AN UPDATED ORGANIC INVENTORY ESTIMATE FOR TITAN. M.J. Malaska[1], R.M.C. Lopes[1], A. Hayes[2]; A. Schoenfeld[3], T. Verlander[4], M. Florence[1], S. Birch[2], A. Le Gall[5], A. Solomonidou[6], J. Radebaugh[7], R. Lorenz[8] [1]Jet Propulsion Laboratory / California Institute of Technology, Pasadena, CA. [2]Cornell University, Ithaca, NY. [3]University of California, Los Angeles, CA. [4]University of Oklahoma, Norman, OK. [5]LATMOS/IPSL, UVSQ Université Paris-Saclay, France. [6]European Space Agency, Madrid, Spain. [7]Brigham Young University, Provo, UT. [8]Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland. (Michael.J.Malaska@jpl.nasa.gov).

Introduction: Saturn's moon Titan is an organic chemist's paradise. High in Titan's atmosphere, complex organic molecules are constructed from photochemical reactions involving methane and nitrogen. These products eventally make their way down to the surface where they create organic landforms that cover Titan's icy crust. With the completion of a global map of Titan's surface [1], as well as characterization of the different geological terrain units [2] we reexamined the amount of organics on Titan surface originally estimated by estimated by Lorenz et al., (2009) [3].

Given accurate photochemical production rates, the total inventory of organics on Titan can help constrain the amount of time that Titan's organic factory has been producing complex organic moleucles. The expected vs. observed ratio of solid to liquid materials can be also used to infer hidden reservoirs of organics on Titan.

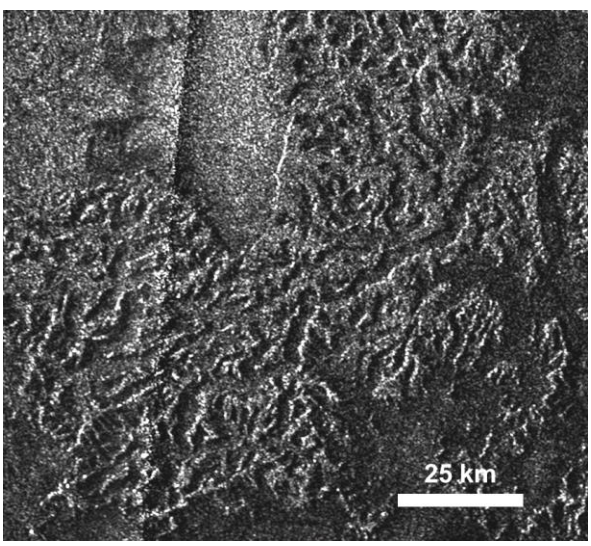

Fig. 1. SAR image of the southwest portion of Sikun Labyrinthus. Radar illumination is from the left, north is towards the top. Image is centered at (78°S, 32°W). The plateaux, valley fill, and empty lake basin (at center) are all consistent with a composition of organic materials with limited amounts of water ice.

Methods: Using a set of Synthetic Aperture Radar (SAR) mosaics from the Cassini mission through the final T126 radar pass, a global geomorphological map of Titan was created using ArcGIS functionalities. The different terrain classes were characterized by radar backscatter, microwave emissivity, and infrared surface spectra collected by Cassini's Visual and Infrared Mapping Spectrometer (VIMS) instrument. In general, high emissivity terrains are more consistent with organic materials, since water ice generally has a longer microwave pathlength,increasing chances for volume scattering. From our mapping, the surface area of the terrain types could be multiplied by an estimated average organic thickness (effective thickness) across the surface in order to determine the volume of the organic deposit contained in each terrain unit. In particular, this work constrained of the amount of organics contained in the labyrinth terrains.

Results: The major terrains classes and types consistent with organic materials include: undifferentiated plains, dune sediments, labyrinth terrains, and lakes.

Undifferentiated Plains: Titan's vast undifferentiated plains have high emissivity and are thus likely composed of organic material [4], although VIMS suggests a surficial coating of –OH bearing materials in some of the high-latitude plains [5]. The undifferentiated plains cover 17% of Titan's surface, or 1.4E7 km^2. While the exact depth of this deposit is unknown, Lopes et al. (2016) suggested that the smooth topography is suggestive of a thickness larger than 25 m thick [4]. Since microwaves can interrogate up to 1 m deep [6], we used 1 m as an absolute minimum thickness of the organic deposit. Due to their extensive surface area and potential thickness, the undifferentiated plains of Titan are a major driver of Titan's total organic inventory.

