SURFACE DISSOLUTION MODEL FOR TITAN KARST. M. Malaska[1], J. Radebaugh[2], K. Mitchell[3], R. Lopes[3], S. Wall[3], R. Lorenz[4], [1]SCYNEXIS, Inc., P.O. Box 12878, Research Triangle Park, NC 27709-2878 mike.malaska@scynexis.com, [2]Brigham Young University, Provo, UT, [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, [4]Johns Hopkins University Applied Physics Laboratory, Laurel, MD.

Introduction: Saturn's giant moon Titan is a world where organic chemistry reigns supreme. Its thick haze layers of photochemical products obscure a surface containing vast amounts of organic molecules and polymers [1, 2]. The Cassini mission's synthetic aperture RADAR (SAR) instrument has been able to penetrate the haze and discern a surface heavily dissected with fluvial features. But at Titan's frigid temperature of 95 K, it is methane-based precipitation that is the working fluid rather than H_2O. Previous studies have detailed possible karstic lakes [3] and karst-like valley networks and terrains [4] that may have resulted from hydrocarbon dissolution of Titan's surface materials. As an example, the images in Figure 1 present several different types of valley networks in the Sikun Labyrinthus region of Titan that appear to resemble terrestrial karst-like terrains [4]. Our study estimates the potential for hydrocarbon dissolution and types of materials dissolved based on recent photochemical production rates.

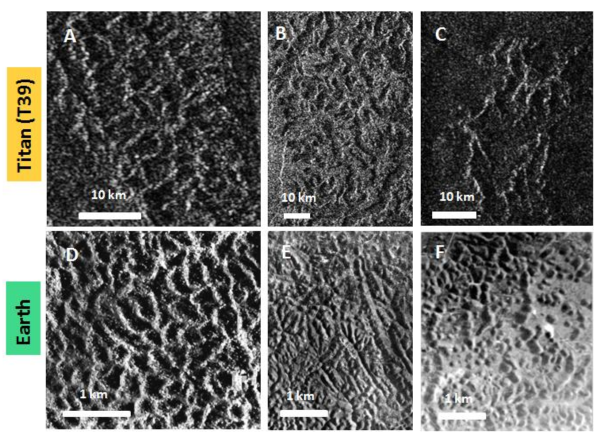

Fig.1. (A): Polygonal karst-like terrain (near Sikun Labryinthus, Titan); (B): Fluviokarst-like terrain (Sikun Labryinthus, Titan); (C): Tower karst-like terrain (near Sikun Labryinthus, Titan); (D): Polygonal karst, Darai Hills, Papua New Guinea (E): Labyrinth karst, Gunung Kidul kegelkarst, Java, Indonesia (F): Residual cone karst, Gunung Kidul kegelkarst, Java, Indonesia. Note difference in scale.

Methods: The basic model assumes that organic materials created by organic chemistry in Titan's atmosphere have deposited a uniform layer on the top of Titan's surface. To estimate the amount and types of material emplaced on Titan, two recent literature models for atmospheric material flux rates were used in this study: Krasnopolsky (2009) [5] and Lavvas et al., (2008) [6]. The amounts and compositions of the deposited materials in m height over a 1 Gyr period is shown in Figure 2.

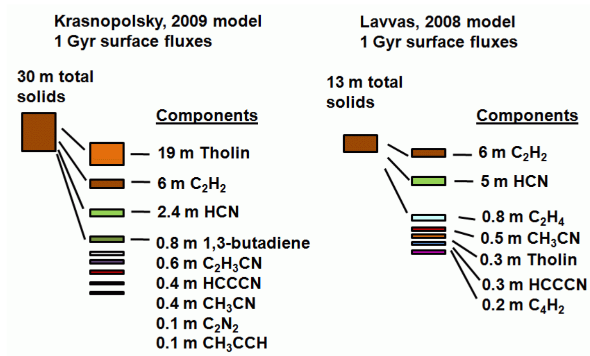

Fig. 2. Composition (in m) of initial surface deposit after 1 Gyr from both Krasnopolsky and Lavvas models. Only quantities >0.1 m shown.

Many of these materials are soluble when exposed to Titan's hydrocarbon rainfall, which is assumed to fall in the Graves et al. [7], "big drop" case with a composition of 77% CH_4 / 23% N_2 / trace C_2H_6. This rainfall will percolate through the deposited surface materials and eventually dissolve materials using the solubilities determined by Raulin [8] and Cordier et al. (for HCN) [9]. A simplified diagram of the putative organic cycle on Titan is shown in Figure 3.

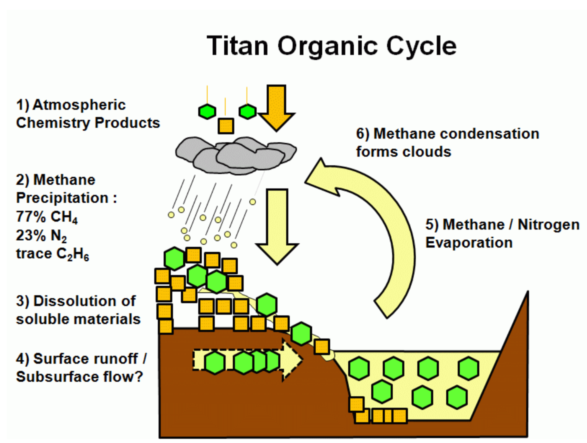

Fig. 3. Diagram showing putative organic cycle on Titan. Orange squares represent insoluble solid atmospheric chemistry products, while green hexagons represent soluble solid atmospheric chemistry products.

