Res. Lett. 42, 3746–3754. [6] Werynski, A., et al. (2019), Icarus, 321, 508-521. [7] Solomonidou, A., et al. (2018), J. Geophys. Res, 123, 2, 489-507 [8] Malaska, M., et al. (2016), Icarus, 270, 130. [9] Le Mouélic, S., et al. (2019), Icarus, 319, 121. [10] Lopes, R., et al. (2019), Space Sci. Rev., 215, 33. [11] Janssen, M., et al. (2016), Icarus, 270, 443. [12] Solomonidou, A., et al. (2020b), Icarus, 344, 113338. [13] Malaska, M., et al. (2020), Icarus, 344, 113764. [14] Crosta, A., et al. (2021), LPSC.