Dune sediments. Microwave emissivity and VIMS spectra are both consistent with the dune sediments being composed of organic materials [3, 7-8]. The amount of organic material was estimated by Rodriguez et al., (2014) [8] to be from 1.7 – 4.4E5 km^3.

Labyrinth terrains. Labyrinths are thick, dissected plateaux found at a variety of latitudes [9]. The plateaux, valley fill, and areas surrounding the labyrinth terrains, likely deposits from erosive removal of the plateaux, are all consistent with organic materials (Fig. 1). We measured the amount of dissection and the plateaux height from the regional base in order to determine the amount of plateau remaining, as well as the amount removed. For this exercise, we inventoried only the amount of organic plateau remaining. The average plateau height was 215 m. For those few labyrinths (ca 9% by labyrinth area) where we could not derive height information, we

picked a conservative height of 100 m. From this calculation, the total volume of material contained in the plateaux is 1.3E5 km^3, this is more than all the organics contained in the visible filled lakes.

Lakes. Titan's filled hydrocarbon lakes have a total surface area of 9.04E5 km^2 and an estimated liquid volume of 0.7E5 km^3 [10]. Assuming that roughly 10% of the lake liquid volume is composed of dissolved nitrogen [11], this would leave a remnant amount of liquid hydrocarbons (and of that, most of it would be methane) of 0.63E5 km^3.

Updated organic inventory estimate: For each terrain unit, the measured surface area, percent of the Titan total surface area, effective estimated thickness, and volume are shown in Table 1. We also include the percentage of the total organic volume based on a "rich" organic deposit scenario with 25 m thick undifferentiated plains scenario and 30 m thick average dunes and dune sediments, and a "lean" organic deposit scenario with 1 m thick undifferentiated plains and 12 m thick average dune sediment deposit.

Table 1. Estimated organic volume of Titan terrains.

Terrain unit	Surface area [km^2]	Effective thickness [km]	Volume [km^3]
Undifferentiated plains	14E6 (17%)	>0.025-0.001	>3.5-0.14E5 (>30%-4%)
Dune sediments	14.6E6 (17.6%)	0.03-0.012	4.4-1.7E5 (44%-44%)
Labyrinth	1.1E6 (1.4%)	0.12[c]	1.3E5 (13%-35%)
Filled Lakes	0.9E6 (1.1%)	0.07	0.63E5 (7%-18%)

For the "rich" scenario, the sum total organic deposit of organics on Titan is 9.9E5 km^3 material, while for the lean scenario, the total is 3.8E5 km^3 total organic material. This corresponds to an average global layer of 12 m and 6 m respectively. If the liquids are removed from the estimate, the solids would account for 11 and 4 m thickness of organic material. A major reservoir of solid organic materials are the labyrinth terrains; although they only comprise <2% of the surface area, their thicknesss allows them to hold 13-35% of Titan's estimated organic inventory.

What we might have missed: The absolute thickness of the undifferentiated plans is unknown; the muted topography in the mid-latitude plains suggests the average layer could be significantly higher than 25 m thick. The amount of organics in the variable featured plains and in the scalloped plains is not estimated. Both of these units have large areal coverage, so even some incorporation of organics into these units would significantly add to the total amount of organic material. Discovery of additional labyrinth terrains in non-SAR imaged areas, likely at higher latitudes, could also increase the volume contribution from this unit. A porous regolith [12-13] could hold significant amounts of Titan's organic liquids in pore spaces; a pore-satured subsurface was invoked for thrust belt lubrication on Titan [14]. If these subsurface reservoirs have a higher ethane or propane content, they could also hold significant amounts of dissolved organic solids. Crustal clathrate reservoirs could also hold smaller organic molecules [15-17]. Finally, organics that were transported deeper into the crust, or even all the way to the subsurface ocean, perhaps at an earlier thin-crust epoch, would not be accounted for in our surface mapping.

Acknowledgements: This research was partly supported by the NASA Astrobiology Institute through its JPL-led team entitled "Habitability of Hydrocarbon Worlds: Titan and Beyond" and CDAP grant #NN13D466T. This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. Government sponsorship is acknowledged.

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