For this first approximation model, the kinetic effects of dissolution, although likely significant at Titan's low temperature of 95 °K, are assumed negligible – only saturation equilibrium solubilities are considered. Table 1 lists the estimated equilibrium solubilities of Titan's surface material components under Titan conditions [8,9] and compares them to common terrestrial karst forming materials [10].

Table 1. Solubilities of surface materials of Titan and Earth in their respective environments

Material	chemical formula (structure)	estimated solubility in 77%% CH4/23%N2 at 95 K [mg/L]	solubility in H2O at 298 K [mg/L]
"tholin" polymer	R(CH2)n(HCN)m	0	
ice (meteor influx)	H2O	0.000000002	
Gibbsite	Al(OH)3		0.001
cyanogen	C2N2	0.2	
butadiyne	C4H2 (HCCCCH)	0.25	
cyanoacetylene	HC3N (HCCCN)	0.26	
benzene (C6H6)	C6H6	0.78	
1,3-butadiene	C4H6 (H2C=C-C=CH2)	1.1	
acetonitrile	CH3CN	2.9	
acrylonitrile	C2H3CN (H2C=CHCN)	3.2	
propyne	CH3CCH	8	
Quartz	SiO2		12
carbon dioxide	CO2	44	
Amorphous silica	SiO2 (amorphous)		120
Dolomite	CaMg(CO3)2		300
Calcite	CaCO3		400
n-butane (C4H10)	C4H10 (CH3CH2CH2CH3)	580	
hydrogen cyanide	HCN	1080	
acetylene	C2H2 (HCCH)	1300	
Gypsum	CaSO4		2400
ethylene	C2H4 (H2C=CH2)	2810	
Halite	NaCl		360000

By taking the presumed surface flux rates over a given period (1 Gyr was used in this study) and the estimated amount of dissolved material given an assumed hydrocarbon rainfall rate, the amount and types of materials dissolved and potentially removed in the surface deposit can be estimated.

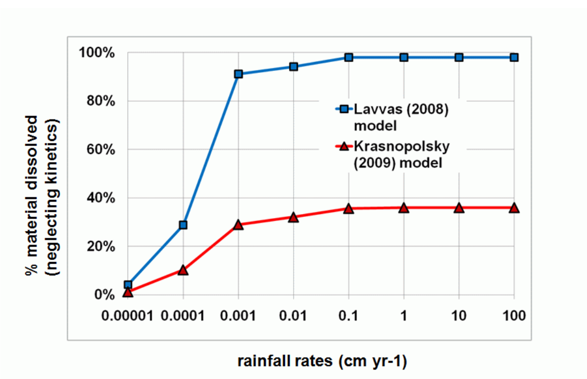

Fig. 4. Plot of % deposited material removed by hydrocarbon precipitation vs. hydrocarbon precipitation rates. Surface flux rates of both the Lavvas model (squares, blue) and the Krasnopolsky model (triangles, red) are considered.

Results: For both atmospheric flux models, the amount of total solid organic materials removed through dissolution and transport is graphed against hydrocarbon precipitation rates. As can be seen from the plots (Figure 4), both the Krasnopolsky and Lavvas surfaces have significant material dissolved from them with rainfall rates as small as 0.0001 cm yr^{-1} (10% and 29% respectively). With rainfall rates at 0.1 cm yr^{-1}, both models achieve "saturation" with the Lavvas surface almost completely dissolved (98%) and the Krasnopolsky surface roughly 36% dissolved.

Discussion: During the seven years of observation of the Cassini mission of Titan, several storm systems have been observed to occur. Surface darkening was seen after storms in both polar and equatorial regions that were ascribed to surface wetting and the possible formation of temporary playa hydrocarbon lakes, furnishing evidence that hydrocarbon rainfall does reach the ground and wet the surface [11, 12]. While the absolute frequency of rainfall events on Titan, and thus yearly average rainfall is not known, the size of the channels indicate that when the rains do come, they can be quite intense, furnishing rates as high as 1 cm hr^{-1} as estimated from stream morphometry for bankfull discharge [13]. Lorenz et al. [14] estimated the average yearly precipitation as 0.5 cm yr^{-1} based on available convection energy (0.05 W m^{-2}) – this is roughly equivalent to average yearly precipitation amounts in the hyper-arid Atacama Desert in Chile.

Despite this low estimated yearly rainfall on Titan, examination of Figure 4 shows that this would still allow the removal of significant amounts of deposited organic surface materials on Titan. This dissolution could be uniform or it could result in the formation of karst-like terrains, such as pitting, sinkholes, or subsurface caves.

References: [1] Lorenz et al., *GRL* 35 (2008) L02206. [2] Clark et al., *JGR* 115 (2010) E10005. [3] Mitchell et al., *LPSC* 39 (2008) Abstract 2170. [4] Malaska et at., *LPSC* 41 (2010) Abstract 1544. [5] Krasnopolsy, V.A., *Icarus* 201 (2009) 226-256. [6] Lavvas et al., *Planetary and Space Sci.* 56 (2008) 67-99. [7] Graves et al., *Planetary and Space Sci.* 56 (2008) 346-357. [8] Raulin, F., *Adv. Space Res.* 7 (1987) 71-81. [9] Cordier et al., *Astrophysical J.* 707 (2009) L128-L131. [10] Ford, D. and Williams, P. "Karst Hydrology and Geomorphology", 2007, Wiley, Chichester, Great Britain. [11] Turtle et al., *GRL* 36 (2009) L02204. [12] Turtle et al., *Science* 331(2011) 1414-1417. [13] Lorenz et al., *Planetary and Space Science* 56 (2008) 1132-1144. [14] Lorenz, R.D. *Science* 290 (2000) 467-468.